BODY FLUIDS AND CIRCULATION

Contents

3. BODY FLUIDS AND CIRCULATION
3.1 Introduction
- Every cell needs a regular supply of nutrients, O_2 etc. to provide energy for the growth and repair.
- It also needs a constant removal of wastes like CO_2, ammonia, urea etc. to prevent their accumulation which may prove toxic to it.
- In lower organisms like one-celled protozoans example- *Amoeba, Paramecium* etc., since the cell is in direct contact with the surrounding water and there is direct exchange of materials between the cell and the water, there is no need of circulatory system.
- In higher and multicellular organisms, there is no direct supply of the useful materials to-or removal of wastes from-body cells, so there is need of an internal transport system, which is called the circulatory system.
- General functions performed by the circulatory system in animals are -
  - Transportation of nutrients like glucose, amino acids, fatty acids, vitamins etc.
  - Transportation of nitrogenous wastes like ammonia, urea, uric acid etc.
  - Transportation of respiratory gases between the organs of respiration and the body cells example- haemoglobin transports 97-99% of oxygen as oxyhaemoglobin from the lungs to body cells. It also transports 23% CO_2 from the body cells to the lungs as carbaminohaemoglobin.
  - Transportation of hormones (information molecules) from the endocrine glands to their specific target organs.
  - Transportation of intermediate metabolites example- transportation of lactic acid produced from glycogen during the muscle contraction to the liver cells where about 80% of the lactic acid is rechanged into glycogen.
  - Transportation of heat from one region to another for homeothermy.
  - Transportation of water, H^+ and chemical substances all over the body for their uniform distribution.

3.2 Blood
- The blood is red vascular and softest connective tissue.
- It is opaque, somewhat sticky and viscous fluid (viscosity = 4.7).
- Human blood is five times more viscous than distilled water.
- It is slightly heavier than water (specific gravity = 1.057 in males and 1.053 in females).
- It is slightly alkaline in nature (Average pH = 7.4).
- The oxygenated blood is bright red, while the deoxygenated blood is purple coloured.
- Blood forms about 6-10% (Average 7-8%) of the body weight.
- The volume of blood in an adult person is about 6.8 litres.
- The blood is formed of 2 parts -
  - Plasma
  - Formed elements.

3.2.1 Plasma
- It is a faint yellow coloured non-living fluid which forms about **55-60%** of the blood volume.
- Chemically, the plasma is a mixture of molecule solution of many organic and inorganic substances.
- Glucose is the main nutritive material carried by blood while urea is the main nitrogenous waste in blood.
- Most of other materials of plasma are temporary components as these are added to the blood at some specific organ, called source (example- exchange organs like intestine and depots of materials like liver) to specific sites where these are removed from blood, called sinks (example- exchange organs like kidneys).

Chemical composition of blood plasma

Contents	% age
Water	90-92%
Proteins (Albumen (4.0%), Globulin (2.5%), Properdin, Prothrombin (0.03%), Fibrinogen (0.3%).	6-8 %
Inorganic Salts (Cations are Na, K, Mg, Ca, Fe and Mn. Anions are chloride, bicarbonate and Phosphate)	1-2%
Others ○ **Food Materials** (Glucose, Amino Acids, Fatty Acids, Triglycerides) ○ **Waste Materials** (Urea, Uric Acid and Creatinine) ○ **Regulatory Substances** (Hormones, Vitamins, Enzymes) ○ **Anticoagulants** (Heparin) ○ **Cholesterol** ○ **Antibodies** ○ **Dissolved Gases** (O_2, CO_2, N_2)	1-2 %

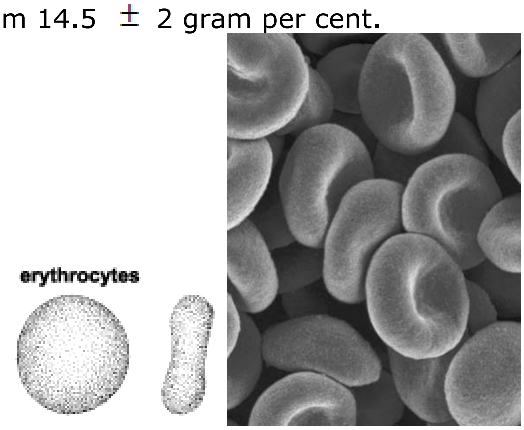
- **Functions of Plasma**
  - Transportation-Plasma transports simple food components like glucose, amino acids, fatty acids, vitamins etc. from the intestine and liver to other body parts; 1-3% O_2 from the lungs to the body tissues for oxidation of food; 7% CO_2 from the cells to the lungs for expiration; metabolic wastes like urea, uric acid etc. from body tissues to the kidneys for their excretion; hormones from the endocrine glands to their target organs; lactic acid from the muscles to the liver to change it partly into glycogen. So blood plasma helps in nutrition, excretion, respiration and homeostasis.
  - Homeothermy-Plasma helps in homeothermy by transporting heat from the muscles and glands to other organs of the body.
  - pH constancy-Certain minerals (example- bicarbonates) and proteins of plasma act as acid-base buffers and help in keeping a constant pH of blood.
  - Blood clotting. Prothrombin and fibrinogen, blood proteins, help in blood clotting at the injury.
  - Immunity- γ-globulin proteins of plasma act as immuno-globulins which provide resistance against a number of diseases.
  - Osmotic tension- The albumins of blood-plasma can hold water so are responsible for osmotic tension of blood (about 25 mm of Hg).
  - As a middle man- The plasma forms the tissue fluid which keeps the tissues moist and acts as middle man for exchange of materials between the blood and the body cells.
  - Properdin destroys certain bacteria and neutralizes certain viruses.
  - Erythropoiesis-Erythropoietin (secreted by kidneys) stimulates the RBC formation.
  - Transportation of minerals-Transferrin globulin carries the iron while ceruloplasmin globulin carries copper.

3.2.2 Formed Elements

- These include the blood corpuscles which float freely in the plasma.
- These form 40-45% of blood-plasma.
- Blood cells are three types of blood corpuscles
  - Erythrocytes or Red blood corpuscles (RBCs).
  - Leucocytes or White blood corpuscles (WBCs).
  - Platelets/Thrombocytes.

3.2.2.1 Erythrocytes or Red blood corpuscles (RBCs)

- **Shape**
  - In all vertebrates except mammals, the erythrocytes are oval, biconvex and nucleated.
  - In mammals except camel and Ilama, the mature erythrocytes are circular, biconcave and non-nucleated.
- **Size**
  - A human RBC is about 7-8 μm in diameter.
  - It is 2 μm in thickness near the rim and 1 μm or less at the centre (30 μm in frog).
- **Number**
  - The RBCs are much more in number than the WBCs.
  - The total number of RBCs per μL is called RBC count.
  - Normal RBC count is slightly lower in a woman than a man.
  - Normal RBC count in an adult human male is 5-5.5 (Average 5.4) million per cubic millimeter of blood ($5.0\text{-}5.5 \times 10^{12}$/litre of blood) while it is 4.5-5.0 (Average 4.8) million per cubic millimetre of blood ($4.5\text{-}5.0 \times 10^{12}$/litre of blood) in a normal adult woman.
  - The instrument used to determine RBC count is haemocytometer.
  - When RBC count decreases then it is called anaemia (main cause being inadequate intake of iron in the diet), while RBC count increases much more than the normal level in polycythemia.
- **Colour**
  - An RBC appears yellow when seen singly but these appear red when in bulk due to presence of a colloidal solution of an iron containing pigment haemoglobin in their cytoplasm. Moving RBCs tend to adhere with one another to form rows called rouleaux.
- **Structure**
  - A human RBC is bounded by an elastic and semi-permeable plasma-membrane which enables it to squeeze through narrow capillaries.
  - The mature mammalian RBC is also characterized by absence of nucleus, mitochondria and endoplasmic reticulum so there is low consumption of oxygen by itself.
  - Haemoglobin is a purple-coloured, iron-containing respiratory pigment of cytoplasm of RBC.
  - Haemoglobin is a conjugated protein and is formed of 4 haeme groups and a protein called globin.
  - Each haeme group contains an iron-containing porphyrin ring formed of 4 pyrrole rings. Globin is formed of 4 polypeptide chains-2α and 2β chains.
  - One RBC has about 280 million haemoglobin molecules.
  - Amount of haemoglobin per 100 ml of blood is called haemoglobin count and is measured by an instrument called haemometer.
  - The haemoglobin content of adult female amounts 12 $\pm$ 2 gram per cent whereas in adult male it amounts from 14.5 $\pm$ 2 gram per cent.



Red Blood Corpuscles

- **Life Span**
  - Due to absence of nucleus, the RBCs are short lived.
  - The old and worn out erythroycytes are destroyed by the reticuloendothelial cells of liver, spleen (Commonly called graveyard of RBCs) and bone marrow.
  - The process is called haemolysis.
  - The haemoglobin of haemolysed erythrocytes is changed into the bile pigments bilirubin and biliverdin.
  - Each RBC takes about 250,000 circuits in the body before haemolysis. RBCs are haemolysed at the rate of about 2.5-3 million per second (about 1% of total RBCs) but are also formed at the same rate so their number is maintained in the blood.
  - Average life span of human RBC is 115 – 120 days.

- **Formation**
  - The formation of red blood cells is called erythropoeisis while the organs forming red blood cells are called erythropoeitic organs.
  - In the developing foetus, the haemopoeitic tissues are liver and spleen while after the birth, RBCs are mainly produced in the bone marrow of the long bones.
  - The haemopoeisis is also controlled by iron and proteins while the maturation of RBC is controlled by folic acid and vitamin B_{12}.
  - Therefore, deficiency of these substances in the blood causes anaemia.
- **Functions**
  - Haemoglobin has high affinity for oxygen and carries about 97-99 % of oxygen from the lungs to body tissues as oxyhaemoglobin.
  - One molecule of haemoglobin can carry upto 4 molecules of oxygen at high partial pressure of oxygen (PO_2).

$$\underset{Haemoglobin}{Hb + 4O_2} \underset{Acid, Warm\,(tissues), Low\,Po_2, High\,Pco_2}{\overset{Neutral, Cool\,(lungs), High\,Po_2, Low\,Pco_2}{\rightleftharpoons}} Hb_4O_8$$

  - Haemoglobin also transports about 23 % of carbon dioxide as carbamino-haemoglobin from the tissue to the lungs.
  - Haemoglobin also acts as buffer and helps in maintaining a constant pH.

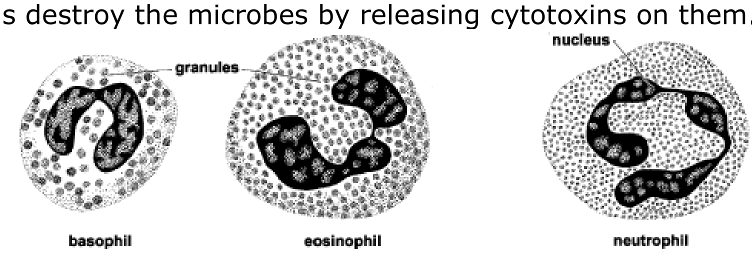
Differences between a Mammalian RBC of a Non-mammalian RBC

Characters	Mammalian RBC	Non-mammalian RBC
Shape	Circular or biconcave	Oval and biconvex.
Nucleus	Enucleated.	Nucleated.
Cell organelles	Mostly absent.	Mostly present.
Mode of respiration	Anaerobic.	Aerobic.
Haemoglobin	More in amount.	Less in amount.
Function	More transportation of O_2 and CO_2.	Less transportation of O_2 and CO_2.

3.2.2.2 **Leucocytes** or **White blood corpuscles (W.B.C.)**
- **Shape**
  - These are rounded or amoeboid, nucleated, non-pigmented cells. These are wandering cells and are capable of coming out of blood capillaries by amoeboid movements, called diapedesis.
- **Size**
  - WBCs are larger than RBCs and their size range is 8-15 µm but may be upto 20 µm.

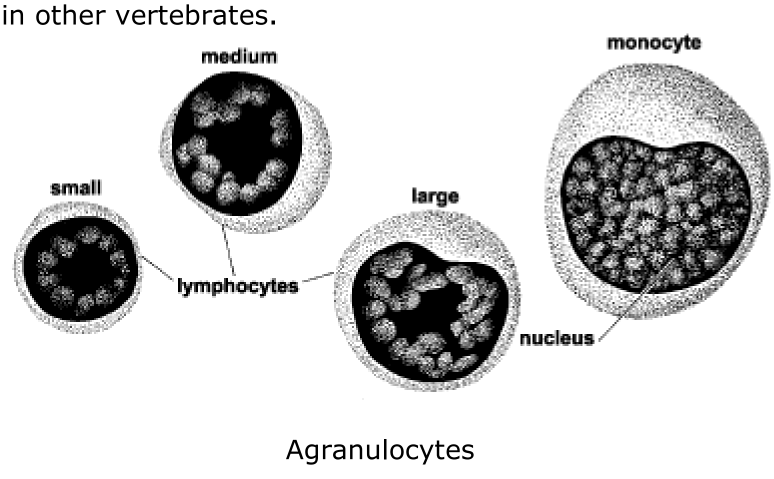
- **Number**
  - WBCs are much less in number than RBCs (1:600).
  - Total number of leucocytes per microlitre or per cubic millimetre is called total leucocyte count (TLC) and is a diagnostics feature of many diseases.
  - The number of WBCs in a healthy person ranges from 5,000 to 10,000 per cubic millimetre of whole blood.
  - Average WBC count is 6000-8000 per cubic millimetre.
  - But in an acute infection like appendicitis or pneumonia, the total leucocytes increase upto 20,000 to 30,000 per cubic millimetre of blood.
  - This rise in WBC count is called leucocytosis while the fall of WBC count below 4,000, is called leucopenia example- in folic acid deficiency and tuberculosis.
  - Leukemia (blood cancer) is a pathological increase in number and denotes one type of neoplastic disease.
  - The formation of leucocytes occurs in bone marrow, Peyer's patches, lymph nodes, thymus, spleen etc. is called leucopoiesis.

- On the basis of cytoplasmic granules, the leucocytes are divided into following two categories-
- **Granulocytes**
  - These have granular to plasma and lobed nucleus, so also called polymorphonuclear leucocytes.
  - These are produced in the red bone-marrow from the precursor cells called myeloblasts (myeloid tissue).
  - These form about 65% of total leucocytes (6.5 x 10^9 per litre).
  - These are of three sub-types on the basis of the shapes of their nuclei and the staining reactions of their granules -
    - Neutrophils-These comprise about 60-65% of the total number of white cells so most abundant sub-type. Their count is 4900 per mm^3 of blood. These vary in size from 10 to 12 μm. The cytoplasm is with fine granules which stain with both acidic and basic dyes so appear violet in colour. These granules are actually lysosomes and Golgi bodies. The nucleus is 3-5 lobed. The life span is of 10-12 hours. These are the chief phagocytic cells of the body engulf the microbes by phagocytosis so neutrophils are called soldiers of the body.
    - Basophils-These comprise about 0.5-1% of the TLC so are least in number. These vary in size from 8-10 μm. The cytoplasmic granules are coarse which take up basic stains like methylene blue, so appear blue in colour. The nucleus is 2 or 3 lobed or S-shaped. Their life-span is 8-12 hours. Basophils secrete heparin and histamine and thus have important role in local anticoagulation and formation of ground substance.
    - Acidophils-These constitute about 2-3% of the TLC. These are slightly larger in size than the neutrophils and size range is 10-15 μm. The cytoplasmic granules are coarse and take acidic stains like eosin, so also called eosinophils. The nucleus is bilobed. The life span is of 14 hours. These increase in number in allergic diseases, such as asthma or hay fever, and in parasitic infections, example- Ascariasis. These also help in healing of wounds as destroy the microbes by releasing cytotoxins on them.



Granulocytes

- **Agranulocytes**
  - These are non-granular white blood cells that contain non-lobulated nuclei. These form about 35% of the total leucocytes (3.5×10^9 per litre). These are divided in 2 sub-types -
    - Monocytes. These are the largest sized leucocytes ranging from 12-15 μm in diameter but may be upto 20μm. These form about 6-8 % of all the leucocytes. The number of monocytes varies from 100-400 per cubic mm of blood. The nucleus is oval, kidney or horse-shoe shaped and is usually excentric. These are usually formed in the lymph nodes and the spleen from the precursor cells called monoblasts. These are highly motile and phagocytic in action and engulf the bacteria so these form the second line of defence. These also differentiate into macrophages or scavenger cells which remove the damaged and dead cells to clean the body.
    - Lymphocytes. These constitute about 20-25 % of TLC. Their number varies from 1,500-2,700 per cubic mm of blood. Their size ranges from 8 to 12 μm. The nucleus is large and rounded so that cytoplasm forms a thin peripheral layer. Depending upon size, there are 2 types of lymphocytes-small (about 7 μm) and large lymphocytes (about 20 μm). These are formed in the thymus and lymphoid tissues like lymph nodes, spleen, tonsils etc. from the precursor cells called lymphoblasts. These are non-motile and non-phagocytic. Primary function of the lymphocytes is to produce antibodies and opsonins.
      - Blood-platelets - These are smallest sized blood corpuscles and have a diameter of 2-3 μm. These occur only in the blood of mammals. These are colourless, oval-shaped and discoidal cytoplasmic fragments formed from the giant cells called megakaryocytes of bone-marrow. These are non-nucleated. Each has a mass of basophilic granules at the centre so giving the appearance of a nucleus. Their number varies from $1.5 – 3.5 \times 10^5$ per cubic mm of blood. A marked decrease in the number of platelets in the blood is called thrombocytopenia (example-100,000 μl) (reported in purpurea disease) characterized by clotting disorders which lead to excessive bleeding. Increase in number of blood platelets is called thrombocytosis. Their life span is of about one week (average 10 days) after which these are phagocytosed by leucocytes. These play major role in the process of blood clotting. At injury, the platelets release a number of platelet factors and an enzyme thromboplastin which cause the coagulation of blood and clot formation to prevent excessive bleeding.
    - Thrombocytes - also called spindle cells, are spindle-shaped and nucleated cells found in blood of vertebrates other than mammals. Nucleus is oval shaped. These help in blood clotting in other vertebrates.



Agranulocytes

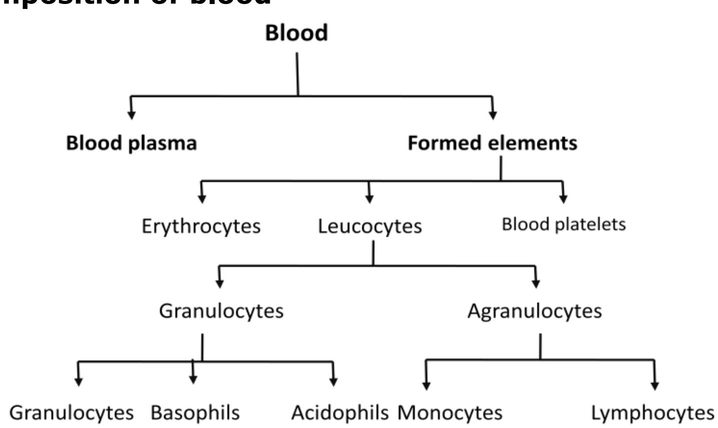
Differences between Erythrocytes and Leucocytes

Characters	Erythrocytes	Leucocytes
Number	More in number; 5-5.5 millions per cubic mm. of blood.	Less in number, 5000-10000 per cubic mm. of blood.
Size	Smaller in size (7-8 μm).	Larger in size (8-15 μm).
Shape	Circular and biconcave.	Rounded or amoeboid.
Nucleus	Denucleated.	Nucleated.
Haemoglobin	Present.	Absent.
Colour	Red-coloured.	Colourless.
Motility	Non-motile so float in plasma.	Motile and can undergo diapedesis.
Cell-organelles	Mostly absent.	Present.
Life span	About 120 days.	A few hours to several years.
Function	Haemoglobin transports O_2 as well as CO_2.	Defence and immunity of the body.

Characteristics of different types of leucocytes

Characters	Neutrophils	Basophils	Acidophils	Monocytes	Lymphocytes
% of leucocytes	60-65 %	0.5-1 %	2-3 %	6-8 %	20-25 %
Diameter	10-12 μm	8-10 μm	10-15 μm.	12-15 μm.	8-12 μm.
Nucleus	Multilobed	S-shaped.	Bilobed.	Kidney-shaped.	Rounded.
Cytoplasm	Neutrophilic	Basophilic	Eosinophilic	Basophilic	Basophilic
Granules	Fine granular	Coarse granular.	Coarse granular.	Absent.	Absent.
Life span	10-12 hours	8-12 hours.	14 hours.	10-20 hours.	Months to years.
Formation	Red bone marrow.	Red bone marrow.	Red bone marrow.	Spleen and lymph nodes.	Lymph nodes and Thymus.
Function	Soldiers acting as phagocytes	Heparin and histamine secretion.	Antiallergic and healing of wounds.	Scavenger.	Antibodies formation.

- **Summary of composition of blood**



3.2.3 Blood Groups

- On the surface of plasma membrane of RBCs, certain glycoproteinous molecules, called antigens, are present.
- These antigens differ in different persons and give specific blood grouping properties to them.
- Two very important and common types of blood groups are –

3.2.3.1 ABO-Blood groups

- A German biochemist, Karl Landsteiner (1901), on the basis of the blood-transfusion results, proposed that blood of different persons has some biochemical differences.
- He confirmed the presence of two types of proteins in the human blood-
  - Agglutinogen or antigens- It is a glycoprotein present on the surface of RBCs, also called corpuscle factor. There are two types of antigens – A and B. A person may have neither of them or one of them or both of them.
  - Agglutinin or antibody- It is a γ-globulin protein present in the blood plasma, so is also called plasma factor. There are two types of antibodies a and b. A person may have neither of them or one of them or both of them.
- Both antigen 'A' and antibody 'a' (also called Anti-A) are incompatible, and antigen 'B' and antibody 'b' (also called Anti-B) are incompatible to each other and cause self-clumping.
- So these s how agglutination when incompatible bloods come together.
- On the basis of nature of antigens present, four types of blood groups have been recognized.
- The person with O-blood group is called universal donor as it has no antigen and can donate its blood to any person, while the person with AB-blood group is called universal recipient as it has no antibody in their blood-plasma so can receive blood from any blood group.

Different types of blood groups

Blood Group	Antigen	Antibody	Can give blood to	Can receive blood from	Genotype
A	A	B	A, AB	A,O	AA or AO
B	B	a	B,AB	B,O	BB or BO
AB	A, B (Both)	None	AB	All **(Universal recipient)**	AB
O	None	a, b (Both)	All **(Universal donor)**	O	OO

  - Blood group A has A-antigen and b-antibody.
  - Blood group B has B-antigen and a-antibody.
  - Blood group AB has both A and B antigens but no antibody.
  - Blood group O has no antigen but with both antibodies.
- Knowledge of blood groups is used in safe blood transfusion so that the corpuscle factor of the donor's blood must be compatible with the plasma factor of recipient.
- If donor's and recipient's blood are incompatible, then donor's blood is agglutinated.
- Safest blood for blood transfusion is O^-.
- ABO-Incompatibility during blood transfusion
  - Blood transfusion involves the transfer of blood from one person to another.
  - No problem arises when a compatible blood is transfused.
  - But when an incompatible blood is transfused (example- Donor with B-blood group and recipient with A-blood group or vice versa), then reaction occurs between donor's antigen and recipient's antibody causing the clumping of donor's blood inside the blood vessels of the recipient resulting in blockage of the blood vessels which may be fatal to the recipient.

ABO-Incompatibility during pregnancy

- Blood group incompatibility between the maternal blood and foetal blood may cause problems example-If female with A-blood group (with A-antigen and anti-A antibody) carries a foetus with B-blood group (with B-antigen and anti-B antibody).
- Then antibodies of maternal blood enter the foetal blood circulation and may destroy red blood cells of the foetus having incompatible antigen.
- This may cause anaemia, jaundice, etc. in the baby, called haemolytic disease of new born.

3.2.3.2 Rh Grouping

- Rh factor is an antigenic protein present on the surface of red blood cells in the human beings.
- It was first discovered by Landsteiner and Weiner (1940) on the plasma-membrane of RBCs of rhesus monkey; *Macaca rhesus*, so it is called Rh-factor or D-antigen.
- Later, it was also found in about 85% of Americans and 93% of Indians and were called Rh-positive (Rh^+).
- The person with no Rh-factor on the surface of their RBCs is called Rh negative (Rh^-).
- Rh-factor character is controlled by a pair of genes-R and r.
- R-gene is dominant and controls the synthesis of RH-factor while r-gene cannot synthesize Rh-factor, so different possible genotypes are-

Phenotype	Genotype
Rh-positive	RR or Rr
Rh-negative	rr

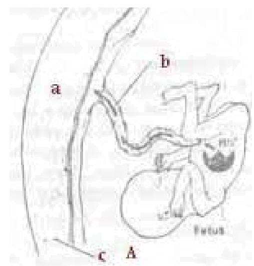
Incompatibility of Rh factor during pregnancy

- The child of a homozygous Rh-positive male and his Rh-negative wife will always be Rh-positive. Rh+ child develops in the womb of a Rh- mother.
- When foetal and maternal blood come closer during placenta formation, then small amount of Rh-antigen of the developing foetus enters the maternal blood and stimulates her WBCs to produce antibody called anti-Rh-factor which remains effective in maternal blood for several months or years.
- Since the total amount of Rh-antigen in the foetus is very small, so total amount of antibodies formed in the mother will be less and may not cause any harm to the first baby and is delivered normal.
- But from the second pregnancy onward, the accumulated antibodies from the maternal blood enter the foetal blood and cause agglutination of foetal blood cells.
- This is called erythroblastosis foetalis (Fig. 18.13) and causes the immediate death of the baby due to severe anaemia, or a few days after the birth due to increased destruction of Hb and overproduction of bilirubin which damages the baby's brain.
- In such cases, blood-transfusion of baby just after the birth is recommended.
- Now shortly after each birth of first Rh^+ baby, the mother is given an injection of anti-Rh antibodies, called Rh-immunoglobulin (Rhlg) or Rhogam.
- These passively acquired antibodies destroy any foetal cells that got into her circulation before they can initiate an active immune response in her.
- No abnormality arises when the wife is-Rh positive and her husband is Rh-negative.

Incompatibility of Rh factor in blood transfusion

- Blood transfusion involves transfer of blood from one person to another person.
- Human blood does not normally contain any antibody for Rh^- factor.
- However, if the blood of a Rh^+ donor is injected into the blood of a Rh^- recipient in blood transfusion, anti-Rh antibody is formed and gradually accumulates in the blood of the recipient.

- But no complication occurs in the recipient after the first transfusion.
- Consequently, any subsequent transfusion of Rh^+ blood to the same patient will cause clumping of donor’s RBCs in recipient’s body, causing blocking of blood capillaries and death.



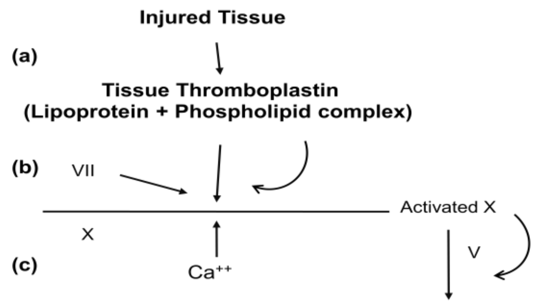
3.2.4 Coagulation of Blood

- The property of blood to change from fluid to gel state within a few minutes of its coming in contact with air is called blood coagulation or blood clotting.
- To prevent excessive loss of blood from an injury, so is a natural defensive mechanism.
- The blood clot begins to form within 15 to 20 seconds but is fully formed within 3 to 6 minutes in a normal person.
- According to International Commission on Blood Coagulation (1954), thirteen coagulation factors are involved -
  - Fibrinogen (Synthesized by liver and released in blood plasma).
  - Prothrombin (Synthesized by liver in the presence of vitamin K).
  - Tissue Thromboplastin (Released from injured tissues and blood platelets at injury).
  - Calcium ions
  - Labile factor
  - Accelerin
  - Stable factor or Proconvertin
  - Antihaemophilic factor (AHF)
  - Christmas factor
  - Stuart Prower factor
  - Plasma Thromboplastin Antecedent (PTA)
  - Hageman or Surface factor
  - Fibrin stabilizing factor.

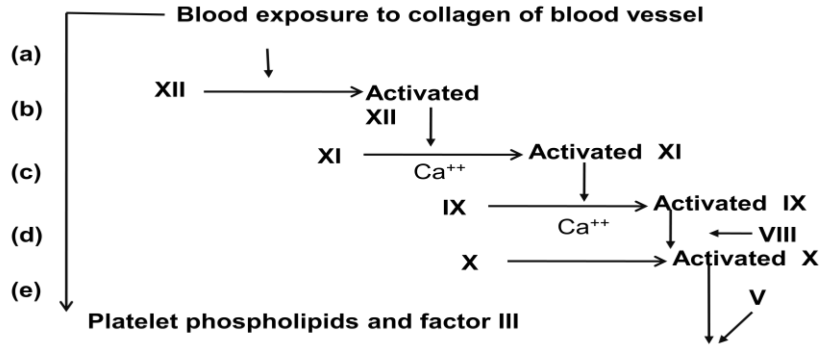
- Most of these clotting factors circulate in the blood as inactive precursors, called native form.
- These are activated by proteolytic cleavage becoming active proteases by other factors of the system.

3.2.4.1 Mechanism of Blood coagulation

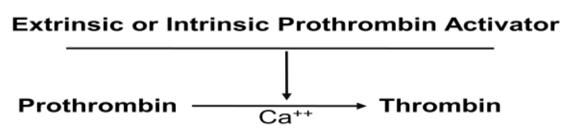
- According to Biggs and Macfarlone (1966), blood clotting is a cascade mechanism (chain reaction with multiplication at every step) and involves three essential steps -
  - Formation of Prothrombin Activator.
    - It is a combination of activated factors like X, V, platelet phospholipids and calcium.
    - Xa is the fundamental agent while others act as cofactors. It is formed in two ways -
      - Extrinsic pathway-This mechanism begins with a trauma to the blood vessel and the surrounding tissue and involves the formation of prothrombin activator by three steps-



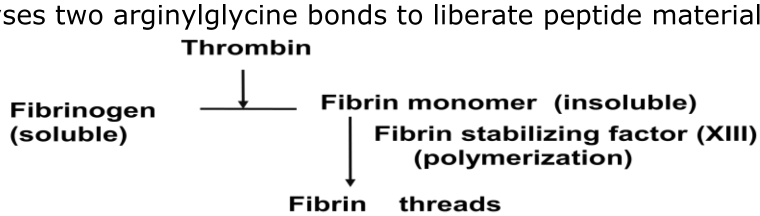
- Intrinsic pathway-This mechanism begins with a trauma to blood itself for when the blood comes in contact with the collagen of injured blood vessel and involves the formation of prothrombin activator by a series of five steps showing cascade reactions



- Conversion of Prothrombin to thrombin.
  - Thrombin causes further aggregation and breakdown of the platelets at the injured site of the blood vessel for more thromboplastin.
  - This is called positive feedback mechanism.

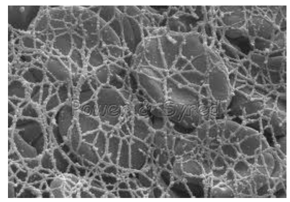


- Conversion of Fibrinogen to fibrin and formation of blood clot.
  - Conversion of Fibrinogen into Fibrin by a protein enzyme thrombin which removes four low mol wt peptides from fibrinogen to form a fibrin monomer.
  - Thrombin hydrolyses two arginylglycine bonds to liberate peptide material.



  - Formation of fibrin threads is very rapid process and takes only 10 to 15 seconds.
  - Fibrin threads polymerize and form a meshwork which traps blood cells, platelets etc. to form a clot or coagulum so the process is called blood clotting.
  - In the beginning, fibrin monomers in fibrin threads are joined by weak non-covalent H-bonds and threads are not cross-linked.
  - This is called soft clot.

- But within a few minutes, activated Factor XIII (Fibrin stabilizing factor) stimulates the formation of covalent bonds and cross-linkages by disulphide bonds between fibrin threads to form hard clot.
- So a blood clot consists of a plug of platelets eumeshed in a network of insoluble fibrin molecules.
- Within a few minutes, the clot begins to contract and a pale-coloured fluid called serum is formed within 20 to 60 minutes.
- This is called clot-retraction.



- Serum differs from blood plasma in being without blood clotting proteins like prothrombin and fibrinogen so cannot clot the blood.
- So serum is basically plasma minus blood clotting proteins.
- Blood clotting is a vicious cyclic process in which the blood clot formed itself promotes more clot formation.
- It is so because thrombin exerts a positive feedback stimulation of proteolytic conversion of more prothrombin to thrombin.

Differences between Plasma and Serum

Characters	Plasma	Serum
Composition	Liquid part of blood and has more proteins and calcium.	Liquid which oozes out of blood clot and has less proteins and calcium.
Prothrombin and fibrinogen	Present so has clotting power.	Absent so has no clotting power.
Physical appearance	Pale-yellow coloured and turbid.	Colourless with no turbidity.

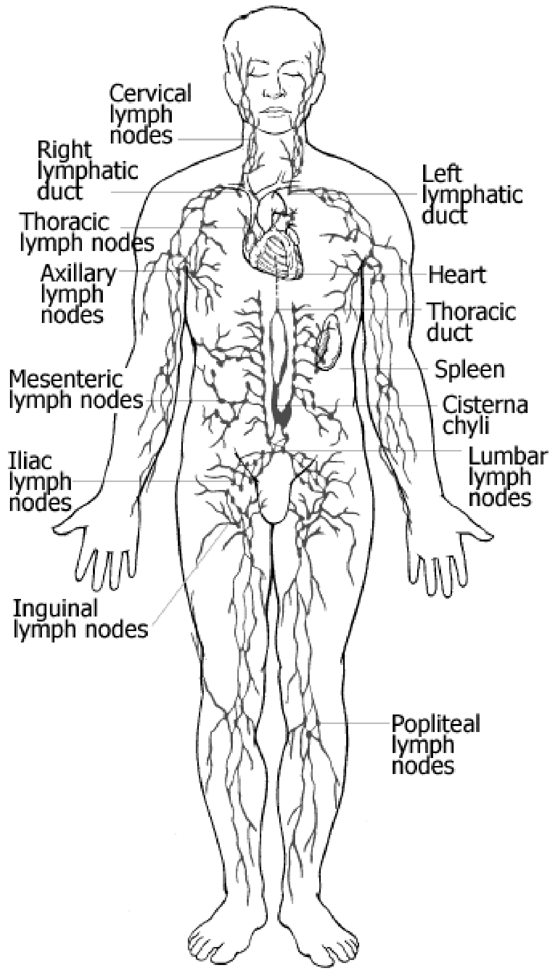
3.3 Lymphatic System

- The lymphatic system is formed of following parts -
- Lymph, Lymphatic capillaries, Lymphatic vessels and Lymphatic nodes

3.3.1 Lymph/Tissue Fluid

- Lymph is a white vascular connective tissue.
- It is highly translucent, alkaline fluid present in the lymph vessels and between the blood capillaries and the tissues.
- It also forms the tissue fluid which surrounds the body tissues.
- Lymph is formed of 2 parts -
  - Plasma-It is fluidy matrix of lymph. It is similar to that of the blood except that it has less proteins, calcium and phosphorus. It is actually derived from the blood by the process of ultrafiltration.
  - Leucocytes (WBCs)-These are floating amoeboid cells of lymph. These also resemble with those of blood. These also come from the blood by diapedesis. The main cells are lymphocytes. These are also less in number.
- So the lymph is the blood minus RBCs, platelets and some proteins.

- **Functions**
  - The lymph acts as middle man between the blood and the tissue cells as it passes on food and oxygen from blood to tissue cells and hands over excretory wastes, hormones and carbon dioxide from the body cells to the blood.
  - Lymph present in the lacteals of intestinal villi helps in absorption of fats.
  - It also transports fat food from the intestine to the venous blood.



Differences between Blood and Lymph

Characters	Blood	Lymph
Type of tissue	Red vascular tissue.	While vascular tissue.
Occurrence	In blood vessels.	In lymph vessels; around body tissues.
Composition	Formed of plasma, erythrocytes, leucocytes and platelets. Neutrophils are most abundant.	Formed of plasma and leucocytes only. Erythrocytes and platelets are absent. Lymphocytes are most abundant.
Haemoglobin	Present in RBCs.	Absent.
Nature of plasma	Plasma has more proteins, calcium and phosphorus.	Less proteins, calcium and phosphorus.
Functions	Transportation of materials inside the body.	Acts as middle-man between blood and body cells.

3.3.2 Lymphatic capillaries

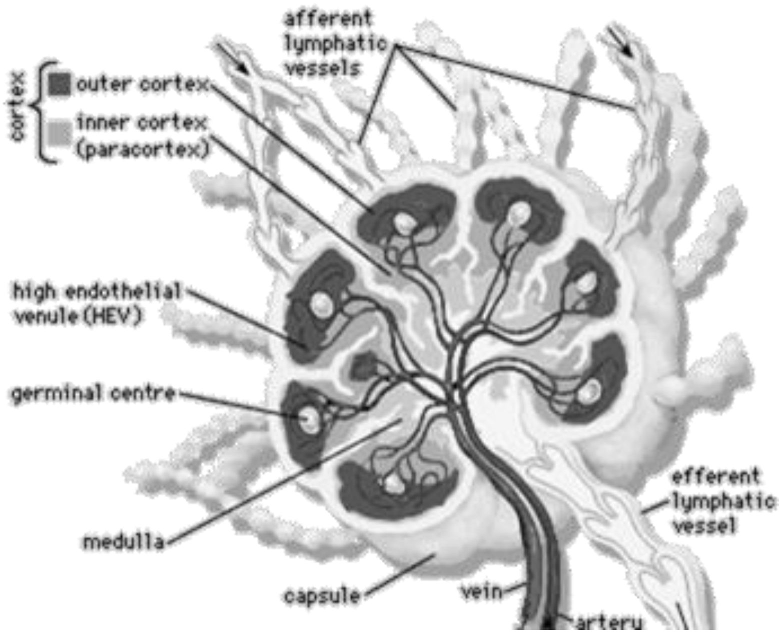
- These are small, thin-walled vessels which are present in nearly all the body tissues.
- These are thin-walled but wider than the blood capillaries.
- Each is lined by an endothelium of thin and flat cells.
- Lymph capillaries present in the villi of the small intestine are milky-coloured due to presence of chylomicrons and are called lacteals.

3.3.3 Lymphatic vessels

- These are formed by the joining of the lymphatic capillaries.
- These resemble the veins in having valves to prevent the backflow.
- These have thinner walls but numerous valves which give them a beaded appearance.
- These join and rejoin and finally form two main lymphatic ducts -
  - Thoracic duct
    - It collects the lymph from alimentary canal by the lacteals which first join to form a receptaculum chyli.
    - It also receives the lacteals from the abdomen, from left side of thorax, left upper limb and left side of neck.
    - It runs upward in front of the vertebral column and opens into the venous system the junction of left subclavian and left internal jug veins.
  - Right lymphatic duct
    - It is shorter and collects the lymph from the right side of thorax, right upper limb and right side of neck.
    - It finally opens into the venous system at the junction of right subclavian and right internal jugular veins.

3.3.4 Lymph nodes

- These are small, oval or bean bodies placed in the course of the lymphatic vessel.
- These act as filters and are the sites of formation of lymphocytes.
- These mainly lie in the neck, axilla, thorax, abdomen and groin.
- Lymph nodes are maximum in armpit and groin.
- A lymph node has an inner border called hilum.
- It is composed of fibrous and muscular tissues externally covered by a fibrous capsule which is produced into a number of partitions called trabeculae.
- Inner matrix of lymph node is differentiated into two parts
  - Central medulla
  - outer cortex
- Cortex has follicular aggregations of B-lymphocytes which form spherical masses of cells called primary nodules.
- These transform into secondary nodules when stimulated by the antigens.
- Each secondary follicle has a germinal centre at the centre which is surrounded by B-cell areas.
- Germinal centre is the site of maturation of B-cells.
- These contain the phagocytic WBCs, lymphocytes, plasma cells and macrophages which remove micro-organisms and cellular debris.
- Lymph nodes also destroy cancer cells.
- These are also the sites of formation of lymphocytes which form antibodies to provide immunity.



Differences between Blood capillaries and Lymph capillaries

Characters	Blood capillaries	Lymph capillaries
Components of	Blood vascular system.	Lymphatic system.
Fluid present	Red-coloured blood.	Colourless lymph.
Wall	Endothelium is simple and basement membrane is distinct.	Endothelium is attenuated and basement membrane is poorly developed.
Size	Narrower with uniform diameter.	Wider with non-uniform diameter.
Fluid pressure	High.	Low.
Function	Add tissue fluid in the intercellular spaces.	Absorb tissue fluid from intercellular spaces.

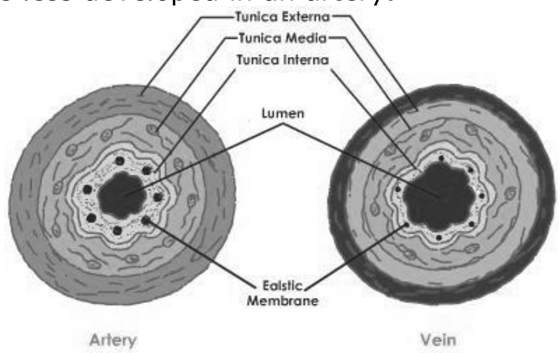
3.4 Circulatory Pathways

3.4.1 Human Circulatory System

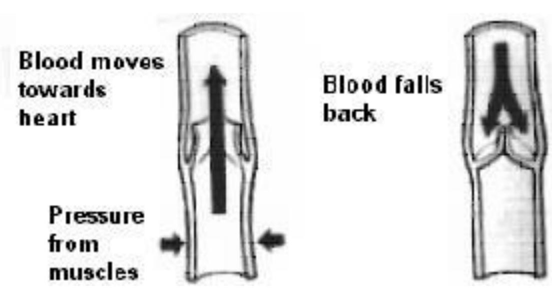
- A well developed blood vascular system is present in higher invertebrates from the annelids to the echinoderms and all the chordates.
- It is advantageous as blood is not affected by changes in environmental factors like temperature, light, pollution, etc.
- It is so because :
  - These have thick body wall to prevent the evaporation of water of the body, so exchange of the materials between the body cells and environment by diffusion is not possible.
  - These have higher metabolic rate and need greater supply of nutrients and oxygen and the rapid removal of wastes and CO_2.
  - Annelids are the first metazoans to have a well developed circulatory system.
- Blood vascular system consists of three components -
  - Heart- It is a thick, muscular, automatic pulsating and contractile organ which pumps the blood to the various parts of the body through the blood vessels.
  - Blood vessels-These are hollow, tubular vessels which conduct the blood from the heart to body tissues and from the tissues to the heart. These blood vessels are of three types -Arteries, veins and capillaries.
    - **Arteries** -A blood vessel (artery or vein) is formed of three coats -

- **Tunica interna**-It is innermost and is formed of two parts :
    - ✓ **Endothelium**- It is inner lining of flattened endothelial cells joined edge to edge. It rests on basement membrane. The endothelial cells are more elongated in the artery than in the vein.
    - ✓ **Elastic membrane**-It is outer layer and is formed of yellow fibrous tissue. It is more developed in an artery.

- **Tunica media**- It is the middle coat formed of smooth circular muscle fibres and a network of elastic fibres. It is better developed in an artery. So artery is more elastic and more contractile.
- **Tunica externa (Tunica adventitia)**- It is the outermost coat and is formed of collagen-rich connective tissue which blends with the general tissues of the body. The collagen fibres give strength to the blood vessels and prevent overdilation of the blood vessels. It is less developed in an artery.



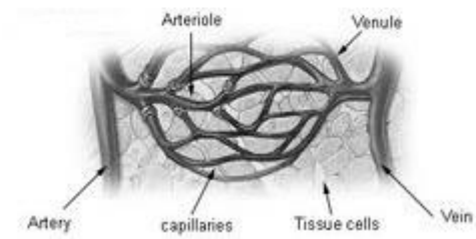
- **Veins**
    - In the circulatory system, veins (from the Latin vena) are blood vessels that carry blood towards the heart.
    - Most veins carry deoxygenated blood from the tissues back to the heart; exceptions are the pulmonary and umbilical veins, both of which carry oxygenated blood to the heart.
    - Veins differ from arteries in structure and function; for example, arteries are more muscular than veins, veins are often closer to the skin and contain valves to help keep blood flowing toward the heart, while arteries carry blood away from the heart.



- **Capillaries**
    - The artery further divides into thinner branches called arterioles inside the organ. Average diameter of arteriole is 120 μm.
    - The arteriole further divides into smaller vessels called meta-arterioles (70μm) which in turn divide into capillaries.
    - The capillaries are thinnest blood vessels of the order of 10 μm in diameter.
    - Each capillary is lined by a single layer of flat cells, called endothelium.
    - The endothelium allows the exchange of materials like the nutrients, respiratory gases, waste products, the hormones etc. between the blood and the surrounding

tissue cells through the tissue fluid. i.e. passage of nutrients and oxygen from blood into the tissue fluid, and passage of nitrogenous wastes and CO_2 from the body cells into the blood on the principle of diffusion.

- These also allow the loss of water from the blood at the aterial end of capillaries due to higher hydrostatic pressure than colloidal osmotic pressure (caused by plasma proteins especially albumins) while receive the water into blood at the venous end due to higher value of osmotic pressure than hydrostatic pressure.
- Arterial capillaries rejoin and form the venous capillaries which further join to form the venules which finally join and form a vein.
- The vein comes out of the organ.
- Average diameter of a venule is 150 μm while large veins have a diameter greater than 10 μm. Veins join to form greater veins called venae cavae which open in the heart.



Differences between an Artery and a Vein

Characters	**Artery**	**Vein**
Direction of blood	From heart to body organs.	From body organs to heart.
Nature of blood	Mostly oxygenated.	Mostly deoxygenated.
Pressure and speed of the blood	Pressure is high and speed is faster.	Pressure is low and speed is slow.
Nature of wall	Wall is thicker and more elastic.	Wall is thinner and less elastic.
Lumen	Narrow.	Wide.
Position	Deep seated.	Superficial.
Valves	Without valves.	With valves to prevent back flow.

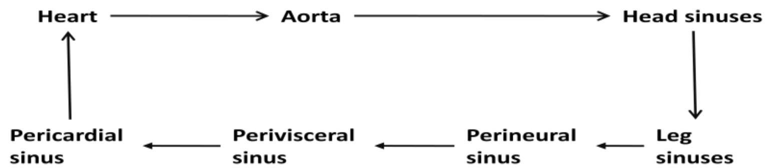
- **Blood-** Blood is the red vascular connective tissue which contains some carrier molecules examples- haemoglobin, haemocyanin, plasma proteins etc. which can transport large amounts of nutrients, respiratory gases etc.

3.4.1.1 Types of Circulatory Pathways

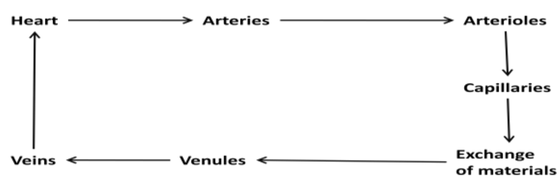
- The circulatory patterns are of two types -
  - Open circulatory system- It is found in leeches among the annelids, most of the molluscs except cephalopods, and Arthropods (prawns, crabs, insects, spiders).

    In this, blood finally comes out of the blood vessels in open spaces and channels called lacunae and sinuses. In arthropods (example- cockroach) and molluscs, these sinuses to form a body cavity with blood called the haemocoel. In leeches, it is called haemocoelomic system.
    - Open circulatory system is characterized by
      - Blood flows at a very low velocity and at low pressure due to absence of smooth muscles.

- There is a direct contact between the body cells and blood so there is direct exchange of materials between them.
- The respiratory pigment, when present, is dissolved in the plasma of the blood and there are no red corpuscles.



- Closed circulatory system
  - It is found in most of annelids (examples- earthworm, Nereis); cephalopods among the molluscs and all vertebrates including human beings.
  - In this, blood flows in closed tubular structures called blood vessels (arteries, veins and capillaries).
  - It is characterized by -
    - ✓ As arteries and arterioles have smooth circular muscles in their walls which undergo contraction and relaxation, so blood is always at high pressure.
    - ✓ There is no direct contact between body tissues and blood. The exchange of materials between the blood and cells takes place through the tissue fluid.



3.4.1.2 Significance of Closed circulatory system

- Closed circulatory system has two-fold significance
  - Due to presence of muscular and contractile blood vessels, the speed of circulation is more rapid in the blood vessels than in open channels. So blood takes shorter time to circulate through them. This enhances the supply and removal of materials to and from the tissues by the blood. This increases the efficiency of circulation.
  - By controlling the contraction and relaxation of muscles of blood vessels, volume of blood flowing through a tissue or organ can be regulated.

Difference between Open and Closed circulatory system

Characters	**Open circulatory system**	**Closed circulatory system**
Occurrence	In some annelids, most of molluscs and arthropods.	In most of annelids, cephalopod molluscs and all vertebrates.
Position of blood	Blood does not remain confined in the blood vessels and comes in lacunae or sinuses.	Blood remains confined, in the blood vessels.
Blood pressure	Blood flows at low pressure and cannot be regulated.	Blood flows at high pressure and can be regulated.
Velocity of blood	Blood flows at low velocity.	Blood flows at high velocity.
Exchange of materials	Direct exchange between blood and body cells.	Exchange occurs through the tissue fluid.
Respiratory pigment	When present, it is dissolved in blood plasma.	Always present and is usually present in RBCs e.g. vertebrates.
Efficiency	Less efficient as blood takes	More efficient as blood circulation

	more time to complete one circulation.	is completed in short period.

3.4.1.3 Mammalian Heart

- **Position and shape**
  - It is a thick, muscular, reddish brown, mesodermal in origin, conical organ present in the mediastinal space of thoracic cavity between two pleura enclosing the lungs.
  - Its broader side, called base, is forward and upward, while pointed side, called apex, is backward and downward and is about 9 cm to the left of the median axis. Human heart is about the size of a person's closed fist.

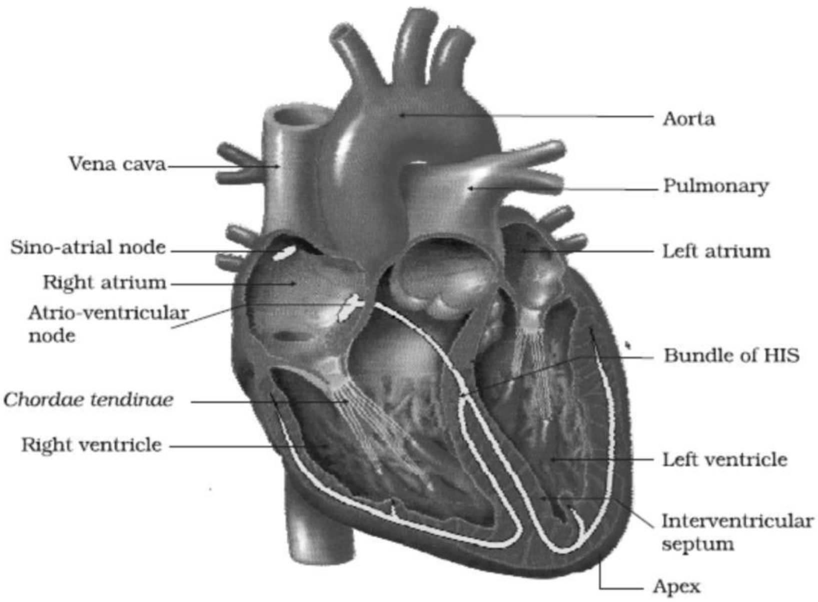
- **Pericardium**
  - It is a thin, transparent two layered serous sac around the heart. Inner layer is called visceral pericardium, while outer layer is called parietal pericardium.
  - A narrow cavity between two layers is called pericardial cavity which is filled with a watery fluid called pericardial fluid (about 15 ml) which performs two functions -
    - It allows frictionless movements of heart.
    - It protects the heart from mechanical shocks.

- **External structure**
  - On the surface of the heart, there are **two grooves** :
    - Coronary sulucs (Atrio-ventricular groove)- It is a transverse groove which divides the heart in anterior, smaller, thinner and softer part, auricular part, and posterior, longer, thicker and harder part, ventricular part.
    - Interventricular groove- It is an oblique longitudinal groove on the ventral side of ventricular part. Apex of heart is formed of only left ventricle.
    - Each auricle is produced into a process in front of the respective ventricle, called auricular appendix.

- **Internal structure**
  - Internally, the human heart is four chambered- two auricles (atria) and two ventricles and there is complete separation of oxygenated and deoxygenated blood.
    - **Auricles or Aria**
      - Both auricles are thin walled because they have to push the blood only upto ventricles.
      - Both auricles are smooth walled except a low network of ridges called musculi pectinati.
      - Both auricles are separated by a thin vertical interatrial (interauricular) septum which prevents mixing of oxygenated and deoxygenated blood.
      - Right atrium is larger in size. Interatrial septum has an oval-shaped depression, fossa ovalis, which is a vestige of an oval aperture, foramen ovale, present in the foetus and connecting two auricles.
        - ✓ Right auricle-It receives deoxygenated blood by three large veins : superior vena cava (pre-caval) from head, fore limbs and upper part of chest; inferior vena cava (post caval) from lower part of trunk and hind limbs and coronary sinus from wall of heart. Opening of inferior vena cava is guarded by a valve of Eustachius, while opening of coronary sinus is guarded by valve of Thebesius. Right auricle opens in right ventricle through a wide circular right auriculoventricular aperture guarded by right auriculoventricular valve which is formed of three flaps, called cusps, so it is also called tricuspid valve. It regulates unidirectional flow of blood from right auricle to right ventricle but prevents the back flow of blood with the help of a

number of whitish, elastic threads called chordate tendineae which extend from tricuspid valve to wall of right ventricle.

- ✓ Left auricle-It receives oxygenated blood from lungs by four pulmonary veins (two from each lung). These have no valve. Left auricle opens in left ventricle by a wide crescentic aperture called left auriculoventricular aperture. It is guarded by left auriculoventricular valve which is formed of two flaps or cusps, so is also called bicuspid valve (mitral valve). It regulates the flow of blood from left auricle to left ventricle but prevents backflow of blood with the help of chordate tendineae similar to those in right ventricle.



Human Heart

Differences between Tricuspid valve and Bicuspid (mitral) valve

Characters	**Tricuspid valve**	**Bicuspid (Mitral) valve**
Location	Guards the right atrioventricular aperture.	Guards the left atrioventricular aperture.
Structure	Formed of three flaps of different sizes.	Formed of two flaps of equal size.
Function	Prevents backflow of blood from right ventricle to right auricle.	Prevents backflow of blood from left ventricle to left auricle.

Differences between Right auricle and Left auricle

Characters	**Right auricle**	**Left auricle**
Size	Larger in size.	Smaller in size.
Wall	Comparatively thin-walled.	Comparatively thick-walled.
Type of blood	Receives deoxygenated blood from the body parts by 3 great veins.	Receives oxygenated blood from the lungs by pulmonary veins.

- **Ventricles**
  - ➢ Both the ventricles are thick walled.
  - ➢ Left ventricle is much thicker than right ventricle (about three times) because left ventricle has to push the blood to all the body parts while right ventricle has to push the blood to closely lying lungs only.

- Both ventricles are rough walled and have ridges and grooves.
- Ridges are of two types - A low network of ridges called columnae carneae and a few well developed ridges called papillary muscles or musculi papillares to which chordae tendineae are attached.
- Both ventricles are separated by a thick vertical interventricular septum which is placed obliquely towards the right side.
- So there is no mixing of deoxygenated and oxygenated blood in the ventricular part of heart.
  - ✓ Right ventricle-From left anterior corner of right ventricle, there originates the pulmonary arch or pulmonary aorta which carries deoxygenated blood to the lungs.
  - ✓ Left ventricle-From right anterior corner of left ventricle, there originates aortic (systemic) arch which carries oxygenated blood to various body parts.
- At the base of each of pulmonary and aortic arches, there is a valve called pulmonary valve and aortic valve, respectively.
- Each valve is formed of three semilunar valves which are directed away from the ventricle.
- These allow blood to enter the great artery from ventricle, but prevent the back flow of blood into the ventricle.
- In adult, two arches are interconnected by a yellow fibrous band called ligamentum arteriosum, which is the vestige of ductus arteriosus or duct of Botalli present in the embryonic heart.

Differences between Right Ventricle and Left Ventricle

Characters	**Right Ventricle**	**Left ventricle**
Size	Smaller in size.	Larger in size.
Shape	Crescent-shaped.	Nearly biconvex.
Wall	Thin-walled.	Thick-walled (about 3 times).
Moderator-band	Present.	Absent.
Nature of blood	Deoxygenated.	Oxygenated.

Differences between Mammalian and Amphibian heart

Characters	**Mammanlian heart**	**Amphibian heart**
Number of chambers	3-chambered (2 auricles and unpartioned ventricle).	4-chambered (2 auricles and 2 ventricles). Ventricle is partitioned.
Sinus venosus	Present.	Absent.
Truncus arteriosus	Divides in 3 pairs of arches.	Only 2 arches.
Atrio-ventricular valve	Both auricles open in ventricle by a common aperture guarded by atrioventricular valve.	Presence of bicuspid and tricuspid valves.
Nature of blood	Mixed blood passes through heart.	Oxygenated blood in left half and deoxygenated blood in right half of heart.

- **Types of heart**
  - On the basis of control of hearbeat, there are two types of hearts
    - Myogenic hearts
    - Neurogenic hearts

Differences between Myogenic and Neurogenic heart

Characters	Myogenic heart	Neurogenic heart
Occurrence	Molluscs and vertebrates.	Annelids, crustaceans and insects
Initiation of hearbeat	Under nodal tissues of muscle fibres so under muscular control.	Under a nerve ganglion present on the heart so under nervous control.
Path of impulses	Spread via cardiac muscle fibres.	Spread via nerve fibres.

3.4.1.4 Heart in Different Vertebrates

- Heart is a thick, muscular, contractile and automatic pumping organ of blood vascular system. Internally, the heart is formed of a number of interconnected chambers. The number of chambers varies in different vertebrates example-
  - Fishes- In most of fishes, the heart is two-chambered (with one auricle and one ventricle), venous and branchial heart (as it pumps deoxygenated blood to the gills) with single circulation (blood passes once through heart to supply once to the body). Only the lung fishes have 3-chambered heart.
  - Amphibians (frog) - Heart is 3-chambered (two auricles separated by an inter auricular septum and an unpartitioned ventricle). Right auricle receives deoxygenated blood while left auricle receives oxygenated blood. The ventricle supplies only mixed type of blood. Heart is arteriovenous and has double circulation. In amphibians, truncus arteriosus is formed by the fusion of conus arteriosus and ventral aorta.
  - In most of reptiles -The heart is 3-chambered but ventricle is incompletely divided by an interventricular septum. Heart is 4-chambered in the crocodiles, alligator and gharial. Reptilian heart is also arteriovenous and has double circulation.
  - In birds and mammals - Heart is 4-chambered (with two auricles completely separated by an interauricular septum and two ventricles completely separated by an interventricular septum). In them, the heart is arteriovenous and has double circulation.

3.4.1.5 Heart - Rhythm Control and Impulse Conduction

- The heart is formed of cardiac muscles which have the property of excitability and conductivity.
- So, when the cardiac muscles are stimulated by a specific stimulus, these got excited and initiate the waves (depolarization) of electric potential, called cardiac impulses, which are conducted along the specific cardiac muscle fibres on the wall of the heart chambers.
- Initiation of heart beat is under three special bundles of cardiac muscles called nodal tissues, so is called myogenic -
  - Sinu-auricular or sino-atrial node (S.A. node).
    - It lies in the right wall of right auricle, below the opening of superior vena cava.
    - It has a rest potential of only -55 to -60 mV.
    - It is also called pacemaker as it is first to originate the cardiac impulses and determines the rate of heart beat.
    - So the atrial contraction precedes the ventricular contraction.
    - It has the highest degree of autorhythmicity (self-contraction) (70-75 times/minute) but least conductivity.
    - It maintains the basic rhythm of heart beat.
    - These cardiac impulses are conducted along the tracts of special cardiac muscle fibres (called internal pathways) over both the auricles at the rate of 1 meter/second.
    - These impulses reach the A.V. node about 0.03 second after their origin from S.A. node.

- This delay of the contractile signals at the A.V. node allows the intrinsic regulation and allows the complete contraction of the atria.
- These impulses cannot be passed to the wall of ventricles as the cardiac muscle fibres of auricles and ventricles are separated by a thin layer of fibrous connective tissue, annular pad.

- Atrio-ventricular node (A.V. node)
  - It is also called pace setter.
  - It lies in the right atrium near the junction of interauricular and interventricular septum close to opening of coronary sinus.
  - It is stimulated by the waves of contraction initiated by S.A. node.
  - It generates the cardiac impulses, which are conducted to the muscles of the ventricles through bundle of His and Purkinje fibres at the rate of 1.5 to 4 metres/second.
- Bundle of His
  - It is also called A.V. bundle.
  - It arises from A.V. node, descends in the interventricular septum and divides into two branches which descend along two sides of interventricular septum and supply the wall of ventricle of their own side by a network of fine fibres called Purkinje fibres (a specialized type of neuro muscular cells) in the myocardium of the ventricles.
  - These bring about synchronous contraction of the ventricles from the apex of heart which forces the blood into the pulmonary arch and aortic arch.
  - S. A. node, A. V. node, Bundle of His (A. V. bundle) and Purkinje fibres collectively from the conducting system of the heart and is responsible for autorhythmicity of heart.
  - When S. A. node is damaged, then it is not able to generate the cardiac impulses, then the heart beat becomes irregular called arrhythmia. It is corrected by an artificial pacemaker. It is set in the chest of the patient, by surgical grafting, to pump the required amount of blood.
  - It stimulates the heart electrically at regular intervals to beat at normal rate. So human heart is called myogenic or autorhythmic heart.

Differences between S.A. node and A.V. node

Characters	**S.A. node**	**A.V. node**
Position	In right atrium near the opening of superior vena cava.	It is right atrium near the base of interauricular septum.
Rhythmicity	It has maximum rhythmicity.	It has less rhythmicity.
Stimulation	It is regulated by the cardiac centres present in medulla oblongata.	It is stimulated by cardiac impulses started by S.A. node.
Function	Acts as pacemaker.	Acts as pace-setter.

3.4.2 Cardiac Cycle

- It involves alternate contraction (called systole) and relaxation (called diastole) of heart at the rate of 70-72 times per minute at rest.
- All the chambers do not beat simultaneously. Right and left auricles contract simultaneously while both ventricles also work simultaneously.
- The sequence of events that occur during one heart beat is called cardiac cycle.
- During the cardiac cycle, blood flows through the cardiac chambers in a specific manner and direction, the backflow is prevented by the valves.
- During atrial diastole, the atria enlarge and receive the blood from the veins.
- Right atrium receives deoxygenated blood from superior and inferior vena cava, while left atrium receives oxygenated blood from the lungs by the pulmonary veins.
- Cardiac cycle is formed of three phases –
  - Atrial systole

- It involves contraction of atria from anterior to posterior side which pushes blood to respective ventricle.
- It increases the blood flow into the ventricles by about 30 percent. It is also called mid-late diastole.
- There is no reflux of blood from the auricles to large veins because-
  - Contraction of auricles from anterior to posterior part of the heart.
  - Presence of valves at the opening of inferior vena cava and coronary sinus.
  - Blood is already present in large veins.
  - Sphincters present in the wall of great veins.
- Atrial systole takes 0.1 second while atrial diastole is of about 0.7 seconds.

- Ventricular systole
  - It involves simultaneous relaxation of atria (atrial diastole) and contraction of ventricles (ventricular systole).
  - Due to ventricular systole, the pressure on the blood in the ventricles is increased compared to that in the atria.
  - The auriculoventricular valves close rapidly to prevent the backflow of blood from ventricles to auricles.
  - Finally, the pressure in the ventricles increases than that in the great arteries (pulmonary and aortic arches), so semilunar valves open and blood enters great arteries.
  - Deoxygenated blood from right ventricle enters pulmonary arch which carries it to the lungs.
  - Oxygenated blood from left ventricle enters aortic arch which carries it to all other body parts.
  - Each ventricle pumps out about 70 ml of blood (called stroke volume).
  - Ventricular systole takes about 0.3 seconds while ventricular diastole takes about 0.5 seconds.
- Joint diastole or complete cardiac diastole.
  - Ventricular systole is followed by ventricular diastole.
  - As atria are already in diastole, so all the chambers of heart enter the diastolic phase.
  - It is called complete cardiac diastole or joint diastole or early diastole. Due to ventricular diastole, ventricles relax and the pressure in ventricles decreases than that in the great arteries.
  - To prevent backflow of blood from great arteries to ventricles, the semilunar valves close rapidly.

- **Heart Sounds**
  - During a cardiac cycle, two heart sounds can be heard
    - Lub or systolic sound or First heart sound. It is heard during the beginning of ventricular systole and is due to rapid closing of atrioventricular valves to prevent back flow of blood from the ventricles to atria.
    - Dub or diastolic sound or Second heart sound. It is heard during the beginning of ventricular diastole and is due to rapid closing of semilunar valves to prevent back flow of blood from the great arteries to the ventricles.
  - The heart sounds can be heard by an instrument called stethoscope by placing its receiver on left side of the chest.
  - These sounds enable the physician to know working of valves of the heart so have clinical diagnostic significance.
  - The defects in the valves may lead to backflow of blood either from ventricles to auricles or from aortae to ventricles.
  - Defects are easily detected by changes in the nature of heart sounds called murmur.
  - The defective valves may be repaired or replaced surgically.

- During complete cardiac diastole, blood form the great vein (superior and inferior venae cavae) flows into the atria.
- Gradually, the pressure in the ventricles decreases and finally becomes lower than atrial pressure.
- Then the auriculoventricular valves open and blood from atria starts entering into relaxing ventricles.
- Complete cardiac diastole takes only 0.4 seconds. So, a cardiac cycle is completed in 0.8 seconds.

Differences between Lub and Dub

Characters	**Lub**	**Dub**
Produced due to	Rapid closing of bicuspid and tricuspid valves.	Rapid during of semilunar valves.
Period of occurrence	At the time of beginning of ventricular systole.	At the time of beginning of ventricular diastole.
Duration	Longer (0.14 seconds).	Shorter (0.11 seconds)
Pitch	More louder.	Less louder.
Frequency	25 to 45 cycles per second.	50 cycles per second.

Differences between Atrial systole and Ventricular systole

Characters	**Atrial systole**	**Ventricular systole**
Parts of heart affected	Auricles contract.	Ventricles contract.
Direction of blood	Blood flows from auricles to ventricles.	Blood flows from ventricles to great arteries.
Time taken	0.1 second.	0.3 seconds.

Differences between Systole and Diastole

Characters	**Systole**	**Diastole**
Definition	If involves contraction of the heart chambers.	It involves relaxation of the heart chambers.
Blood pressure	Increases.	Decreases.
Blood flow	Blood is ejected out of the heart chambers.	Heart chambers receive the blood.

3.4.2.1 Extrinsic Control of Cardiac Activity

- The heart beat is regulated by the myogenic control exercised on the heart beat by the nodal tissues, it is also regulated by two controls so that the rate of heart beat can be adjusted according to the body needs example it increases during exercise, fear, anger etc. while decreases during the rest. Heart always works against a brake and adjusts the rate of heart beat according to the metabolic need of body.
  - Autonomic nervous control
    - The rate of heart beat as well as the strength of the beat are under two cardiovascular centres of the autonomic nervous system. These centres are located in the upper part of the ventral wall of the medulla oblongata.
      - Cardiac acceleratory centre
        - ✓ It is associated with the cervical sympathetic chain ganglia and sympathetic nerve fibres which, in turn, are associated with the S.A. node.

- ✓ Otto Loewi reported that these nerve fibres stimulate and increase the rate and depth of the contraction of S.A. node through neurotransmitter chemical called adrenalin (epinephrine).
- ✓ It increases the rate of heart beat (about 200 to 250 times/minutes) as well as strength of heart beat (two-fold). This increases the cardiac output by two to three fold.

➢ Cardiac inhibitory centre

- ✓ It is associated with the vegal or parasympathetic nerve fibres which, in turn, are associated with the S.A. node.
- ✓ Otto Loewi reported that these nerve fibres inhibit and decrease the rate and depth of contraction of S.A. node through a neurotransmitter chemical called acetylcholine.
- ✓ It decreases the rate of heart beat (about 20 to 30 times/minute) as well as strength of heart beat (by 20 to 30 per cent). This decreases the cardiac output.

- Cardiac acceleratory centre dominates during exercise while cardiac inhibitory centre dominates during the rest.

- Hormonal control
  - It consists of two amine hormones-epinephrine (adrenalin) and norepinephrine (noradrenalin) which are secreted by adrenal medulla of adrenal gland.
  - Both hormones accelerate the rate of heart beat but operate in different conditions.
  - Epinephrine increases the heart beat during emergency conditions, while norepinephrine increases heart beat during normal conditions.

- **Circulation of Blood through Mammalian Heart**
  - Mammalian heart is four-chambered and has complete double circulation which means blood passes twice through the heart to supply once to the body. Double circulation involves two circulations-
    - Systemic or Greater circulation - In this, blood completes its circulation from left ventricle to right auricle through body organs. Here, the left ventricle pumps oxygenated blood into systemic arch which supplies it to body organs other than the lungs through a number of arteries. Deoxygenated blood from these organs is returned to the right auricle through two large veins, superior and inferior venae cavae. Right auricle pumps the deoxygenated blood in the right ventricle.
    - Pulmonary or Lesser circulation -In this, blood completes its circulation from right ventricle to left auricle through the lungs. Here, the right ventricle pumps deoxygenated blood into pulmonary arch which supplies it to the lungs where oxygenation of blood takes place. Oxygenated blood from the lungs is returned to left auricle by four pulmonary veins. Left auricle pumps the blood to left ventricle.

Differences between Pulmonary circulation and Systemic circulation

Characters	**Pulmonary circulation**	**Systemic circulation**
Extension	Starts from right ventricle and ends in left auricle.	Starts from left ventricle and ends in right auricle.
Intermediate	Lungs.	Body organs except lungs.
Nature of blood	Pumps deoxygenated blood while brings oxygenated blood.	Pumps oxygenated blood and brings deoxygenated blood.

Differences between Single circulation and Double circulation

Characters	Single circulation	Double circulation
Occurrence	Found in only fishes.	Found in amphibians, reptiles, birds and mammals.
Mode of circulation	Blood passes only once through the heart to supply once to the body.	Blood passes twice through the heart to supply once to the body.
Nature of blood	Only venous blood passes through the heart.	Mixed or oxygenated or venous blood passes through heart.
Efficiency	Less efficient as gill capillaries slow down the blood flow so the body receives blood at a low pressure which decreases the rate of oxygen supply to the cells.	More efficient as blood flows at higher pressure, especially in birds and mammals, which increases the rate of food and oxygen supply to the cell and also rapid removal of wastes from them.

- **Aterial Blood Pressure**
  - Heart does not pump blood in a continuous stream but ejects the blood in spurts (about 70 ml of blood per systole and is called stroke volume), so the blood pressure is different in arteries during different stages of the heart beat.
    - It is the pressure exerted by the blood on the wall of the blood vessels in which it is present.
    - Arterial blood pressure is of two types
      - Systolic Blood Pressure (SBP)-It is the pressure which the blood exerts on the wall of blood vessels at the end of systolic contraction of ventricles. In a normal resting adult man, it is about 120 mm Hg or 16 kPa (1 mm Hg = 0.133 kPa). It is maximum in the arteries because the arteries are always stretched but it gradually decreases from arteries to arterioles, capillaries, venules, veins etc. and there is a marked gradient of the blood pressure.
      - Diastolic Blood Pressure (DBP)-It is the pressure which the blood exerts on the wall of the arteries when the ventricles are maximally relaxed. In a normal resting adult man, it is about 80 mm Hg or 11.0 kPa.
    - So, during each heart beat, the arterial blood pressure rises to about 120 mm Hg in the systolic phase and falls to about 80 mm Hg in the diastolic phase.
    - The difference between the systolic and diastolic pressures is called pulse pressure and its normal value is 40 mm Hg.
    - Blood pressure in a normal person = 120/80 mm Hg.
      - Mean arterial pressure. It is defined as the pressure which determines the average rate of blood flow through the systemic vessels. As the blood remains in the systolic phase for shorter period and in the diastolic phase for longer period, so the mean pressure of blood lies near the diastolic pressure. It varies at different levels of the circulatory system. It is about 100 mm Hg in the aorta; 85 mm Hg at the junction of small arteries and arterioles; 30 mm Hg at the junction of arterioles and the capillaries; 10 mm Hg at the venous end of capillaries and about 0 mm Hg in the venae cavae near their opening into the right atrium. It is this gradient of blood pressure which is responsible for the blood flow in the circulatory system.
      - Measurement Now-a-days, the blood pressure is measured by auscultatory method (indirect measurement) with the help of an instrument, sphygmomanometer. It was invented by Karot Koff (1905). In this, the blood

pressure is measured in terms of air pressure when the air pressure becomes equal to the blood pressure in the radial artery. This is called auscultatory method and is the indirect measurement of systolic and diastolic pressure.

- In this method, a blood pressure cuff is placed around the upper arm and is connected to a mercury manometer of sphygmomanometer.
- The cuff is inflated with air and a stethoscope is placed over the brachial artery just below the elbow joint.
- Air pressure in the cuff is increased is about 200 mm Hg at which radial artery collapses so there is no blood flow and no sound in heart by the stethoscope.
- Then the cuff pressure is gradually reduced and following two pressures are noted.
  - Systolic pressure when first time tapping-sounds are heard.
  - Diastolic pressure when loud tapping sounds start muffling.

Differences between Systolic and Diastolic pressure

Characters	**Systolic pressure**	**Diastolic pressure**
Period of occurrence	During maximum ventricular systole.	During maximum ventricular diastole.
Value in a normal person	120 mm Hg.	80 mm Hg.
Period of recording	At the time of first tap-like sound.	When loud sound changes to a softer muffled sound.

- **Factors affecting Blood Pressure**
  - Age-The values of both systolic and diastolic pressures increase with age e.g., blood pressure of a newly born baby is 90/55 mm Hg; in a young adult it is 120/80 mm Hg; while in old age it is 150/90 mm Hg. It is so because with age; the arterial wall becomes rigid and less elastic after the age of 60 years. It is normally calculated as 100+ age of the person.
  - Cardiac output- Arterial pressure increases with the increase in cardiac output because-
    Arterial pressure = Cardiac output x Total peripheral resistance.
  - Elasticity of blood vessel- Blood pressure is inversely related to the elasticity of the blood vessel. In old age, due to deposition of Ca^{++} or cholesterol, the blood vessels become less elastic (arteriosclerosis), so there is increase blood pressure sometimes causing a pulse pressure of 100 mm of Hg or more.
  - Total peripheral resistance-It is the resistance offered by the wall of blood vessels to the passage of the blood due to friction of the viscous blood against their wall. In general, constriction of blood vessels will increase the arterial pressure while their dilation will lower the pressure.
  - Other factors responsible for increasing the blood pressure are -exercise, tension, fear, adrenal secretion, nephritis, obesity, etc.

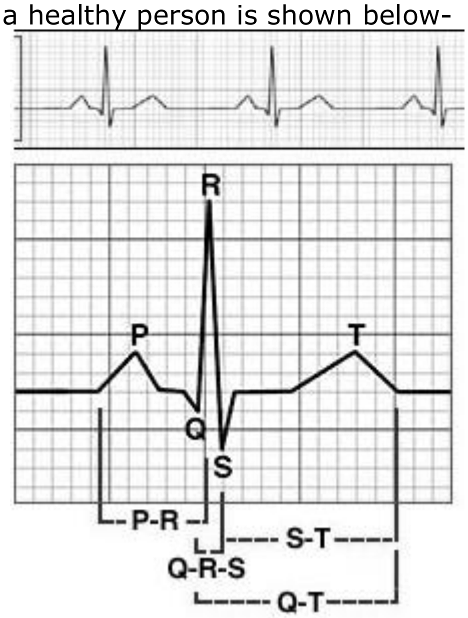
Differences between Hypertension and Hypotension

Characters	**Hypertension**	**Hypotension**
Definition	A persistent increase in blood pressure.	A persistent decrease in blood pressure.
Valve	150/90 mm Hg.	100/50 mm Hg.
Reasons	Overeating; obesity; physical and emotional stress; intake of cholesterol-rich diet; arterosclerosis; smoking; etc.	Haemorrhage; chronic vasodilation; failure of pumping action of heart; etc.
Effects	May cause heart attack, nephritis, blindness, etc.	Fainting.

- **Regulation of Blood Pressure**
  - Blood pressure operates through a vasomotor centre present in the medulla oblongata of brain.
  - It operates through a baroreceptor system formed of stretchreceptors in the wall of carotid bodies and aortic bodies.
  - This baroreceptor system acts as a pressure buffer system and regulates the blood pressure by regulating :
    - Rate of heart beat and
    - Regulating the diameter of blood vessels.
  - When there is rise in blood pressure then it is brought to normal by :
    - Decreasing rate and strength of heart beat.
    - Vasodilation of arterioles so decreasing peripheral resistance.

3.4.3 Electrocardiograph (ECG)

- A graphic record of the electrical variations produced by the beating of the heart is called electrocardiogram (ECG) or EKG.
- These variations are due to the development of electrical negativity of excited muscles as compared with unexcited tissues.
- An instrument used to observe the working of the heart is called electrocardiograph.
- Electrocardiograph was discovered by Einthoven (1903), commonly called “Father of
- Electrocardiography”, while ECG was first recorded by Waller.
- Most modern clinical electrocardiograph used is Pen recorder.
- It may be connected to an oscilloscope which displays it on a TV-type screen.
- ECG taken when patient is lying down, is called resting ECG while ECG taken when patient is exercising is called stress ECG.
- A standard ECG involving three monitoring leads is formed of a series of ridges and furrows.
- Normal pattern of ECG for a healthy person is shown below-



- In this, P-wave indicates the impulse of contraction generated by S.A. node which causes atrial depolarization.
- The interval PQ represents atrial contraction (0.1 second).
- QRS-wave indicates the spread of impulse of contraction from A. V. node to the wall of ventricles causing ventricular depolarization.

- The RS of QRS-wave and ST interval represents ventricular contraction (0.3 seconds).
- T-wave represents the relaxation (repolarization) of ventricles.
- So ECG is formed of both depolarization and repolarization waves.
- The P, R and T waves are above the base line of ECG and are called positive waves while Q and S waves are below the base line and are called negative waves.
- T-wave is followed by U-wave which is very small and involves repolarization of specialized muscle cells which make up the pace maker system.
- Any abnormality in the working of the heart changes the wave pattern of ECG and can be interpreted by a trained physician to diagnose a particular disorder.
- The technique to detect the abnormalities of the heart like high blood pressure, rheumatic heart, congenital heart defects, and effects of certain drugs on heart, etc. with the help of ECG is called electrocardiography.
- ECG also indicates the rate of heart beat as indicated by number of QRS complexes that occur in a given time period.

Differences between P-wave and T-wave

Characters	**P-wave**	**T-wave**
Symbol of	Depolarization of cardiac muscles of S. A. node and their spreading to the muscles of both and auricles.	Repolarization of cardiac muscles of A. V. node and their spreading to muscles of both the ventricles.
Effect	Both auricles contract.	Both ventricles relax.

- **Pulse**
  - Pulse is defined as a wave of distension and recoiling felt in the radial artery due to the contraction of left ventricle which forces about 70-90 ml of blood in already full aorta.
  - When the left ventricle contracts, blood is forced the aorta which gets distended but contracts during the ventricular diastole and pushes the blood forward.
  - This wave of contraction and relaxation started in the aorta travels down to the wall of the arteries and is called the pulse.
  - It can also be felt in the temporal artery over the temporal bone, or the dorasalis pedis artery at the bend of the ankle.
  - The pulse is not the blood pumped by the heart into the aorta, but it is the pressure wave which travels more rapidly (about 10-15 times) than blood.
  - The pulse normally travels at the rate of 5-8 metres/second, while the blood flows at the rate of 300-500 mm/second in most of the arteries and 0.5-1 mm/second in the blood capillaries.
  - Since each heart beat generates one pulse in the arteries so the pulse rate per minute indicates the rate of heart beat.
  - So the pulse rate in a normal adult person is 72/minute which may rise as high as 120/minute during vigorous exercise.
  - The pulse rate is affected by a number of factors like posture of body (more in standing position than rest), age (more rapid in children example about 140 times in the newly born baby and 120 times during the first year), sex (more rapid in females), exercise, emotions etc.

- **Cardiac Output**
- It is the volume of blood ejected from the heart in the aorta in one minute, and is also called minute volume.
- It is calculated as the product of stroke volume (Amount of blood pumped out from each ventricle during ventricular systole) and the rate of heart beat.

Cardiac output = Stroke volume x Rate of heart beat.

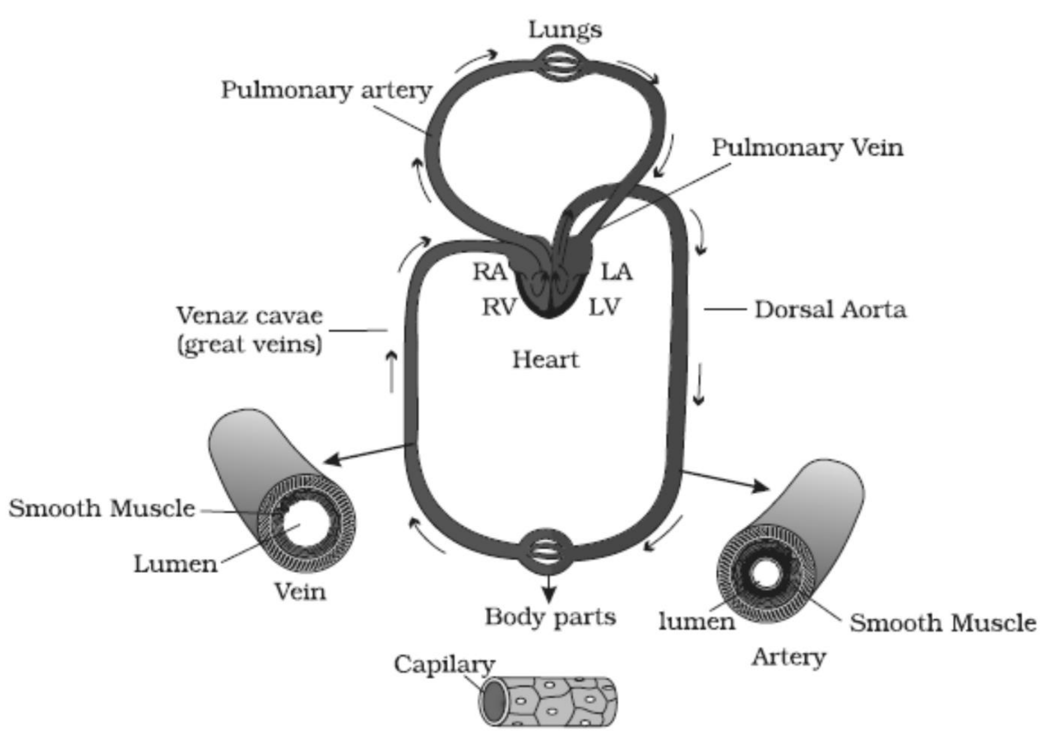
= 70 ml x 70-72 times/minute

= about 5 litres per ventricle
(Total amount of blood in human body is about 6.8 litres).
= 10 litres of both ventricles of heart.

- With the change in age, size, sex, temperature there is a change in heart rate.
- During vigorous exercise, the heart rate may be 185 times per minute and the stroke volume over 162 ml, so the cardiac output in exercise may rise to 25 to 30 litres per minute which is about 5 to 6 times than that of the normal amount.
- An exactly equal volume of blood is returned to the heart by the veins each minute.
- During mild exercise like walking cardiac output is approximately 11 litres.
- Cardiac output is directly proportional to size of the organism, amount of blood entering into the heart, metabolic rate, etc.
- Cardiac output is inversely proportional to age and peripheral resistance.

3.5 Double Circulation

- As mentioned earlier, the blood pumped by the right ventricle enters the pulmonary artery, whereas the left ventricle pumps blood into the aorta.
- The deoxygenated blood pumped into the pulmonary artery is passed on to the lungs from where the oxygenated blood is carried by the pulmonary veins into the left atrium.
- This pathway constitutes the pulmonary circulation.
- The oxygenated blood entering the aorta is carried by a network of arteries, arterioles and capillaries to the tissues from where the deoxygenated blood is collected by a system of venules, veins and vena cava and emptied into the right atrium.
- This is the systemic circulation.



- The systemic circulation provides nutrients, O_2 and other essential substances to the tissues and takes CO_2 and other harmful substances away for elimination.
- A unique vascular connection exists between the digestive tract and liver called hepatic portal system.

- The hepatic portal vein carries blood from intestine to the liver before it is delivered to the systemic circulation.
- A special coronary system of blood vessels is present in our body exclusively for the circulation of blood to and from the cardiac musculature.

3.6 Regulation of Cardiac Activity

- Normal activities of the heart are regulated intrinsically, i.e., auto regulated by specialised muscles (nodal tissue), hence the heart is called myogenic.
- A special neural centre in the medulla oblongata can moderate the cardiac function through autonomic nervous system (ANS).
- Neural signals through the sympathetic nerves (part of ANS) can increase the rate of heart beat, the strength of ventricular contraction and thereby the cardiac output.
- On the other hand, parasympathetic neural signals (another component of ANS) decrease the rate of heart beat, speed of conduction of action potential and thereby the cardiac output.
- Adrenal medullary hormones can also increase the cardiac output.

3.7 Disorders of Circulatory System

3.7.1 High Blood Pressure (Hypertension)

- High Blood Pressure (Hypertension): Hypertension is the term for blood pressure that is higher than normal (120/80).
- In this measurement 120 mm Hg (millimetres of mercury pressure) is the systolic, or pumping, pressure and 80 mm Hg is the diastolic, or resting, pressure.
- If repeated checks of blood pressure of an individual is 140/90 (140 over 90) or higher, it shows hypertension.
- High blood pressure leads to heart diseases and also affects vital organs like brain and kidney.

3.7.2 Coronary Artery Disease (CAD)

- Coronary Artery Disease, also known as atherosclerosis, affects the vessels that supply blood to the heart muscle.
- It is caused by deposits of calcium, fat, cholesterol and fibrous tissues, which makes the lumen of arteries narrower.

3.7.3 Angina

- It is also called ‘angina pectoris’.
- A symptom of acute chest pain appears when no enough oxygen is reaching the heart muscle.
- Angina can occur in men and women of any age but it is more common among the middle-aged and elderly.
- It occurs due to conditions that affect the blood flow.

3.7.4 Heart Failure

- Heart failure means 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.
- Heart failure is not the same as cardiac arrest (when the heart stops beating) or a heart attack (when the heart muscle is suddenly damaged by an inadequate blood supply).

3.8 Points to Remember

- Vertebrates circulate blood, a fluid connective tissue, in their body, to transport essential substances to the cells and to carry waste substances from there.
- Another fluid, lymph (tissue fluid) is also used for the transport of certain substances.
- Blood comprises of a fluid matrix, plasma and formed elements.
- Red blood cells (RBCs, erythrocytes), white blood cells (WBCs, leucocytes) and platelets (thrombocytes) constitute the formed elements.
- Blood of humans are grouped into A, B, AB and O systems based on the presence or absence of two surface antigens, A, B on the RBCs.
- Another blood grouping is also done based on the presence or absence of another antigen called Rhesus factor (Rh) on the surface of RBCs.
- The spaces between cells in the tissues contain a fluid derived from blood called tissue fluid.
- This fluid called lymph is almost similar to blood except for the protein content and the formed elements.
- All vertebrates and a few invertebrates have a closed circulatory system.
- Our circulatory system consists of a muscular pumping organ, heart, a network of vessels and a fluid, blood.
- Heart has two atria and two ventricles.
- Cardiac musculature is auto-excitable.
- Sino-atrial node (SAN) generates the maximum number of action potentials per minute (70-75/min) and therefore, it sets the pace of the activities of the heart. Hence it is called the Pacemaker.
- The action potential causes the atria and then the ventricles to undergo contraction (systole) followed by their relaxation (diastole).
- The systole forces the blood to move from the atria to the ventricles and to the pulmonary artery and the aorta.
- The cardiac cycle is formed by sequential events in the heart which is cyclically repeated and is called the cardiac cycle. A healthy person shows 72 such cycles per minute.
- About 70 mL of blood is pumped out by each ventricle during a cardiac cycle and it is called the stroke or beat volume.
- Volume of blood pumped out by each ventricle of heart per minute is called the cardiac output and it is equal to the product of stroke volume and heart rate (approx 5 litres). The electrical activity of the heart can be recorded from the body surface by using electrocardiograph and the recording is called electrocardiogram (ECG) which is of clinical importance.
- We have a complete double circulation, i.e., two circulatory pathways, namely, pulmonary and systemic are present.
- The pulmonary circulation starts by the pumping of deoxygenated blood by the right ventricle which is carried to the lungs where it is oxygenated and returned to the left atrium.
- The systemic circulation starts with the pumping of oxygenated blood by the left ventricle to the aorta which is carried to all the body tissues and the deoxygenated blood from there is collected by the veins and returned to the right atrium.
- Though the heart is auto excitable, its functions can be moderated by neural and hormonal mechanisms.