

# CHAPTER 18

## BODY FLUIDS AND CIRCULATION

- 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 to transport such materials like **Blood and lymph (tissue fluid)**.

### BLOOD

Blood is a special connective tissue consisting of a fluid matrix, plasma, and formed elements.

#### 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.
- Fibrinogen, globulins and albumins are the major proteins
- Fibrinogens are needed for clotting or coagulation of blood.
- Globulins involved in defense mechanisms of the body and the albumins help in osmotic balance.
- Plasma also contains small amounts of minerals like  $\text{Na}^+$ ,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{HCO}_3^-$ ,  $\text{Cl}^-$ , etc.
- Glucose, amino acids, lipids, etc., are also present in the plasma as they are always in transit in the body.
- Factors for coagulation or clotting of blood are also present in the plasma in an inactive form.
- Plasma without the clotting factors is called **serum**.

#### Formed Elements

- Erythrocytes, leucocytes and platelets are collectively called formed elements and they constitute nearly 45 per cent of the blood.

#### Erythrocytes or red blood cells (RBC)

- Most abundant of all the cells in blood.
- **Count** – (In a healthy adult man) 5 - 5.5 millions of RBCs  $\text{mm}^{-3}$  of blood.
- **Formed in** – Red bone marrow in the adults.
- **Nucleus** – absent in most of the mammals
- **Shape** – biconcave
- **Haemoglobin** – red coloured, iron containing complex protein. hence the colour and name of cells.
- **Haemoglobin count** – 12-16 gms of haemoglobin in every 100 ml of blood. These molecules play a significant role in transport of respiratory gases.
- **Average life span** - 120 days.
- **Destroyed in** – spleen (graveyard of RBCs).

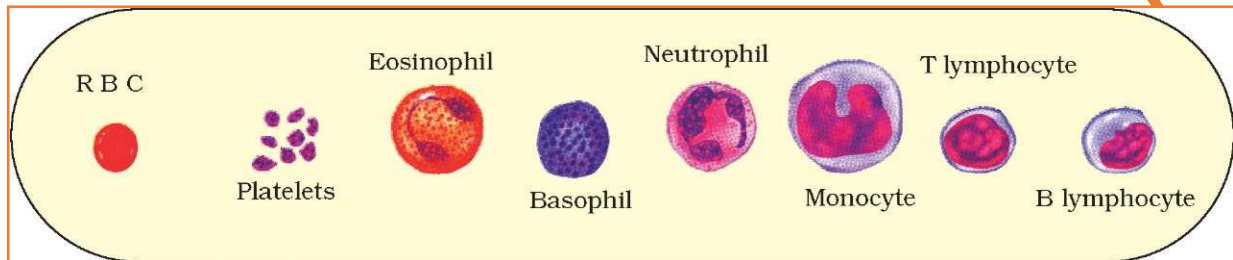
#### Leucocytes or white blood cells (WBC)

- Colourless due to the lack of haemoglobin.
- Nucleus – present
- **Count (TLC – total leucocyte count)** - 6000-8000  $\text{mm}^{-3}$  of blood.
- Leucocytes are generally short lived.
- We have two main categories of WBCs - **granulocytes and agranulocytes**.
- Neutrophils, eosinophils and basophils are different types of granulocytes, while lymphocytes and monocytes are the agranulocytes.
- **Neutrophils** - most abundant cells (60-65 per cent), phagocytic.
- **Basophils** - least abundant (0.5-1 per cent), secrete histamine, serotonin, heparin, etc., and are involved in inflammatory reactions.
- **Monocytes** - (6-8 per cent), phagocytic cells.
- **Eosinophils** - (2-3 per cent), resist infections and are also associated with allergic reactions.

- **Lymphocytes** - (20-25 per cent) are of two major types - 'B' and 'T' forms. Both B and T lymphocytes are responsible for immune responses of the body.

#### Platelets or thrombocytes

- Cell fragments produced from megakaryocytes (special cells in the bone marrow).
- Count - 1,50,00-3,50,00 platelets  $\text{mm}^{-3}$  of blood.
- Role - release a variety of substances most of which are involved in the coagulation or clotting of blood.
- A reduction in their number can lead to clotting disorders which will lead to excessive loss of blood from the body.



**Fig:** Diagrammatic representation of formed elements in blood

## BLOOD GROUPS

- Various types of grouping of blood has been done.
- Two such groupings - the ABO and Rh - are widely used all over the world.

### ABO grouping

- 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).
- During blood transfusion, any blood cannot 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 (destruction of RBC).

### Blood Groups and Donor Compatibility

Blood Group	Antigens on RBCs	Antibodies in Plasma	Donor's Group
A	A	anti-B	A, O
B	B	anti-A	B, O
AB	A, B	nil	AB, A, B, O
O	nil	anti-A, B	O

- Group 'O' blood can be donated to persons with any other blood group and hence 'O' group individuals are called 'universal donors'.
- 'AB' group can accept blood from persons with AB as well as the other groups of blood. Therefore, such persons are called 'universal recipients'.

### Rh grouping

- Another antigen, the Rh antigen similar to one present in Rhesus monkeys (hence Rh), is also observed on the surface of RBCs of majority (nearly 80 per cent) of humans. Such individuals are called **Rh positive** (Rh+ve) and those in whom this antigen is absent are called **Rh negative** (Rh-ve).
- An Rh-ve person, if exposed to Rh+ve blood, will form specific antibodies against the Rh antigens. Therefore, Rh group should also be matched before transfusions.

- **Erythroblastosis foetalis -**

- A special case of Rh incompatibility (mismatching) observed between the Rh-ve blood of a pregnant mother with Rh+ve blood of the foetus.
- Rh antigens of the foetus do not get exposed to the Rh-ve 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 small amounts of the Rh+ve blood from the foetus.
- In such cases, the mother starts preparing antibodies against Rh in her blood.
- in case of her subsequent pregnancies, the Rh antibodies from the mother (Rh-ve) can leak into the blood of the foetus (Rh+ve) and destroy the foetal RBCs.
- This could be fatal to the foetus or could cause severe anaemia and jaundice to the baby.
- This condition is called ***erythroblastosis foetalis***.
- This can be avoided by administering anti-Rh antibodies to the mother immediately after the delivery of the first child.

### Coagulation of Blood

- Blood exhibits coagulation or clotting in response to an injury or trauma. This is a mechanism to prevent excessive loss of blood from the body.
- a dark reddish brown scum formed at the site of a cut or an injury over a period of time is a clot or coagulum, formed mainly of a network of threads called fibrins in which dead and damaged formed elements of blood are trapped.
- Fibrins are formed by the conversion of inactive fibrinogens in the plasma by the enzyme thrombin.
- Thrombins, in turn are formed from another inactive substance present in the plasma called prothrombin.
- An enzyme complex, thrombokinase, is required for the above reaction.
- This complex is formed by a series of linked enzymic reactions (cascade process) involving a number of factors present in the plasma in an inactive state.
- An injury or a trauma stimulates the platelets in the blood to release certain factors which activate the mechanism of coagulation.
- Certain factors released by the tissues at the site of injury also can initiate coagulation.
- Calcium ions play a very important role in clotting.

### LYMPH (TISSUE FLUID)

- As the blood passes through the capillaries in tissues, some water along with many small water soluble substances move out into the spaces between the cells of tissues leaving the larger proteins and most of the formed elements 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.
- Exchange of nutrients, gases, etc., between the blood and the cells always occur through this fluid.
- An elaborate network of vessels called the lymphatic system collects this fluid and drains it back to the major veins. The fluid present in the lymphatic system is called the lymph.
- Lymph is a colourless fluid containing specialised lymphocytes which are responsible for the immune responses of the body.
- Lymph is also an important carrier for nutrients, hormones, etc. Fats are absorbed through lymph in the lacteals present in the intestinal villi.

## CIRCULATORY PATHWAYS

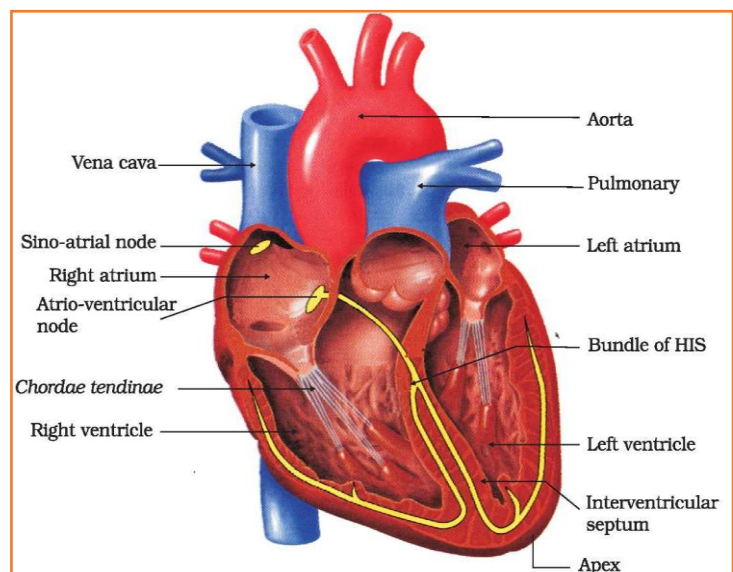
- The circulatory patterns are of two types - open or closed.
- **Open circulatory system** is present in arthropods and molluscs in which blood pumped by the heart passes through large vessels into open spaces or body cavities called sinuses.
- Annelids and chordates have a **closed circulatory system** in which the blood pumped by the heart is always circulated through a closed network of blood vessels. This pattern is considered to be more advantageous as the flow of fluid can be more precisely regulated.
- All vertebrates possess a muscular chambered heart.
- 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 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 (**single circulation**).
- In amphibians and reptiles, the left atrium 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 (incomplete double circulation).
- In birds and mammals, oxygenated and deoxygenated blood received by the left and right atria respectively 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, hence, these animals have **double circulation**.

## HUMAN CIRCULATORY SYSTEM

- Human circulatory system, also called the blood vascular system consists of a muscular chambered heart, a network of closed branching blood vessels and blood, the fluid which is circulated.

### HEART

- **Heart**, the mesodermally derived organ, is situated in the thoracic cavity, in between the two lungs, slightly tilted to the left.
- It has the size of a clenched fist.
- It is protected by a double walled membranous bag, **pericardium**, enclosing the pericardial fluid.
- Our heart has four chambers, two relatively small upper chambers called **atria** and two larger lower chambers called **ventricles**.
- A thin, muscular wall called the interatrial septum separates the right and the left atria, whereas a thick-walled, the inter-ventricular septum, separates the left and the right ventricles.
- The atrium and the ventricle of the same side are also separated by a thick fibrous tissue called the atrio-ventricular septum.
- However, each of these septa are provided with an opening through which the two chambers of the same side are connected.
- The opening between the right atrium and the right ventricle is guarded by a valve formed of three



**Fig:** Section of a human heart

muscular flaps or cusps, the tricuspid valve, whereas a bicuspid or mitral valve guards the opening between the left atrium and the left ventricle.

- The openings of the right and the left ventricles into the pulmonary artery and the aorta respectively are provided with the semilunar valves. The valves in the heart allows the flow of blood only in one direction, i.e., from the atria to the ventricles and from the ventricles to the pulmonary artery or aorta. These valves prevent any backward flow.
- The entire heart is made of cardiac muscles.
- The walls of ventricles are much thicker than that of the atria.
- A specialised cardiac musculature called the nodal tissue is also distributed in the heart.
- A patch of this tissue is present in the right upper corner of the right atrium called the **sino-atrial node (SAN)**.
- Another mass of this tissue is seen in the lower left corner of the right atrium close to the atrio-ventricular septum called the **atrio-ventricular node (AVN)**.
- A bundle of nodal fibres, atrioventricular bundle (AV bundle) continues from the AVN which passes through the atrio-ventricular septa to emerge on the top of the interventricular septum and immediately divides into a right and left bundle.
- These branches give rise to minute fibres throughout the ventricular musculature of the respective sides and are called purkinje fibres.
- These fibres alongwith right and left bundles are known as bundle of HIS.
- 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 can generate the maximum number of action potentials, i.e.,  $70-75 \text{ min}^{-1}$ , and is responsible for initiating and maintaining the rhythmic contractile activity of the heart. Therefore, it is called the pacemaker.
- Our heart normally beats  $70-75$  times in a minute (average  $72 \text{ beats min}^{-1}$ ).

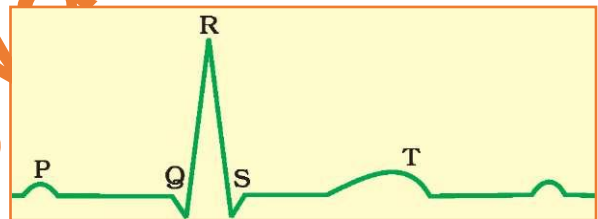
### CARDIAC CYCLE

- To begin with, all the four chambers of heart are in a relaxed state, i.e., they are in joint diastole.
- As the tricuspid and bicuspid valves are open, blood from the pulmonary veins and vena cava flows into the left and the right ventricle respectively through the left and right atria. The semilunar valves are closed at this stage.
- The SAN now generates an action potential which stimulates both the atria to undergo a simultaneous contraction - the atrial systole. This increases the flow of blood into the ventricles by about 30 per cent.
- The action potential is conducted to the ventricular side by the AVN and AV bundle from where the bundle of HIS transmits it through the entire ventricular musculature.
- This causes the ventricular muscles to contract, (ventricular systole), the atria undergo relaxation (diastole), coinciding with the ventricular systole.
- Ventricular systole increases the ventricular pressure causing the closure of tricuspid and bicuspid valves due to attempted backflow of blood into the atria.
- As the ventricular pressure increases further, the semilunar valves guarding the pulmonary artery (right side) and the aorta (left side) are forced open, allowing the blood in the ventricles to flow through these vessels into the circulatory pathways.
- The ventricles now relax (ventricular diastole) and the ventricular pressure falls causing the closure of semilunar valves which prevents the backflow of blood into the ventricles.
- As the ventricular pressure declines further, the tricuspid and bicuspid valves are pushed open by the pressure in the atria exerted by the blood which was being emptied into them by the veins. The blood now once again moves freely to the ventricles.

- The ventricles and atria are now again in a relaxed (joint diastole) state, as earlier. Soon the SAN generates a new action potential and the events described above are repeated in that sequence and the process continues.
- This sequential event in the heart which is cyclically repeated is called the cardiac cycle and it consists of systole and diastole of both the atria and ventricles.
- The heart beats 72 times per minute, i.e., that many cardiac cycles are performed per minute.
- From this it could be deduced that the duration of a cardiac cycle is 0.8 seconds.
- During a cardiac cycle, each ventricle pumps out approximately 70 mL of blood which is called the **stroke volume**.
- The stroke volume multiplied by the heart rate (no. of beats per min.) gives the **cardiac output**.
- Therefore, the cardiac output can be defined as the volume of blood pumped out by each ventricle per minute and averages 5000 mL or 5 litres in a healthy individual.
- The body has the ability to alter the stroke volume as well as the heart rate and thereby the cardiac output. For example, the cardiac output of an athlete will be much higher than that of an ordinary man.
- During each cardiac cycle two prominent sounds are produced which can be easily heard through a stethoscope.
- The first heart sound (lub) is associated with the closure of the tricuspid and bicuspid valves whereas the second heart sound (dub) is associated with the closure of the semilunar valves. These sounds are of clinical diagnostic significance.

### ELECTROCARDIOGRAPH (ECG)

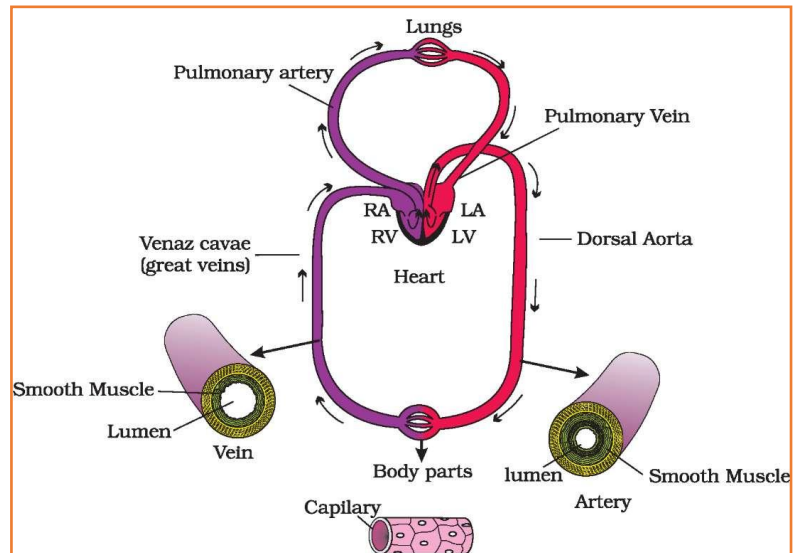
- ECG is a graphical representation of the electrical activity of the heart during a cardiac cycle.
- To obtain a standard ECG, a patient is connected to the machine with three electrical leads (one to each wrist and to the left ankle) that continuously monitor the heart activity.
- For a detailed evaluation of the heart's function, multiple leads are attached to the chest region.
- 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.
- 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.



**Fig:** Diagrammatic presentation of a standard ECG

## DOUBLE CIRCULATION

- 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<sub>2</sub> and other essential substances to the tissues and takes CO<sub>2</sub> and other harmful substances away for elimination.



**Fig:** Schematic plan of blood circulation in human

- 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.

## 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.

## DISORDERS OF CIRCULATORY SYSTEM

### 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.

### Coronary Artery Disease (CAD):

- Coronary Artery Disease, often referred to 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.

**Angina:**

- It is also called 'angina pectoris'.
- A symptom of acute chest pain appears when not 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.

**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).

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