Body Fluids & Circulation

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INTRODUCTION

Every living cell needs constant supply of materials (i.e., nutrients, oxygen and other essential substances) and simultaneously the removal of wastes or harmful substances. It is, therefore, essential to have efficient mechanisms for the movement of these substances to the cells and from the cells. Different groups of animals have evolved different methods for this transport. Simple organisms like sponges and coelenterates circulate water from their surroundings through their body cavities to facilitate the cells to exchange these substances. More complex organisms use special fluids within their bodies (body fluids) to transport such materials. Blood and lymph are the most commonly used body fluids in most of the higher organisms including humans.

BODY FLUIDS

Body fluids are the medium of transport of the materials in the body. The body fluids can be distinguished into two types: the intracellular fluid and the extracellular fluid.

a. Intracellular Fluid (ICF). The fluid which is present within the cells is called intra-cellular fluid.

b. Extracellular Fluid (ECF). All the fluids outside the cells are collectively called extracellular fluid. Out of these fluids, blood and lymph are involved in the transporation of materials.

BLOOD

Blood is a special connective tissue consisting of a fluid matrix, the plasma and cells, the blood corpuscles. About 5 litres of blood circulates in the body of an adult person. It is slightly alkaline fluid having pH 7.4. Blood consists of a watery fluid called plasma containing floating bodies termed formed elements of blood.

1. Plasma :

- Plasma is a straw coloured, viscous fluid constituting nearly 55 per cent of the blood. 90-92 per cent of plasma is water and proteins contribute 6-8 per cent of it.
- Factors for clotting of blood are also present in the plasma in an inactive form. Plasma without the clotting factors is called **serum**.

Plasma Proteins :

- Proteins are the second largest (i.e., 7 percent) constituents ofplasma. Albumins, globulins and fibronogen are the important types of proteins present in the plasma.

- Albumin and globulins retain water in blood plasma.
- Certain globulins called immunoglobulins (glycoproteins) act as antibodies. Prothrombin help in blood clotting by changing soluble fibrinogen to insoluble fibrin. Plasma also contain small amount of minerals like Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-

Functions of Blood Plasma. The blood plasma functions in

(i) transport

(ii) prevention of blood loss

(iii) retention of fluid in blood due to plasma proteins.

(iv) uniform distribution of heat all, over the body

2. Formed Elements (Blood Corpuscles)

The formed elements include blood corpuscles or blood cells and blood platelets or thrombocytes. The blood corpuscles are of two types : erythrocytes or red blood corpuscles (RBCs) and leucocytes or white blood corpuscles (WBCs). Nearly 45 percent volume of blood consists of formed elements.

1. Erythrocytes (Red Blood Corpuscles or RBCs) :

- They are the most abundant of all types of cells in the blood.
- Red blood corpuscles of all adult mammals are enucleated (non-nucleated), and lack cell organelles. They are biconcave and circular in shape. However, in camel and Llama, RBCs are nucleated and oval in shape.
- A healthy adult man has, on an average 5 millions to 5.5 millions of RBCs /mm^3 of blood. The total count of RBCs is more in man than in a woman. It is due to the fact that women undergo menstruation. An abnormal rise in RBC count is termed as **polycythemia**. Decrease in the number of RBCs is called **erythrocytopenia.**
- The RBCs contain a red coloured, iron containing complex protein called haemoglobin, hence the colour and name of these cells. 100 ml of blood of a normal man contains about 14-16 g of haemoglobin and of normal woman an average of 12-14 g haemoglobin. Thus, the quantity of haemoglobin is less in women as they undergo menstruation.

The process of erythrocyte formation is called **erythropoiesis.** In the early few weeks of embryonic life, primitive nucleated RBCs are produced in yolk sac (one of the embryonic membranes). In later embryonic stage, RBCs are mainly produced in the liver and spleen. But from birth ownwards RBCs are produced in the bone marrow by the hemacytoblasts (erythrocyte forming cells).

- Iron and proteins are necessary raw materials for the synthesis of haemoglobin. However, vitamin B_{12} and folic acid stimulate the maturation of RBCs. Deficiency of any these nutrients can cause anaemia.
- The RBCs have an average life span of 120 days after which they are destroyed in the spleen. Therefore, spleen is called the graveyard of RBCs. .
- The adult haemoglobin molecule is made of 2 alpha chains and 2 beta chains. Each alpha chain consists of 141 amino acids while, each beta chain has 146 amino acids.

Functions of RBCs.

Haemoglobin of RBCs plays a significant role in transport of respiratory gases (i.e., oxygen and carbon dioxide).

2. Leucocytes (White Blood Corpuscles or WBCs) :

- The leucocytes are the most active and motile constituents of blood as well as lymph. They are colourless due to the lack of haemoglobin. They are nucleated and rounded or irregular in shape.
- They can change their shape like Amoeba and are thus, capable of amoeboid movement. This enables them to squeeze out of blood capillaries into the tissues. This process is called **diapedesis.**

♦ The leucocytes are relatively lesser in number. This varies from 4000 to 11000/mm^3 of blood in adult humans. Rise in WBC count is termed **leucocytosis**. Increased TLC shows acute bacterial infection or malignancies like leukemia (blood cancer). Fall in WBC count is called **leukopenia.**

The leucocyets are of two main types : Granulocytes and **Agranulocytes**

(i) Granulocytes : They contain granules and irregularly lobed nucleus in the cytoplasm. Based on their staining property, the granulocytes are divided into three types.

(a) Eosinophils : They are characterised by a bilobed nucleus. They contain numerous coarse granules that are stained bright red with acidic dye (e.g., eosin). The proportion of eosinophils is 2-3 per cent. They resist infections and are also associated with **allergic reactions.**

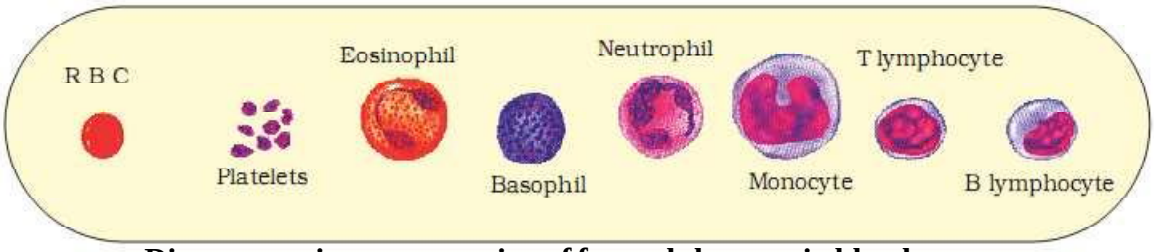
(b) Basophils : They have two to three lobed nucleus. Basophils contain fewer coarse granules, which can be stained with basic dyes, (e.g., methylene blue). They are the least (0.5-1.0per cent) among WBCs. Basophils secrete histamine, serotonin and heparin and are involved in inflammatory reactions.

(c) Neutrophils : They have **two to seven** lobed nucleus. Neutrophils do not take colour when exposed to acidic, as well as basic dyes. They are the most abundant cells (60-65 per cent) of the total WBCs. Neutrophils are phagocytic cells which destroys foreign organisms entering the body.

(ii) Agranulocytes : They lack granules in their cytoplasm. Agranulocytes are of two types.

(a) Lymphocytes. They are smaller in size with large rounded nucleus. They possess scant pale blue cytoplasm. They have a proportion of about 20-25 per cent. They produce serum globulins (antibodies) to destroy microbes and their toxins, reject graft and kill tumour cells. **Lymphocytes occurs in two major types-B lymphocytes** (B. cells) and **T-lymphocytes** (T-cells).Both are responsible for immune responses of the body.

(b) Monocytes. They are the largest of all types of WBCs and somewhat amoeboid in shape. They have kidney shaped nucleus. Monocytes constitute 6-8 per cent of total WBC. They are motile and phagocytic in nature and engulf bacteria and cellular debris. Generally they change into macrophages after entering tissue spaces.



Diagrammatic representation of formed elements in blood

3. Thrombocytes (Blood Platelets) :

♦ They are flat and non-nucleated fragments of the cells rather than true cells. Thrombocytes are fewer than the RBCs and more than the WBCs in number. There are about 1,500,00-4,500,00 platelets/mm^3 of the blood.

♦ Platelets are formed from the megakaryocytes (special cells in the bone marrow). Formation of thrombocytes is called thrombopoiesis. The normal life span of blood platelet is about a week.

♦ Platelets can release a variety of substances called platelet factors (e.g., thromboplastin) most of which are involved in the **coagulation of blood.** A reduction in the number of platelets **(thrombocytopenia)** can lead to clotting disorders which will lead to excessive loss of blood from the body.

3. **Haemopoiesis :** The process of formation of blood is called haemopoiesis and the tissues which form blood corpuscles are termed haemopoietic tissues. In mammals, yolk sac (one of the embryonic membrane), liver, bone marrow, lymph nodes, spleen and thymus are the haemopoietic organs in the embryo. In adult most of the blood corpuscles are formed in the **red bone marrow** of long bones. Lymphocytes are, however, formed in **thymus**, some in spleen, lymph nodes, tonsils and Peyer's patches.

SUMMARY OF HUMAN BLOOD CORPUSCLES

Type of Corpuscle and Number per mm3 of blood	Characters	Formation and Life span	Function
1. Erythrocytes (RBCs) 5-5.5 million in males and 4.5–5 million in females. Number increases during exercise and at high altitudes.	Circular, biconcave, denucleated, have elastic plasma membrane and homogeneous cytoplasm with haemoglobin, cell organelles absent 7–8 μm wide, 1 – 2 μm thick	By yolk sac in the early few weeks of embryonic life, in later embryonic stage by the liver and spleen, from birth onwards by bone marrow, life span 120 days.	Transport of oxygen and some amount of carbon dioxide.
2. Leucocyets (WBCs) 4000–11000. Number in increases during infection	Colourless, rounded or irregular, nucleated 12-20 μm wide.	Bone marow, lymph nodes, spleen, thymus, tonsils and Peyer's Patches.	Act as soldiers, scavengers, some help in healing.
(i) Granulocytes	Cytoplasm has granules, nucleus lobed.		
(a) Eosinophils 2–3% of leucocytes	Bilobed nucleus, coarse granules in cytoplasm, take acidic stain.	Bone marrow, life 4 to 8 hours in the blood, 4 to 5 days in the tissue	Resist infections, associated with allergic reactions.
(b) Basophils 0.5–1.0% of leucocytes.	Two to three lobed nucleus, fewer number of coarse granules, take basic stain.	Bone marrow, life 4 to 8 hours in the blood, 4 to 5 days in the tissues	Release histamine, serotonin and heparin, involved in inflammatory reactions.
(c) Neutrophils 60–65% of leucocytes.	Two to seven lobed nucleus, fine granules, do not take acidic as well as basic stains.	Bone marrow, life 4 to 8 hours in the blood, 4 to 5 days in the tissue	Phagocytic, engulf germs and dead cells.
(ii) Agranulocytes	Cytoplasm lacks granules nucleus not lobed.		
(a) Lymphocytes 20%–25% of leucocytes.	Large rounded mucleus, scant cytoplasm.	Lymph nodes, spleen, thymus, tonsils, bone marrow, Peyer's patches, life few days or months or even years.	Motile, non-phagocytic, secrete antibodies, help in healing.
(b) Monocytes 6–8% of leucocytes	Largest of all types of leucocytes, nucleus beam shaped, enough cytoplasm.	Bone marrow life 10 to 20 hours.	Motile, phagocytic, engulf germs and cell debris, often change into macrophages.

4. Blood Groups : Human beings have more than 30 types of antigens on the surface of blood cells. They give rise to different types ofblood groups. Two such grouping-theABO and Rh are widely used all over the world.

1. ABO Blood Groups :

- *Karl Landsteiner* (1900) reported first time ABO blood groups in human beings. He discovered A, Band O blood groups. While AB blood group was found out by *de Castello and Steini* (1902).ABO grouping is based on the **presence or absence of two surface antigens** (chemicals that can induce immune response) on the RBCs namely A and B. Similarly, the plasma of different individuals contain two natural antibodies (proteins produced in response to antigens).
- The distribution of antigens and antibodies in the four groups of blood ,A, B,AB and O are given in Table.

Blood groups and Donor Compatiblity

Blood Group	Antigen on RBCs	Antibodies in Plasma	Donor's Group (Can get blood from)	Recipient's Group (can give blood to)
A	A	anti-B	A, O	A, AB
B	B	anti-A	B, O	B, AB
AB	A, B	None	A, B, AB, O	AB
O	None	anti A, B	O	A, B, AB, O

- During blood transfusion, any blood can not be used. The blood of a donor has to be carefully matched with the blood of a recipient before any blood transfusion to avoid severe problems of clumping (production of clots that clog capillaries).
- The group O blood can be donated to persons with any other blood group. Therefore, the individuals with blood group O are called **'universal donors'.** Persons with AB group can accept blood from persons with any group of blood. Therefore, such persons are called **'universal recipients'.**

2. Rh (Rhesus) Blood Groups :

- *Landsteiner and Weiner* (1940) discovered another protein on the surface of red blood corpuscles of rhesus monkey and many human beings. They called it as Rh factor or Rh-antigen.
- Depending on the race, 80 to 99 percent of humans possess this factor and are Rh positive (Rh+), Others who do not have this factor are knownas Rh negative (Rh^-).
- Phenotypically, Rh positive and Rh negative individuals are normal. The problem arises when an Rh - ve person, is exposed to Rh + ve blood during blood transfusion or pregnancy.

(i) Incompatibility During Blood Transfusion : The first transfusion of Rh^+ blood to the person with Rh^- blood causes no harm. However, the recipient starts preparing antibodies (anti Rh factor) against Rh antigen in his/her blood. If the recipient person receives Rh^+ blood second time, the anti Rh factor present in his/her blood attack and destroy red blood corpuscles of the received blood.

(ii) Incompatibility During Pregnancy :

- A special case of Rh incompatibility (mismatching) has been observed between the **Rh^- blood of a pregnant mother and Rh+ blood of the foetus.** The Rh antigens of the foetus do not get exposed to the Rh- blood of the mother in the first pregnancy as the two bloods are well separated by the placenta. However, during the delivery of the first child, there is a possibility of exposure of the maternal blood to the Rh^+ blood from the foetus.
- In such cases, the mother starts preparing antibodies (anti-Rh factor) against Rh antigen in her blood. In case of her subsequent pregnancies, the Rh antibodies from the mother (Rh^-) blood can leak into the blood of foetus (Rh^+) and destroy the foetal RBCs.

♦ This could be fatal to the foetus or could cause severe anaemia and jaundice to the baby, i.e., the haemolytic disease of the new born (HDN). This condition is called **erythroblastosis foetalis** (destruction of the erythrocytes of foetus). This can be avoided by administering **anti-Rh antibodies** to the mother immediately after the delivery of the first child.

5. Blood Coagulation (Blood Clotting) :

♦ When an injury is caused, the wound does not continue to bleed for a long time. Usually the blood stops flowing outside after sometimes due to blood coagulation or blood clotting. This is a mechanism to prevent excessive loss of blood rom the body.

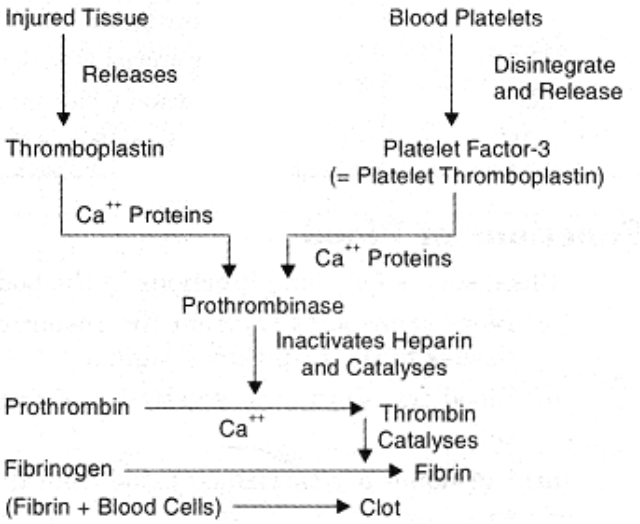
♦ Inside an intact blood vessel, blood does not coagulate due to the presence of active anticoagulants, heparin and antithrombins. Procoagulants also occur in the blood but are in an inactive state.

♦ The process of coagulation can be described in three major steps.

(i) At the site of an injury, the blood platelets disintegrate and release a phospholipid, called platelet factor-3 (platelet thromboplastin). Injured tissue also release a lipoprotein factor called thromboplastin. These two factors combine with calcium ions (Ca2+) and certain proteins of blood plasma to form an enzyme called prothrombinase.

(ii) In presence of calcium, the prothrombinase inactivates heparin (or antipro thrombin-anticoagulant). Prothrombinase also catalyses the conversion ofprothrombin (an inactive plasma proetin) into an active protein called thrombin and some small peptide fragments.

(iii) Thrombin acts as enzyme and first causes depolymerization of fibrinogen (a soluble plasma protein) into its monomers. Later thrombin stimulates repolymerization of these monomers into long insoluble fibre like polymers called **fibrin.** The thin long and solid fibres of fibrin form a dense network upon the wound and trap blood corpuscles and platelets to form a clot. The clot seals the wound and checks the bleeding. A clot is formed at the wound in about 2-8 minutes after injury. Soon after, the clot starts contracting (clot retraction) and a pale yellow fluid called serum, starts oozing out from it. This serum is blood minus the corpuscles and fibrinogens.



Role of Vitamin K in Blood Clotting. Vitamin K is necessary for the synthesis of prothrombin in the liver. When vitamin K is not sufficient in the body, blood clotting becomes inefficient.

6. Functions of Blood : Blood serves following functions in the body :

(i) Blood transports O_2 from the respiratory organs to the tissues and CO_2 from the tissues to the respiratory organs.

(ii) Blood transports the digested food from the alimentary canal to the different body cells.

(iii) Hormones are carried by blood from the endocrine glands to the target organ.

(iv) Blood transports excretory matter to the kidneys or other excretory organs.

(v) Blood allows the transfer of heat from the deeper tissues to surface of the bodywhere it can be lost.

(vi) Some leucocytes are phagocytic in nature, and certain leucocytes produce antitoxins to neutralize the toxins released by the foreign germs.

(vii) Bloodmaintains the body temperature to a constant level after distributing heat within the body.

(viii) The clotting factors present in the blood prevent loss of blood from the site of injury by the formation of clot.

LYMPH

(1) Lymph : is a colourless mobile connective tissue present in the lymphatic system. When the blood passes through the capillaries in tissues, some water along with many small watersoluble substances and some leucocytes (WBCs) move out into the spaces between the cells of tissues leaving the larger proteins and erythrocytes (RBCs) in the blood vessels. This fluid released out is called the **interstitial fluid or tissue** fluid. It has the same mineral distribution as that in plasma. An elaborate network of vessels called lymphatic system collects this fluid and drain it back to the major veins.

The fluid present in the lymphatic system is called the **lymph**.

Lymph consists of **lymph plasma** (fluid) and **lymph corpuscles** (cells).

Differences between Blood and Lymph

1.	It is red in colour due to the presence of haemoglobin in red cells.	1.	It is colourless as red blood cells are absent.
2.	It moves away from the heart and towards the heart.	2.	It moves in one direction i.e. , from tissues to sub-clavians.
3.	It consists of plasma, RBC, WBC, and plastelets.	3.	It consists of plasma and WBC (maximum lymphocytes)
4.	Its plasma has more proteins, calcium and phosphorus.	4.	Its plasma has less protein, calcium and phosphorus.
5.	Glucose concentration is low.	5.	Glucose concentration is higher in lymph.
6.	Flow of blood is fast.	6.	Lymph flows very slowly.

Functions of Lymph :

1. Lymph acts as 'middle man' which help in exchange of nutrients and gases between the blood and the cells.
2. Fats are absorbed through lymph in the lacteals present in the intestinal villi.
3. When the volume of blood decreases in the blood vascular system, the lymph rushes from the lymphatic system to the blood vascular system to maintain the bloodvolume in the body.
4. It destroys the invading microorganisms and foreign particles in the lymph nodes.
5. To produce and secret Antibodies.

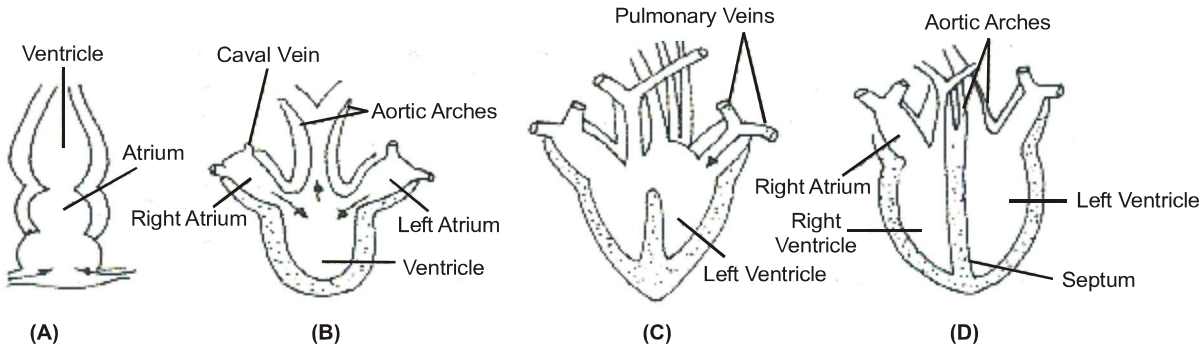
CIRCULATORY PATHWAYS

- The circulatory patterns are basically of two types : open and closed. **In open circulatory system,** the blood is pumped by the heart, which passes through large vessels into open spaces or body cavities called sinuses. This type of system is present in arthropods and molluses.

  In closed circulatory system, the blood pumped by the heart is always circulates through a closed network of blood vessels. This system of circulation is more advantageous because the flow of fluid is regulated in better way.
- All vertebrates possess a muscular and chambered heart. It acts as a pumping organ of the blood vascular system. It receives blood from

and pump the blood to the various organs and tissues ofthe body.Fishes have a 2-chambered heart with an atrium and a ventricle, Amphibians and the reptiles (except crocodiles) have a 3-chambered heart with two atria and a single ventricle whereas, crocodiles, birds and mammals possess a 4-chambered heart with two atria and two ventricles.

- In fishes, the heart handles only deoxygenated blood. Such a heart is called **venous heart.** It pumps out deoxygenated blood which is oxygenated by the gills and supplied to the body parts from where deoxygenated blood is returned to the heart. It is called **single circulation.**
- In amphibians and reptiles, the heart receives both deoxygenated and oxygenated blood and is called **arteriovenous heart.** The left atrium of the heart receives oxygenated blood from the gills/lungs/skin and the right atrium gets the deoxygenated blood from other body parts. However, they get mixed up in the single ventricle which pumps out mixed blood. It is called **incomplete double circulation.**
- In crocodile, birds and mammals oxygenated and deoxygenated blood received by the left and right atria respetively passes on to the ventricles of the same sides. The ventricles pump it out without any mixing up, i.e., two separate circulatory pathways are present in these organisms. It is called **double circulation.**



Hearts of different vertebrates A – Fish; B – Amphibian; C – Reptilian; D – Mammalian heart

Differences between Open and Closed Circulatory Systems

	Open System		Closed System
1.	Blood flow through open spaces called lacunae or sinuses.	1.	Blood flow through blood vessels.
2.	Body tissues are in direct contact with blood.	2.	Body tissues are not in direct contact with blood.
3.	Blood flows at low pressure through lacunae and sinuses.	3.	Blood flow at high pressure through closed blood vessels.
4.	Body cavity containing blood is called haemocoel.	4.	Body cavity does not contain blood and is called coelom.
5.	Exchange of materials is direct between blood and body cells.	5.	Exchange of materials take place through tissue fluid.
6.	It is slow and less efficient.	6.	It is fast and more efficient.
7.	Volume of blood flowing through tissues and organs is not regulated.	7.	Volume of blood flowing through tissues and organs is well regulated by contractile arteries and other blood vessels.
8.	Found in arthropods (prawns, crabs, lobsters, insects, spiders), in annelids (leech), in non-cephalopod molluscs (pila, snails, oysters and clamps) and protochordates like tunicates or Herdmania.	8.	Found in annelids (earthworms, Neries), in cephalopod molluscs (octopus, squids), in echinoderms and vertebrates.

HUMAN CIRCULATORY SYSTEM

Human circulatory system also called the blood vascular system consists of a muscular heart, a network of closed branching blood vessels and the blood.

1. Human Heart : The human heart is mesodermally derived organ located between the lungs in thoracic cavity.

- The heart is protected by a double walled membranous sac called pericardium. It consists of a fibrous layer called perietal pericardium and an inner serous layer called visceral pericardium. The latter is attached to the heart. In between the two layers, there is a very narrow space, called the **pericardial cavity** which is filled with a **pericardial fluid.** It protects the heart from shocks and mechanical injuries and also allow its free movements.

2. External Structure :

- Human heart consists of four chambers : two relatively small upper chambers called atria (sing.atrium) and two larger lower chambers called ventricles. The left and right atria are separated externally by a shallow vertical interatrial groove. A transverse groove is present between the atria and ventricles, called **coronary sulcus**. It is slightly towards atria so ventricles appear bigger than atria.
- Two groove are also present on the ventricle. These are called the anterior interventricular sulcus and posterior interventricular sulcus. These sulci have **coronary arteries** through which the heart receives blood.
- The right atrium is slight larger than the left atrium because interauricular groove is slightly towards left auricle. The right and left atria receive blood from different body parts. The right atrium receives deoxygenated blood from all parts of the body,except the lungs, through the superior and inferior vena cava. Pulmonary veins bring oxygenated blood to the left atrium from the lungs. The right and left atria pour their blood into the right and left ventricles, respectively.
- From the right ventricle arises a pulmonary trunk, which soon bifurcates to form right and left pulmonary arteries, which supply deoxygenated blood to the lungs of the respective side.
- The left ventricle gives rise to an ascending aorta , through which the oxygenated blood is supplied to the coronary artries and the systemic circulation of the body. Left ventricle is large because interventricular sulcus is towards right side.

3. Internal Structure : Internally, the four chambers of the heart are separated by septa and valves.

- The right and left atria are separated by inter-atrial septum. An oval depression is present on this septum, called as **fossa ovalis.** It represents the remanant of foramen ovale (an opening in the interatrial septum of the foetal heart).
- The right atrium receives the openings of superior vena cava, inferior vena cava and coronary sinus. The opening of inferior vena cava is guarded by Eustachian valve. The opening of coronary sinus has coronary orThebasian valve. The left atrium receives four openings of pulmonary veins.
- The two ventricles are separated by interventricular septum.

Heart wall consists of three layers

(1) Epicardium :

- Outermost
- Composed of simple squamous epithelium
- Mesodermal in origin.

(2) Myocardium :

- Middle layer
- Thickest layer of heart wall.
- Composed of cardiac muscles. These muscles are branched, striated and involuntary in nature. They contract whole life and do not get fatigue.
- In these muscles fast contractions occur.

(3) Endocardium :

- Inner most
- Composed by Simple squamous Epithelium.
- It is endodermal in origin.

- Each atria open in ventricle of its side by Atrio – ventricular foramen [A.V. foramen]. On right A.V. foramen, a valve of 3 folds is present called as **Tricuspid valve.** On left A.V. foramen a valve of two folds is present called **Bicuspid / Mitral valve.**
- These valves prevent reverse flow of blood. Ends of these cusps/flaps are attached with muscular processes of wall of ventricles [papillary muscles] by thread like structures called as **chorda Tendinae.**
- These threads prevent valve to shift in opposite direction.
- From right ventricle pulmonary arch and from left ventricle carotido – system Arch arise. At the base of each Arch 3 semilunar valves are present.
- Outside of heat where both these arch intersect, they are interconnected by fibrous strip called ligamentum Arteriosus. During embryonic development at the place of this ligament a narrow Ductus Arteriosus is present, which close before birth.

4. Pumping Action of Human Heart : Heart is a complex pumping organ which receives blood from different parts of the body in its atria and pump it to the various body parts from ventricles.

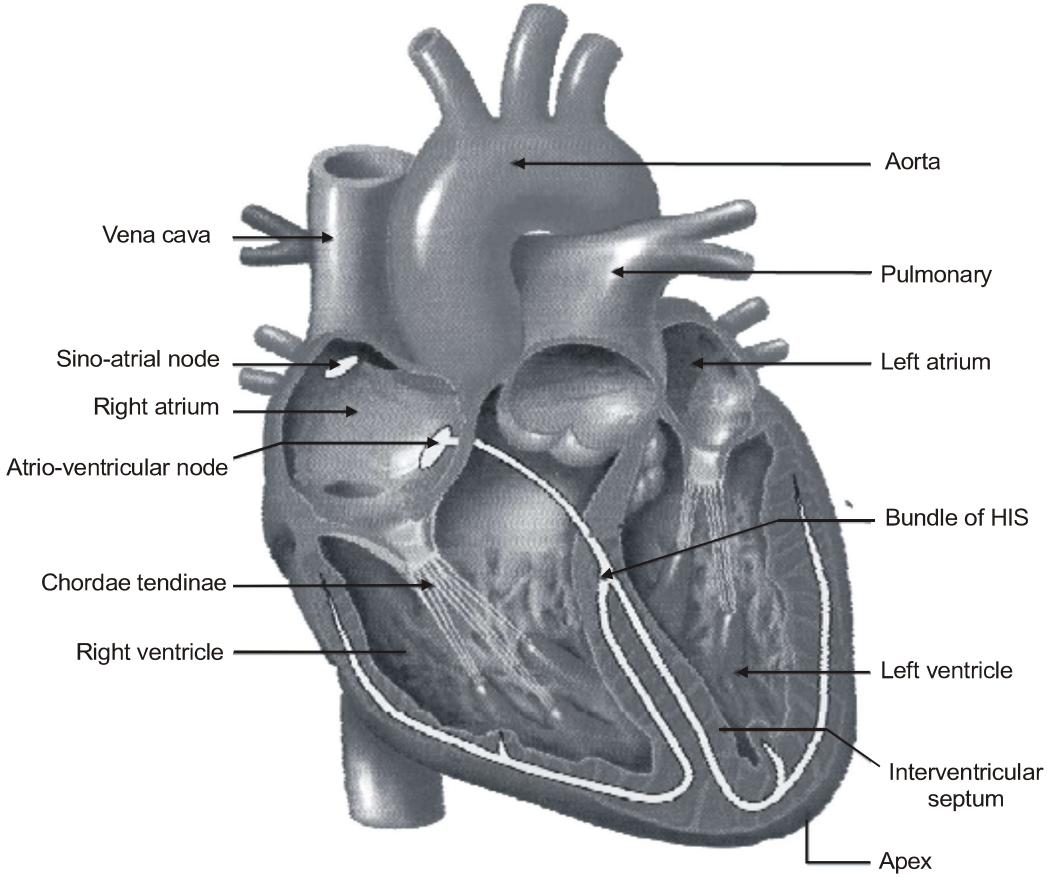
- Heart muscles continuously generate impulses in a manner that causes rhythmic contraction and relaxation of the heart chambers in a specific sequence.
- A contraction of the heart is called a **systole** and its relaxation a **diastole.** The atria and ventricles contract alternately. The contraction of heart (systole) and the relaxation of heart (diastole) constitute the heart beat.

Nodal Tissue or Excitatory and Conductive System of the Heart. The heart rhythm is maintained by a highly specialised excitatory and conductive system, which includes sinoatrial node (SA node), inter nodal pathways, the atrio-ventricular node (AVnode), the AVbundle and the bundle of purkinje fibres.

- The sino-atrial node or SA node (SAN also called **pace maker**) is a small, flatened and ellipsoid strip of muscle fibre of 0.3 mm size, which is situated in the upper lateral wall of the right atrium.
- The atrio-ventricular node or AV node (AVNalso called pace setter) is another strip of muscle fibre, lies in the wall between the right atrium and right ventricle. A bundle of nodal fibres called atrio-ventricular bundle (AVbundle) arises from the AVN and passes through the atrio-ventricular septa. It emerges on the top of the interventricular septum and immediately divides into a right and left bundle.
- These bundles give rise to minute fibres throughout the ventricular musculature of the respective sides and are called **Purkinje fibres.** These fibres along with right and left bundles are known as **bundle of His.**

Working of Nodal Tissue :

- The nodal musculature has the ability to generate action potentials without any external stimuli, i.e., it is **autoexcitable.** However, the number of action potentials that could be generated in a minute, vary at different parts of the nodal system.
- The SAN (SA node) can generate the maximum number of action potentials, i.e., 70-75 min ", and is responsible for initiating and maintaining the rhythmic contractile activity of the heart. Therefore, it is called the pacemaker.
- The action potential generated in the SAN spontaneously initiates a wave of contraction which spreads over both the atria more or less simultaneously. This also stimulates the AVN (AVnode) through internodal pathway, which generates a fresh wave of contraction that passes over both the ventricles simultaneously along the bundle of His and Purkinje fibres.
- The ventricular contraction begins at the apex of the heart and passes quickly towards the origin of the pulmonary and systemic arches. The entire conduction of the impulse is organised in such a way that, there is a delay in transmission of impulse from SA node to the ventricle.



Section of a human heart

The human heart is myogenic (myo = muscle, genic = originating from), as the action potential for its rhythmicity originates from a muscle, however, it is regulated by the nerves.

Differences between Neurogenic heart and Myogenic heart

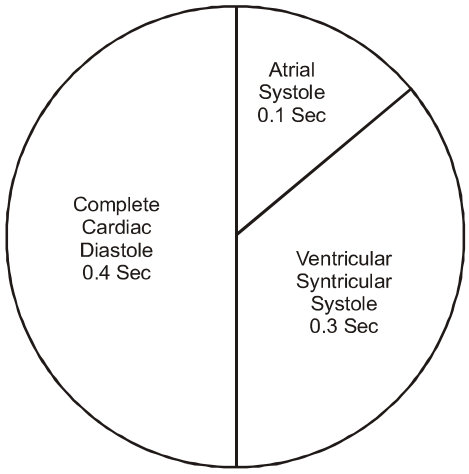
S.No.	Neurogenic heart	Myogenic heart
1	The heart beat is initiated by a ganglion situated near the heart.	The heart beat is initiated by a patch of modified heart muscle
2	The impulse of contraction orginates from nervous system.	The impulse of contraction orginates itself in the heart
3	The heart normally stops beating immediately after removal from the body. Therefore, heart transplantation is not possible.	The heart removed from the body continues to beat for some time. Therefore, heart transplantation is possible.
4	Examples: Hearts of some annelids and most arthropods.	Examples: Hearts of molluscs and vertebrates

CARDIAC CYCLE

- The sequence of events, which occur from the beginning of one heart beat to the beginning of the next (completion of one heart beat), is called cardiac cycle.
- During a heart beat there is contraction and relaxation of atria and ventricles. The contraction phase is called the **systole** while the relaxation phase is called the **diastole**. When both the atria and ventricles are in diastolic or relaxed phase, it is referred as **joint diastole**.
- A complete heart beat consists of a systole and diastole of both the atria, plus the systole and diastole of both the ventricles.
- During **joint diastole**, the blood flows from the superior and inferior vena cavae into the atria. But there is no flow of blood from the ventricles to the aorta and pulmonary trunk as the semilunar valves remain closed.

The pumping action during single cardiac cycle involves following steps :

1. **Atrial Systole :** The two atria contract simultaneously due to wave of contraction stimulated by the SAnode. The blood is pumped into the ventricles as the bicuspid and tricuspid valves are open. Atrial systole takes about 0.1 second. Soon after systole, the atria enters into diastole phase for the next 0.7 second. From the atria, nearly 70% of the blood passively flows into the ventricles. The rest of the blood is pumped into the ventricles by the contraction of atria.
2. **Ventricular Systole:** When the atrial systole approaches its end, the ventricles begin to contract due to a wave of contraction, stimulated by the AVnode. The bicuspid and tricuspid valves close immediately producing part ofthe first heart sound. When the ventricles complete their contraction, the blood flows into the pulmonary trunk and aorta as the semilunar valves open. The ventricular systole takes about 0.3 seconds.



3. **Ventricular Diastole.** Soon after systole, the ventricles undergo relaxation and the semilunar valves are closed. This causes second heart sound. The bicuspid and tricuspid valves open, when the pressure in the ventricles falls and blood flows from the atria into the ventricles. The period of ventricular diastole is of about 0.5 seconds.
4. **Joint Diastole.** During this phase both the atria and ventricles are in diastole. As no contraction is present anywhere, the phase ofjoint diastole is also called general pause. The total duration of a cardiac cycle is 0.8 seconds. Thus, many cardiac cycles are performed per minute.

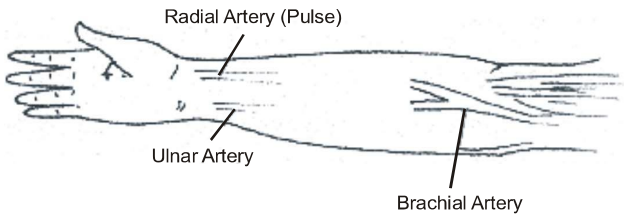
Heart Sounds :

- The beating heart produces characteristic sounds which can be heard by placing the ear against the chest or by using **stethoscope** (an instrument which magnifies sounds and conduct them to ear).
- The first heart sound-**Lub** is associated with the closure of the bicuspid and tricuspid valves. It is low pitched (not very loud) and of long duration (lasts for 0.15 seconds). The second heart sound-**dup** is associated with the closure of the semilunar valves. It is highly pitched (louder/sharper) and shorter in duration (lasts for 0.1 seconds).
- The heart sounds are of clinical diagnostic significance. Damage to the bicuspid or tricuspid valve effects the quality of the first heart sound. When the semilunar valves are injured, a soft hissing noise "lub shhh" is heard in place of the

second sound. This is called a **heart murmur.** It may be caused by the syphilis, rheumatic fever or any other disease which injures the semilunar valves and affects their working. As a result, the blood can leak back from the pulmonary trunk and aorta into the ventricles.

HEART BEAT AND PULSE

- The rhythmic contraction and relaxation of the heart constitute the heart beat. Each heart beat includes one systole and one diastole of the heart to distribute and receive blood to and from the body.Our heart normally beats 70-75 times in a minute (average 72 beats min-I).
- As a result of heart beat, a wave of distention passes along the arteries, immediately after a ventricular systole. This wave of distention is called arterial pulse. It can be felt by placing a finger tip on the artery (radial artery) near the wrist. This artery palpitates at a rate corresponding to that of heart beat.
- Thus, pulse rate increases during exercise, fever and emotional and psychological excitements. The pulse rate is more rapid when a person is standing than when he/she is lying down.



1. Regulation of Heart Beat : Although the cardiac impulse has a myogenic origin, the rate of its formation and conduction is regulated by the neural and endocrine systems.

A. Neural Regulation : The cardiac centre lies in the medulla oblongata of the brain. From cardiac centre, the SA node receives two sets of nerve fibres. Sympathetic that stimulates the SA node and accelerate the heart beat, and parasympathetic (vagus nerve) that inhibit the SA node and retard the heart beat.

B. Hormonal Regulation : The hormones secreted by the medulla of the adrenal glands uiz adrenaline (epinephrine) and noradrenaline (norepinephrine) playa significant role in the regulation of heart beat. Noradrenaline accelerates the heart beat under normal conditions while adrenaline does this function at the time of emergency.These hormones directly influence the SA node.

Another hormone, thyroxine secreted by thyroid gland increases heart rate.

Body temperature also affects the pace maker. Just 1°C rise in temperature increases the heart rate by about 10 beats/minute. This is why our pulse rate is much higher in fever.

Heart rate in some animals

Smaller animals have higher heart rate because of their higher metabolic rate.

Elephant - 29/min.

Human - 70-80/min.

Foetus (human) - 140-150/ min.

Rat - 300-500/min.

Other Factors :

Exercise → Rate of heart beat ↑

Emotion
Tension → HR ↑
Excitement

Body temperature ↑ → Rate of heart beat ↑

- Just after taking food rate of heart beat increase.

BLOOD PRESSURE

Blood flows in Arteries and it exerts some pressure on their wall called Blood Pressure.

- B.P. was first measured by → Stephan Halls in Horse
- B.P. measured by → sphygmomanometer
- This instrument invented by → Riva Rocci
- B.P. measured in → Brachial Artery
- B.P. is of two types :

(1) Systolic B.P. :

During systole pressure exerted by blood. 120 mm Hg [110 – 140]

(2) Diastolic B.P. :

During diastole of heart pressure exerted by blood. 80 mm Hg [70 – 90]

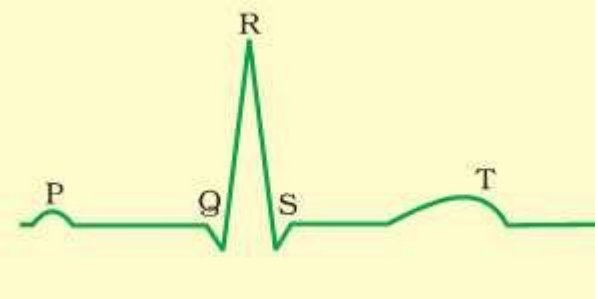
ELECTROCARDIOGRAPH (ECG)

- ECG is a graphical representation of the electrical activity of the heart during a cardiac cycle.
- Each peak in the ECG is identified with a letter from P to T that corresponds to a specific electrical activity of the heart.

  The **P-wave** represents the electrical **excitation (or depolarisation) of the atria**, which leads to the contraction of both the atria.

  The **QRS complex** represents the **depolarisation of the ventricles**, which initiates the ventricular contraction. The contraction starts shortly after Q and marks the beginning of the systole.

  The **T-wave** represents the return of the ventricles from excited to normal state **(repolarisation)**. The end of the **T-wave** marks the end of systole.
- Obviously, **by counting the number of QRS complexes that occur in a given time period, one can determine the heart beat rate of an individual.** Since the ECGs obtained from different individuals have roughly the same shape for a given lead configuration, any deviation from this shape indicates a possible abnormality or disease. Hence, it is of a great clinical significance



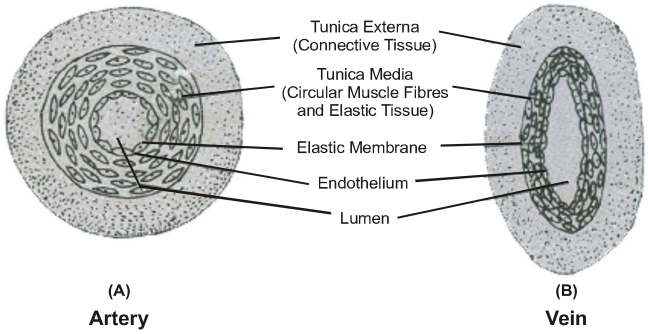
Diagrammatic presentation of a standard ECG

BLOOD VESSELS

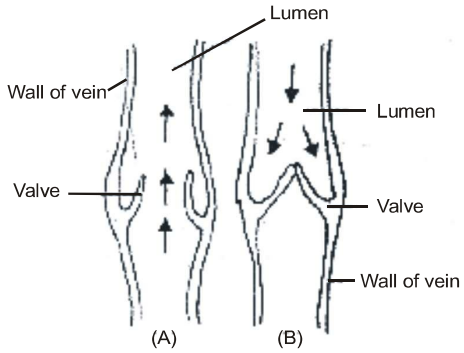
The blood flows strictly through a fixed route through the arteries and veins. Arteries carry blood from the heart to different body parts. Veins bring blood from different body parts to the heart.

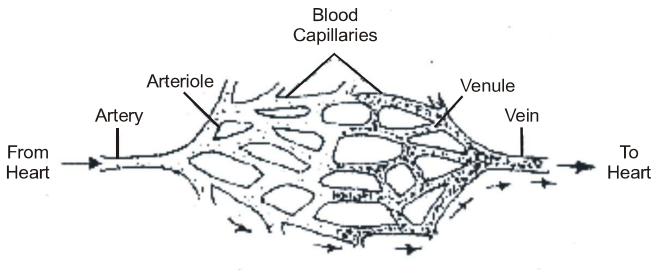
- Basically, each artery and vein consists of three layers or coats.

1. Tunica intima. It is the innermost coat which is made up of an elastic membrane made up of elastic tissue of yellow fibres and squamous endothelium lining the lumen.
2. Tunica media. It is a middle coat which is formed of elastic connective tissue and smooth muscle fibres. It is thicker in artery .
3. Tunica externa (= tunica adventitia). It is the outermost coat formed of connective tissues.

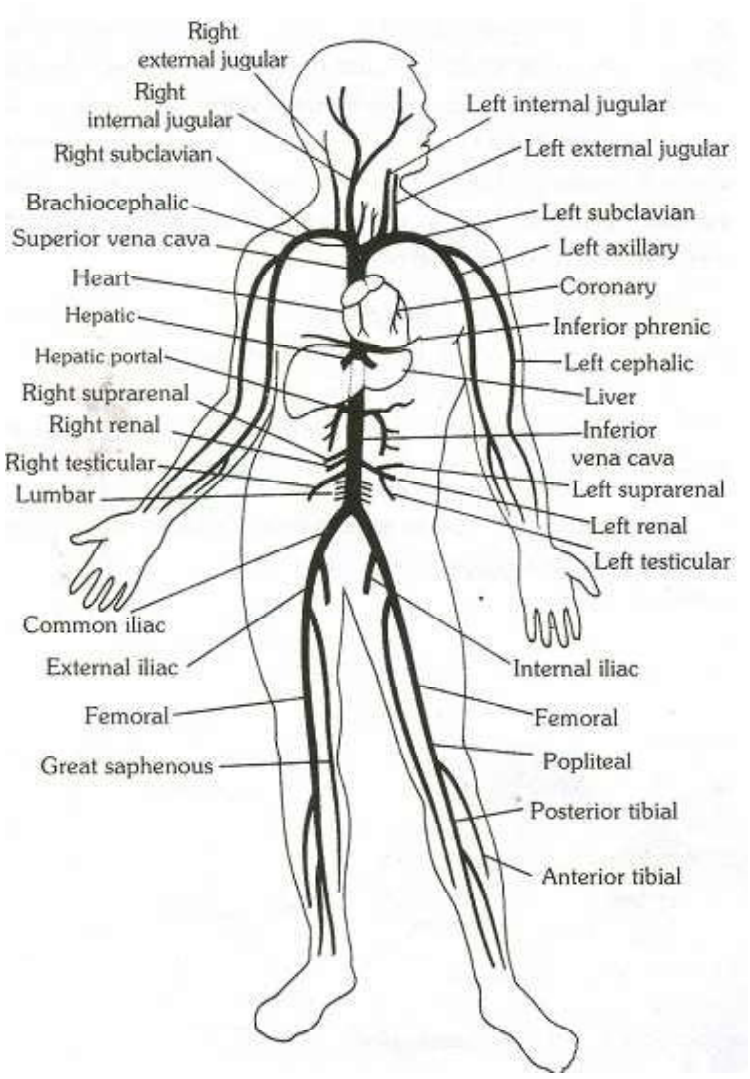


- The veins have valves to prevent backward flow of blood. In the organs both arteries and veins divide to form arterioles and venules respectively.
- The arterioles and venules further divide into the thin walled vessels called capillary. The wall of capillaries is made up of endothelium only.The nutrients, hormones, gases, etc. can diffuse into the tissue cells through the wall of capillaries and vice versa.





Differences between Arteries and Veins	
Arteries	**Veins**
1. Arteries carry blood from the heart to the different parts of the body.	1. Veins bring back blood from different parts of the body to the heart.
2. They are usually deep seated.	2. They are superficially situated.
3. The wall of arteries are thick and muscular.	3. The wall of the veins are thin and non muscular.
4. Arteries have no valves.	4. Veins have valves to prevent backflow of the blood
5. In arteries the blood flows with jerks.	5. In veins blood flows smoothly.
6. The flow of the blood is fast as the blood in arteries is under great pressure.	6. The flow of blood in veins is not so fast because the blood in veins is under low pressure.
7. Except the pulmonary arteries all the arteries carry oxygenated blood.	7. Except pulmonary veins all the vein carry deoxygenated blood.



Venous system in male human being

CIRCULATION

The movement of blood follows double circulation (systemic and pulmonary circulation) and circulation through special regions.

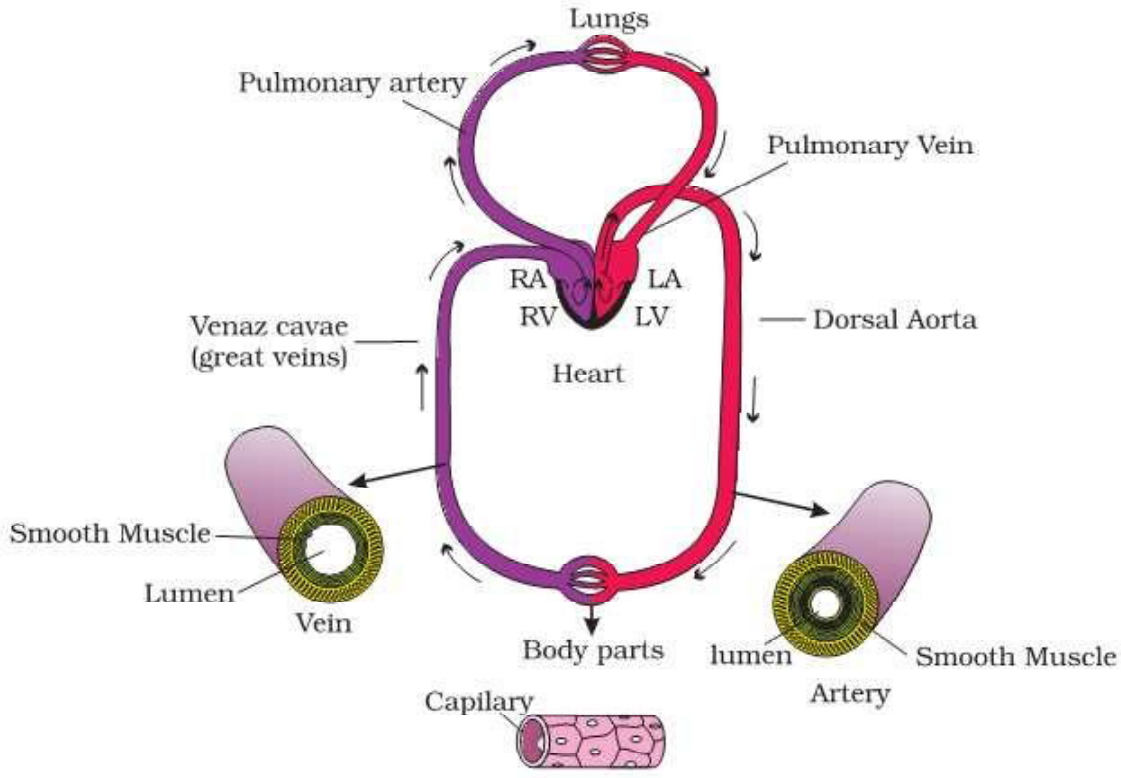
1. Double Circulation :

(i) Systemic Circulation. It involves the flow of oxygenated blood from the left ventricle to all parts of the body and deoxygenated blood from various body parts to the right atrium. It is also called systemic circulation.

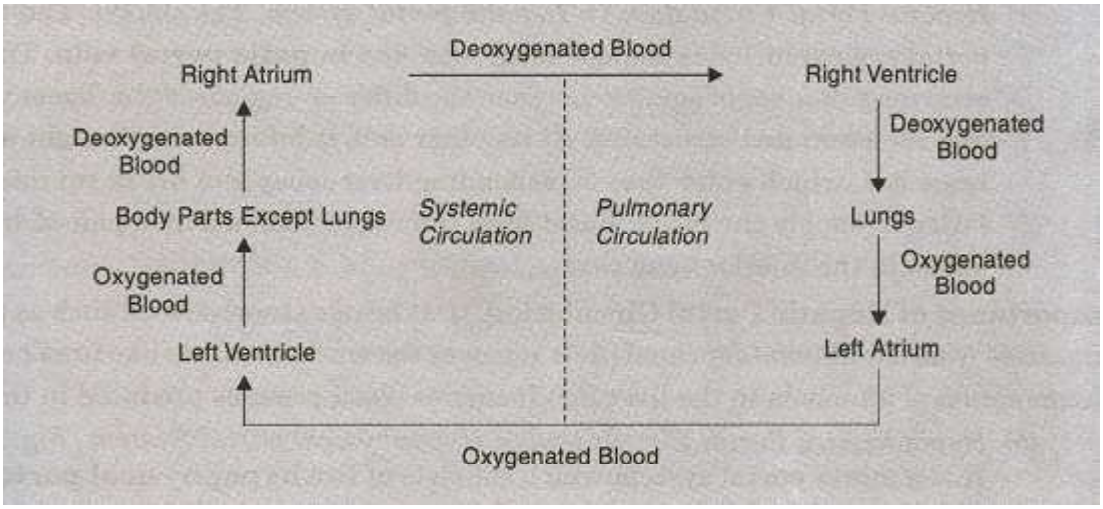
- The systemic circulation starts from the left ventricle of the heart, passes to the aorta, to the arteries originating from it and to all their branches, thence to the arterioles, capillaries, venules and the veins of the whole body and finally to the two vena cavae which enter the right atrium.
- As the systemic circulation supplied blood to most of the tissues of the body, it is also called the greater circulation or peripheral circulation. The systemic circulation carries oxygen and nutrients to body tissues and removes carbon dioxide and other wastes from the tissues.

(ii) Pulmonary Circulation : The flow of deoxygenated blood from the right ventricle to the lungs and the return of oxygenated blood from the lungs to the left atrium is called the pulmonary circulation.

- The pulmonary trunk arises from the right ventricle and then divides into the right pulmonary artery and left pulmonary artery which supply deoxygenated blood to the right and left lungs respectively.
- Two pulmonary veins from each lung transport the oxygenated blood to the left atrium. The systemic circulation and pulmonary circulation constitute the double circulation.
- The left side ofthe heart (left atrium and left ventricle) has oxygenated blood and is called systemic heart, and the right side of the heart (right atrium and right ventricle) has deoxygenated blood and is called pulmonary heart.



Schematic plan of blood circulation in human



Differences between Systemic and Pulmonary Circulations	
Systemic Circulation	**Pulmonary Circulation**
1. It is a larger circuit, which supplies blood to the various parts of the body and back to the heart.	1. It is smaller circuit which carries blood to the lungs and back to the heart.
2. It supplies oxygenated blood to all parts of the body.	2. It carries deoxygenated blood to the lungs for oxygenation.
3. The blood is pumped by left ventricle and received by the right atrium.	3. The blood is pumped by right ventricle and received by left atrium.

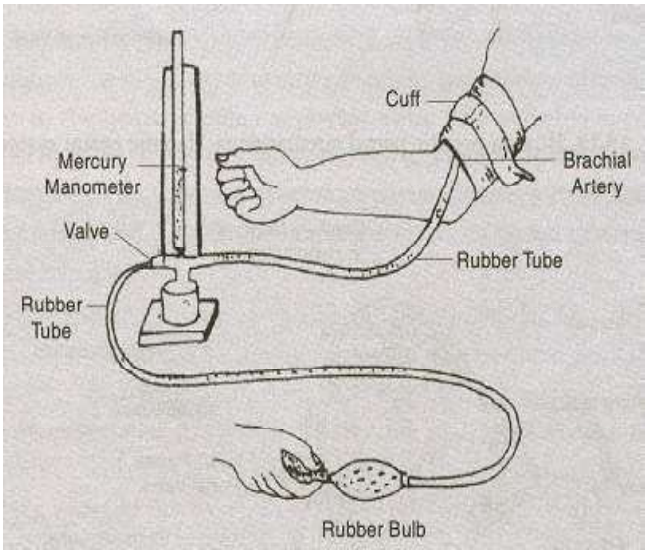
2. **Coronary Circulation** Besides, the systemic circulation and pulmonary circulation, the supply of blood to the heart muscles (myocardium) is also important. The flow of oxygenated blood from the ascending aorta to the heart muscle and the return of deoxygenated blood from the heart muscle to the right atrium is called coronary (cardiac) circulation. The right and left coronary arteries arise from the ascending aorta which supply oxygenated blood to the heart muscle. The coronary veins bring deoxygenated blood to the coronary sinus. The latter carries deoxygenated blood to the right atrium.

DISORDERS OF CICULATORY SYSTEM

1. High Blood Pressure (Hypertension) : The pressure exerted by the flow of blood on the elastic walls of the arteries is called blood pressure. The blood pressure is greater during the systole than during the diastole. In normal young person, the systolic pressure is 120 mm Hg and diastole pressure is 80 mm Hg. It is normally expressed as 120/80. The pressure varies with age. It is also influenced by the rate of heart beat.

♦ The increase in the blood pressure beyond 140mm Hg (systolic) and 90 mm Hg (diastolic), is referred to as high blood pressure. A continuous or sustained rise in the arterial blood pressure is known as **hypertension** High blood pressure is a silent killer. It can damage vital organs like heart, brain, kidneys and eyes.

♦ Fall in blood pressure is termed as low blood pressure or hypotension. H
Measurement of Arterial Blood Pressure. Blood pressure is measured with the help of a apparatus called **sphygmomanometer.**



2. **Atheroslerosis :** It is caused due to the deposition of lipids (specially cholesterol) on the wall lining the lumen of large and medium sized arteries. Such a deposition is called atheromatous or atherosclerotic plaque.

3. **Angina :** It is also called 'angina pectoris. It appears when no enough oxygen is reaching the heart muscle. As a result, a symptom of acute chest pain appear in the chest. Angina can occur in men and women of any age but it is more common among the middle aged and elderly persons. It occurs due to the conditions that affect the blood flow.

4. **Heart Failure :** It is the state of heart when it is not pumping blood effectively enough to meet the needs of the body. It is sometimes called 'congestive heart failure' because congestion of the lungs is one of the main symptoms of this disease.

5. **Heart Attack :** It is the condition, when a part of heart muscles is suddenly damaged by an inadequate blood supply. It is also called **myocardial infarction.**

6. **Cardiac Arrest :** It is a condition of complete stoppage of the heart beat i.e., sudden and complete loss of cardiac function.

HEART VOLUMES ANS INDEX

(1) **Cardiac output :** Volume of blood which is pumped by heart per minute is called cardiac output. It is 5 ltr/min.

(2) **Stroke volume :** Volume of blood which is pumped by left ventricle in aorta in each heart beat.

$$S.V. = \frac{C.O.}{\text{Rate of Heart beat}}$$

$$= \frac{5 \text{ lit}}{72}$$

S. V. = 70 ml