BLOOD CIRCULATORY SYSTEM OF MAN

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-R-36] State the location of heart in the body and define the role of pericardium.
2. [B-12-R-37] Describe the structure of the walls of heart and rationalize the thickness of the walls of each chamber.
3. [B-12-R-38] Trace the flow of blood through the heart as regulated by the valve.
4. [B-12-R-39] State the phases of heartbeat.
5. [B-12-R-40] Explain the roles of A node, AV node and Purkinje fibers in controlling the heartbeat.
6. [B-12-R-41] List the principles and uses of Electrocardiogram.
7. [B-12-R-42] Describe the detailed structure of arteries, veins and capillaries.
8. [B-12-R-43] Describe the role of arterioles in vasoconstriction and vasodilation.
9. [B-12-R-44] Describe the role of pre-capillary sphincters in regulating the flow of blood through the capillaries.
10. [B-12-R-45] Trace the path of the blood through the pulmonary and systemic circulation (coronary, hepatic-portal and renal circulation).
11. [B-12-R-46] Compare the rate of blood flow through arteries, arterioles capillaries, venules and veins.
12. [B-12-R-47] Define blood pressure and explain its periods of systolic and diastolic pressure.
13. [B-12-R-48] State the role of baroreceptors and volume receptor in regulating the blood pressure.
14. [B-12-R-49] Define the term thrombus and differentiate between thrombus and embolus.
15. [B-12-R-50] Identify the factors causing atherosclerosis and arteriosclerosis.
16. [B-12-R-51] Categorize Angina pectoris, heart attack, and heart failure as the stages of cardiovascular disease development.
17. [B-12-R-52] State the congenital heart problem related to the malfunction of cardiac valves.
18. [B-12-R-53] Describe the principles of angiography.
19. [B-12-R-54] Outline the main principle of coronary bypass, angioplasty and open-heart surgery.
20. [B-12-R-55] Define hypertension and describe the factor that regulate blood pressure and lead to hypertension and hypotension.
21. [B-12-R-56] List the changes in lifestyles that can protect man from hypertension and cardiac problems.
22. [B-12-R-57] Describe the formation, composition and function of intercellular fluid.
23. [B-12-R-58] Compare the composition of intercellular fluid with that of lymph.
24. [B-12-R-59] State the structure and role of lymph capillaries, lymph vessels and lymph trunks.
25. [B-12-R-60] Describe the functions of lymph nodes and state the role of spleen as containing lymphoid tissue.

Why do we need a transport system? You have read in the previous chapter that what is digestion? In chapter 1 you have read what are cells? All the cells of our body need food from small intestine and oxygen from the lungs. Carbon dioxide and waste chemicals have to be removed from the lungs and kidneys respectively. Our bodies are too large for materials to simple diffuse in and out. So we have a system of internal transport - a circulatory system that transports oxygen and carbon dioxide, distributes nutrients to the body cells and conveys the waste products of metabolism to specific site for disposal. The cardiovascular system consists of a strong muscular heart, three kinds of blood vessels: arteries, capillaries, veins and blood. The study of the diseases of cardiovascular system is called **angiology**.

2.1 HUMAN HEART

Location: Although the size of heart varies with the body size, the heart of an average adult is about 14 cm long and 9 cm wide. The heart is within the mediastinum, which is bordered laterally by the lungs, posteriorly by the backbone, and anteriorly by the sternum. It base lies beneath the second rib. It distal end extend downward and to the left, terminating as bluntly pointed apex at the level of the fifth intercostal space.

Role of pericardium

The pericardium is a closed sac that surrounds heart. The inelastic nature of the pericardium as a whole prevents the heart from being overstretched or overfilled with blood. The pericardium is a fibre membrane found as an external covering around the heart. It protects the heart by producing a serous fluid, which serves to lubricate the heart and prevent friction between the surrounding organs. Apart from the lubrication, the pericardium also helps by holding the heart in its position and by maintaining a hollow space for the heart to expand itself when it is full. The pericardium consists of two parts, the outer part and inner part. **Visceral Layer** is directly covers the outside of the heart. **Parietal Layer** forms a sac around the outer region of the heart that contains the fluid in the pericardial cavity.

2.2 STRUCTURE OF WALLS OF HEART

The heart consists of four chambers: two atria (meaning, entrance chamber) and two ventricles (meaning, belly). The atria lie above the ventricles. The heart wall is composed of the three layers of tissue: The epicardium, the myocardium, and the endocardium. The **epicardium** is a thin serous membrane comprising of the smooth outer surface of the heart. The thick middle layer of the heart, the **myocardium**, is composed of cardiac muscle cells. The smooth inner surface of the heart chambers is the **endocardium**, which consists of simple squamous epithelium over a layer of connective tissue. The heart valves are formed by a fold of the endocardium, making a double layer of endocardium with connective tissue in between.

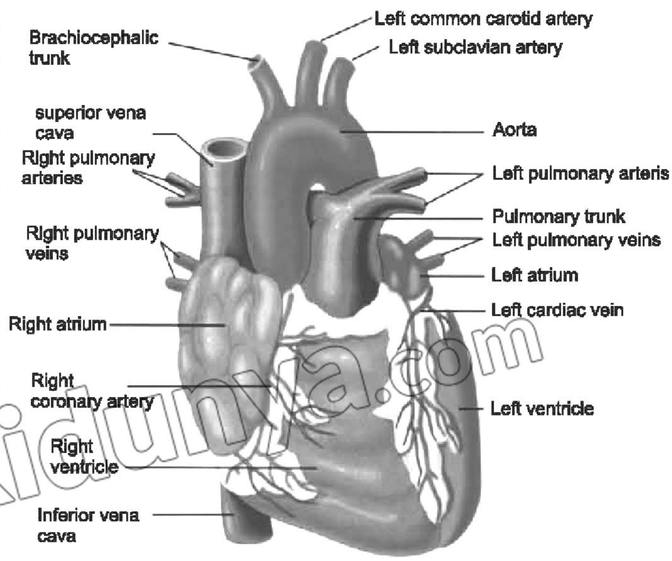


Fig. 2.1: Human heart, external view

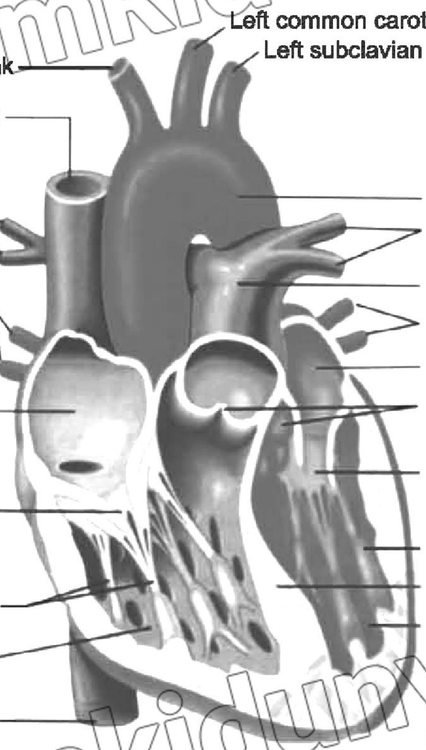


Fig. 2.2: Dissection of a human heart, as seen from the front, with the ventral part of both atria and both ventricles removed

The thickness of the walls of each chamber is different: The atria have comparatively thin walls as they only have to force blood into the ventricles and this does not require much power. On the other hand, the ventricles have to force blood out of the heart hence they have relatively thick walls, especially the left ventricle which has to pump blood around the whole body. The right ventricle has thinner walls than the left ventricle in a ratio of 1:3, it pumps blood to the lungs, which are at a short distance from the heart.

The **right atrium** receives the superior vena cava, the inferior vena cava, and the coronary sinus. The **left atrium** receives the four pulmonary veins. The two atria are separated from each other by the **interatrial septum**.

The atria open into the ventricles through **atrioventricular canals**. The **right ventricle** opens into the pulmonary trunk, and the **left ventricle** opens into the aorta. The two ventricles are separated from each other by the **interventricular septum**.

An **atrioventricular valve** is on each atrioventricular canal and is composed of **cusps**, or flaps. The atrioventricular valve between the right atrium and the right ventricle has three cusps and is called the **tricuspid valve**. The atrioventricular valve between the left atrium and left ventricle has two cusps and is therefore called the **bicuspid or mitral valve**. Each ventricle contains cone-shaped muscular pillars called **papillary muscles**. These muscles are attached by thin, strong connective tissue strings called **chordae tendineae** to the cusps of the atrioventricular valves. The papillary muscles contract when the ventricles contract and prevent the valves from opening into the atria by pulling on the chordae tendineae attached to the valve cusps. The aorta and pulmonary trunk possess **aortic** and **pulmonary semilunar valves**.

2.3 FLOW OF BLOOD THROUGH THE HEART

The superior vena cava and the inferior vena cava, both carrying deoxygenated blood, enter the right atrium. The right atrium sends blood through the tricuspid valve to the right ventricle. The right ventricle sends blood through the pulmonary semilunar valve into the pulmonary trunk and the two pulmonary arteries to the lungs. Four pulmonary veins, carrying oxygenated blood from the lungs, enter the left atrium. The left atrium sends blood through the bicuspid valve to the left ventricle.

The left ventricle sends blood through the aortic semilunar valve into the aorta to the body proper. The heart is a double pump because the right ventricle of the heart sends blood to the lungs, and the left ventricle sends blood throughout the body.

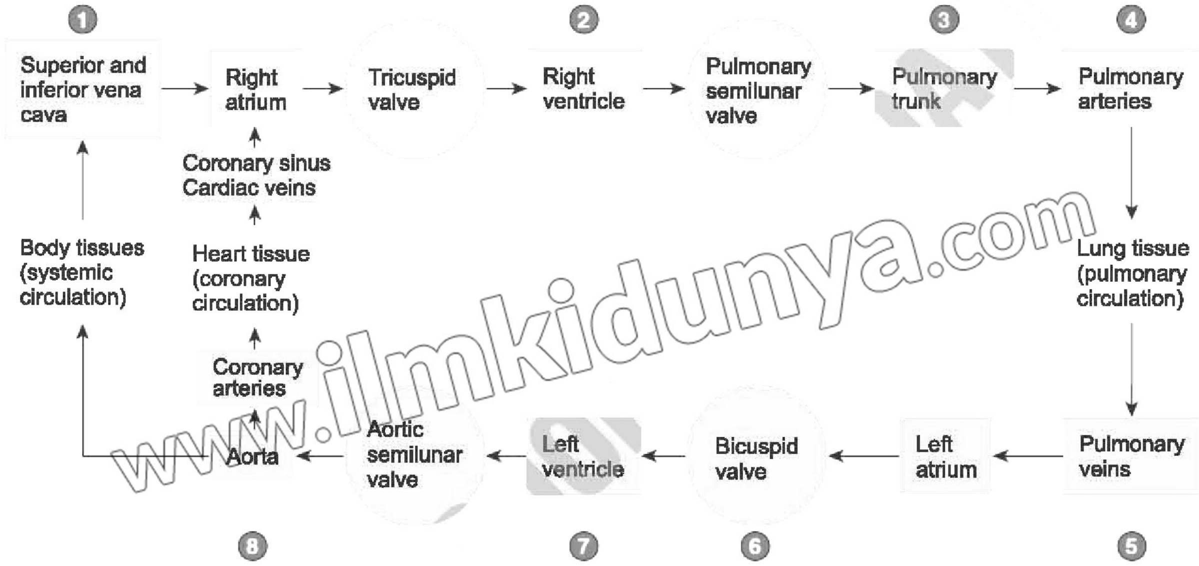


Fig. 2.3: Passage of blood through heart

2.4 PHASES OF HEARTBEAT

In a continuous, rhythmic cycle heart is passively filled with blood from the large veins and then the heart actively contracts, propelling the blood throughout the body. Its alternating relaxations and contractions make up the **cardiac cycle**. The cardiac cycle is a sequence of one heartbeat.

Phases of heartbeat

The term **systole** means to contract and **diastole** means to dilate. Atrial systole is contraction of the atrial myocardium and atrial diastole is relaxation of the atrial myocardium. Similarly ventricular systole is contraction of the ventricular myocardium and ventricular diastole is the relaxation of the ventricular myocardium. When the word "systole" and "diastole" are used without reference to specific chambers, they mean ventricular systole or diastole.

In **atrial diastole** blood enters the right atrium from the body through the vena cavae. At first the bicuspid and tricuspid valves are closed, but as the atria fill with blood, pressure in them rises. Eventually it becomes greater than that in the relaxed ventricles and the valves are pushed opens. In atrial systole the two atria contract simultaneously and blood is pushed through the atrio-ventricular valve into the still relaxed ventricles.

At this phase semilunar valve is closed, tricuspid and bicuspid valves are open.

In **ventricular systole** almost immediately the ventricles contract. When this occurs the pressure in the ventricles rises and closes the atrioventricular valves, preventing blood from returning to the atria. This pressure forces, open semilunar valves of the aorta and the pulmonary artery and blood enters these vessels. In this phase the tricuspid and bicuspid valves are closed.

In **ventricular diastole** the high pressure developed in the aorta and pulmonary artery tends to force some blood back towards the ventricles and close the semilunar valves of the aorta and pulmonary artery. Hence back flow in the heart is prevented. In this phase bicuspid valve and tricuspid valve are open, aortic semilunar valve, and pulmonary semilunar valve are closed. The normal cardiac cycle is of 0.7 to 0.8 second depending on the capability of cardiac muscle to contract. The heart muscle rests 0.1 to 0.3 second between the beats.

SCIENCE TITBITS

When a stethoscope is used to listen to the heart sounds, distinct sounds normally are heard. The first heart sound is a low-pitched sound, often described as a "lub" sound. It is caused by vibration of the atrioventricular valves which close near the beginning of ventricular systole. The second heart sound is a higher pitched sound often described as a "dub" sound. It results from closure of the aortic and pulmonary samilunar valves, near the end of systole. 'lub' is also written as 'lubb' and 'dub' as 'dupp'.

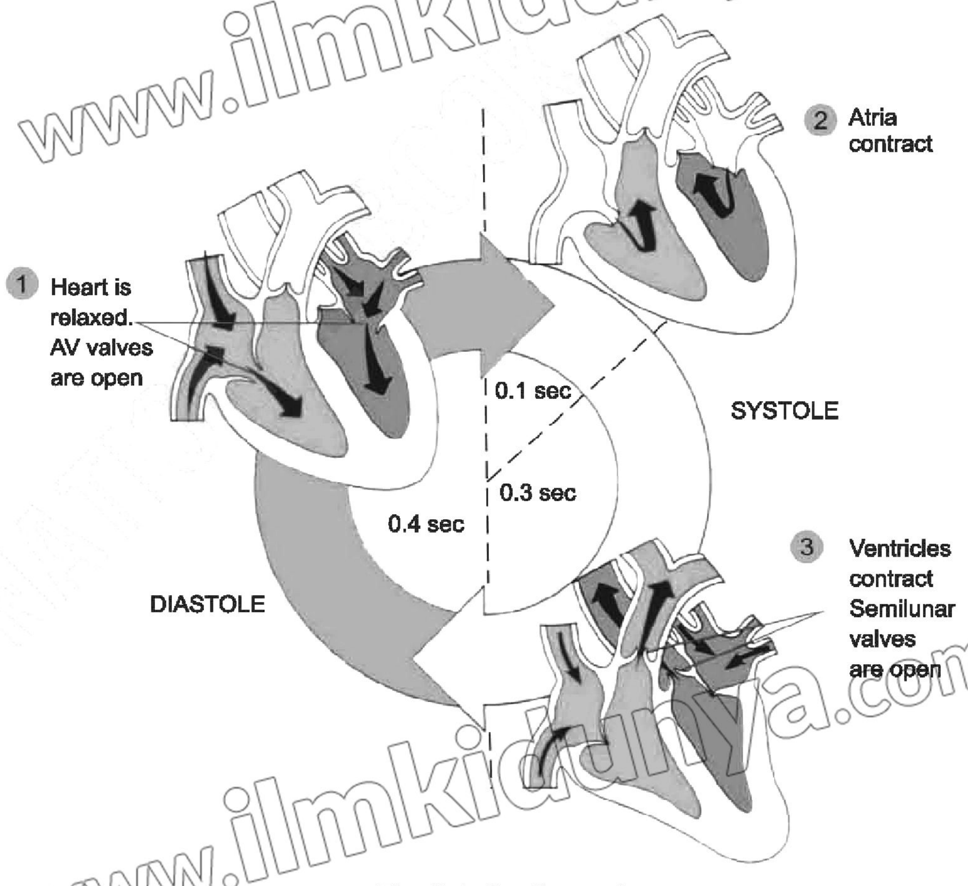


Fig. 2.4: Cardiac cycle

2.5 CONDUCTING SYSTEM OF THE HEART

The heart will go on beating after it has been cut right out of the body. Cardiac muscles are **myogenic** i.e., its rhythmic contraction arise from within the muscle itself. Cardiac muscle has an intrinsic rhythmicity that allows the heartbeat to originate in and be conducted through the heart without extrinsic stimulation. Specialized strands of interconnecting cardiac muscle tissue that coordinate cardiac contraction constitute the **conduction system**. The conduction system constitutes the cardiac cycle. The components of the conduction system are the (a) Sinoatrial node, (b) Atrioventricular node, (c) Atrioventricular bundle (d) Conducting myofibrils.

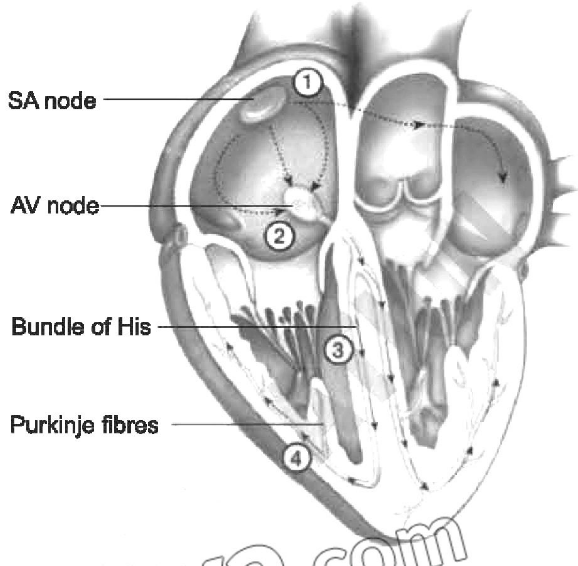


Fig. 2.5: Conducting system of the heart
1. Action potentials originate in the sinoatrial (SA) node and travel across the wall of the atrium (arrows) from the SA node to the atrioventricular (AV) node.
2. Action potentials pass through the AV node and along the atrioventricular (AV) bundle, which extends from the AV node, through the fibrous skeleton, into the interventricular septum.
3. The AV bundle divides into right and left bundle branches, and action potentials descend to the apex of each ventricle along the bundle branches.
4. Action potentials are carried by the Purkinje fibres from the bundle branches to the ventricular walls.

Sinoatrial node in short is called **SA node**. It consists of specialized plexus of cardiac muscles embedded in the upper wall of the right atrium. It is close to where vena cavae enter the atrium. The SA node has been developed from the sinus venosus and has become a part of the atrium, so it is called sinoatrial node. There is another specialized group of cardiac muscle fibres called **atrioventricular node**. In short it is called **AV node**. It is present near the junction of right atrium and right ventricle.

AV node is connected to a strand of specialized muscles (in the ventricular septum) known as **atrioventricular bundle or bundle of His**. This bundle passes through a small opening in the fibrous skeleton to reach the interventricular septum, where it divides to form right and left bundle branches, which extend beneath the endocardium on either side of the interventricular septum to the apices of the right and left ventricles respectively. The inferior, terminal branches of the bundle branches are called **Purkinje fibres**, which are large-diameter cardiac muscle fibres. They have fewer myofibrils than most cardiac muscle cells and do not contract forcefully. **Intercalated disks** are well developed between the Purkinje fibres and contain numerous gap junctions. As a result of these structural modifications, action potentials travel along the Purkinje fibres much more rapidly than through other cardiac muscle tissue. Cardiac muscle cells have the capacity to generate spontaneous action potentials, but cells of the SA node do so at a greater frequency. As a result, the SA node is called the **pacemaker** of the heart. When the heart beats under resting conditions, approximately 0.04 second is required for action potentials to travel from the SA node to the AV node. Within the AV node action potentials are propagated slowly compared with the remainder of the conducting system. As a consequence, there is a delay of 0.11 second from the time action potentials reach the AV node until they pass to the AV bundle. The total delay of 0.15 second allows completion of the atrial contraction before ventricular contraction begins.

Science, Technology and Society Connections

- **Rationalize the use of artificial pacemaker in patients of cardiac arrhythmias.**

A **cardiac arrhythmia** is a disturbance in electrical rhythm of heart. It may be **bradycardia** (heart beat less than 40 beats per minute) or **tachycardia** (heart beat more than 100 beats per minute). Pacemaker supplies electrical initiation to myocardial contraction. The pacemaker is put surgically under the skin where it may be programmed. It generates electrical rhythm at a set rate, so in this way arryhthmia are controlled.

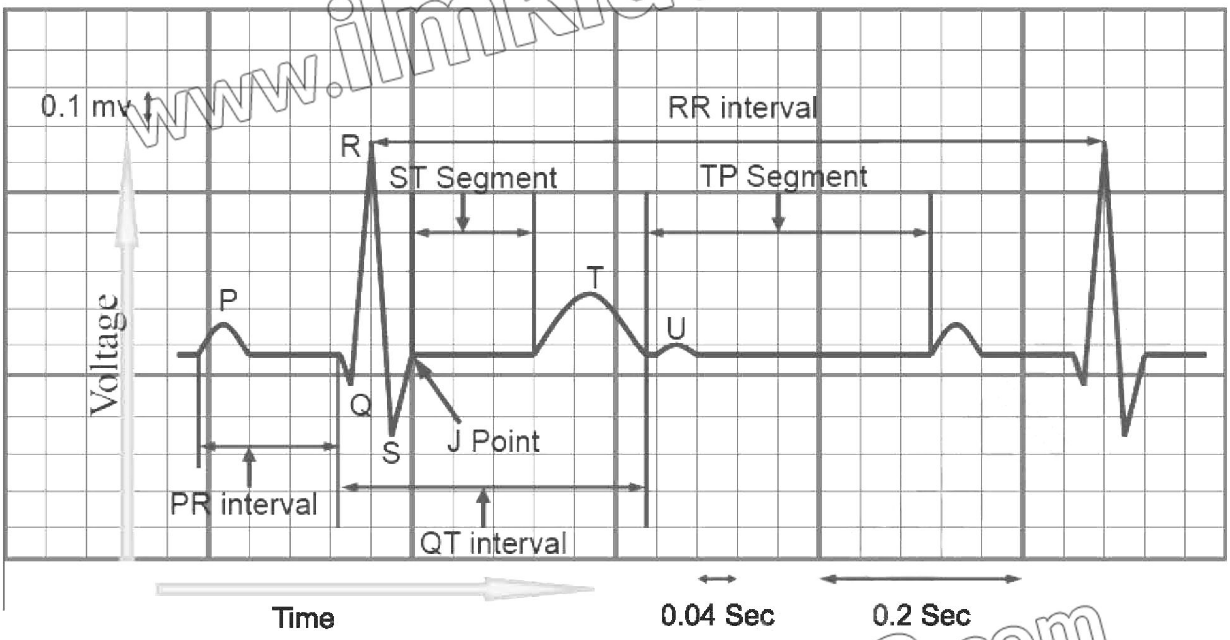
2.6 ELECTROCARDIOGRAM

The electrical impulses that pass through the conduction system of the heart during the cardiac cycle can be recorded as an electrocardiogram (ECG). The electrical changes result from depolarization and repolarization of cardiac muscle fibres and can be detected on the surface of the skin using an instrument called the **electrocardiograph**. The principal aspects of an ECG are shown in the given figure. The wave deflections, designated P, QRS, and T, are produced as specific events of the cardiac cycle occur.

Depolarization of the atrial fibres of the SA node produces the **P wave**. The ventricles of the heart are in diastole during the expression of the P wave. On the ECG recording, the **P-R interval** is the period of time from the start of the P wave to the beginning of the QRS complex. This interval indicates the amount of time required for the SA depolarization to reach the ventricles. The **QRS complex** begins as a short downward deflection (Q), continues as a sharp upward spike (R), and ends as a downward deflection (S). The QRS complex indicates the depolarization of the ventricles. During this interval, the ventricles are in systole and blood is being ejected from the heart. The time duration known as the **S-T segment** represents the period between the completion of ventricular depolarization and initiation of repolarization. The **T wave** is produced by ventricular repolarization. A normal ECG indicates that the heart is functioning properly. The P wave represents excitation and occurs just prior to contraction of the atria. The second wave, or the QRS complex, occurs just prior to ventricular contraction. The third, or T, wave occurs just before the ventricles relax. The J (junction) point in the junction between termination of the QRS complex and the beginning of the ST segment.

Uses of electrocardiogram

An ECG is a painless test that measures heart electrical activity to show whether or not it is working normally. ECG can detect arrhythmias (irregular heartbeat), conduction defects, size and position of heart chambers, damage to heart muscle, impaired blood flow to heart muscle, the effect of cardiac medicines and function of artificial pacemakers.



• PR interval	0.12 - 0.20 sec	• QT interval	0.4 - 0.43 sec
• QRS duration	0.08 - 0.10 sec	• RR interval	0.6 - 1.0 sec

Fig. 2.6: Electrocardiogram (ECG)

2.7 BLOOD VESESLS

There are three types of blood vessels, the **arteries** (and arterioles), which carry blood away from the heart, the **veins,** which return blood to the heart, and **capillaries**, which permit exchange of materials with the tissues.

2.7.1 Arteries

Arteries carry blood away from the heart. Arteries are pink in colour and are situated within the muscles. Arteries vary in size.
Arteries branch into **arterioles** and **capillaries.** The lumens of arteries have no valves. The wall of an artery consists of three coats or tunics: tunica adventitia, tunica media and tunica intima.
The outermost layer is called **tunica adventitia.** It is composed of white fibrous connective tissue. The middle layer is called **tunica media**, and has variable amount of elastic fibres. It is many layered in thickness. It consists of one or two layers of circular smooth muscle cells.

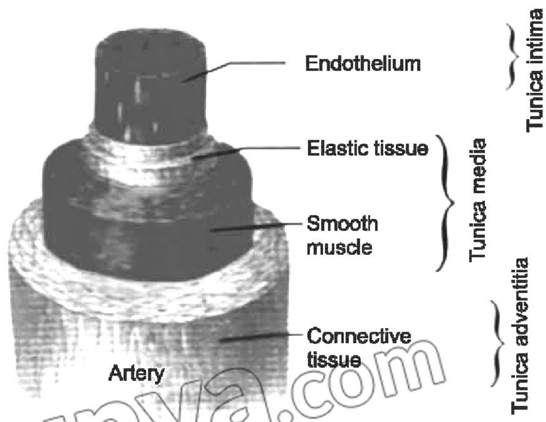


Fig. 2.7: Artery

The innermost layer of the artery is called **tunica intima.** It is composed of simple squamous epithelium and elastic fibres composed of elastin. Arterioles transport blood from small arteries to capillaries. Aorta is approximately 23 mm and arterioles are about 0.2 mm in diameter.

2.7.2 Capillaries

The capillary wall consists primarily of endothelial cells. Most capillaries range from 7 to 9 µm in diameter, and thus branch without a change in their diameter. Capillaries are approximately 1 mm long. Red blood cells flow through most of capillaries in a single file.

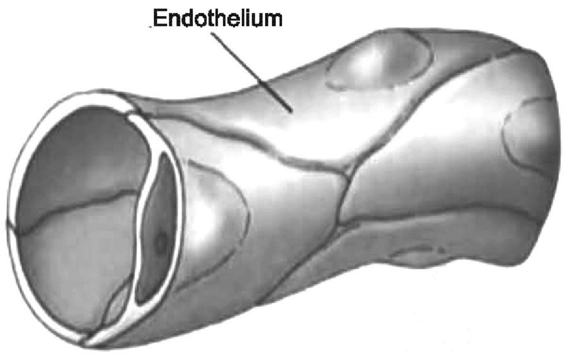


Fig. 2.8: Capillary

2.7.3 Veins

The blood vessels that bring blood back to the heart are called veins. Veins are relatively not deep in the muscles. Veins can be seen as blue vessels under the skin. A vein also consists of **tunica adventitia**, tunica media and tunica intima. Tunica adventia is composed of collagenous connective tissue. **Tunica media** is composed of a thin layer of circularly arranged smooth muscle cells, collagen fibres and a few sparsely distributed elastic fibres. **Tunica intima** is a smooth muscle and consists of endothelial cells, thin layer of elastic fibres. **Venules** with a diameter of 40 to 50 µm are tubes composed of endothelium. The venules collect blood from the capillaries and transport it to the small veins.

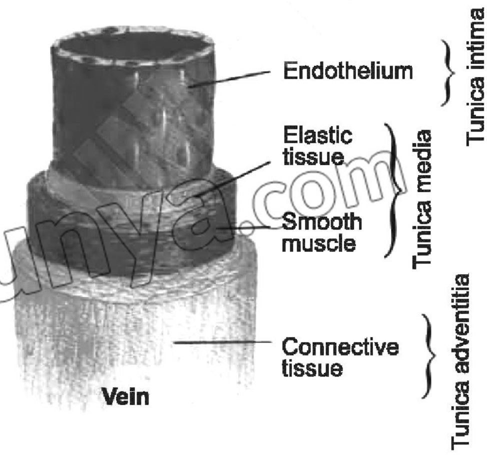


Fig. 2.9: Vein

Valves in veins

Veins having diameters greater than 2mm contain valves that allow blood flow toward the heart but not in the opposite direction. Valves are present only in the lower part of the body especially in the abdomen and hind limbs. In the upper region above the heart there is no valve. As the blood pressure in the veins is comparatively low, so the flow of blood in the veins is helped by gravity, semilunar valve and muscular contraction.

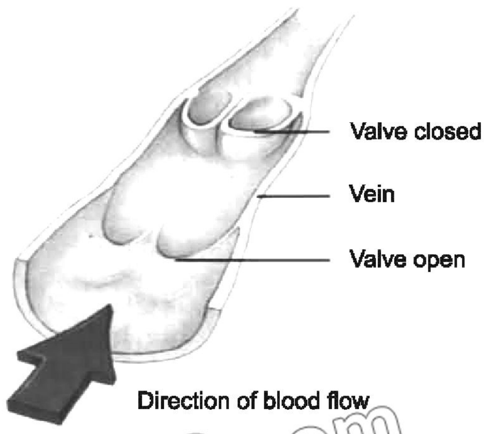


Fig. 2.10: Valves in veins

2.8 ROLE OF ARTERIOLES IN VASO-CONSTRICTION AND VASODILATION

The amount of blood flowing through a blood vessel can be regulated by contraction or relaxation of smooth muscle in the tunica media. A decrease in blood flow results from **vasoconstriction**, a decrease in blood vessels diameter caused by smooth muscle contraction whereas an increase in blood flow is produced by **vasodilation** an increase in blood vessel diameter because of smooth muscle relaxation. Blood circulation is also controlled by hormones (vasoconstriction agents) acting on arterioles. Norepinephrine is an especially powerful vasoconstriction hormone, and epinephrine is less.

Several substances called kinins (vasodilator agents) can cause powerful vasodilation are formed in the blood and tissue fluids of some organs. e.g., histamine. Most of the prostaglandins are vasodilator agents though some of the prostaglandins are vasoconstrictor.

- **Justify how Vasodilation and Vasoconstriction is Reflective of Emotions?**

During emotional rage such as apprehension and rage vasodilation occurs due to secretion of epinephrine. It is a hormone that is responsible for fear, flight and fright conditions. The sympathetic vasodilator fibres are part of a regulatory system that originates in cerebral cortex and ends at postganglionic neurons in blood vessels on skeletal muscles, activate them to release acetylcholine, and vasodilation occurs. Blood discharge through thoroughfare channels rather than capillaries so heat loss occurs and the skin becomes hot and red. While in vasoconstriction blood supply becomes less to skin, so heat is preserved and the skin becomes cold. Situations such as shock, hypotension and tachycardia occur by stimulation of arterial stretch receptors and production of hypertension and bradycardia (slowness of the heart) occur by increased intracranial pressure.

2.9 ROLE OF PRE-CAPILLARY SPHINCTERS

Arterioles supply blood to each capillary network, blood then flows through the capillary network and into the venules. Blood flows from arterioles through metarterioles. From a metarteriole blood flows into a thoroughfare channel. Several capillaries branch from the thoroughfare channels. Flow in these capillaries is regulated by smooth muscle cells called precapillary sphincter, which are located at the origin of the branches. This sphincter can open and close the entrance to the capillary. Precapillary sphincters are normally either completely open or completely closed, and the degree of constriction of the metarteriole also varies. The precapillary sphincters and metarterioles often open and close cyclically several times per minute, with the duration of the open phases being about proportional to the metabolic needs of the tissue. The cyclic opening and closing is called vasomotion.

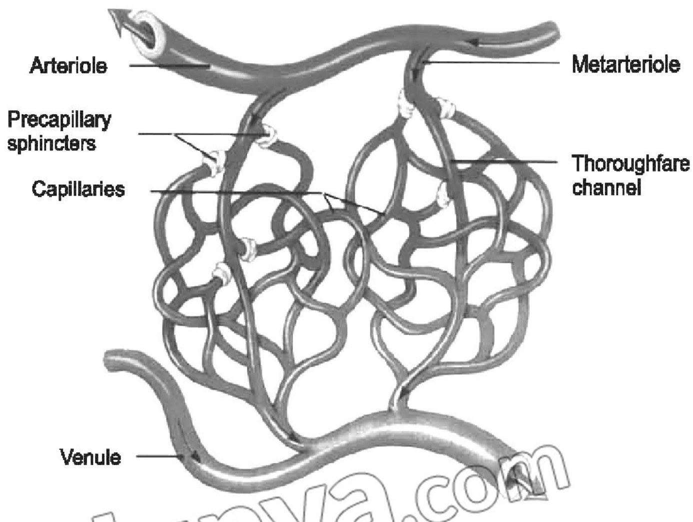


Fig. 2.11: Capillary network

2.10 PATH OF BLOOD THROUGH THE PULMONARY AND SYSTEMIC CIRCULATION

We will discuss here the path of blood through the pulmonary and systemic circulation.

Pulmonary circulation

The left atrium receives oxygenated blood from the lungs through a pair of **pulmonary veins,** which open by common aperture into it. From left atrium the blood flows into the left ventricle. The superior and inferior vena cavae bring deoxygenated blood and open into the right atrium. From right atrium blood flows into the lungs for oxygenation by a **pulmonary arch** or **trunk** which divides into two **pulmonary arteries**, each going to the lung of its own side. This part of circulation is called **pulmonary circulation** or **circuit.** The pulmonary arteries carry deoxygenated blood and pulmonary veins carry oxygenated blood.

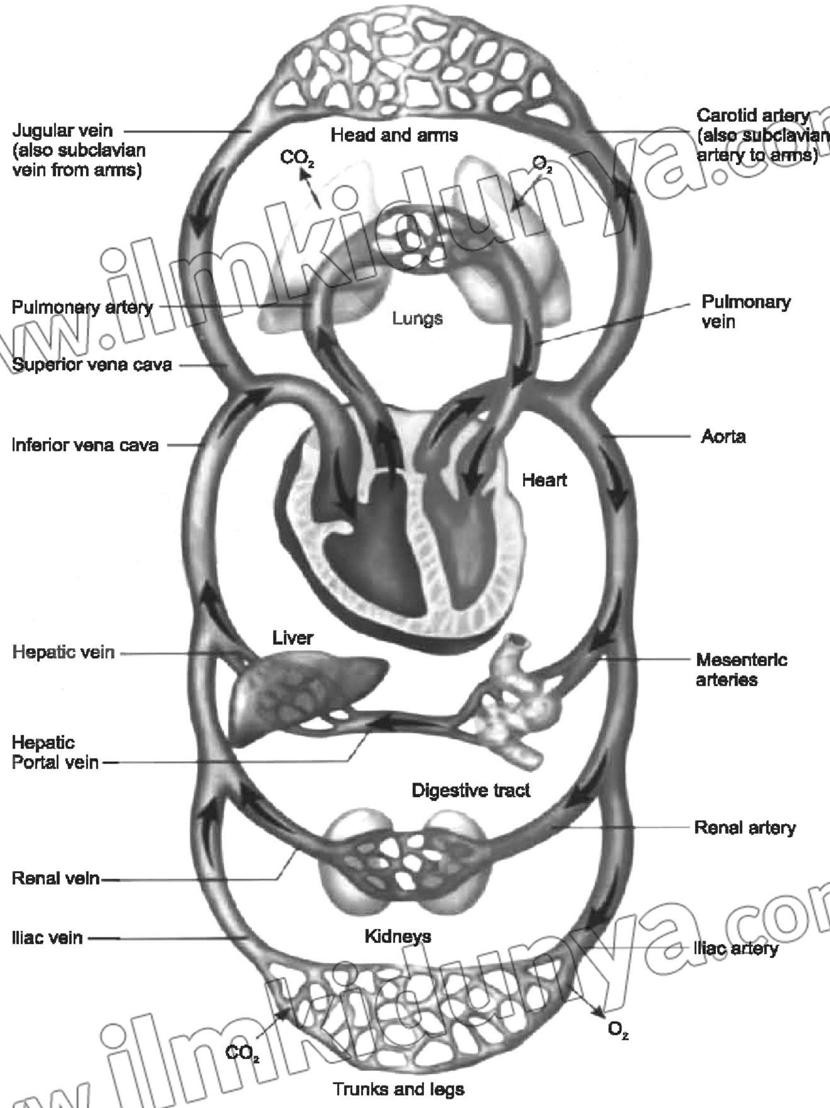


Fig. 2.12: Cardiovascular system

Systemic circulation

The systemic circuit includes all the **arteries** and **veins** other than involved in pulmonary circuit. The largest artery in the systemic circuit is the **aorta**. The largest veins are the **superior** and **inferior venae cava**. The path of systemic blood to any organ in the body begins in the **left ventricle** which pumps blood in the aorta. Branches from aorta go to the organs and major body regions. The **superior vena cava** collects blood from the head, the chest and the arms. The **inferior vena cava** collects blood from the lower body regions. Both enter the right atrium. The aorta and the vena cavae are the major pathways in the systemic circuit. In most instances the artery and the vein that serve the same organ are given the same name.

Coronary circulation

The wall of the heart has its own supply of blood vessels to meet its vital needs. The myocardium is supplied with blood by the **right** and **left coronary arteries**. From the capillaries in the myocardium, the blood enters the **cardiac veins**. The course of these vessels parallels that of the coronary arteries. These cardiac veins converge to form the **coronary sinus channel** on the posterior surface of the heart. The coronary venous blood then enters the heart through an opening into the right atrium.

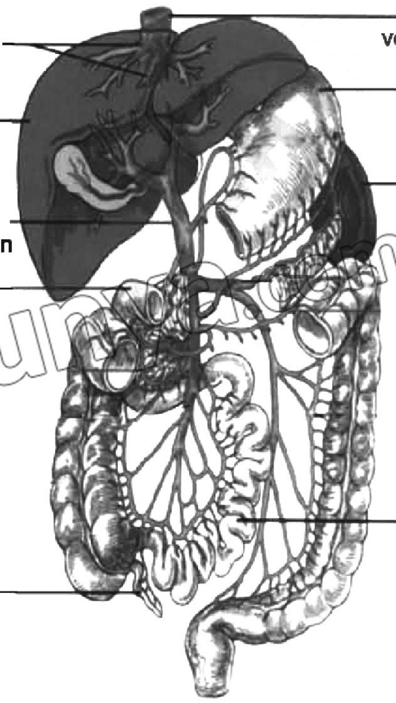


Fig. 2.13: Hepatic portal system

Hepatic portal system

A **portal** system is vascular system that begins and ends with capillary beds and has no pumping mechanism such as the heart. The **portal system** that begins with capillaries in the viscera and ends with the capillaries in the liver is the hepatic portal system. The **hepatic portal vein**, the largest vein of the system, is formed by the union of all the veins coming from digestive system. Within the liver the blood flows through a series of dilated capillaries which empty into hepatic veins. The **hepatic veins** join the inferior vena cava.

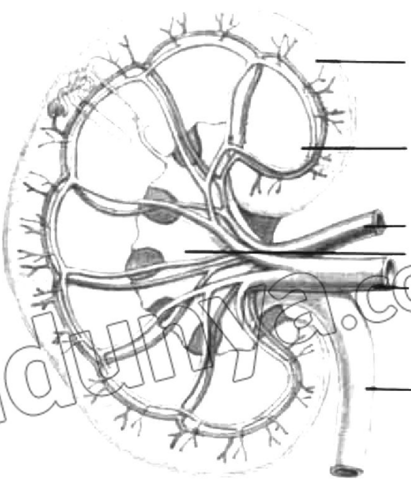


Fig. 2.14: Principal arteries and veins of kidney

Renal circulation

Renal artery enters into kidney and gives branches which pass through medulla. In cortex they give rise to **afferent**

glomerular arterioles From here blood enters the **peritubular capillaries** and **vasa recta**. From these capillary networks the blood is drained through veins and leave the kidney as a single renal vein that empties into the inferior vena cava.

2.11 RATE OF BLOOD FLOW IN BLOOD VESSELS

Blood flow means simply the quantity of blood that passes through a given point in the circulation in a given period. The overall blood flow in the circulation of an adult at rest is about 5000 ml/min. This is called **cardiac output**. It is the amount of blood pumped by the heart in a unit period.

Comparison of the rate of blood flow through arteries, arterioles, capillaries, venules and veins

Blood travels over a thousand times faster in the aorta, i.e., about 30cm/sec on average than in capillaries i.e., about 0.26 cm/sec. You might think that blood should travel faster through capillaries than through arteries, because the diameter of capillaries is very small. However, it is the total cross-sectional area of capillaries that determines flow rate. Each artery conveys blood to such an enormous number of capillaries that the total cross-sectional area is much greater in capillary beds than in any other part of the circulatory system. For this reason the blood slows substantially as it enters the arterioles from arteries and slows further still in the capillary beds. As blood leaves the capillaries and enters the venules and veins it speeds up again as a result of the reduction in total cross-sectional area. The carotid sinus and aortic arch baroreceptor reflexes are important in regulating blood pressure moment to moment.

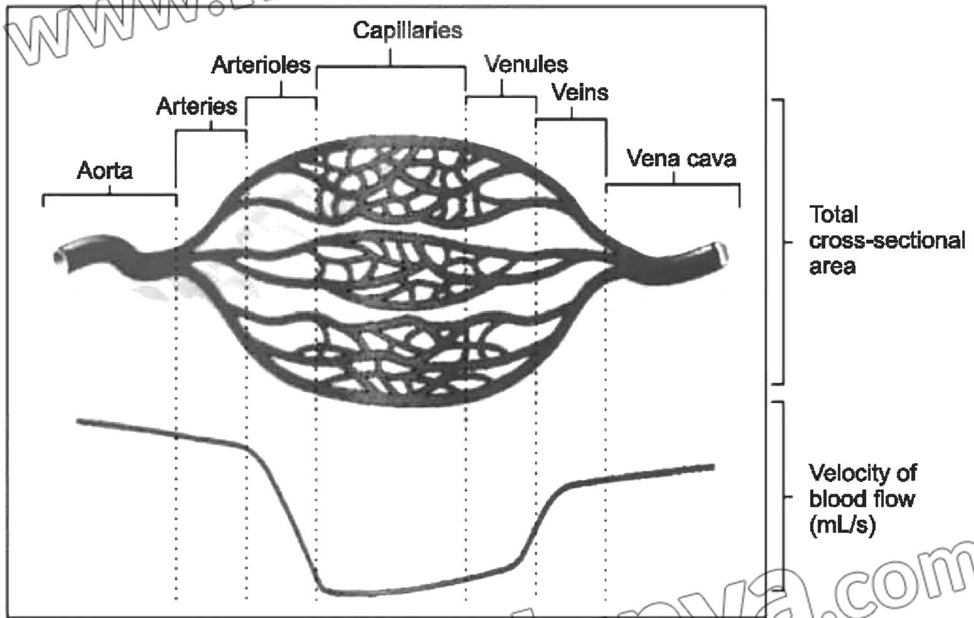


Fig. 2.15: Blood vessel types and velocity of blood flow: Total cross-sectional area for each of the major blood vessel types is the space through which blood flows, measured in square centimeters. The cross-sectional area of the aorta is about 2.5 cm^2. The crosssectional area of each capillary is much smaller, but there are so many that the total cross-sectional area is more than that of the aorta. The line at the bottom of the graph shows that blood velocity drops dramatically in arterioles, capillaries, and venules. As the total cross-sectional area increases the velocity of blood flow decreases

2.12 BLOOD PRESSURE

Blood pressure is the force exerted by the blood against any unit area on the inner walls of the blood vessel. The standard reference for the blood pressure is the mercury (Hg) manometer, which measures pressure in millimetres of mercury (mm Hg). If the blood pressure is 100 mm Hg the pressure is great enough to lift a column of mercury 100 mm. When the ventricles of the heart contract the arterial blood pressure is the highest. It is called **systolic pressure**. When the ventricles of the heart relax, the arterial blood pressure is the lowest. It is called **diastolic pressure**.

2.13 BARORECEPTORS AND VOLUME RECEPTORS

Baroreceptors can be divided into two categories based on the type of blood vessel in which they are located: high-pressure arterial baroreceptors and low-pressure baroreceptors or volume receptors

High-pressure arterial baroreceptors

These are mechanoreceptors located in the walls of the aorta and carotid sinus in the carotid arteries. They sense the blood pressure and relay the information to the brain, so that a proper blood pressure can be maintained. Stimulation of parasympathetic nerves in these areas caused by cardiac output, produces vasodilatation throughout the body and consequent reduction in blood pressure as well as a slowing the heart rate. The opposite occurs when blood pressure is low. In this case, a fall in blood pressure increases nerve impulse transmission along sympathetic nerves. This causes body-wide vasoconstriction and a rise in blood pressure. Baroreceptors act immediately as part of a negative feedback system called the **baroreflex**.

Low-pressure baroreceptors or volume receptors

Low-pressure baroreceptors or volume receptors are found in the atria of the heart and carotid arteries. When these receptors detect a blood volume decrease in the atria, a signal is transmitted from the receptors to the hypothalamus in the brain. The hypothalamus, in turn, increases the production of antidiuretic hormone (ADH) which will cause water retention in kidney. This increases the blood volume, resulting in the increase of blood pressure.

2.14 CARDIOVASCULAR DISORDERS

Cardiovascular disorders or diseases (CVD) are the diseases of the heart and blood vessels. The CVD are the leading cause of untimely death.

2.14.1 Thrombosis and Embolism

The formation of a clotted mass of blood within a vessel or the heart during life is called **thrombosis**. The clotted mass of blood within a vessel or the heart during life is called **thrombus**. The occlusion (a closing of an opening) of some part of the cardiovascular system by any mass transported to the site through the blood stream is called embolism. **Embolus** (plural: emboli) is a detached intravascular solid, liquid or gaseous mass that is carried to a site distant from its point of origin. About 99% emboli arise from dislodgement of thrombi and are therefore called **thromboemboli**. Thrombus and embolus cause death.

2.15 HEART PROBLEMS

In this section we will discuss cardiovascular diseases, such as: atherosclerosis and arteriosclerosis.

2.15.1 Atherosclerosis and arteriosclerosis

Atherosclerosis is the plaque deposition of cholesterol in the arteries resulting in the narrowing of the arteries lumen. Later, fibres are deposited in the cholesterol and these often start to calcify and become hard, a process known as **arteriosclerosis**. The plaque first forms thrombus and may detach to form embolus. The major factors that cause atherosclerosis and arteriosclerosis are: Hypercholesterolemia, (hyperlipidemia), Hypertension, Cigarette smoking, Diabetes mellitus, the other minor risk factors are: (a) Increasing age, (b) Lack of exercise, (c) Stressful competitive life, (d) Obesity.

2.16 STAGES OF CARDIOVASCULAR DISEASE DEVELOPMENT

In this section we will discuss cardiovascular diseases, such as: angina pectoris, heart attack, heart failure.

2.16.1 Angina pectoris

Due to atherosclerosis a person may feel occasional chest pain, a condition known as angina pectoris. Angina is most likely to occur when the heart is labouring hard because of physical or emotional stress. Angina is a signal that part of the heart is not receiving a sufficient supply of oxygen and that part of the heart attack could occur in future.

2.16.2 Heart attack

Many heart attacks occur without warning. A blood clot may completely block a coronary artery, or atherosclerosis may reach a critical level causing massive damage to the heart muscle. All of a sudden, the person feels a heavy squeezing ache or discomfort in the centre of the chest. The pain may radiate to shoulder, arm neck or jaw. Other symptoms may include sweating, nausea, shortness of breath and dizziness or fainting. The whole process is called **myocardial** (heart muscle) **infarction** (death due to lack of oxygen). When heart muscles die, they are not replaced because cardiac muscles do not divide. When a person survives a heart attack scar tissue (a type of connective tissue) grows into the areas where the heart muscles have died. The scar tissue cannot contract as cardiac muscle. As a result the damaged heart is permanently weakened.

2.16.3 Heart failure

Congestive heart failure is inability of heart to pump all the blood coming to it. The cardiac output is unable to keep pace with the venous return.

2.16.4 Congenital heart problem

Congenital heart problems result from abnormalities in the embryonic development. It can be related to the malfunctioning of cardiac valves e.g., **Valvular stenosis.**

2.17 DIAGNOSIS OF CARDIOVASCULAR DISORDERS

Modern research efforts have resulted in improved diagnosis of CVD, their treatment and preventions.

a. Principles of angiography

Cardiac catheterization is a technique in which specially designed catheter is inserted into a vein or artery and advanced into the heart under radiographic fluoroscopic guidance. This allows the operator to obtain angiograms by injecting contrast media into an area of interest. It is used to evaluate disease of the mitral valve, aortic valve and aorta, to determine the size and function of the left ventricle.Coronary angiography is used to detect stenosis (narrowing of a tube) and guide revascularisation procedures such as balloon angiography and stenting.

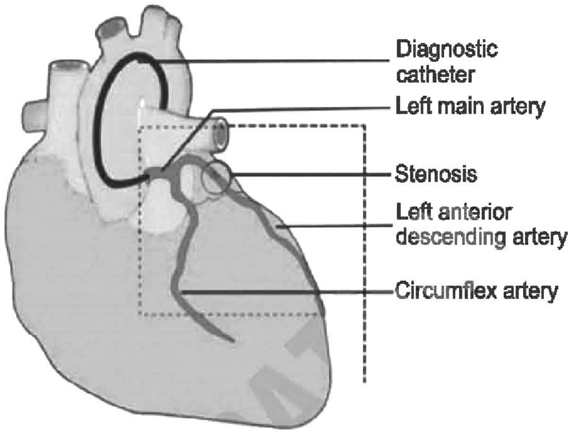


Fig. 2.16: Coronary angiogram-schematic of the vessels and branches

b. Coronary bypass

A coronary bypass is a surgical procedure that relieves the effects of obstruction in the coronary arteries. The technique involves taking healthy segments of blood vessel from other parts of the patient's body usually a vein from the leg or an artery of thorax to bypass obstructions in the coronary arteries.

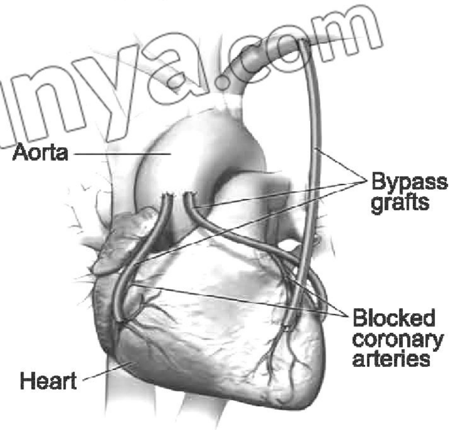


Fig. 2.17: Coronary artery bypass graft.

c. Angioplasty

In angioplasty a cardiologist threads a plastic tube into an artery of an arm or a leg and guides it through a major blood vessel toward the heart. When the tube reaches the region of plaque in a coronary artery a balloon is attached to the end of the tube is inflated forcing the vessel open. However, the artery may not remain open, so slotted tubes called **stents** are expanded inside the artery to keep the artery open. Stents are coated with heparin to prevent blood clotting and chemicals to prevent arterial closing.

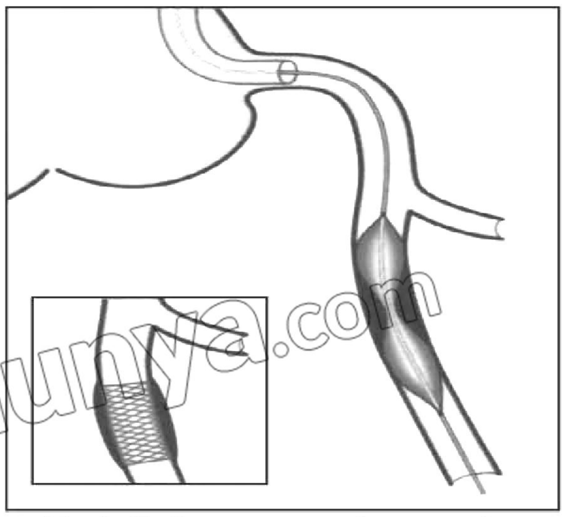


Fig. 2.18: Coronary artery bypass graft.

d. Open heart surgery

This is a surgery in which the patient's chest is opened. The surgery is performed on the heart. The term "open" refers to the chest, not to the heart itself. The heart may or may not be opened depending on the particular type of surgery. Heart surgery is used to correct heart problems in children and adults. An incision is made through the breastbone (sternum) while the patient is under general anesthesia. Tubes are used to re-route the blood through a special pump called a heart-lung bypass machine. This machine adds oxygen to the blood and keeps the blood warm and moving through the rest of the body while the surgeon is repairing the heart. Using the machine allows the heart to be stopped. Stopping the heart makes it possible to repair the heart muscle itself, the heart valves, or the blood vessels outside the heart. After the repair is done, the heart is started again, and the machine is removed. The breastbone and the skin incision are then closed.

2.18 HYPERTENSION AND HYPOTENSION

Hypertension

Blood pressure (BP) is the measurement of the pressure or force of blood pushing against blood vessel walls. The BP reading has two numbers. The top number is the **systolic blood pressure**, which measures the pressure on the artery walls when the heart beats or contracts. The bottom number is the **diastolic blood pressure**. This measures the pressure on the artery walls between beats when the heart is relaxing. The physicians' measure blood pressure in millimeters of mercury (mmHg).Your blood pressure may be different at different times of the day. High blood pressure is also called **hypertension**. When the blood pushes harder against the walls, your blood pressure goes up.

Definition: Hypertension is defined as blood pressure higher than 140/90 mmHg.

A diagnosis of hypertension may be made when one or both readings are high. 120/80 mmHg is normal blood pressure

2.18.1 Factors regulating blood pressure

Blood pressure is influenced by various factors. These factors can be broadly categorized into controllable and uncontrollable risk factors.

Controllable Factors

a. Diet: High sodium intake, a diet low in potassium, and excess saturated fat can elevate blood pressure.
b. Physical Activity: Lack of regular exercise is a significant risk factor.
c. Weight: Being overweight or obese increases the risk of high blood pressure.
d. Stress: High stress levels can lead to temporary increases in blood pressure.
e. Sleep: Insufficient or poor quality sleep can affect blood pressure regulation.
f. Medications: Some medications, including cough and cold medicines, can interfere with blood pressure control.

Uncontrollable Factors

a. Age: The risk of high blood pressure increases with age.
b. Genetics: Family history of hypertension can increase your predisposition.

c. Medical Conditions: Conditions like kidney disease, thyroid problems, and obstructive sleep apnea (Sleep apnea is a common condition that occurs when you're breathing stops and restarts many times while you sleep) can affect blood pressure.

Other Factors

Baroreceptors: These are sensory receptors in blood vessels that monitor blood pressure and send signals to the brain to adjust heart rate and blood vessel constriction.

a. **Cardiac Output:** This refers to the amount of blood pumped by the heart with each beat, and it is influenced by heart rate and stroke volume.

b. **Total Peripheral Resistance:** This is the resistance to blood flow in the blood vessels, and it is affected by factors like blood vessel diameter and blood viscosity.

c. **Blood Volume:** The amount of blood in the circulatory system also impacts blood pressure.

d. **Blood Viscosity:** The thickness of blood can affect its flow and pressure.

2.18.2 Hypotension

Low blood pressure is a condition in which the force of the blood pushing against the artery walls is too low. It's also called hypotension. Blood pressure is measured in millimeters of mercury (mm Hg). In general, low blood pressure is a reading lower than 90/60 mm Hg.

2.18.3 Protection from hypertension and cardiac problem

To protect yourself from hypertension and cardiac problems, make significant lifestyle changes. Look at these changes:

1. Heart-Healthy Diet

a. Focus on fruits, vegetables, whole grains, and lean protein: These foods are rich in nutrients and fiber, which can help lower blood pressure and cholesterol.

b. Limit saturated and Tran's fats: These fats can raise LDL cholesterol, increasing the risk of heart disease.

c. Reduce sodium intake: High sodium levels can contribute to high blood pressure.

d. Choose anti-inflammatory foods: Foods like dark green leafy vegetables, orange-colored vegetables, and legumes can help reduce inflammation, which is linked to heart disease.

2. Regular Physical Activity

a. Aim for at least 150 minutes of moderate-intensity aerobic activity or 75 minutes of vigorous activity per week: This could include walking, running, swimming, or dancing.

b. Incorporate strength training exercises: These help build muscle, which can improve overall metabolism and help manage weight.

3. Maintain a Healthy Weight

a. Calculate your Body Mass Index (BMI) to determine if you're at a healthy weight: Being overweight or obese increases the risk of hypertension and heart disease.

b. Combine a healthy diet with regular physical activity to lose weight and maintain it: This helps lower blood pressure and cholesterol levels.

4. Quit Smoking

a. Smoking damages blood vessels and increases the risk of heart attack and stroke: Quitting smoking is one of the most important steps you can take to improve your heart health.

5. Manage Stress

a. Find healthy ways to manage stress, such as exercise, yoga, meditation, or spending time with loved ones: Chronic stress can contribute to high blood pressure and other health problems.
b. Get enough sleep: Aim for 7-9 hours of quality sleep per night to allow your body to recover and manage stress.

2.19 INTERCELLULAR FLUID AND LYMPH

The lymphatic system includes lymph, lymphocytes, lymphatic vessels, lymph nodes, tonsils, spleen and thymus gland. About one sixth of the body consists of spaces between the cells, which collectively are called the **interstitium**. The fluid in these spaces is the **interstitial fluid** or **intercellular fluid**.

2.19.1 Interstitial fluid

Formation: The fluid in the interstitium is derived by filtration and diffusion from the capillaries.

Composition: Interstitial fluid contains almost the same constituents as plasma except for much lower concentrations of proteins because proteins do not pass outward through the walls of the capillaries with ease.

Function: The interstitial fluid allows rapid transport of water molecules electrolytes, nutrients, cellular excreta, oxygen, carbon dioxide etc. Materials are exchanged between the blood and interstitial fluid and between the interstitial fluid and the body cells. In other words, to get from the blood to body cells or vice versa, materials must pass through the interstitial fluid.

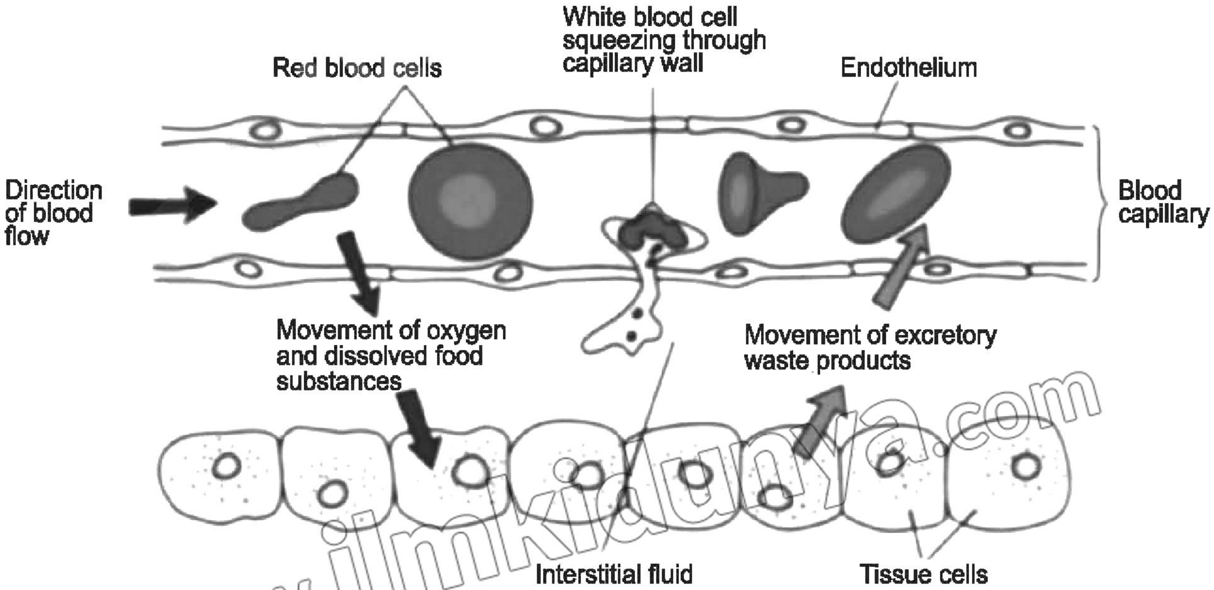


Fig. 2.19: Relationship between a blood capillary, interstitial fluid and tissue cells

2.19.2 Comparison of the composition of interstitial fluid and lymph

The composition of intercellular fluid is primarily water. along with electrolytes sugars, salts, acids, hormones, neuro-transmitters and cell wall products. The tissue fluid that had entered the lymphatic capillaries is called **lymph** and passes through the lymphatic vessels back to the blood. In addition to water lymph contains solutes such as ions, nutrients, gases and some proteins, hormones, enzymes and waste products. As lymph moves through the lymphatic system it accumulates more white blood cells (lymphocytes) proteins.

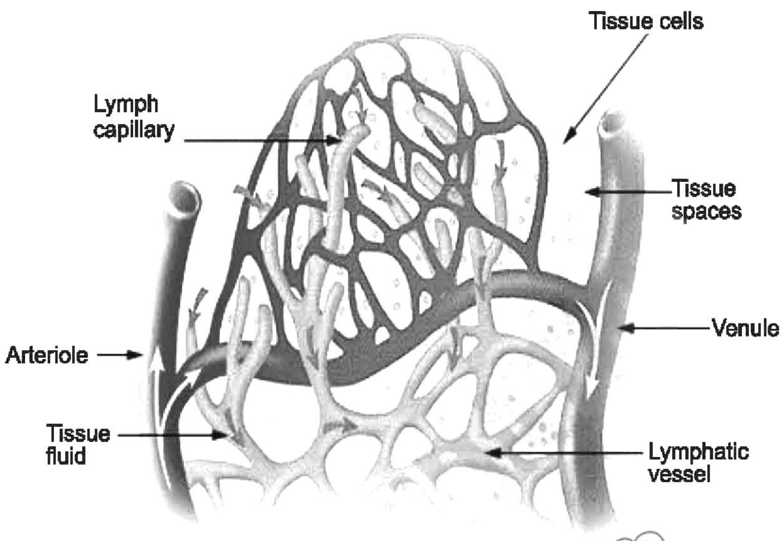


Fig. 2.20: Lymphatic vessels

Table 2.1 Differences between composition of intercellular fluid and lymph

Feature	Intercellular Fluid	Lymph
Major Electrolytes	High potassium, high phosphate, moderate magnesium, low sodium	High sodium, high chloride, moderate potassium, moderate phosphate
Proteins	Higher concentration of proteins	Lower concentration of proteins than plasma
White Blood Cells	–	Significantly higher, particularly lymphocytes
Red Blood Cells	–	Absent normally
Water	High water content	High water content
Fats	–	Can be high in lymph from the digestive system (chyle)
Origin	Fluid inside cells	Derived from blood plasma and interstitial fluid

2.20 LYMPHATIC SYSTEM OF MAN

The lymphatic system includes lymph, lymphocytes, lymphatic vessels, lymph nodes, tonsils, spleen and thymus gland.

2.20.1 Lymph vessels

Lymphatic pathways begin as lymphatic capillaries. These tiny tubes emerge to form larger lymphatic vessels, which in turn lead to the collecting ducts that unite with the veins in the thorax.

a. Lymphatic Capillaries

Lymph capillaries are microscopic, closed-ended tube. See the figure given (Fig: 2.21). They extend into the spaces within interstitial spaces, forming complex networks that parallel the networks of blood capillaries. The walls of the lymphatic capillaries, like those of blood capillaries, consist of a single layer of squamous epithelial cells. This thin wall makes it possible for interstitial fluid from interstitial spaces to enter the lymphatic capillary. Once the fluid is inside a lymphatic capillary, it is called **lymph**. Each villus contains a lymph capillary called **lacteal**. The lacteal absorbs fats and other substances from digestive tract.

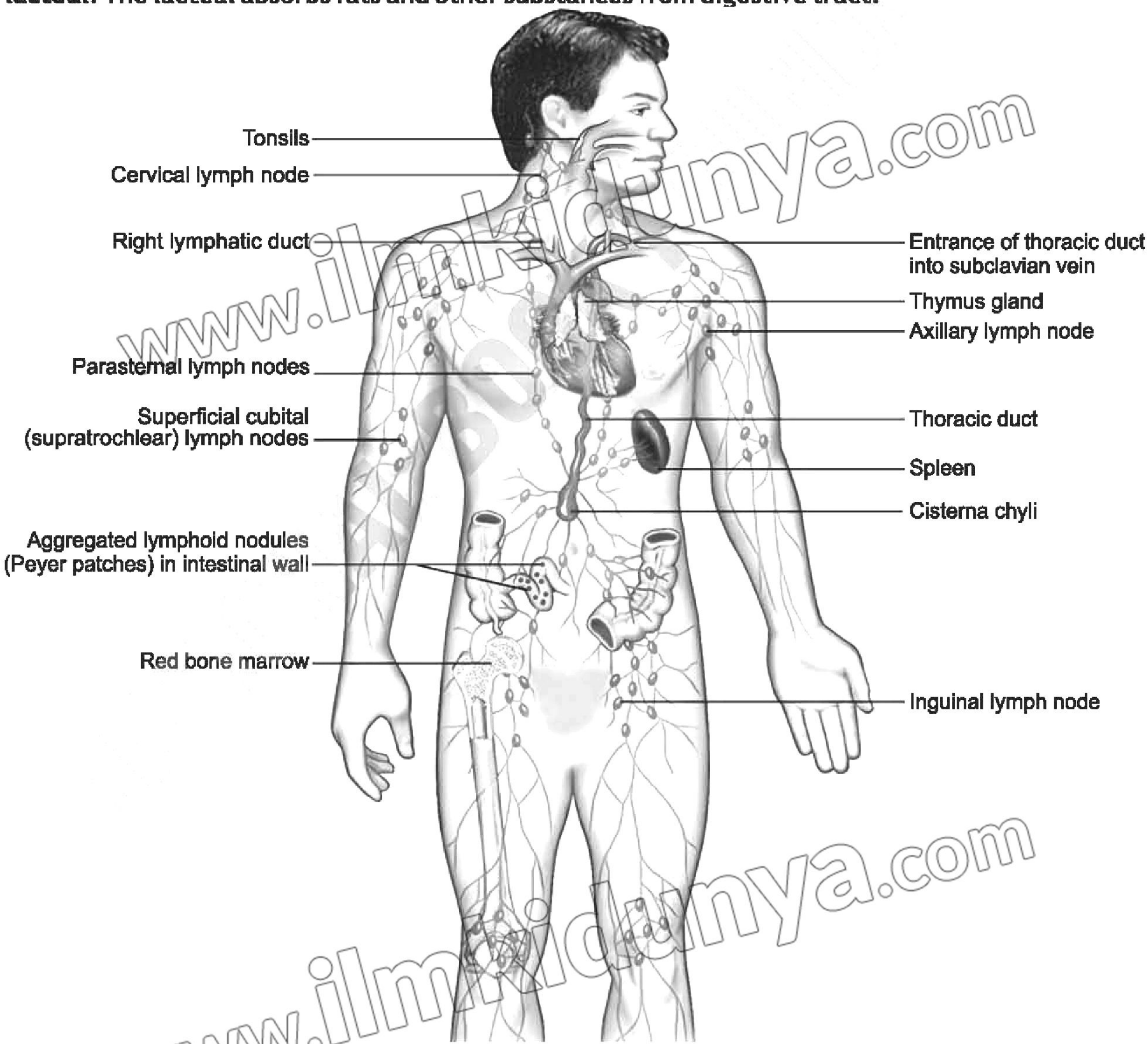


Fig. 2.21: Lymphatic system of man

b. Lymphatic Vessels

Lymphatic vessels are formed by merging of lymphatic capillaries, have walls similar to those of veins. Also like veins, lymphatic vessels have flap like valves, which help to prevent the backflow of lymph. Typically, the lymphatic vessels lead to specialized organs called **lymph nodes**. After leaving these structures, the vessels merge to form still larger lymphatic trunks.

c. Lymphatic Trunks

Lymphatic trunks, the drain lymph from relatively larger portions of the body, are named for the region they serve. The lymphatic trunks then join one of two collecting ducts, the thoracic duct or the right lymphatic duct. The **thoracic duct** is the larger and longer of the two collecting ducts. It receives lymph from the lower body regions, left side, and left side of the head and neck, and empties into the left subclavian vein near the junction of the left jugular vein. The **right lymphatic duct** receives lymph from the right side of the head and the neck, right arm and right thorax. It empties into the subclavian vein near the junction of the right and jugular vein.

2.20.2 Lymph nodes and spleen

a. Lymph nodes

The **lymph nodes** are structures located along the lymphatic pathways.

Functions of lymph nodes: The lymph nodes contain a large number of lymphocytes. The lymph nodes act against foreign particles, such as bacteria and viruses. The lymph nodes also contain macrophages, which engulf and destroy foreign substances, damaged cells and cellular debris.

b. Spleen

The spleen helps get rid of germs. It contains white blood cells called lymphocytes and macrophages. These cells work to attack and destroy germs and remove them from the blood that passes through the spleen. Filters blood by removing cellular waste and getting rid of old or damaged blood cells. It stores blood and iron for future use. It makes white blood cells and antibodies that help to fight infection. It maintains the levels of fluid in your body.

STEAM ACTIVITY 2.1

When we are active, the heart pumps faster to help blood move around our bodies more quickly. As the heart beats and pumps blood around your body, you can feel a slight throbbing or thumping in some parts where an artery (blood vessel carrying blood from the heart around the body) comes close to the surface of your skin. This is called your pulse. Your pulse tells you how fast your heart is beating; this is called your heart rate. The heart rate is measured in beats per minute, sometimes shortened to BPM.

There are few places pulse can be felt but the two main places where the pulse can be felt; the neck and the wrist

Neck: Put two fingers of your left hand onto the side of the windpipe in your throat. Push down gently and you will find your pulse which feels like a small 'thump' (you can feel it going up and down). It can be a bit tricky to find, so you may have to try moving your fingers around to find the right spot.

Wrist: Using the pointer and middle fingers of your right hand, slide from the base of your left thumb (the squishy part of your palm) to where your hand meets your wrist. You might need to move the fingers around until you find the right spot. When you have found the pulse, count how many times you feel it while timing 30 seconds. Multiply this number by 2 to calculate your heart rate in beats per minute (BPM).

Pulse Experiment

Material required: A stopwatch, timer or clock with a second hand, Pencil Record sheet.

on the wrist

on the neck

Step 1: Begin by finding your resting heart rate by taking your pulse. This is how fast your heart is beating each minute when not doing physical activity. Set a timer for one minute. Sit down and relax, taking slow deep breaths.

Step 2: Then set a timer for 30 seconds and take your pulse on the wrist or neck. Record this number in the table below and multiply it by 2 to calculate your resting heart rate in beats per minute.

Step 3: Jog on the spot for 30 seconds. Set your timer and take your pulse again for 30 seconds. Record and calculate beats per minute.

Step 4: Rest for one minute to allow your heart rate to slow down again.

Step 5: Continue doing the activities named on the record sheet for 30 seconds, taking your pulse after each to find BPM. Ensure you take one minute of rest after each time you take your pulse

Record Sheet			
Name of the activity	**Length of the activity**	**Beats counted in 30 seconds**	**Heart rate .BMP, Multiply by 2 to calculate beats in 60 seconds**
Sitting	60 seconds		X2 = ---------- BPM
Jogging on the spot	30 seconds		X2 = ---------- BPM
Stretching	30 seconds		X2 = ---------- BPM
Running as fast as on the spot	30 seconds		X2 = ---------- BPM

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. Which one of the following has the thickest wall?
   A. right ventricle B. left ventricle C. right atrium D. left atrium

2. The reason why tricuspid and bicuspid valves are closed is
   A. ventricular relaxation B. ventricular filling
   C. atrial systole D. attempted backflow of blood into the atria

3. Tricuspid valve is present between
   A. ventricle and pulmonary artery
   B. ventricle and aorta
   C. left auricle and left ventricle
   D. right auricle and right ventricle

4. From where does the aorta originate?
   A. Right ventricle B. Left atrium C. Right atrium D. Left ventricle

5. How many aortic valves are present?
   A. 1 B. 2 C. 3 D. 4

6. The epicardium:
   A. Is also known as the parietal pericardium.
   B. Is a layer of cardiac muscle.
   C. Is the visceral pericardium.
   D. Lines the heart chambers.

7. The tissue which forms a loose-fitting sac around the heart is the:
   A. Visceral pericardium. B. Parietal pericardium.
   C. Myocardium. D. Epicardium.

8. The valve between the left ventricle and the blood vessel leaving the left ventricle is the:
   A. Bicuspid valve B. Tricuspid valve
   C. Pulmonary semilunar valve D. Aortic semilunar valve

9. During the period of ejection in the cardiac cycle, the atrioventricular valves are .... and the semilunar valves are..................
   A. closed, closed B. closed, open
   C. open, closed D. open, open

10. The second heart sound, described as "dupp" is actually the sound of the

A. Atria contracting

B. Ventricles contracting

C. Atrioventricular valves closing

D. Semilunar valves closing

11. Cardiac output is determined by:

A. heart rate	B. stroke volume

C. blood flow	D. heart rate and stroke volume

12. Which one is the definition of cardiac cycle?

A. The contraction of the atria.

B. Circulation of blood in the heart.

C. The contraction and relaxation of the ventricles.

D. It is sequence of events that occurs during a complete heartbeat.

13. For how long is the cardiac cycle, if the heart rate is 75 beats/min?

A. 0.7 sec	B. 0.8 sec	C. 0.5 sec	D. 0.4 sec

14. The fluid that passes through the lymphatic vessels

A. flows toward the lungs

B. passes from the lymphatic vessels into the arteries

C. enters the left ventricle of the heart through the right thoracic duct

D. moves in a single direction toward the heart

15. Lymph nodes may be located in the human body in the tissues of the

A. stomach and brain	B. groin and neck

C. ventricle and atrium	D. thyroid gland and adrenal gland

16. A red blood cell, entering the right side of the heart, passes by or through the following structures:

1. atrioventricular valve 2. semilunar valve 3. right atrium 4. right ventricle
5. Pulmonary trunk

In which order will the red blood cell passes the structures?

A. 2 → 3 → 1 → 4 → 5

B. 3 → 1 → 4 → 2 → 5

C. 3 → 5 → 1 → 2 → 4

D. 5 → 3 → 1 → 4 → 2

17. The rhythmic beating of cardiac muscle in the mammalian heart is initiated by the.

A. atrio-ventricular node	B. parasympathetic nervous system

C. Purkinje tissue	D. sino-atrial node

18. What produces systolic blood pressure?

A. contraction of the right atrium B. contraction of the right ventricle

C. contraction of the left atrium D. contraction of the left ventricle

19. Human heart is

A. myogenic B. neurogenic C. cardiogenic D. digenic

20. Pacemaker is situated in heart

A. in the wall of right atrium B. on interauricular septum

C. on interventricular septum D. in the wall of left atrium

Section II: Short Answer Questions

1. Why do we have a circulatory system?
2. What are the contraction and relaxation of human heart called?
3. Where is SA node, AV node, Purkinje fibre, Bundle of His located?
4. Why action potentials travel along the Purkinje fibres more rapidly than through other muscle fibres?
5. Name the artery supplying blood to the heart.
6. What is blood pressure?
7. Why SA node is called pacemaker of the heart?
8. What is a cardiac cycle?
9. What is an arterial pulse? What is the normal human pulse rate?
10. Why is AV node essential for the conduction of cardiac impulse?
11. What are the risks associated with atherosclerosis?
12. Why can you feel your pulse in arteries but not in veins? If there is no pulse in your veins what pushes the blood in veins back to the heart?
13. Define the term thrombus and differentiate between thrombus and embolus.
14. Identify the factors causing atherosclerosis and arteriosclerosis.
15. List the advantages and disadvantages of coronary bypass.
16. List the changes in the life styles that can protect man from hypertension and cardiac problems.
17. What is the major feature of human lymphatic system?
18. Justify why blood circulatory system is dependent on the lymphatic system.
19. Interpret why the swelling of the lymph node is cause of concern.
20. Write the differences between:
    (a) bicuspid valve and tricuspid valve
    (b) systole and diastole
    (c) SA node and AV node
    (d) P-wave and T-wave of ECG
    (e) blood capillaries and lymph capillaries
    (f) baroreceptor and volume receptor

Section III: Extensive Answer Questions

1. Draw, label and describe the external structure of human heart.
2. Describe the flow of blood through human heart as regulated by the valves.
3. State the phases of heartbeat in man.
4. Describe the conducting system of human heart.
5. Explain electrocardiogram with the help of diagram.
6. Describe the structure of blood vessels in man.
7. What is the role of precapillary sphincter?
8. Describe pulmonary circulation and systemic circulation.
9. Describe hepatic portal system
10. Give an account of blood pressure in man.
11. Compare the rate of blood flow through arteries, arterioles, capillaries, venules and veins.
12. Explain the following:
    a. Principle of angiography
    b. Coronary bypass
    c. Angioplasty
    d. Open heart surgery
13. Explain hypertension and hypotension. What are the factors that regulate blood pressure?
14. Describe the lymphatic system of man.