Chapter 11

HUMAN CIRCULATORY SYSTEM

STUDENTS' LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- State the location of heart in the body and define the role of pericardium.
- Describe the structure of the walls of heart and rationalize the thickness of the walls of each chamber.
- Trace the flow of blood through the heart as regulated by the valves.
- State the phases of heartbeat.
- Explain the role of SA node, AV node and Purkinje fibers in controlling the heartbeat.
- List the principles and uses of Electrocardiogram.
- Describe the detailed structure of arteries, veins and capillaries.
- Describe the role of arterioles in vasoconstriction and vasodilation.
- Describe the role of precapillary sphincters in regulating the flow of blood through capillaries.
- Trace the path of the blood through the pulmonary and systemic circulation (coronary, hepatic-portal and renal circulation).
- Compare the rate of blood flow through arteries, arterioles, capillaries, venules and veins.
- Define blood pressure.
- State the role of baroreceptors and volume receptors in regulating the blood pressure.
- Define the term thrombus and differentiate between thrombus and embolus.
- Identify the factors causing atherosclerosis and arteriosclerosis.
- Categorize Angina pectoris, heart attack, and heart failure as the stages of cardiovascular disease development.
- State the congenital heart problem related to the malfunctioning of cardiac valves.
- Describe the principles of angiography.
- Outline the main principles of coronary bypass, angioplasty and open-heart surgery.
- Define hypertension and describe the factors that regulate blood pressure and can lead to hypertension and hypotension.
- List the changes in lifestyles that can protect man from factors that regulate blood pressure and can
- lead to hypertension and hypotension.
- List the changes in lifestyles that can protect man from hypertension and cardiac problems.
- Describe the formation, composition and function of intercellular fluid.
- Compare the composition of intercellular fluid with that of lymph.
- State the structure and role of lymph capillaries, lymph vessels and lymph trunks.
- Describe the functions of lymph nodes and state the role of spleen as containing lymphoid tissue.

Humans have two systems for the transport of different materials in different parts of body i.e., blood circulatory system and lymphatic system. The closed blood circulatory system of humans

Recalling:
Blood is the medium in which dissolved nutrients, gases, hormones, and wastes are transported throughout the body. It is composed of two main components (i) plasma and (ii) cells or cell-like bodies (white blood cells, red blood cells, platelets). In a healthy person, plasma constitutes about 55% by volume of the blood, and cells or cell-like bodies about 45% by volume of the blood.

consists of blood, heart, and blood vessels (arteries, capillaries and veins).

11.1- Structure And Functioning Of Heart

Human heart is a hard-working pump that moves blood through body. It is situated in the middle of chest cavity (between the lungs). Its back surface is near vertebral column while its front surface is behind sternum and rib cartilages.

The heart is usually felt to be on the left side because the left side of heart is stronger and larger, since it pumps to all body parts.
Because the heart is between the lungs, the left lung is smaller than the right lung and has a cardiac notch in its border to accommodate the heart.

Pericardium

Heart is enclosed in a sac called **pericardium** (Figure 11.1). Pericardium separates heart from surrounding organs. It is composed of the following two layers;

1. Outer layer of pericardium is called **fibrous pericardium.** It is made of strong connective tissue. It protects heart against external pressure and shocks. It also prevents excessive dilation of heart.
2. Inner layer of pericardium is called **serous pericardium.** It is a sac, made of two sub-layers i.e.,
   a) Outer **parietal** pericardium - present beneath fibrous pericardium.
   b) Inner **visceral** pericardium (also called epicardium) - closely attached to the underlying heart.

The space between parietal and visceral pericardium is called **pericardial cavity.** It contains up to 50 mL pericardial fluid. It lubricates heart and protects it from infections.

Wall of the Heart

The wall of heart is composed of three layers. The inner layer of pericardium i.e., epicardium makes the outer lining of heart wall. Beneath epicardium, there is the thickest layer of heart wall i.e., **myocardium.** Myocardium is made of cardiac muscles. **Endocardium** is present beneath myocardium. It is a single layer of epithelial cells and make the inner linings of heart chambers (Figure 11.1).

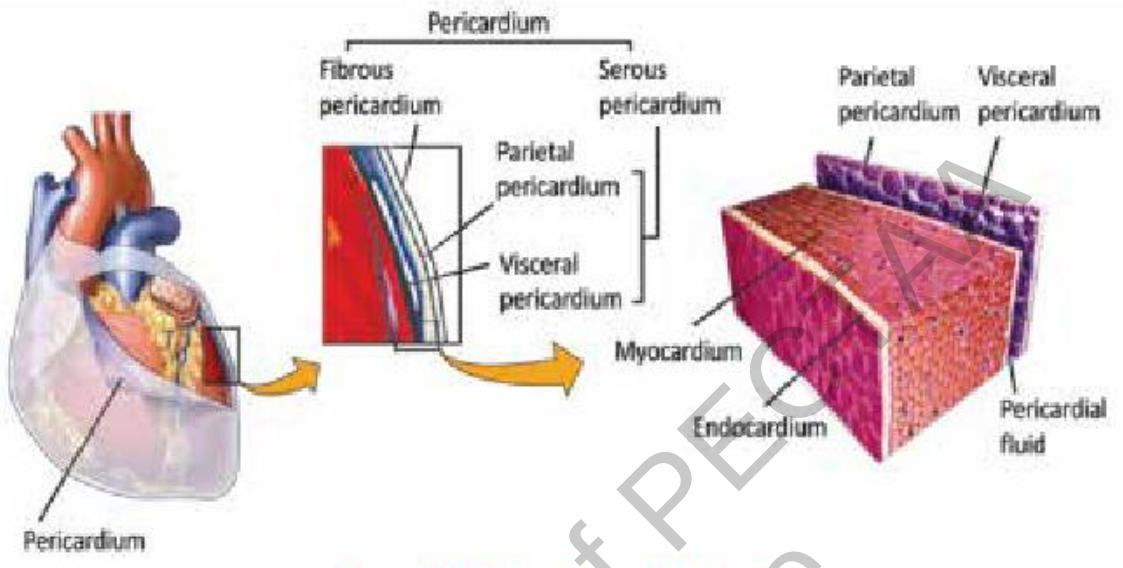

Figure 11.1: Pericardium and heart wall

Chambers and Valves of Heart

There are four chambers of heart i.e., two upper thin-walled **atria** and two lower thick-walled **ventricles**. Atria receive blood from body and pass it to ventricles, which distribute blood to body. Atria and ventricles are separated by **atrioventricular septum**. The left and right atria are separated from each other by an **interatrial septum**. Similarly, the left and right ventricles are separated from each other by an **interventricular septum**. It is much thicker than the interatrial septum.

At the entrance points of ventricles (in atrioventricular septum), there are two atrioventricular valves i.e., a tricuspid valve and a bicuspid valve. **Tricuspid valve** (made of three cusps) is present between right atrium and right ventricle. **Bicuspid (mitral) valve** (made of two cusps) is present between left atrium and left ventricle. When ventricles contract, tricuspid and bicuspid valves close and prevent the back flow of blood into atria.

At the exit points of ventricles, there are two **semilunar valves** (with shapes like a half-moon). These are called pulmonary valve and aortic valve. **Pulmonary valve** is located at the base of pulmonary artery while **aortic valve** is present at the base of aorta. When ventricles relax, pulmonary and aortic valves close. So, they prevent back flow of blood from pulmonary artery and aorta into ventricles.

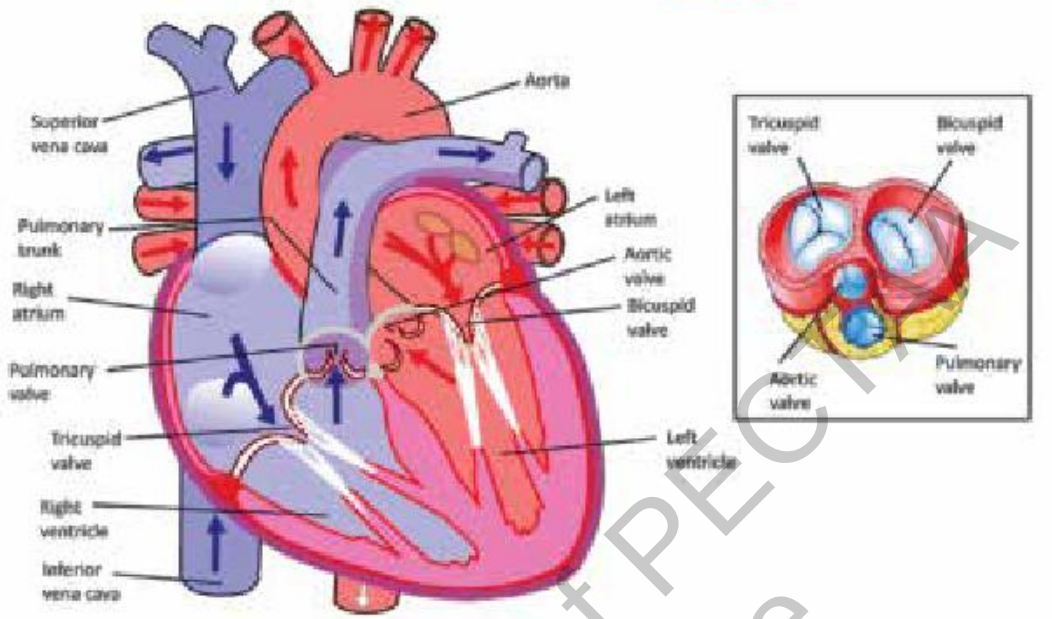

Figure 11.2: Human Heart and valves

Circulation of Blood through HEART

Human heart functions as a **double pump**. It carries out pulmonary circulation (supply of blood to lungs) and systemic circulation (supply of blood to all organs of body – except lungs). Complete separation of deoxygenated (right side) and oxygenated (left side) blood is maintained in heart.

The right atrium receives deoxygenated blood from body via two veins i.e., superior vena cava and inferior vena cava. Right atrium passes this blood to right ventricle via tricuspid valve. When right ventricle contracts, deoxygenated blood is passed to pulmonary trunk via semilunar pulmonary valve. The pulmonary trunk divides into left and right pulmonary arteries which carry this blood to lungs.

The oxygenated blood from lungs is brought to left atrium by pulmonary veins. Left atrium passes this blood to left ventricle via bicuspid (or mitral) valve. When left ventricle contracts, oxygenated blood is passed to aorta via semilunar aortic valve. Aorta carries this blood to all parts of body (except lungs).

The wall of left ventricle is thicker (about 3 times) than that of the right ventricle because it has to push the blood to all over body.

Cardiac Cycle Heartbeat

Heart works in continuous cycles. Its chambers relax and are passively filled with blood from large veins. Then, its chambers contract and propel the blood throughout body. Its alternating relaxations and contractions are collectively called a cardiac cycle or one **heartbeat**.

While atria are relaxed and being filled with blood, the ventricles are also relaxed. This relaxed period of heart chambers is called **diastole**. During diastole, both atria are filled with blood. As blood accumulates in atria, their blood pressure rises, due to which both of them contract. This is called **atrial systole**. It passes the blood through tricuspid and bicuspid valves into the two relaxed ventricles. When ventricles are filled with blood, both of them contract. This is called **ventricular systole** and it pumps the blood to pulmonary arteries and aorta. During ventricular systole, tricuspid and bicuspid valves close while pulmonary and aortic valves open.

In one complete heartbeat, diastole lasts about 0.4 sec, atrial systole takes about 0.1 sec, and the ventricular systole lasts about 0.3 sec. In one's life, heart beats about 2.5 billion times, without stopping.

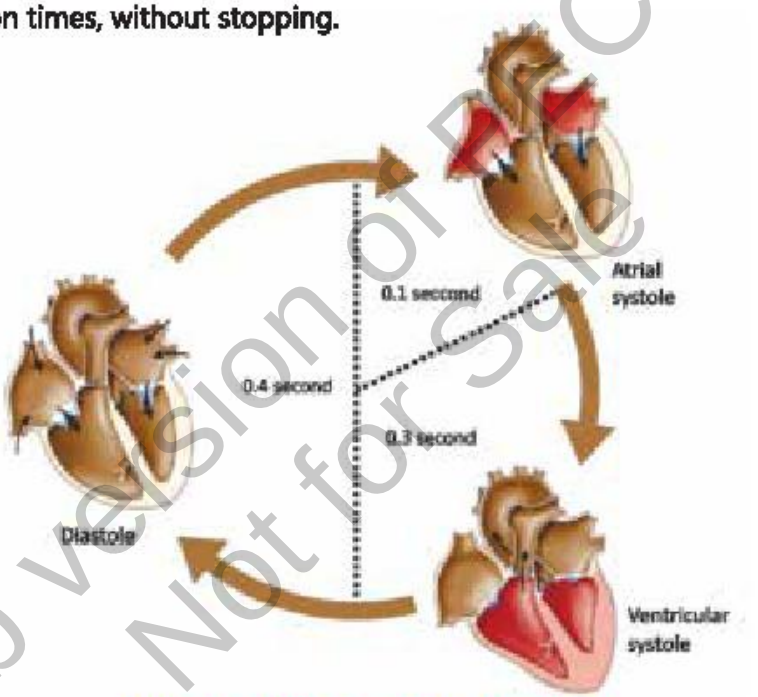

Figure 11.3: Cardiac cycle (one heartbeat)

Sounds of a Heartbeat

When both ventricles contract simultaneously to pump the blood to pulmonary arteries and aorta, the tricuspid and bicuspid valves close and **"lubb"** sound is made. Similarly, when ventricular systole ends and both ventricles relax simultaneously, the pulmonary and aortic semilunar valves close and **"dubb"** sound is made. "Lubb–dubb" can be heard with the help of a stethoscope.

Most cases of heart murmurs are not serious, and those that prove serious can be corrected by replacing the damaged valves with artificial ones or with valves taken from an organ donor.

If the valves are not closing fully, or if they open narrowly, turbulence is created within the heart. This turbulence can be heard as a heart murmur. A murmur sounds like a hiss.

Control of Heartbeat (Heart Excitation and Contraction)

The pumping of heart is initiated by the **Sinoatrial Node** (SA node) or **pacemaker**. The sinoatrial node consists of a small cluster of cardiac muscle cells. It is embedded in the upper wall of right atrium. Heartbeat starts when SA node sends electrical impulses to the walls of atria. It causes both atria to contract simultaneously. The impulses then travel to an **atrioventricular node** (AV node). It is also made of small cluster of cardiac muscle cells. It lies at the lower portion of interatrial septum.

From AV node, the impulses reach an **atrioventricular bundle** or **bundle of His**. It is a network of fibres present in interventricular septum. AV bundle divides into left and right branches, which end at the **Purkinje fibres** in the walls of the ventricles. Stimulation of these fibres causes the ventricles to contract almost simultaneously (Figure 11.4). There is a delay of about 0.15 second in conductance of impulses from the SA node to AV node, permitting atrial systole to be completed before ventricular systole begins.

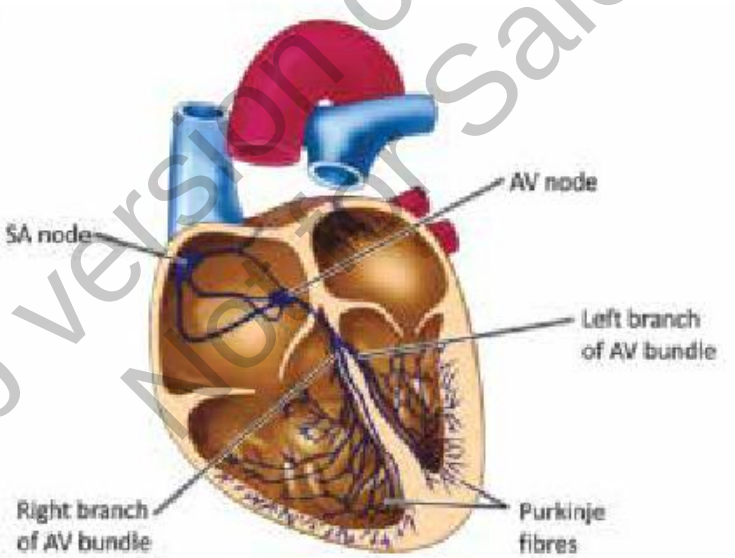

Figure 11.4: Pacemaker and its connections

If there is some block in the flow of the electrical impulses, or if the impulses initiated by SA node are weak; it may delay the rhythmicity of heartbeat or stop it. In such patients of weak SA node, **artificial pacemaker** is used. It is a battery- operated device that is surgically transplanted near the AV node. It emits electrical signals that trigger normal heartbeats.

Rate of Heartbeat

In an adult, about 8,000 litres of blood move through 96,000 km of blood vessels every day.

The heart of an average adult beats about 70 times per minute. It pumps the entire blood volume (about 5 litres) every minute. The normal speed of heartbeat is made and maintained by pacemaker and AV node. Brain also exerts some influence on heart rate. For example, during fever and exercise, the control centre in brain sends nerve signals to both the pacemaker and the AV node, making them to increase the heart rate. It is to cope with the situation. In contrast, when we are asleep or at rest, the brain's control centre slows down the activity of pacemaker and AV node.

Electrocardiogram

The recording of electrical potentials, generated by the currents of cardiac impulses, is known as electrocardiogram (ECG). When cardiac impulse passes over the surface of heart, a minute electrical current is generated. This current spreads into the tissues surrounding heart. This minute electrical current also travels to the surface of body. In ECG, the electrical potentials generated by this current are measured and recorded. For this purpose, electrodes are placed on skin on the opposite sides of heart. The electrodes are attached to a machine called **electrocardiograph** that records electrical potentials generated by this current. ECG helps to diagnose the abnormalities in conduction system of heart. ECG shows the following waves of electrical impulses produced at specific events of cardiac cycle. (Figure 11.5).

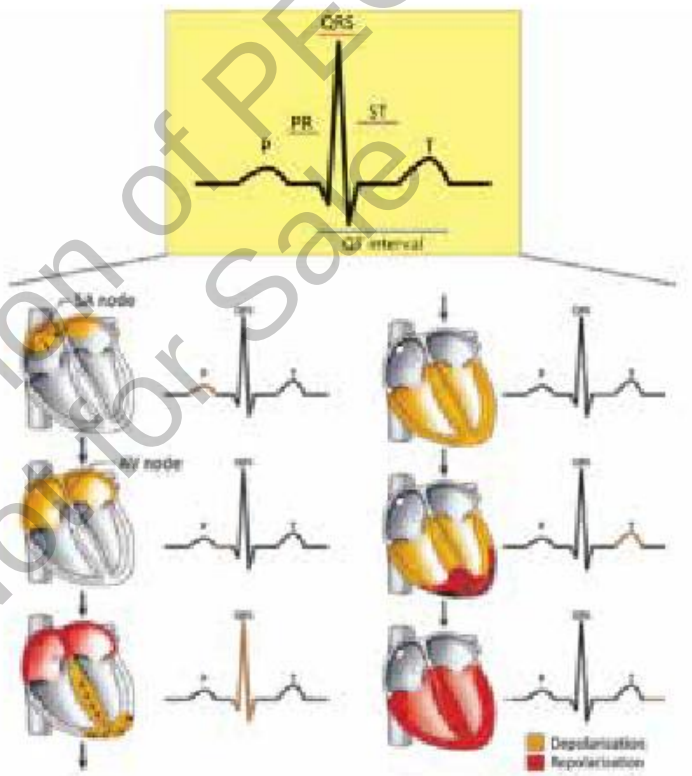

Figure 11.5: ECG reading of a single heartbeat

P wave: It shows beginning of atrial depolarization, initiated by SA node. It causes atrial contraction. Irregular or absent P waves may indicate arrhythmia (lack of rhythmicity).

PR segment: It shows the completion of atrial depolarization. It is usually 0.12 to 0.20 seconds. A prolonged PR indicates a first-degree heart block.

QRS: It shows the beginning of depolarization of ventricles. Atrial re-polarization also occurs during this phase. Abnormalities in the QRS complex may indicate bundle branch block, ventricular tachycardia (faster rate of contraction), or other ventricular abnormalities.

Some abnormal babies may have blueness (cyanosis) of skin. They are called blue babies. It is due to the mixing of oxygenated and deoxygenated blood between two atria. Mixed blood is supplied to the body of new born babies resulting in blueness of skin. Cyanosis results due to the failure of **interatrial foramen** to close, during development. Interatrial foramen is a temporary opening in the embryonic heart between right and left atria. Normally, it is closed during development. Cyanosis may also happen due to failure of **ductus arteriosus** to fully constrict, during development. Ductus arteriosus is a temporary channel between the embryonic pulmonary artery and aorta. Normally, it constricts during development.

ST segment: It shows the completion of depolarization of ventricles. It can be depressed in ischemia (decreased flow of blood and oxygen to heart muscles) and elevated in myocardial infarction. This segment ordinarily lasts about 0.08 second.

T wave: It represents the beginning of repolarization of ventricles. T wave abnormalities may indicate electrolyte disturbance. The hyper-acute T wave shows the earliest findings of acute myocardial infarction.

QT Interval: The QT interval is from the beginning of the QRS complex to the end of the T wave. A normal QT interval is usually about 0.40 seconds.

11.2- Blood Vessels

Arteries, veins, and capillaries are the main blood vessels in human circulatory system.

1. Arteries

Arteries are the blood vessels which carry blood away from heart to different parts of body. All arteries carry oxygenated blood, except pulmonary arteries. The central core of artery is **lumen**. The walls of arteries are made up of three layers. Outer layer i.e., **tunica externa** or adventitia is made of connective and elastic tissue. Middle layer i.e., **tunica media** is made of thick muscular tissue and elastic fibres. Inner layer i.e., **tunica intima** is made of thin layer of endothelial cells. Middle layer is important and it can withstand higher blood pressure during ventricular systole. Arteries divide into smaller vessels called **arterioles**. Arterioles divide repeatedly until they form a dense network of very fine branches i.e., capillaries.

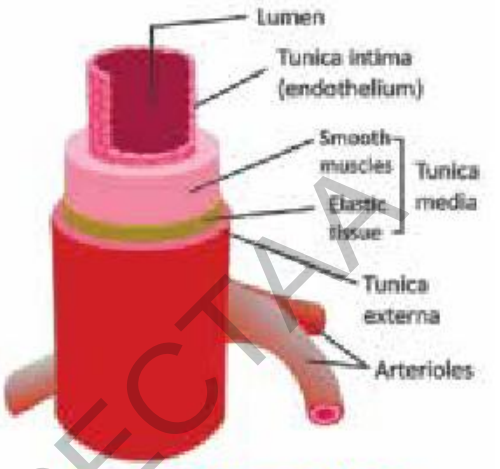

Figure 11.6: Structure of artery

2. Capillaries

These vessels are formed by the division of arterioles. Capillaries join to form venules. Capillaries penetrate all tissues and have approach to the cellular level. The walls of capillaries are made of a single layer of **endothelial** cells. The internal diameter of a capillary is about 8 micrometres. Capillaries are the sites where materials are exchanged between blood and body tissues by diffusion or active transport. Water and diffusible substances can pass through capillary walls. Materials pass through the endothelial cells or through the intercellular spaces of capillary wall. Some materials are also taken up by capillary wall cells by endocytosis. The capillary wall cells then pass these materials to the other side by exocytosis.

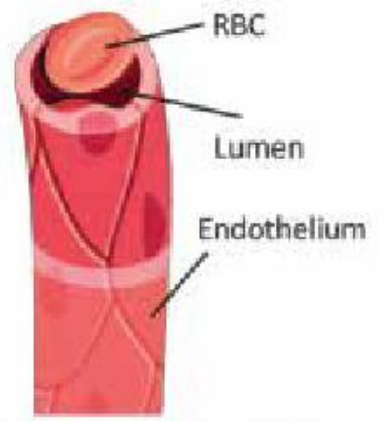

Figure 11.7: Structure of capillary

No cell of the body is more than 100 micrometres away from a capillary. Capillaries are so narrow that RBCs must pass through them in single line. It is estimated that the total length of capillaries in an adult human is over 80, 600 kilometres, enough to encircle the globe twice!

The pressure within capillaries causes a continuous leakage of fluid from the blood plasma into tissues. This fluid, known as **Interstitial fluid** consists of water with dissolved nutrients, hormones, gases, wastes and small proteins. Large proteins, RBCs and platelets remain within capillaries. But some WBCs can squeeze out through the intercellular spaces of capillary wall.

3. Veins

These blood vessels carry blood from different parts of the body towards heart. All veins carry deoxygenated blood, except pulmonary veins. The wall of veins has same three layers as are present in arteries. The outer layer i.e., **tunica externa (adventitia)** is made of connective and elastic tissue. The middle layer i.e., **tunica media** is relatively thin and only slightly muscular, with few elastic fibres. The inner layer i.e., **tunica intima** is made of thin layer of endothelial cells.

The middle layer of veins is relatively thinner than that of arteries because veins do not have to withstand high blood pressure. An empty artery is still a hollow tube but an empty vein collapses like an empty balloon. **Semilunar valves** are present in veins to prevent the back flow of blood, as it is moving towards heart. The pressure generated by the contraction of surrounding muscles presses veins and assists in the return of blood towards heart.

Smaller veins join to form larger veins and ultimately from vena cavae (inferior vena cava and superior vena cava), which pour blood into the right atrium of heart. Pulmonary veins from lungs empty in left atrium.

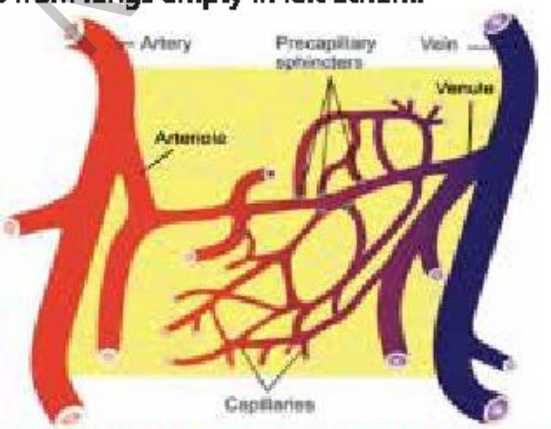

Figure 11.9: Relationship of arterioles, capillaries & venules

Regulation of Blood Flow in Capillaries

The amount of blood flowing in capillaries is controlled by constricting or dilating the capillaries. Nervous stimulation can constrict capillaries and certain chemicals such as histamine can dilate them. Some capillaries are connected with arterioles and venules through loops of other capillaries. The entry of each loop is guarded by a ring of muscles called a **pre-capillary sphincter**. These sphincters regulate the amount of blood flowing through capillaries.

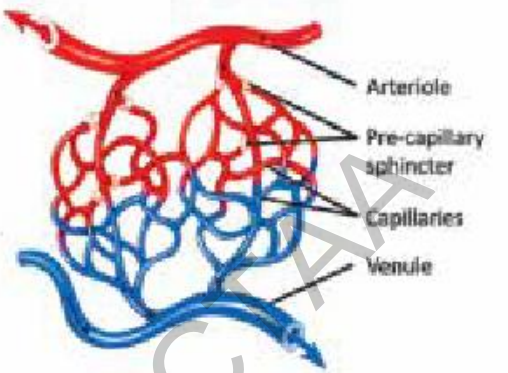

Figure 11.10: Pre-capillary sphincters

Vasoconstriction and Vasodilation inArterioles

In the walls of arterioles, there are more circular muscles than elastic tissue. The contraction of the circular muscles of arterioles is under the control of nervous and endocrine systems. When these muscles contract, arterioles are constricted. It is called **vasoconstriction** and it reduces the flow of blood in arterioles. When these muscles are relaxed, arterioles are dilated. It is called **vasodilation** and it increases blood flow in them.

Vasoconstriction and vasodilation happen in response to changes in metabolic activity of tissues. For example, when metabolic activity in a tissue rises, oxygen decreases and carbon dioxide increases in its interstitial fluid. In its response, the circular muscles of the arterioles in that tissue relax (vasodilation). It increases blood flow in these arterioles and also in capillaries. The increased blood flow supplies more oxygen and removes more carbon dioxide. Similarly, decreased metabolic activity causes vasoconstriction od arterioles.

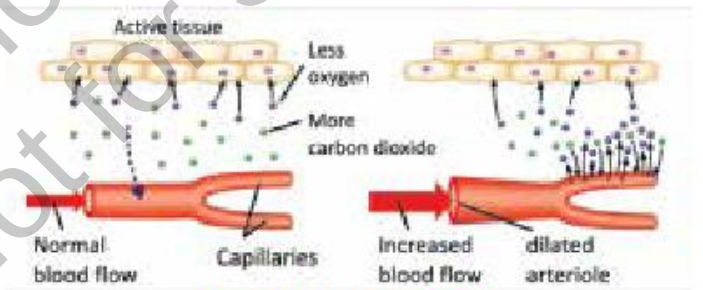

Figure 11.11: Vasodilation

Rate of Blood Flow

The velocity of blood flow is different in different vessels. It is highest in aorta (450-500 mm/sec) and tends to fall along the network of arteries, arterioles and becomes lowest in capillaries (01 mm/sec). It rises again in venules, veins and vena

cavae (250-300 mm/sec). These changes in the velocity of blood result from changes in the total cross section of the vessel system.

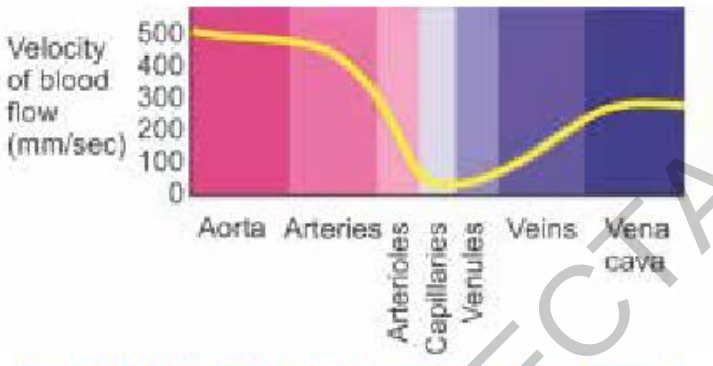

Figure 11.12: Velocity of blood, moving in different vessels

Circulatory Pathways

In humans (and in all mammals and birds), blood circulates throughout body in two main pathways. These are called pulmonary circulation (to and from lungs) and systemic circulation (to and from the other body parts).

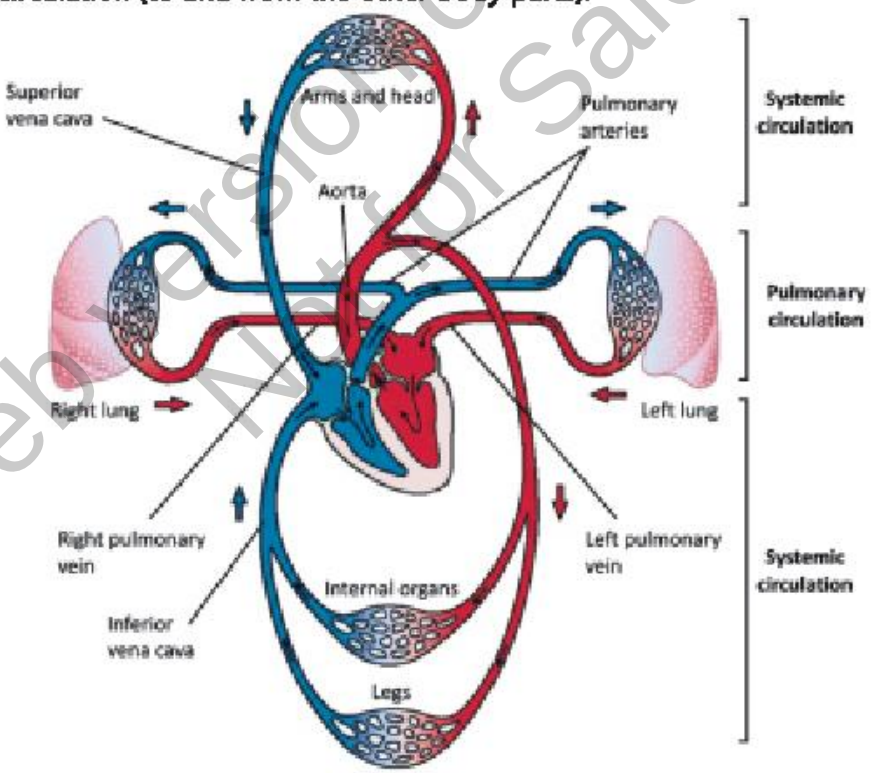

Figure 11.13: Pulmonary and systemic circulations

Pulmonary Circulation

Pulmonary circulation supplies deoxygenated blood to lungs and returns oxygenated blood to heart. A big artery i.e., pulmonary trunk carries deoxygenated blood from the right ventricle of heart. Pulmonary trunk divides into right and left pulmonary arteries, which carry deoxygenated blood to the right and left lungs. Inside each lung, the pulmonary artery divides and makes pulmonary arterioles and lung capillaries. In lung capillaries, blood is oxygenated. Lung capillaries join to form pulmonary venules, which join to form pulmonary vein. Left and right pulmonary veins from lungs open in left atrium.

Systemic Circulation

The systemic circulation supplies oxygenated blood to all the cells, tissues, and organs of the body (except lungs) and returns deoxygenated blood to heart. It consists of the following components:

1. Coronary Circulation

The heart walls are supplied with blood through a small portion of the systemic circulation. Two **coronary arteries** i.e., right and left coronary arteries arise from aorta, near its origin. These arteries divide into many smaller arteries, arterioles and then into capillaries. After supplying oxygenated blood to heart muscles, the capillaries unite to form venules which make many **coronary veins** The coronary veins join to form a **coronary sinus**,which opens in right atrium. Small coronary veins drain directly into right atrium.

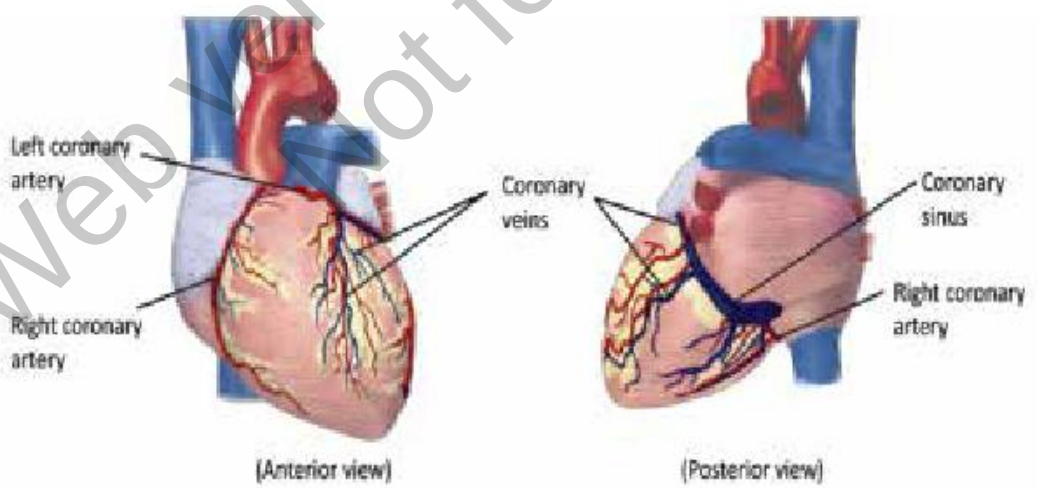

Figure 11.14: Coronary circulation

2. Hepatic Portal Circulation

A portal system is a circulation in which veins end in capillaries. In hepatic portal system, a large **hepatic portal vein** collects blood from spleen and alimentary canal and take it to liver. The blood from liver is taken to heart through **hepatic veins**

The blood that comes from alimentary canal to liver contains substances that are absorbed from small intestine. These substances pass through liver before going to heart. Liver removes harmful substances from blood and absorbs nutrients for storage before sending this blood to heart. Hepatic portal system extends from the lower portion of oesophagus to the upper part of anal canal.

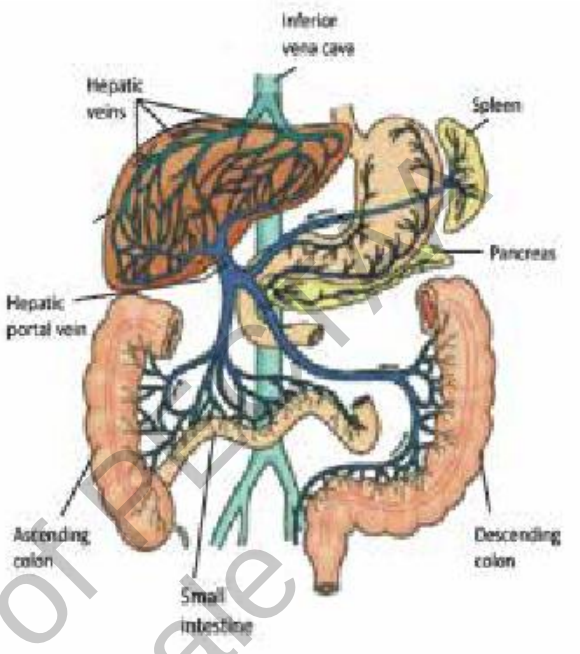

Figure 11.15: Hepatic portal system

3. Renal Circulation

It is another important component of the systemic circulation. Right and left renal arteries carry oxygenated blood to the right and left kidneys. Inside the kidney, each renal artery divides repeatedly to make smaller arteries. The smaller arteries branch into several **afferent arterioles**, which supply blood to nephrons (units of kidney). Each afferent arteriole divides to make the capillaries of **glomeruli.**

The capillaries of glomeruli unite to make **efferent arteriole**, which divides to make two sets of capillaries i.e., (i) **peri-tubular capillaries** (around nephron tubule in cortical portion of kidney), and (ii) **vasa recta** (around nephron tubule in the medulla of kidney). These capillaries unite to form venules that converge and make smaller veins. The smaller veins unit to form a renal vein.

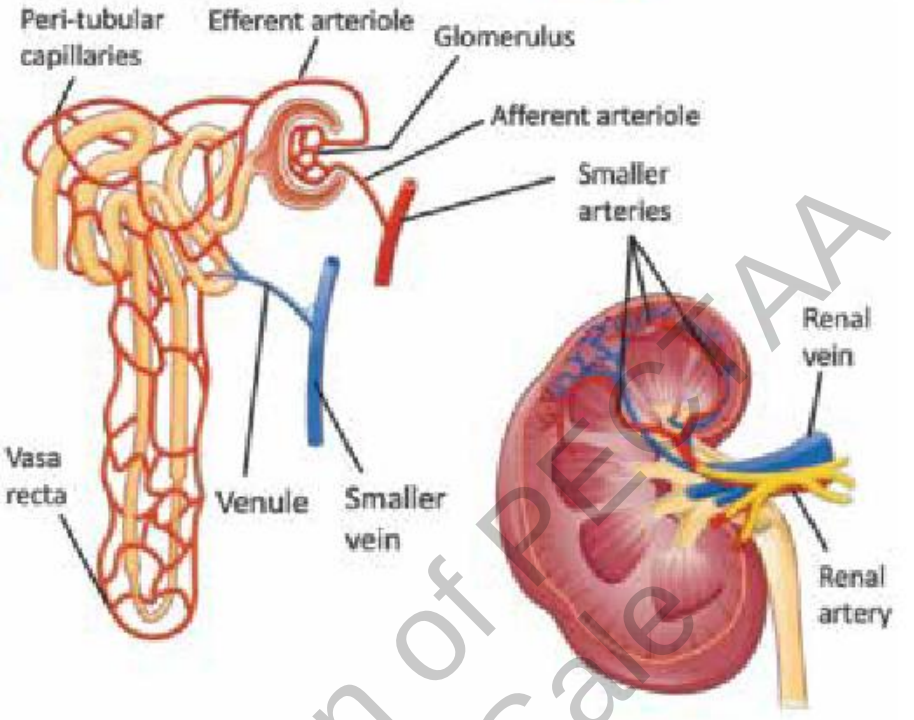

Figure 11.16: Renal portal system

11.3- BLOOD PRESSURE

Blood pressure is the measure of force exerted by blood against the inner walls of blood vessels. This force keeps blood flowing from heart to the entire capillary network in body. Although such a pressure occurs throughout the vascular system, the term blood pressure most commonly refers to **systemic arterial blood pressure**. Blood pressure is highest in aorta and then gradually reduces in systemic arteries. The walls of arteries are elastic. The flow of blood creates rhythmical throbbing of arteries, which is called as **pulse.**

Arterial blood pressure rises and falls corresponding to the phases of cardiac cycle. When ventricles contract (ventricular systole), heart forces blood into pulmonary arteries and aorta. As a result, the pressure in these arteries rises sharply. The maximum pressure during ventricular systole is called **systolic pressure** Systolic pressure in a normal young adult is **120 mm Hg**. When ventricles relax (diastole), the arterial pressure drops. The lowest pressure that remains in arteries before the next ventricular contraction is called **diastolic pressure**. Diastolic pressure in a normal young adult is **80 mm Hg**.

Conventionally, the readings of blood pressure are expressed as 120/80. The instrument sphygmomanometer is used for the manual measurement of systolic and diastolic blood pressures. In this instrument, rise and fall in mercury column shows the readings of blood pressure.

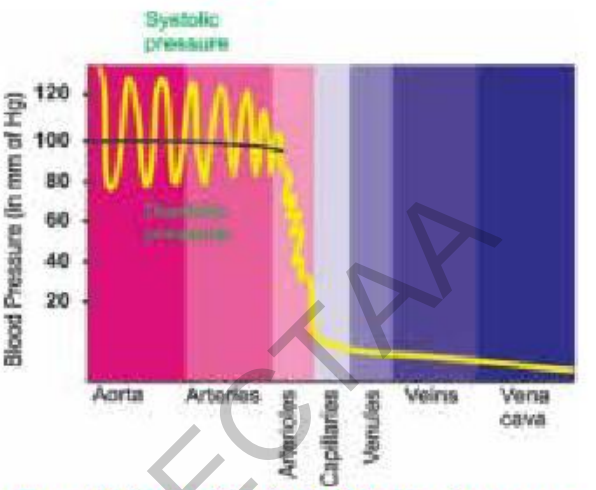

Figure 11.17: Systolic & diastolic blood pressures

Regulation of Blood Pressure

Pressure receptors, known as baroreceptors, are present in carotid arteries (arteries that supply blood to the head region and brain) and aortic arch (portion of artery that bends between the ascending and descending aorta). When blood pressure falls, baroreceptors activate sensory neurons that send information to brain. The control centre in brain reacts by increasing the rate and force of contraction of heart, and by causing vasoconstriction in arterioles. Both these changes restore blood pressure to normal.

The long-term regulation of blood pressure is done through hormones. Certain hormones regulate the volume of blood by effecting the reabsorption of water and salt in kidneys. When there is a decrease in blood volume and blood pressure, special receptors present in brain create thirst. They also stimulate posterior pituitary gland to secrete **antidiuretic hormone (ADH)**. ADH stimulates kidneys to retain more water in blood, excreting less in urine. It restores the blood volume and ultimately blood pressure. ADH also constricts arterioles, which raises arterial blood pressure.

The walls of right atrium contain endocrine cells that secrete **atrial natriuretic hormone (ANH)**. When there is stretching of the atrium by an increased blood volume, the right atrium secretes ANH. It speeds up the excretion of salts and water through urine, which lowers the blood volume and pressure.

11.4- CARDIOVASCULAR DISORDERS

Cardiovascular disorders are the leading cause of death in developed and developing countries. These involve the disorders of blood vessels and heart. Atherosclerosis and arteriosclerosis are the major contributors to cardiovascular disorders.

Atherosclerosis means deposition within arteries. Various materials may accumulate in arteries e.g., fatty materials, abnormal amounts of smooth muscle cells, cholesterol, fibrin, and cellular debris of various kinds. All these build-ups impair the

proper functioning of arteries. The accumulation of cholesterol is thought to be the prime contributor to atherosclerosis. Atherosclerosis can lead to heart attacks, because it causes the narrowing of arteries and increases the risk of the formation of thrombus.

Arteriosclerosis means hardening of arterial walls. It occurs when calcium is deposited in arterial walls. The blood flow through these arteries is restricted and arteries cannot expand normally. This forces the heart to work harder. Severe atherosclerosis usually leads to arteriosclerosis.

Various diagnostic tests are performed on cardiovascular patients to locate the exact problem and to measure the severity of disease. The important tests are ECG and angiography. You have learnt about the readings of ECG, and here you would go through the basic learning of angiography.

Angiography

Coronary angiography is an X-ray examination of blood vessels or chambers of heart. In order to create the X-ray pictures, a physician guides a small tube-like device called **catheter** through the large arteries of body. When the tip of catheter reaches the opening of coronary arteries, a special fluid (called a **contrast medium** or dye) is injected in catheter. This fluid is visible in X-ray machine. Pictures (**angiograms**) of fluid in coronary artery are obtained. If clots are present in the lumen of a coronary artery, the artery appears narrow.

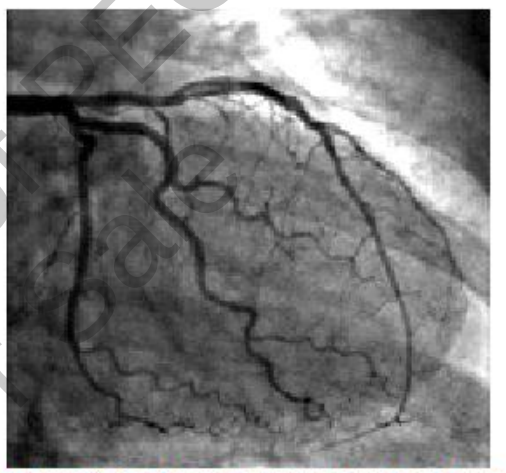

Figure 11.18: An angiogram, showing blood flow in coronary arteries

By changing the **diagnostic catheter** to a **guiding catheter**, physicians can also pass an instrument into coronary artery through the catheter. The most commonly used instruments are guide wires and balloon dilation catheters (see angioplasty).

Thrombosis

Thrombosis is the formation of thrombus. Thrombus is a solid mass or plug of blood constituents (clot) in a blood vessel. This mass may block (wholly or only in part) the vessel. Thrombus formation may be due to; (i) irritation or infection of lining of blood vessels, (ii) reduced rate of blood flow, due to long periods of inactivity, or (iii) pneumonia, tuberculosis, emphysema etc.

Formation of thrombus in a blood vessel and then its carriage to any other location is called **thromboembolism.**

Thrombosis blocks the blood flow to organs. A thrombosis in coronary arteries causes heart attack. Similarly, a thrombus in the vessels of brain causes stroke. A thrombus may be dislodged and carried to some other locations in the circulatory system. Such a thrombus is called **embolus**.

Heart Problems and Treatments

We know that coronary arteries supply oxygen and nutrients to cardiac muscles. If blood flow is blocked in coronary arteries, it results in insufficient supply of blood to one or more parts of cardiac muscle. If heart muscles die due to no supply of oxygen and nutrients, the condition is known as **myocardial infarction** (heart attack).

Heart disease and coronary artery disease are the leading causes of death in developed countries.

Blockage of coronary arteries is usually due to gradual build-up of lipids (especially **cholesterol**) in the inner wall of coronary artery. If such conditions persist, chest pain, called **angina pectoris**, can result during periods of stress or physical exertion. Angina indicates that oxygen demands are greater than its delivery and a heart attack may occur in future.

Recovery from a heart attack is possible if the damaged portion of heart is small enough that the other blood vessels in heart can enlarge their capacity and resupply the damaged tissues.

If lifestyle changes and medication haven't relieved the symptoms or if the narrowed coronary arteries are at imminent risk of a heart attack, coronary bypass surgery or angioplasty is performed.

Coronary Bypass Surgery

The open or beating-heart surgery is done when heart is still beating.

It is one of the most common and effective procedures to compensate the blockage of blood to cardiac muscles. In this surgery, surgeon takes a healthy blood vessel from leg, arm, chest or abdomen of the patient. He attaches the ends of blood vessel above and below the blocked coronary artery. So, blood is bypassed around the damaged or blocked area.

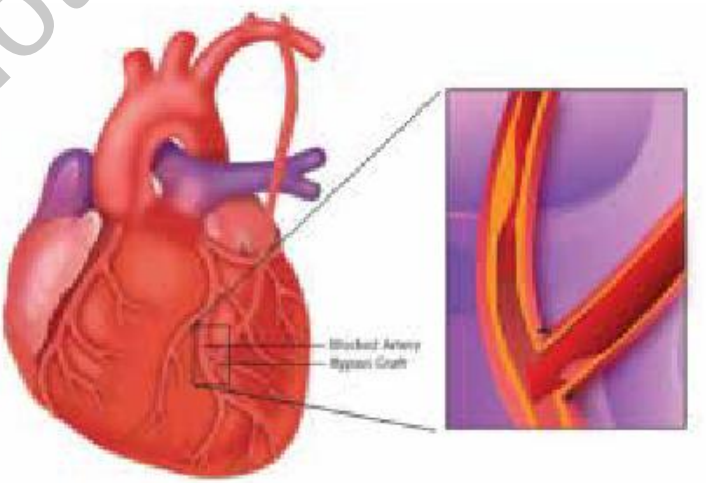

Figure 11.19: Coronary bypass

Coronary bypass surgery doesn't cure the underlying disease process i.e., atherosclerosis or coronary artery disease. Lifestyle changes especially smoking cessation

are crucial to reduce the chance of future blockages and heart attacks, even after successful bypass surgery. In addition, patients need to make other lifestyle changes, such as reducing certain types of fat in diet, increasing physical activity, and controlling high blood pressure, diabetes and other risk factors for heart disease.

Angioplasty and Stenting

Angioplasty is a procedure that opens a blocked or narrowed artery. During an angioplasty, a small wire called a catheter, under x-ray guidance, is passed through the narrowed coronary artery. A small sausage-shaped balloon is then advanced over the wire into the narrowed section of artery. The balloon is then inflated to dilate the narrowed section of the artery. Once the artery is dilated, a small amount of dye is injected to confirm the successful dilatation.

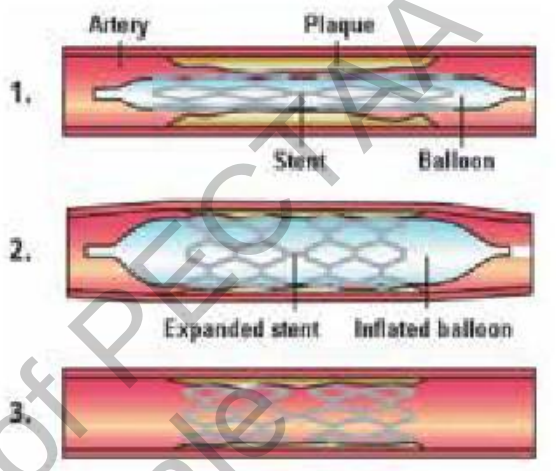

Figure 11.20: Angioplasty and stenting

Stenting may also be done during angioplasty. A **stent** is an expandable stainless steel mesh tube, mounted on a balloon catheter. When the stent/balloon is positioned within the narrowed artery, the balloon is inflated. The inflated balloon expands the stent and the artery. The balloon is removed and the stent remains in place. The stent supports the artery walls and keep the artery open and dilated.

Hypertension

A chronic (long lasting) elevation in blood pressure is called hypertension. It occurs when blood pressure consistently remains above 140/90. Any abnormality in nervous or hormonal mechanisms of blood pressure regulation may cause hypertension. Other causes of hypertension include stress, obesity, high salt intake, and smoking. There may also be hereditary reasons of hypertension.

Whenever blood pressure is chronically elevated, there is an increased chance of the rupture of blood vessels. When this occurs in brain, it is called **brain haemorrhage**. It damages the delicate structure of brain. Hypertension also weakens cardiac muscles. If hypertension is prolonged, heart is unable to pump effectively and blood flow cannot be maintained to meet needs of tissues. In such conditions, blood may be retained in heart and lungs. It is called **congestive heart failure**. Hypertension can also damage the nephrons of kidneys. It leads to further retention of salts and water in blood and therefore further hypertension.

Chest pain, including angina, does not occur during congestive heart failure.

11.5- Lymphatic System Of Human

In human, in addition to the blood circulatory system, there is another system responsible for the transport of materials. It also returns the materials from tissues to blood. This system is called lymphatic system. It consists of lymph vessels, lymphoid masses, lymph nodes and lymph-the fluid which flows in the system.

Lymph Vessels and Lymph

Lymphatic system begins with small vessels called **lymph capillaries**, which have blind endings in extracellular fluid (interstitial fluid). Pressure of the interstitial fluid forces it to enter into lymph capillaries. Lymph capillaries are more permeable than blood capillaries. So, larger molecules can also enter lymph capillaries. When interstitial fluid enters lymph capillaries, it is called **lymph**. Lymph capillaries join to form larger **lymphatic vessels** (or lymphatics or lymph vessels). Lymph vessels join to form larger lymph ducts. There are two main lymph ducts i.e., **right lymphatic duct** and **thoracic duct**. These vessels open into right and left subclavian veins (veins that drain blood from the arms and shoulders to the heart), respectively. The flow of lymph is always from body tissues towards thoracic duct. It is maintained by the activity of skeletal muscles, movement of viscera and breathing movements. The valves present in lymph vessels prevent the back flow of lymph.

Recalling:
The branches of lymph capillaries in villi, are called lacteals. Fatty acids and glycerol are absorbed into the epithelial cells of villi where they form triglycerides. The triglycerides are coated with proteins to form chylomicrons, which enter the lacteals of villi.

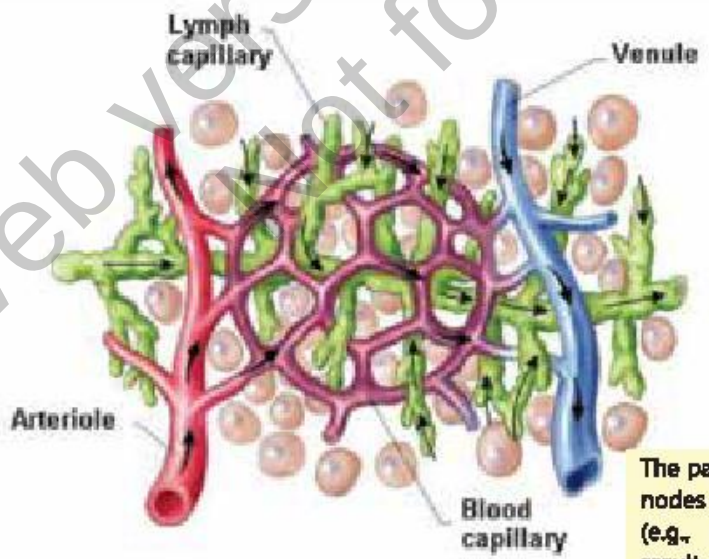

Figure 11.21: Formation of lymph

The painful swelling of lymph nodes in certain diseases (e.g., mumps) is largely a result of the accumulation of dead lymphocytes and macrophages.

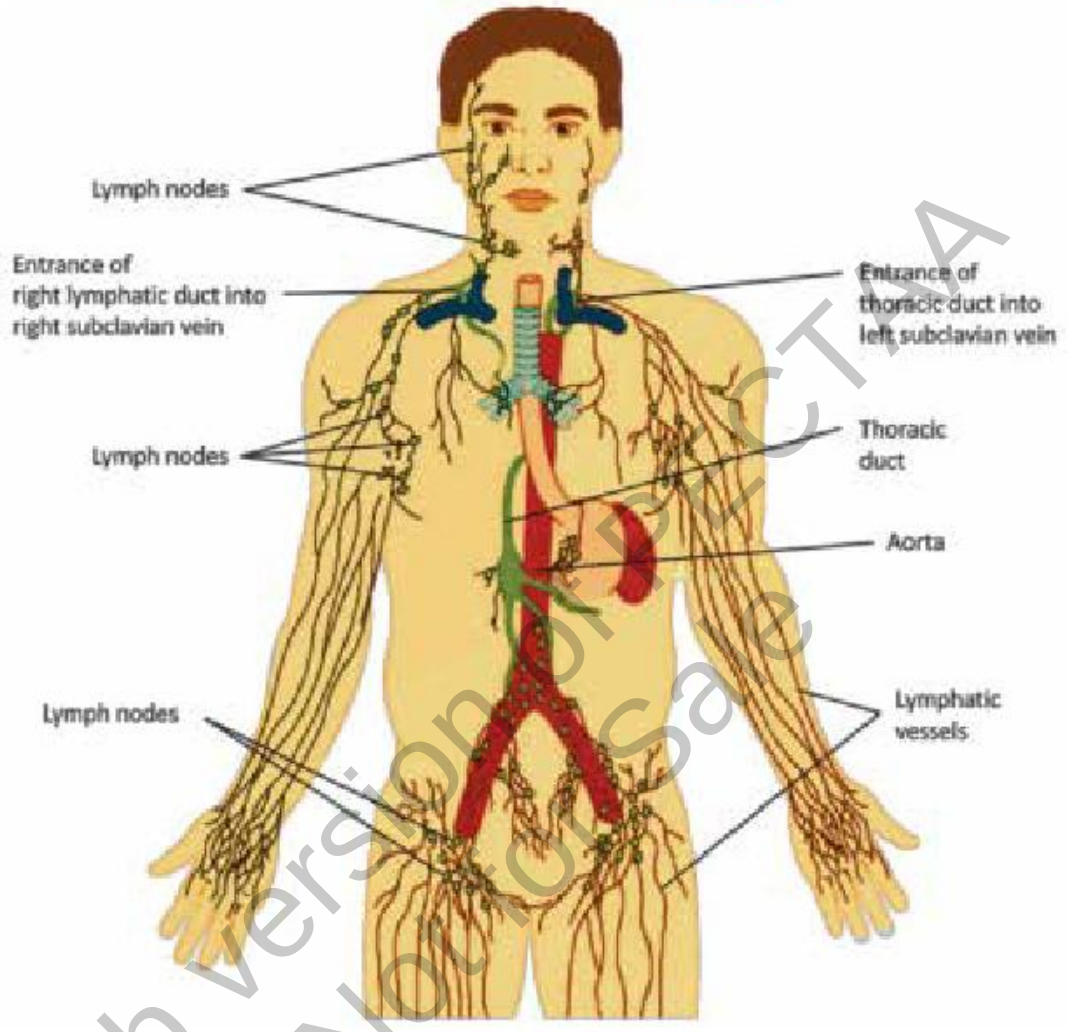

Figure 11.22: Human lymphatic system

Functions of the Lymphatic System

Lymphatic system returns the excess fluid and dissolved proteins and other substances to blood. In an average person, about three litres more fluid leaves blood capillaries daily. But it is absorbed by lymphatic capillaries and returned to bloodstream, before the blood enters heart. Lymphatic system also helps to defend body against foreign invaders. Lymph nodes filter lymph. They have lymphocytes and macrophages that destroy bacteria and viruses present in lymph. Spleen filters blood through its macrophages and lymphocytes that destroy foreign particles and aged RBCs. Spleen also functions to store RBCs.

Lymph Nodes and Lymphoid Masses

At certain spots, the lymph vessels have masses of connective tissue where lymphocytes are present. These are **lymph nodes**. Several afferent lymph vessels enter a lymph node and the lymph is drained by a single efferent lymph vessel. Lymph nodes are present in the neck region, axilla and groin areas of man. In addition to lymph nodes, several **lymphoid masses** are present in different areas e.g., in the mucosa and submucosa of alimentary canal. The larger lymphoid masses are spleen, thymus, tonsils and adenoids. These produce lymphocytes.

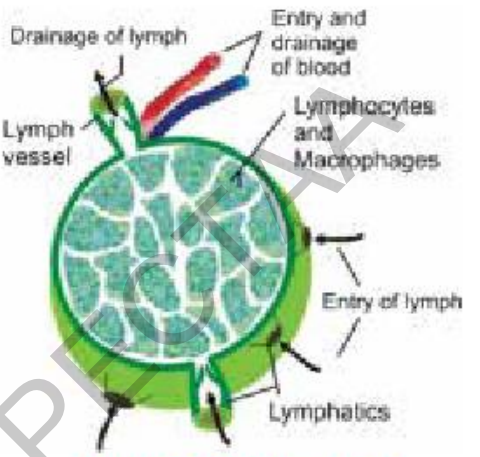

Figure 11.23: A lymph node

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. Compared to vein, an artery;
   (a) Has thinner walls (b) Is located more superficially
   (c) Carries blood away from an organ (d) Has no internal valves
2. Bicuspid valve guards the opening between;
   (a) Stomach and intestine (b) Pulmonary vein and left atrium
   (c) Right atrium and right ventricle (d) Left atrium and left ventricle
3. What is the state of bicuspid and tricuspid valves at the end of the first heart sound?
   (a) Bicuspid is closed, tricuspid is open (b) Bicuspid is open, tricuspid is closed
   (c) Both are open (d) Both are closed
4. By beating at normal speed, our heart pumps how much blood per minute?
   (a) 2 litres (b) 3 litres (c) 5 litres (d) 8 litres
5. Closure of tricuspid and bicuspid valves produces sound;
   (a) "Lubb" (b) "Dubb"
   (c) First Lubb" then "Dubb" (d) None of these but "murmurs"

6. SA-node initiates heartbeat in;
   (a) Right atrium only (b) Right atrium and partially left also
   (c) Right and left both (d) Left atrium and partially right also
7. Systolic pressure in young man is;
   (a) 60 mm of Hg (b) 80 mm of Hg (c) 100 mm of Hg (d) 120 mm of Hg
8. Blood pressure is highest in ____ and blood moves most slowly in;
   (a) Veins, capillaries (b) Arteries, capillaries
   (c) Capillaries, arteries (d) Veins, arteries
9. Instead of normal "lub-dubb" sound, a "lub-hiss, lub-hiss" sound indicates;
   (a) Blocked coronary artery (b) Damaged pacemaker
   (c) Defective semilunar valve (d) High blood pressure
10. In humans which one is the other system for the transport of materials, than blood circulatory system?
   (a) Lymphatic system (b) Digestive system
   (c) Nervous system (d) Respiratory system

SHORT QUESTIONS

1. What is the main difference between the walls of an artery and a vein?
2. Enlist the four valves present in heart and also state their locations.
3. State the phases of heartbeat.
4. List the principles and uses of Electrocardiogram.
5. Define angiography and angioplasty.
6. What is meant by Purkinje fibres?
7. What do you mean by vasoconstriction and vasodilation?
8. What is the rate of blood flow in different types of blood vessels?
9. State the role of baroreceptors and volume receptors in regulating the blood pressure.
10. Differentiate between thrombus and embolus.

LONG QUESTIONS

1. Describe the structure of the walls of heart and rationalize the thickness of the walls of each chamber.
2. Describe the flow of blood through heart as regulated by the valves.
3. Explain how a heartbeat is initiated and controlled.
4. Describe the detailed structure of arteries, veins and capillaries.
5. Describe the role of precapillary sphincters in regulating the flow of blood through capillaries.
6. Write the components of pulmonary circulation.
7. What are the main components of coronary, hepatic-portal and renal circulation?
8. Define blood pressure and explain systolic and diastolic pressure.

9. Identify the factors causing atherosclerosis and arteriosclerosis.
10. Write notes on Angina pectoris, heart attack, and heart failure.
11. Outline the main principles of coronary bypass and angioplasty.
12. Define hypertension and describe the factors that regulate blood pressure and can lead to hypertension and hypotension.
13. List the changes in life styles that can protect man from hypertension and cardiac problems.
14. Describe the structure and role of lymph capillaries, lymph vessels and lymph ducts.

INQUISITIVE QUESTIONS

1. Why is the pressure in the pulmonary circulation lower than in the systemic circulation?
2. Why is it so important for the human heart to develop early and begin functioning within the developing embryo?
3. Justify how vasoconstriction or vasodilation is reflective of emotions.
4. Justify in what way the blood circulatory system is dependent on the lymphatic system.
5. Interpret why the swelling of the lymph nodes is a cause of concern.
6. Trace the path of lymph from a lymph capillary until it is returned to the blood.