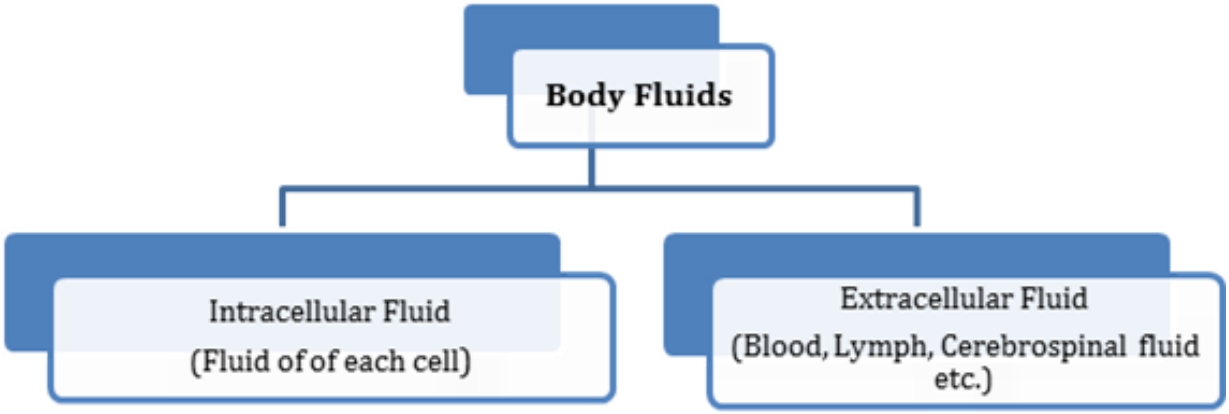
CHAPTER-18

CIRCULATION OF BODY FLUIDS

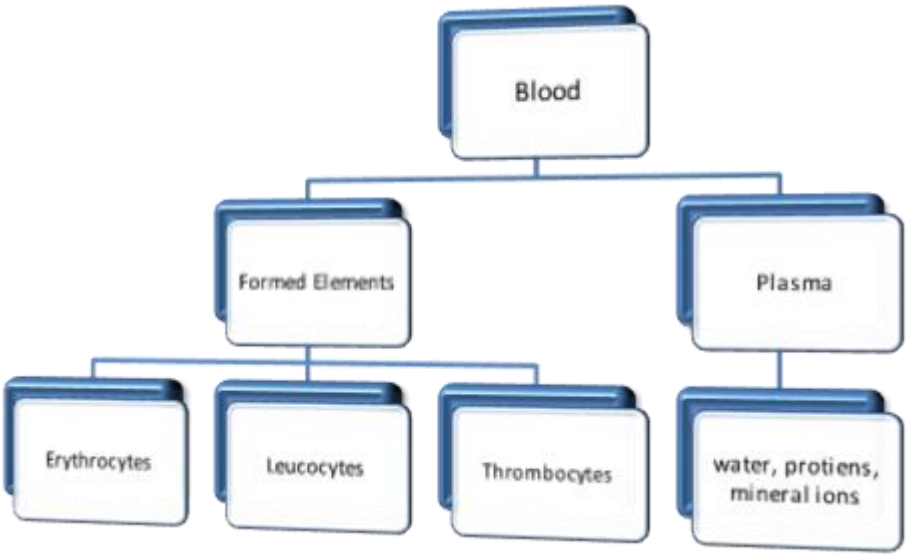
INTRODUCTION



Body fluids are the medium of transport of nutrients, oxygen, and other important substances in the body. Blood is the most commonly used body fluid in most of the higher organisms. Lymph also transports certain substances like protein and fats.

Blood

Blood is a fluid connective tissue composed of a fluid matrix, plasma, and blood corpuscles. It forms about 30-35% of the extracellular fluid. It is a slightly alkaline fluid having pH7.4. Blood is a fluid connective tissue that consists of plasma, blood cells, and platelets. It circulates throughout our body delivering oxygen and nutrients to various cells and tissues. It makes up 8% of our body weight. An average adult possesses around 5-6 litres of blood.



Plasma

Plasma is a straw-coloured, viscous fluid constituting nearly 55 per cent of the blood.

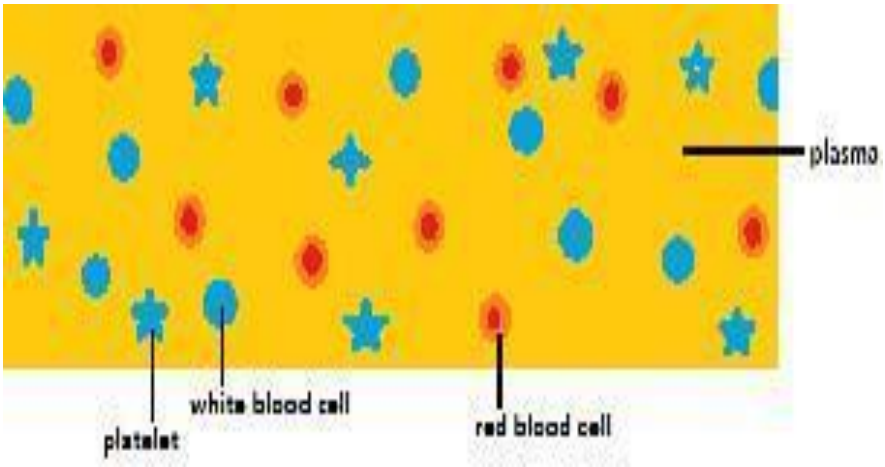
Fibrinogen, globulins, and albumins are the major proteins of plasma.

Fibrinogens are needed for clotting or coagulation of blood, globulins are involved in defence mechanisms of the body, and the albumins help in osmotic balance.

Plasma contains small amounts of minerals like Na^{+}, Ca^{++}, glucose, amino acids, etc.

Factors for coagulation of blood are present in the plasma in an inactive form.

Plasma without the clotting factors is called **serum**.



Types of Blood Cells

We have seen blood consist of cells known as formed elements of blood. These cells have their own functions and roles to play in the body. The blood cells which circulate all around the body are as follows:

Red blood cells (Erythrocytes)

RBCs are the biconcave cells; also known as erythrocytes. RBCs contain the iron-rich protein called haemoglobin; give blood its red colour. RBCs are the most copious blood cell produced in bone marrows. Their main function is to transport oxygen from and to various tissues and organs.

White blood cells (Leucocytes)

Leucocytes are the colourless blood cells. They are colourless because it is devoid of haemoglobin. They further classified as granulocytes and agranulocytes. WBCs mainly contribute to immunity and defence mechanism.

Types of White Blood Cells

There are five different types of White blood cells and are classified mainly based on the presence and absence of granules.

- Granulocytes
- Agranulocytes

Granulocytes

They are leukocytes, with the presence of granules in their cytoplasm. The granulated cells include- eosinophil, basophil, and neutrophil.

Eosinophils

- They are the cells of leukocytes, which are present in the immune system.
- These cells are responsible for combating infections in parasites of vertebrates and for controlling mechanisms associated with the allergy and asthma.
- Eosinophil cells are small granulocyte, which is produced in the bone marrow and makes 2 to 4 per cent of whole WBCs. These cells are present in high concentrations in the digestive tract.

Basophils

- They are the least common of the granulocytes, ranging from 0.01to 0.3 per cent of WBCs.
- They contain large cytoplasmic granules, which plays a vital role in mounting a non-specific immune response to pathogens, allergic reactions by releasing histamine and dilates the blood vessels.
- Around 20 to 25 per cent of basophils are present in WBCs.
- These white blood cells have the ability to be stained when exposed to basic dyes, hence referred to as basophil.
- These cells are best known for their role in asthma and their result in the inflammation and bronchoconstriction in the airways.

Neutrophils

- They are normally found in the bloodstream.
- They are predominant cells, which are present in pus.
- Around 60 to 70 per cent of WBCs are neutrophils with a diameter of 10 to 12 micrometres.
- The nucleus is 2 to 5 lobed and cytoplasm has very fine granules.
- Neutrophil helps in the destruction of bacteria with lysosomes, and it acts as a strong oxidant.
- Neutrophils are stained only using neutral dyes. Hence, they are called so.
- Neutrophils are also the first cells of the immune system to respond to an invader such as a bacteria or a virus.
- The lifespan of these WBCs extend for up to eight hours and are produced every day in the bone marrow.

Agranulocytes

They are leukocytes, with the absence of granules in their cytoplasm. Agranulocytes are further classified into monocytes and lymphocytes.

Monocytes

- These cells usually have a large bilobed nucleus, with a diameter of 12 to 20 micrometres.
- The nucleus is generally of half-moon shaped or kidney-shaped and it occupies 3 to 8 per cent of WBCs.
- They are the garbage trucks of the immune system.

- The most important functions of monocytes are to migrate into tissues and clean up dead cells, protect against the bloodborne pathogens and they move very quickly to the sites of infections in the tissues.
- These white blood cells have a single bean-shaped nucleus, hence referred to as Monocytes.

Lymphocytes

- They play a vital role in producing antibodies.
- Their size ranges from 8 to 10 micrometres.
- They are commonly known as natural killer cells.
- They play an important role in body defence.
- On average, a human body contains about 10 to 12 lymphocytes cells.
- These white blood cells are colourless cells formed in lymphoid tissue, hence referred to as lymphocytes.
- There are two main types of lymphocytes – B lymphocytes and T lymphocytes.
- These cells are very important in the immune systems and are responsible for humoral immunity.

Platelets (Thrombocytes)

- Thrombocytes are specialized blood cells produced from bone marrow.
- Platelets come into play when there is bleeding or haemorrhage.
- They help in clotting and coagulation of blood. Platelets help in coagulation during a cut or wound.

BLOOD GROUPS

Two blood groupings are done

ABO and

Rh

ABO grouping

ABO grouping is based on the presence or absence of two surface antigen on the RBCs namely A and B.

The plasma of different individuals contains two natural antibodies.

The distribution of antigens and antibodies in the four groups of blood, A, B, AB and O.

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, which leads to destruction of RBC.

Group 'O' blood can be donated to persons with any other blood group and hence 'O' group individuals are called '**universal donors**'.

Persons with 'AB' group can accept blood from persons with AB as well as the other groups of blood, and such persons are called '**universal recipients**'.

Rh grouping

The Rh antigen similar to one present in Rhesus monkeys is also observed on the surface of RBCs of majority of humans, hence the antigen is known as Rh antigen.

The individuals having Rh antigen 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, and hence Rh group should also be matched before transfusions.

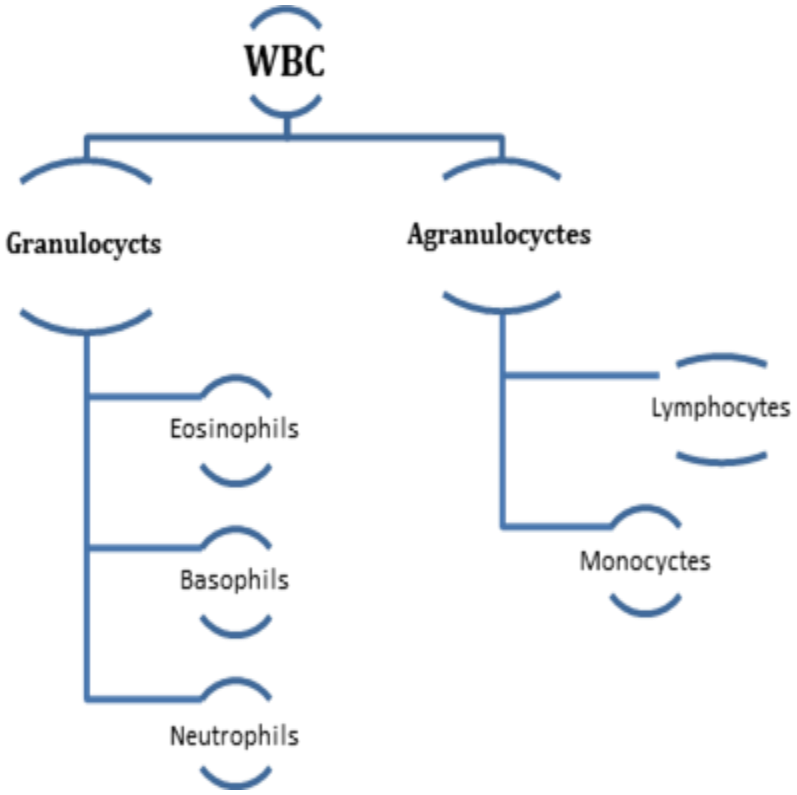
A special case of Rh incompatibility has been observed between the Rh-ve blood of a pregnant mother with Rh+ve blood of the foetus , which leads to a disease known as ***erythroblastosis foetalis.***

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, during the delivery of the first child, maternal blood may get exposed to small amounts of the Rh+ve blood from the foetus and the mother starts preparing antibodies against Rh in her blood.

In case of 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, which cause severe anaemia and jaundice to the baby leading to a condition known ***erythroblastosis foetalis***.

Erythroblastosis foetalis can be avoided by administering anti-Rh antibodies to the mother immediately after the delivery of the first child.

Blood group	Antigens on RBC	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



Plasma

The liquid state of blood can be contributed to plasma as it makes up for 50% of blood. It is pale yellow in colour and when separated, it consists of salts, nutrients, water and enzymes. Blood plasma also contains important proteins and other components necessary for overall health. Hence, blood plasma transfusions are given to patients with liver failure and life-threatening injuries.

LYMPH

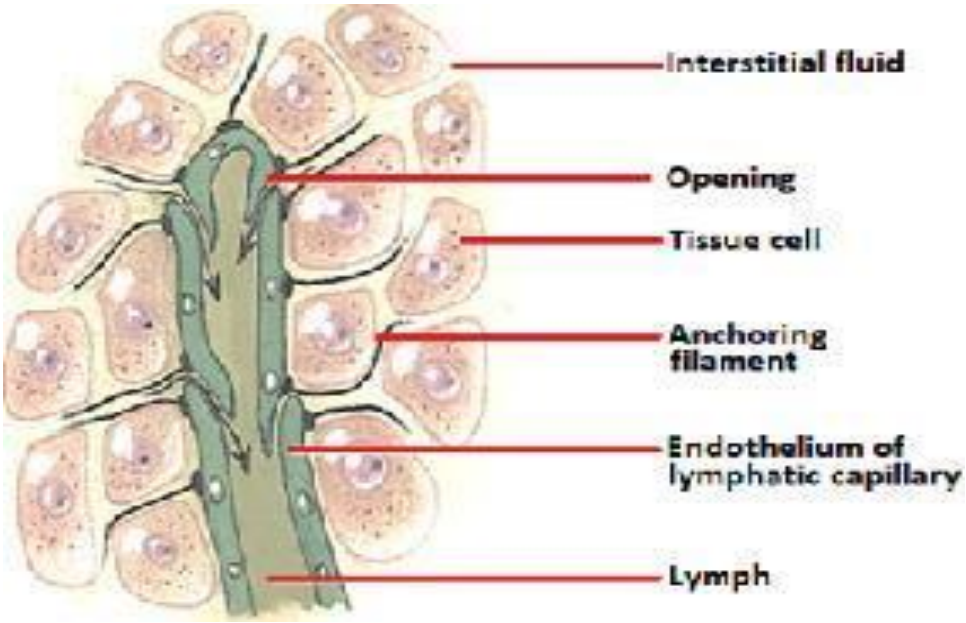
When the blood passes through the capillaries in tissues, some water along with many small water soluble substances move out into the spaces between the cells of tissues leaving the larger proteins and most of the formed elements in the blood vessels, the fluid released out is called the **interstitial fluid** or **tissue fluid**.

Exchange of nutrients, gases, etc., between the blood and the cells always occur through tissue 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, which is a colourless fluid containing specialised lymphocytes which are responsible for the immune responses of the body.

Fats are absorbed through lymph in the lacteals present in the intestinal villi.



Types of Blood Vessels

Three types of blood vessels are:

- Arteries
- Veins
- Capillaries

Arteries

Arteries are strong tubes and muscular in nature. These blood vessels carry oxygen-rich blood from the heart to all the tissues of the body. Aorta is one of the main arteries that arise from the heart and branches further.

Veins

Veins are elastic blood vessels which collect oxygen-depleted blood from all parts of the body, moving it towards the heart. An exception is the umbilical and pulmonary veins which carry oxygenated blood to the heart.

Capillaries

On reaching tissues, arteries branch further into extremely thin tubes called capillaries. They later connect to the heart after joining with the veins. Capillaries bring about the exchange of substances between blood and tissues.

FUNCTION OF BLOODS

Blood is responsible for the following body functions:

Fluid Connective Tissue

Blood is a fluid connective tissue composed of 55% plasma and 45% formed elements including WBCs, RBCs, and platelets. Since these living cells are suspended in plasma, blood is known as a fluid connective tissue and not just fluid.

Provides oxygen to the cells

Blood absorbs oxygen from the lungs and transports it to different cells of the body. The waste carbon dioxide moves from the lungs to the blood and is exhaled.

Transports Hormone and Nutrients

The digested nutrients such as glucose, vitamins, minerals, and proteins are absorbed into the blood through the capillaries in the villi lining the small intestine.

The hormones secreted by the endocrine glands are also transported by the blood to different organs and tissues.

Homeostasis

Blood helps to maintain the internal body temperature by absorbing or releasing heat. When the blood vessels react to outside organisms and changes in internal temperature, they expand and contract. This moves the blood and heat closer to or away from the skin surface.

Blood Clotting at Site of Injury

The platelets help in the clotting of blood at the site of injury. The platelets form a clump at the damaged area. Fibrins are formed to complete the clot.

Transport of waste to the Kidney and Liver

Blood enters the kidney where it is filtered to remove nitrogenous waste out of the blood plasma. The toxins from the blood are also removed by the liver.

Protection of body against pathogens

The White Blood Cells fight against infections. They multiply during the infections.

COAGULATION OF BLOOD

Blood coagulation or clotting is the mechanism to prevent excessive loss of blood from the body.

Reddish brown scum formed at the site of a cut is due to clot 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 are formed from another inactive substance present in the plasma called **prothrombin** by an enzyme complex known as **thrombokinase**.

Calcium ions play a very important role in clotting.

HEART

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**.

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 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.

The entire heart is made of cardiac muscles and a specialised cardiac musculature called the **nodal tissue** is also distributed in the heart.

A patch of the 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).**

Atrioventricular bundle (AV bundle) 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** and fibres along with right and left bundles are known as **bundle of HIS**.

The SAN can generate the maximum number of action potentials, i.e., 70-75 min^{-1}, and is responsible for initiating and maintaining the rhythmic contractile activity of the heart; hence it is called the

Our heart normally beats 70-75 times in a minute.

DOUBLE CIRCULATION

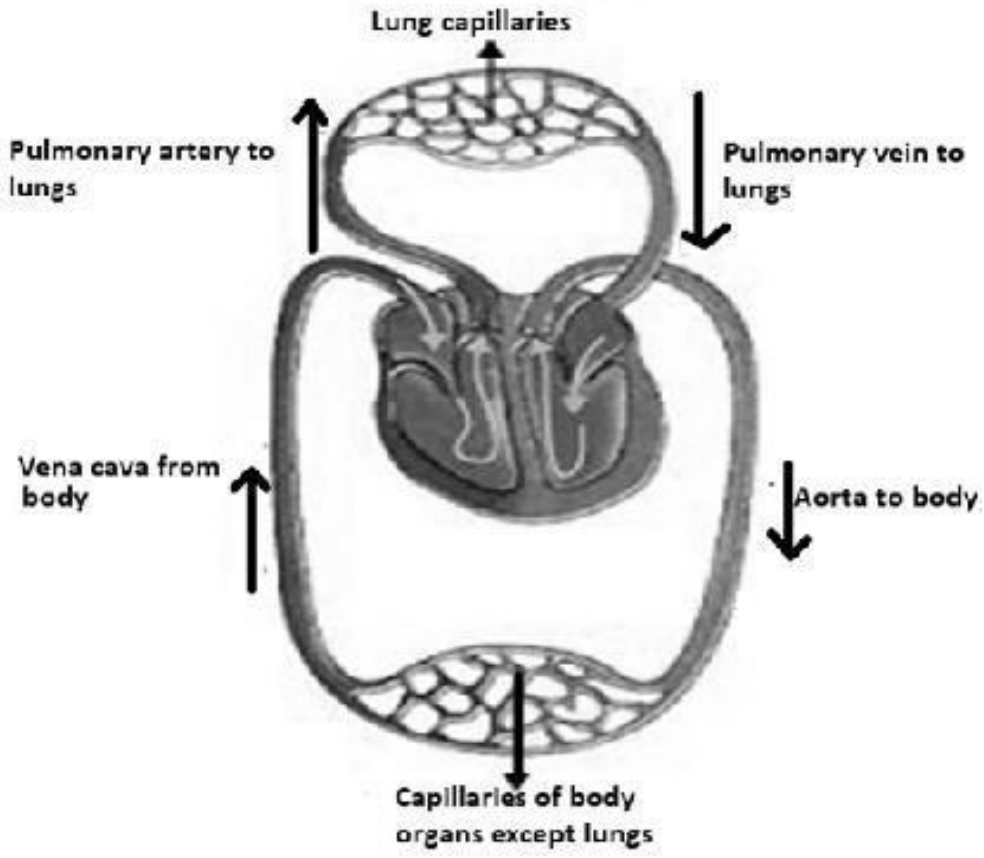
When the deoxygenated blood pumped into the pulmonary artery is passed on to the lungs from where the oxygenated blood is carried by the pulmonary veins into the left atrium; this pathway constitutes the **pulmonary circulation**.

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**.

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



CARDIAC CYCLE

The 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.

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 gives the **cardiac output**.

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.

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 and 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**.

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, which causes the ventricular muscles to contract, (ventricular systole), the atria undergoes relaxation (diastole), coinciding with the ventricular systole.

Ventricular systole increases the ventricular pressure causing the closure of tricuspid and bicuspid valves.

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.

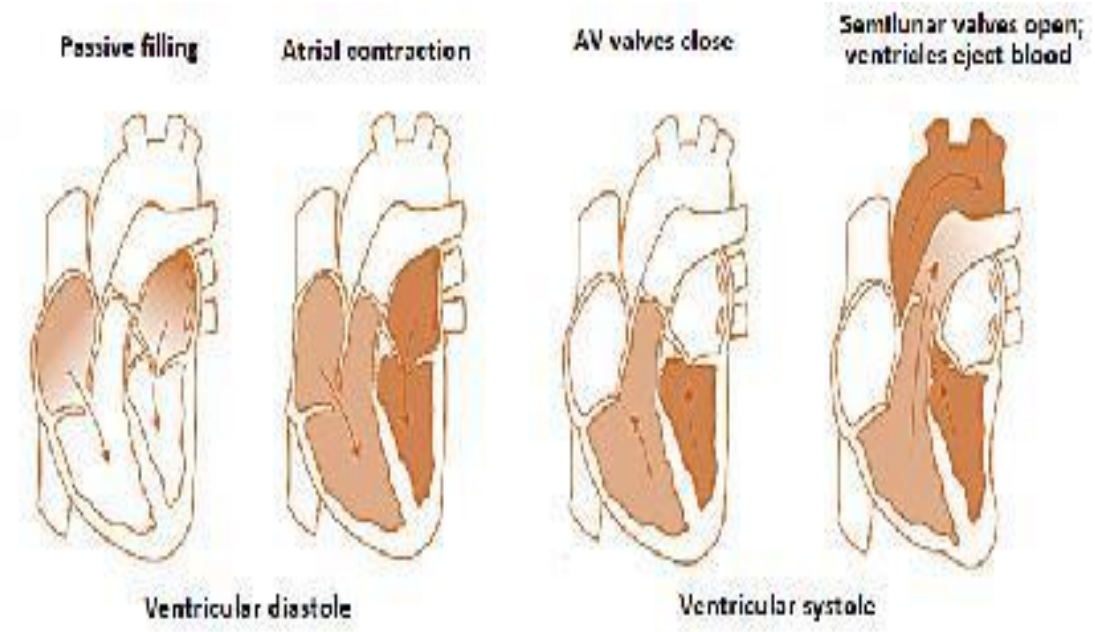
The ventricles now relax (ventricular diastole) and the ventricular pressure falls causing the closure of semilunar valves which prevents the backflow of blood into the ventricles.

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 and the blood now once again moves freely to the ventricles, leading the ventricles and atria again in a relaxed (joint diastole) state.

Again, the SAN generates a new action potential and the events are repeated.

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.



ELECTROCARDIOGRAM

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.

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 **T-wave** represents the return of the ventricles from excited to normal state (repolarisation) and 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.

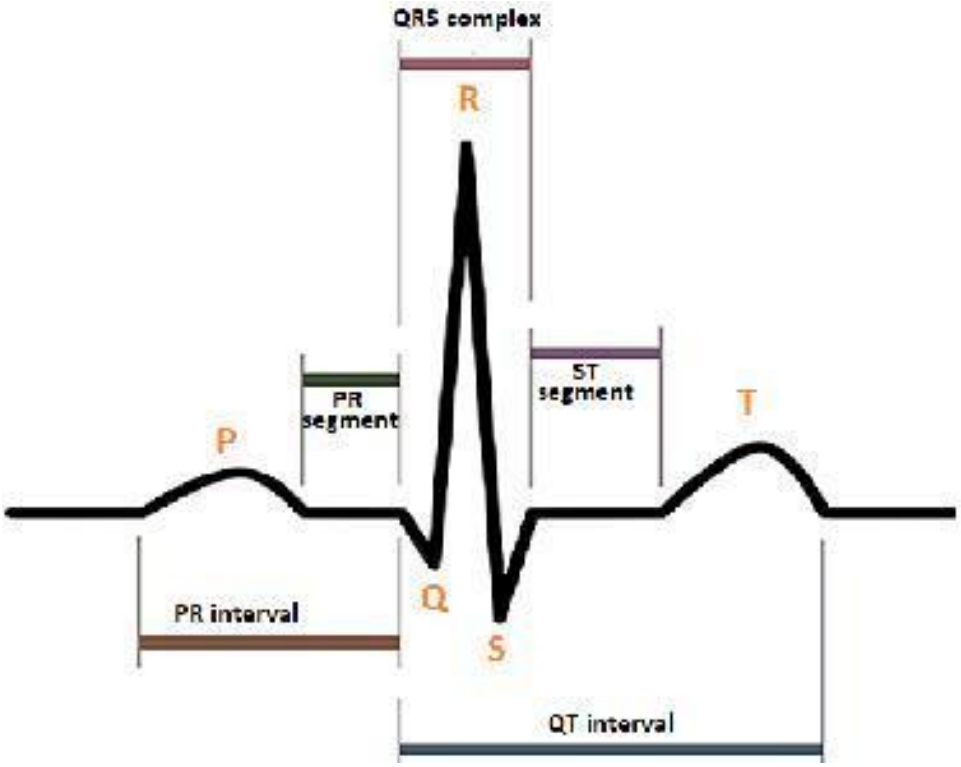


Fig. Double circulation

REGULATION OF CARDIAC ACTIVITY

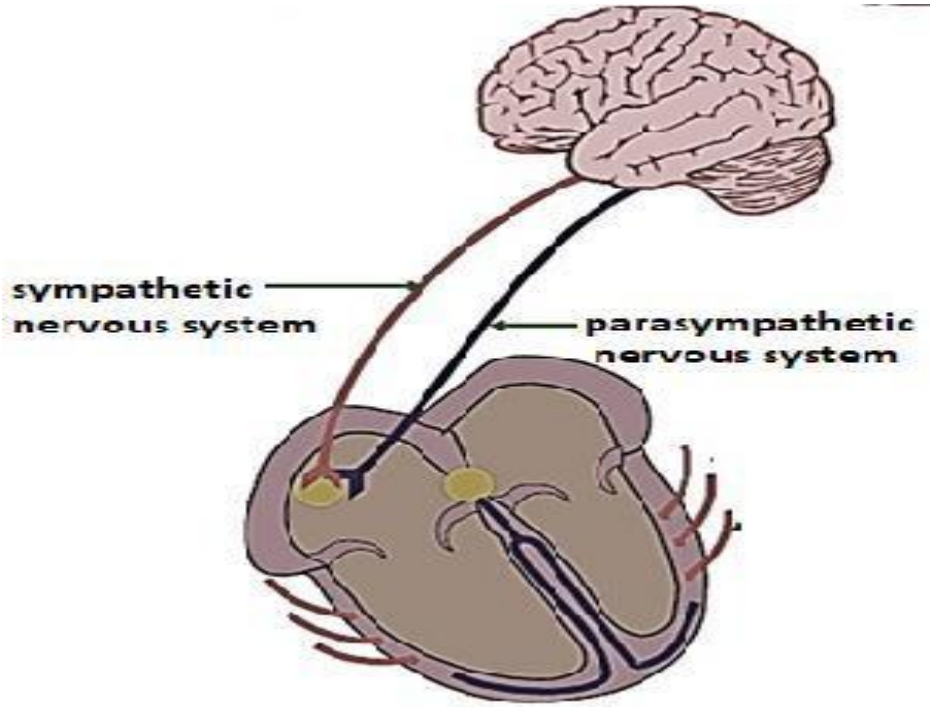
Normal activities of the heart are auto regulated by specialised muscles (nodal tissue), hence the heart is called **myogenic**.

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.

Parasympathetic neural signals 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).

120 mm Hg 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.

Coronary Artery Disease (CAD):

Coronary Artery Disease, often referred to as atherosclerosis, affects the vessels that supply blood to the heart muscle.

CAD 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 no enough oxygen is reaching the heart muscle.

Angina can occur in men and women of any age.

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.

Heart failure is not the same as cardiac arrest or a heart attack.

Cardiac arrest is when the heart stops beating, whereas heart attack is when the heart muscle is suddenly damaged by an inadequate blood supply.

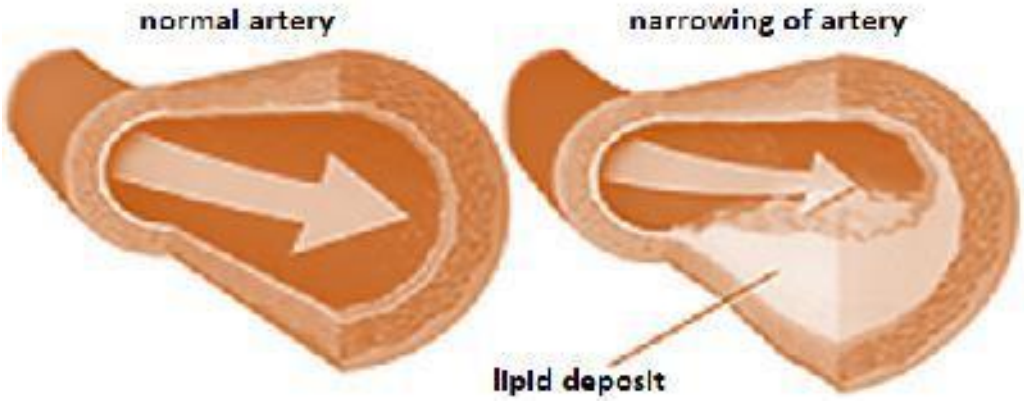


Fig. Coronary artery disease

IMPORTANT TERMS

1. **Albumin :** most abundant plasma protein, accounting for most of the osmotic pressure of plasma.

2. **Antibodies:** (also, immunoglobulins or gamma globulins) antigen-specific proteins produced by specialized B lymphocytes that protect the body by binding to foreign objects such as bacteria and viruses
3. **Aortic valve :** (also, aortic semilunar valve) valve located at the base of the aorta
4. **Arteriole :**(also, resistance vessel) very small artery that leads to a capillary
5. **Arteriovenous anastomosis :**short vessel connecting an arteriole directly to a venule and bypassing the capillary beds
6. **Artery:** blood vessel that conducts blood away from the heart; may be a conducting or distributing vessel
7. **Atrioventricular septum :** cardiac septum located between the atria and ventricles; atrioventricular valves are located here
8. **Atrioventricular valves :** one-way valves located between the atria and ventricles; the valve on the right is called the tricuspid valve, and the one on the left is the mitral or bicuspid valve
9. **Atrium :** (plural = atria) upper or receiving chamber of the heart that pumps blood into the lower chambers just prior to their contraction; the right atrium receives blood from the systemic circuit that flows into the right ventricle; the left atrium receives blood from the pulmonary circuit that flows into the left ventricle
10. **Auricle:** extension of an atrium visible on the superior surface of the heart
11. **Bicuspid valve** :(also, mitral valve or left atrioventricular valve) valve located between the left atrium and ventricle; consists of two flaps of tissue
12. **Blood:** liquid connective tissue composed of formed elements—erythrocytes, leukocytes, and platelets—and a fluid extracellular matrix called plasma; component of the cardiovascular system
13. **Epicardium:** innermost layer of the serous pericardium and the outermost layer of the heart wall
14. **Interventricular septum:** cardiac septum located between the two ventricles
15. **Myocardium:** thickest layer of the heart composed of cardiac muscle cells built upon a framework of primarily collagenous fibers and blood vessels that supply it and the nervous fibers that help to regulate it.
16. **Pulmonary veins:** veins that carry highly oxygenated blood into the left atrium, which pumps the blood into the left ventricle, which in turn pumps oxygenated blood into the aorta and to the many branches of the systemic circuit.
17. **Superior vena cava:** large systemic vein that returns blood to the heart from the superior portion of the body.
18. **Tricuspid valve:** term used most often in clinical settings for the right atrioventricular valve.

19. **ventricle** one of the primary pumping chambers of the heart located in the lower portion of the heart; the left ventricle is the major pumping chamber on the lower left side of the heart that ejects blood into the systemic circuit via the aorta and receives blood from the left atrium; the right ventricle is the major pumping chamber on the lower right side of the heart that ejects blood into the pulmonary circuit via the pulmonary trunk and receives blood from the right atrium.
20. **White blood cells (WBCs) :** (also, leukocytes) one of the formed elements of blood that provides defense against disease agents and foreign materials.