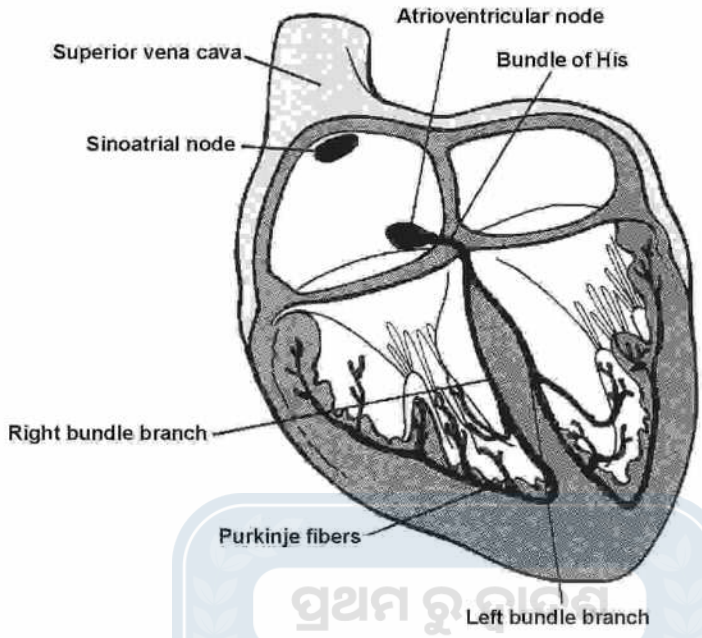


Fig.17.20 : Conducting tissue in the human heart.

17.5.3. Conducting tissue of the heart :

Human heart is myogenic i.e. cardiac muscle cells are specialized to initiate and conduct impulses from atria to ventricles in a rhythmic manner. No innervation is necessary for this work. Contraction of cardiac muscle is due to depolarization of the plasma membrane of the cells making up the muscle. Depolarization creates an **action potential**, which spreads from cell to cell. The initial depolarization arises in a small group of cardiac muscle cells near the entry of the superior venacava into the right atrium. These cells are specialized for initiating and conducting the impulse, which constitute a node, the **sino-atrial (SA) node**.

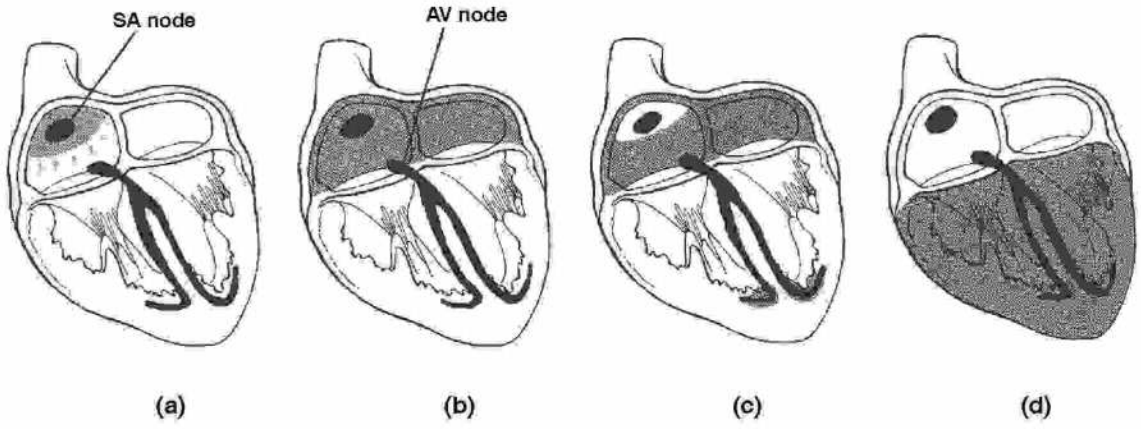


Fig.17.21 (a-d) : Origin and spreading of a heart beat from the atria to the ventricles.

The action potential caused by the depolarization of the sino-atrial node spreads rapidly to the ventricles in a manner that the atria will contract first and then the ventricles. Since the SA node initiates depolarization and spreads it to the ventricles, it is called the **cardiac pacemaker** (Fig. 17.20). The SA node conducts the depolarization to another node, called **atrio-ventricular (AV) node**, situated at the base of the right atrium. There are three bundles of atrial fibers made up of Purkinje type fibers, which connect the SA node to the AV node. These are: **the anterior internodal tract of Bachman, the middle internodal tract of Wenckebach** and the **posterior internodal tract of Thorel**. However, there is a debate on the role of these bundles.

Histologically, the conducting system of the heart consists of modified cardiac muscle cells. The SA node and to a lesser extent, the AV node contain small rounded cells, which are connected by gap junctions. These cells, possibly, act as pacemaker cells and therefore, are known as **P cells**.

The impulse is carried to the ventricles via the conducting fibers in the inter-ventricular septum, constituting **bundle of His**. The bundle divides within the septum into **left and right bundle branches**. The bundle branches are continuous with the **Purkinje fibers**, within ventricular walls.

17.5.4. Working of the heart (Fig.17.22) :

The deoxygenated blood from all parts of the body is poured into the right atrium via the superior and inferior venacavae. Similarly, the left atrium receives oxygenated blood from the pulmonary veins. The contents of the two atria do not mix due to the presence of an inter-atrial septum. Two atria undergo **systole** almost simultaneously and their contents are emptied into the ventricles of their respective sides. The right atrium drains the deoxygenated blood into the right ventricle through the right atrio-ventricular aperture, which is guarded by a tricuspid valve. The name is so, because it consists of three cusps. The valve opens only into the right ventricle and thus prevents the backward flow of blood into the right atrium. The oxygenated blood from the left atrium is pumped into the left ventricle through the left atrio-ventricular aperture, guarded by a bicuspid or mitral valve. It consists of two cusps as against three in the tricuspid valve. It opens into the left ventricle only and thus prevents the backward flow of blood into the left atrium.

As a matter of principle, with the commencement of relaxation of the atria, the ventricles will start contracting. However, the ventricles contract a little later than the commencement of relaxation of the atria. This means that both the atria and ventricles remain in **diastole** for a brief period. Alternately speaking, the entire heart is in diastole during this period. Whatever may be the case, the ventricles undergo systole and the deoxygenated blood from the right ventricle is forced into the pulmonary trunk, guarded by three semilunar valves. Similarly, the oxygenated blood in the left ventricle is forced into the aorta, guarded also by

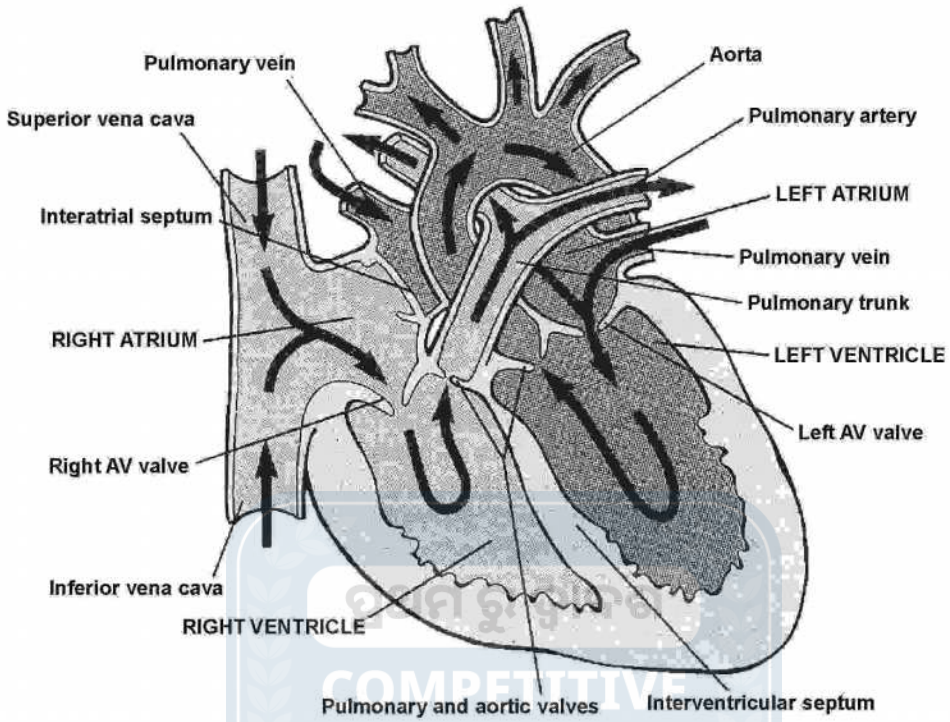


Fig.17.22 : Circulation of blood through the heart.

three semilunar valves. Both the semilunar valves are so arranged that the backward flow of blood from the pulmonary trunk into the right ventricle and from the aorta into the left ventricle is prevented. Thus, the valves ensure unidirectional flow of blood. With this, the cycle is completed. The blood in each half of the heart is completely separated from the other and thus deoxygenated and oxygenated blood do not mix at any point of time.

17.5.5. Heart Beat :

Heart beat is the spontaneous and involuntary contraction of the cardiac muscle fibers in the SA node, which then spreads to whole of the atria and then to the ventricles (Fig.17.21). Like the contraction of a skeletal muscle fiber and the conduction of a nerve impulse, this is an electrical event. This is alternately explained as the propagation of **action potential** from atria to the ventricles. An action potential is a transient depolarization of the membranes of specialized myocardial cells in the SA node. The following events take place during the origin and conduction of impulse in the heart :

1. The resting myocardial cell has more potassium ions (K^+) on the inner side and more sodium ions (Na^+) on the outer side.
2. When the cell is not contracting, it is considered as being in the resting phase. The resting membrane potential is approximately –90 mV (millivolt) (Fig.17.23).

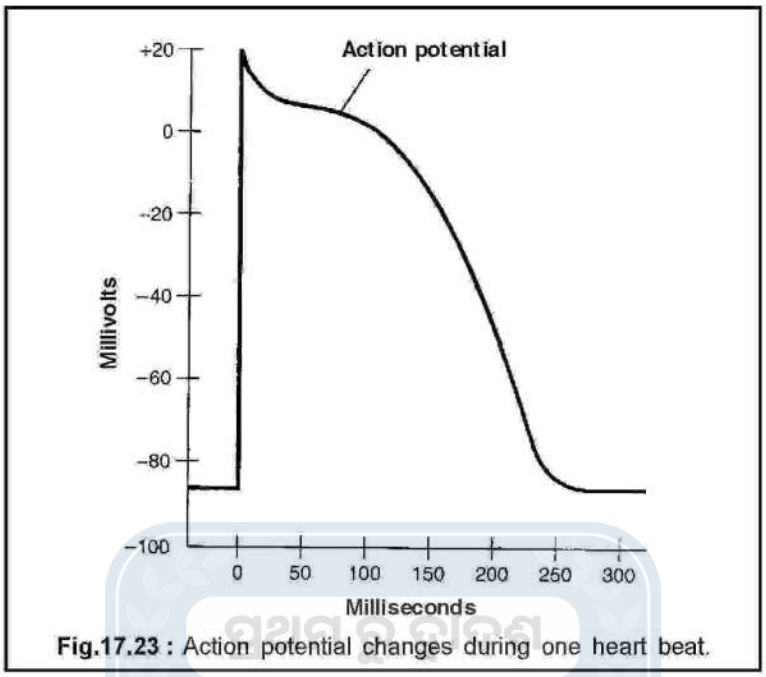


Fig.17.23 : Action potential changes during one heart beat.

*Patients with **congestive heart failure** are treated with a drug, **digitalis**. It inactivates Na^+/K^+ ATPase pumps in the plasma membrane of myocardial cells. Consequently, the cytoplasmic Na^+ concentration rises and diffusion of Na^+ into the cells is decreased. This reduces the ability of Na^+-Ca^{2+} exchanger to extrude Ca^{2+} from the cell. As a result, there is an increase in the cytoplasmic Ca^{2+} concentration and hence, the strength of myocardial contraction is increased.*

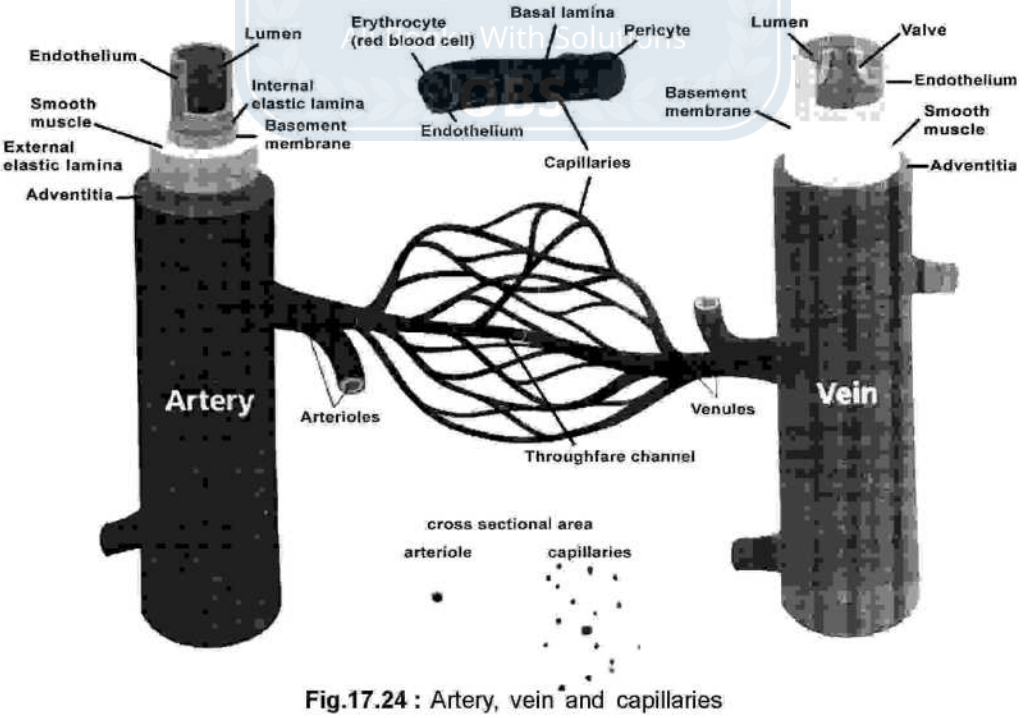


Fig.17.24 : Artery, vein and capillaries

3. When the cell contracts, the resting membrane is depolarized by the rapid influx of Na^+ through rapidly opening Na^+ channels. The potential goes up to a high of + 20 mV (Fig.7.14). This spontaneous, **automatic depolarization** of the pacemaker occurs during diastole and therefore, it is also called **diastolic depolarization**.
4. Na^+ influx is followed by slow Ca^{2+} influx through slowly opening Ca^{2+} channels.
5. Then, there is an efflux of K^+ through voltage-gated K^+ channels. This phase is termed as **repolarization**.

17.6. BLOOD VESSELS :

Types

There are various kinds of blood vessels:

- Arteries
- Elastic arteries
- Distributing arteries
- Arterioles
- Capillaries (the smallest blood vessels)
- Venules
- Veins
    - Large collecting vessels, such as the subclavian vein, the jugular vein, the renal vein and the iliac vein.
    - Venae cavae (the two largest veins, carry blood into the heart).

They are roughly grouped as *arterial* and *venous*, determined by whether the blood in it is flowing *away from* (arterial) or *toward* (venous) the heart. The term "arterial blood" is nevertheless used to indicate blood high in oxygen, although the pulmonary artery carries "venous blood" and blood flowing in the pulmonary vein is rich in oxygen. This is because they are carrying the blood to and from the lungs, respectively, to be oxygenated.

17.7. CARDIAC CYCLE :

The healthy human heart beats 75 times per minute i.e. one beat covers 60/75 sec = 0.8 sec. each beat completes through two distinct phases: **a phase of contraction (systole)** and **a phase of relaxation (diastole)**. Changes, which occur during one beat are repeated in the same rhythm and order in the next beat. This orderly repetition of changes in the heart from beat to beat is known as **cardiac cycle**. A cardiac cycle completes in 0.8 sec. Each event in the cardiac cycle is repeated in an interval of 0.8 sec.

There are four events in the cardiac cycle: **atrial systole**; **atrial diastole**; **ventricular systole**; and **ventricular diastole**. The cardiac cycle may be represented by two concentric

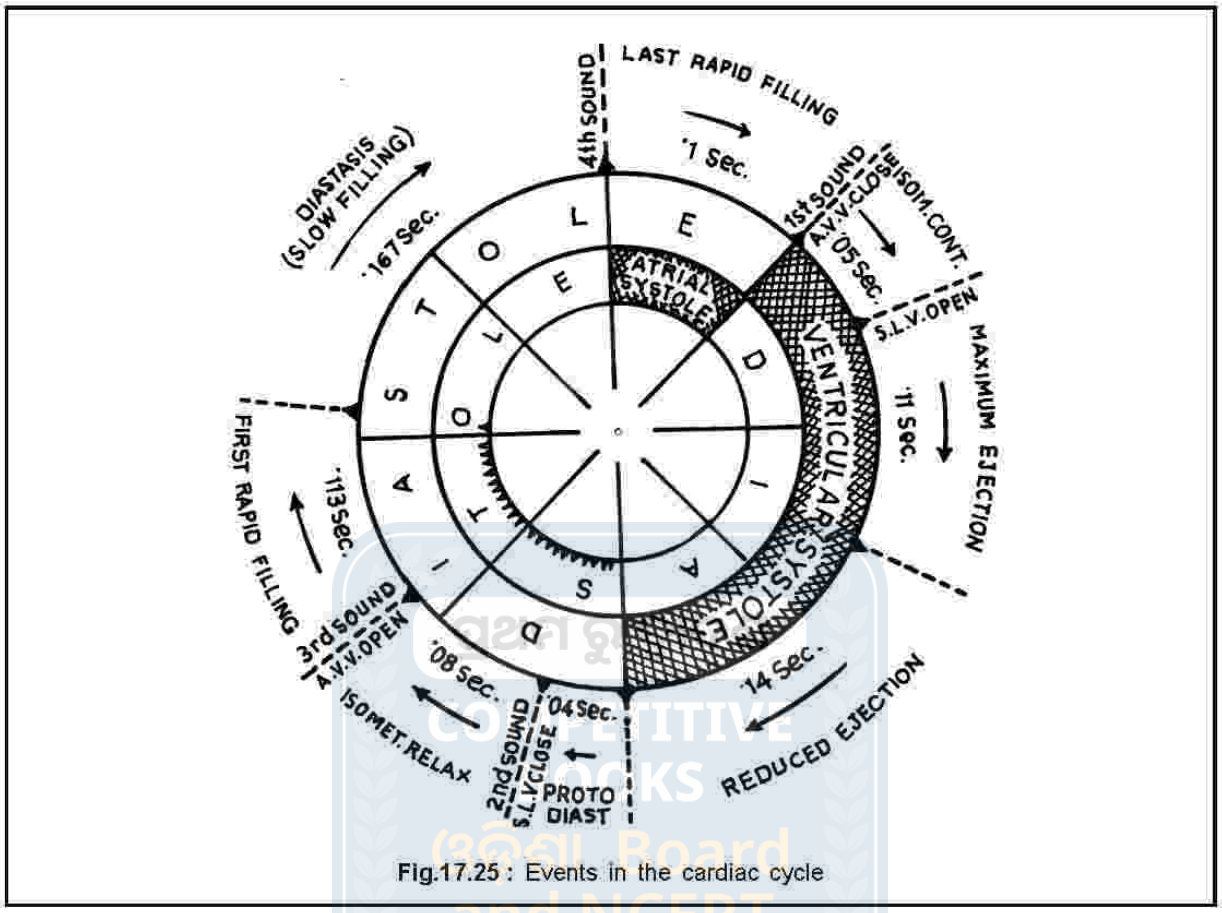


Fig.17.25 : Events in the cardiac cycle

rings, divided into eight equal parts (Fig.17.25). The inner ring represents the events in the atria, while the outer in the ventricles. Each of the equal parts represents a time lapse of 0.1 sec. The atrial systole spans only one division (0.1 sec), while the atrial diastole the rest seven (0.7 sec). The ventricular systole covers three divisions (0.3 sec), while the diastole five (0.5 sec).

17.7.1. Atrial systole and diastole :

The pacemaker is situated in the right atrium and the myocardial wave of contraction initiates from the right atrium and then spreads to the left atrium. However, it is explained that two atria contract almost simultaneously. The force of contraction is stronger in the first half than in the second half. The buildup of pressure causes the atrio-ventricular valves to open and blood to flow from the atria to the respective ventricles. It has been estimated that 80% of the ventricles are filled with blood even before the atria contract. Atrial systole adds the rest 20% to the **end-diastolic volume**, which is the final volume of blood in the ventricles. Following the atrial systole, the atrial diastole (0.7 sec) commences. During this period, the right and left atria relax and receive blood from the venacavae and pulmonary veins, respectively. At the end of this phase, atrial systole is repeated.

17.7.2. Ventricular systole and diastole :

At the end of atrial systole, the ventricular systole commences. **As evident from the Fig.17.25, the two events do not overlap**. The ventricular systole covers a lapse of 0.3 sec. This is followed by ventricular diastole (0.5 sec). At the onset of ventricular systole, the atrio-ventricular (tricuspid and bicuspid) valves are shut, producing the **first heart sound**.

The inter-ventricular pressure builds up to open the semilunar valves, guarding the aorta and pulmonary artery. Consequently, the semilunar valves open a little later than the closure of the AV valves. Thus, at the beginning of the ventricular systole, the ventricles contract as closed cavities for a brief period. This period is known as **isovolumetric contraction period** (0.05 sec). At the end of this period, the semilunar valves open and the blood from the right and left ventricles are ejected into pulmonary artery and aorta, respectively. Ventricular systole ejects about two-third of the blood the ventricles contain. This amount of blood is known as the **stroke volume**. One-third of the initial amount is left in the ventricles as the **end-systolic volume**. During the first part of this period, there is a rapid outflow. Therefore, this period is termed as **rapid ejection period**. The outflow slows down towards the last part and this period is termed as **reduced ejection period**. The ventricular diastole, represented by five divisions, follows ventricular systole. With the relaxation of the ventricles, the intra-ventricular pressure falls. This causes the semilunar valves to shut, producing the **second heart sound**. Thus, **the onset of the ventricular systole is marked by the first sound and its termination by the second sound**.

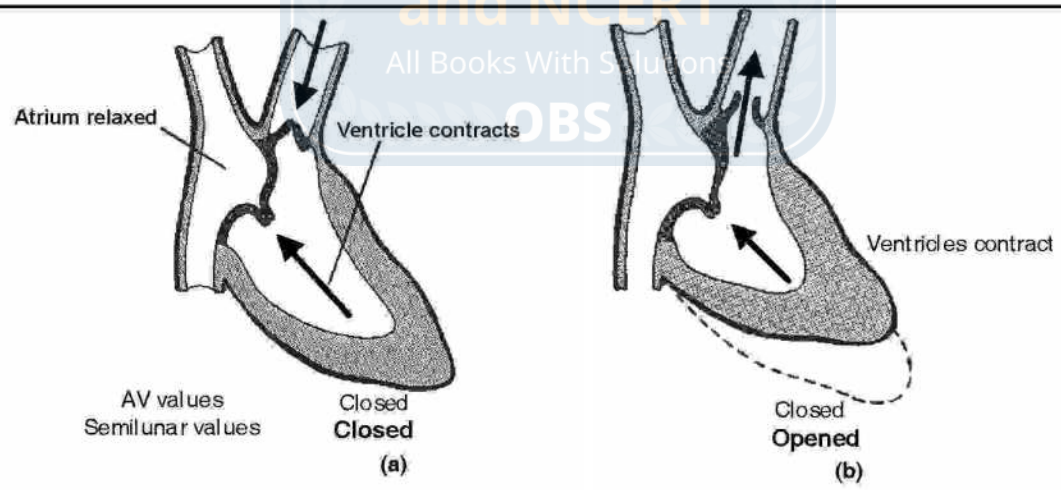


Fig.17.26 : Heart in systole. (a) Isovolumetric ventricular contraction; (b) Ventricular ejection.

*The blood contributed by the contraction of the atria does not seem to be vital for life. Old age people, who have a condition, in which atria fail to contract, appear to have the same average longevity like those having normally functioning atria. This condition is known as **atrial fibrillation**. However, such people are fatigued more easily during exercise.*

Comparison of two rings in the Fig. 7.15 indicates that the last division of the ventricular diastole overlaps with the atrial systole and further, the first four divisions of the ventricular diastole overlap with the last four divisions of the atrial diastole. From these observations, it is said that **the diastole of the atria and ventricles will always partly overlap**. Alternately speaking, **both the chambers are in diastole or the entire heart is in diastole** (**0.4 sec**).

As stated above that the second sound occurs exactly at the end of ventricular systole is not true. The semilunar valves will actually shut, when the intra-ventricular pressure falls below the intra-aortic pressure. Indeed there is a gap between the onset of ventricular diastole and closure of the semilunar valves. This period is known as **protodiastolic period** (0.04 sec).

Although the semilunar valves have closed, the atrio-ventricular valves have not opened. These valves will open only when the intra-ventricular pressure goes below that of the atria. Consequently, there will be a brief period, during which both the valves remain closed and the ventricles are relaxing as closed cavities. This time lapse is known as **isovolumetric relaxation period** (0.08 sec). As soon as the A-V valves open, blood rushes from the atria into the ventricles and the ventricular filling begins. The first part of this period is known as **first rapid filling phase**. Due to a rapid rush of the blood, a **third heart sound** is produced. In the middle part the rate slows down. This phase is known as **diastasis** or **slow inflow phase**. The ventricular diastole overlaps with atrial systole in the last division. This contributes towards the **last rapid filling phase**. It is responsible for the **fourth heart sound**.

Murmers :

Heart murmers are abnormal heart sounds, produced due to abnormal patterns of blood flow due to defective valves. *Defective valves may be congenital or may result due to an auto-immune disorder,* ***rheumatic endocarditis***. *Small defects do not seriously compromise with the pumping of the blood. However, in larger defects, like* ***mitral stenosis****, mitral valves become calcified impairing the blood flow from the left atrium to the left ventricle. Murmers can also be produced due to septal defects.*

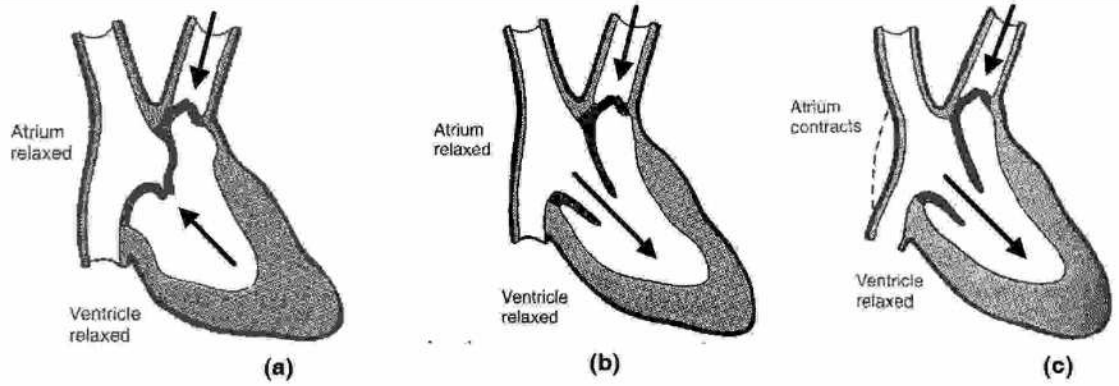


Fig.17.27 : The heart in diastole. (a) Isovolumetric relaxation; (b) & (c) Ventricular filling.

Blood Pressure :

When the left ventricle contracts, the semilunar valves of the aorta open and the blood is rapidly ejected into the aorta. The pressure in the left ventricle and the aorta rises to about 120 mm Hg. This pressure is known as the **systolic blood pressure**. Following this, the ventricles relax and the pressure in the left ventricle falls below the pressure of the aorta. The semilunar valves are shut producing the second heart sound. The pressure in the aorta falls to 80 mm Hg. This pressure is known as the **diastolic pressure**. The blood pressure of a healthy human being is denoted by the systolic pressure upon the diastolic pressure i.e. 120 mm Hg / 80 mm Hg. An instrument used to measure the blood pressure is known as **sphygmomanometer**.

A sphygnomanometer for measuring the blood pressure.

Similar events occur in the right ventricle and pulmonary circulation. **The maximum pressure produced at ventricular systole is 25 mm Hg, which then falls to 8 mm Hg.**

The blood pressure is affected by three parameters: cardiac rate; stroke volume; and total peripheral resistance by vasoconstriction. The arterial blood pressure is directly proportional to the product of cardiac output and total peripheral resistance.

Thus,

Arterial Blood Pressure = A Cardiac output × Total peripheral resistance

Measurement of blood pressure :

Stephen Hales (1677-1761) inserted canula into an artery of the horse. The blood rose to a height and the blood column bounced between two points, the systolic and diastolic pressures. **The modern method of measuring the blood pressure is indirect, known as ascultatory.** The instrument is known as **sphygnomanometer**. In this method, an inflatable rubber bag is wrapped around the upper arm and the stethoscope is applied over the brachial artery. The artery is silent before the inflation of the bag. The bag is inflated by forcing air into it by a rubber pump. As the air is pumped, the mercury column rises and at a point, the blood flow in the artery is stopped by complete constriction and the artery becomes silent. Air from the bag is released slowly by loosening a screw in the pump. When the pressure of the air falls below that of the inflowing arterial blood, there is a sound. This sound is known as the **sound of Korotkoff**. Concurrent with the release of air, there is a fall in the mercury column. **The pressure in mm Hg in the mercury column is recorded at the first sound as the systolic pressure**. As the air is released and the mercury column falls, the intensity of the sound fades and at a point, the last sound of Korotkoff is heard and no more thereafter. **This height of the mercury column at the last sound is recorded as the diastolic pressure in mm Hg**. The average blood pressure in the systemic circulation In human is 120/80 mm Hg. The average pressure in the pulmonary arterial circulation is 22.8 mm Hg.

Pulse:

The blood is forced from the left ventricle into the aorta during the systole. The systole creates a pressure wave that travels along the arteries. The wave stretches the arterial wall as it travels along. The stretching or expansion is palpable i.e. it can be felt or touched as pulse. The rate of movement of the pulse is 4m/sec in the aorta; 8m/sec in large arteries; and 16 m/sec in small arteries. The strength of the pulse is determined by the pulse pressure and bears little relation to the average blood pressure. **The difference between the systolic pressure and diastolic pressure is known as the pulse pressure.** Thus,

The Pulse pressure = 120 mm Hg – 80 mm Hg = 40 mm Hg

The mean arterial pressure is computed from the pulse pressure, like:

Mean arterial pressure = Diastolic pressure + 1/3 Pulse pressure

= 80 + 40/3 = 93 mm Hg.

17.8. CARDIAC OUTPUT :

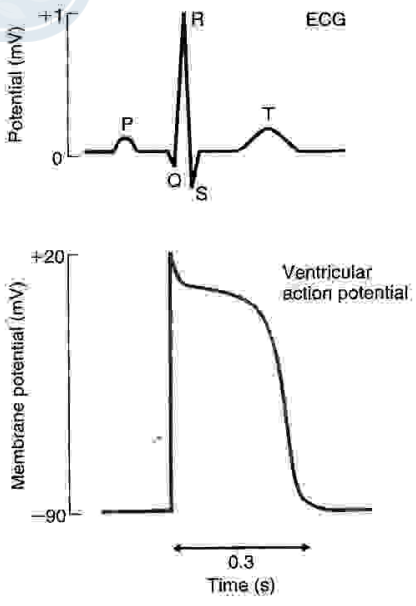
Cardiac output is the volume of blood pumped by each ventricle per minute. It is given by the product of **stroke volume** (mL/beat) and **cardiac rate** (beats/min).The average cardiac rate in an adult human is 75 beats / min and the stroke volume i.e. the volume of blood pumped per beat by each ventricle is 70-80 mL / beat (75 mL/beat on an average).

Thus, **Cardiac output** = 75 mL/min × 75 beats / min = 5625 mL ≈ 5.5 L (approximately)

The total blood volume also averages about 5.5 L. This means that each ventricle pumps an equivalent of the total blood volume each min. Thus, when the cardiac output increases, the arterial blood pressure also increases proportionataly.

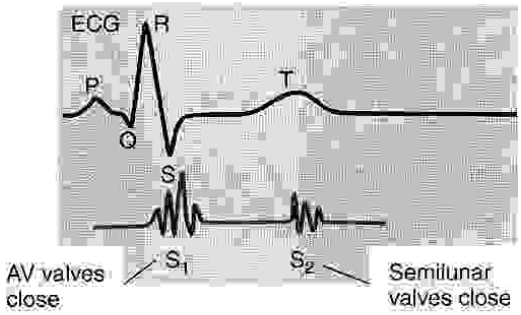
17.9. ELECTROCARDIOGRAM (ECG) (See the figure on the side) :

(**ECG**) is a record of the electrical events in the heart on a piece of moving paper. The body fluid is a good conductor of electricity and therefore, the fluctuations in the potential of myocardial cells are recorded by placing electrodes externally. ECG may be recorded by using a single electrode, known as **active** or **exploring electrode** (**unipolar**) or by using **two active electrodes** (**bipolar**).



As the recoding shows, there are three deflections. The first deflection, called the P-wave, corresponds to the current flowing during **atrial depolarization**. The second deflection is the QRS complex, occurring approximately after 0.15 sec later than atrial depolarization. It is the result of **ventricular depolarization**. The final deflection is the T wave. It is the result of **ventricular repolarization**. Any deviation from the normal ECG points towards an abnormal functioning of the heart.

Correlation of ECG with heart sounds (See figure on the side) :



The depolarization of the ventricles is marked by the QRS wave. The QRS wave is seen at the begining of ventricular systole. The rise in the intraventricular pressure causes the AV valves to close, so that the first heart sound (lub) is produced. It is produced immediately after the QRS wave. Repolarization of the ventricles is indicated by the T wave. It is synonymous with diastole. The fall in the intraventricular pressure causes the pulmonary and aortic semilunar valves to close, producing the second heart sound (dup).

17.10. CLOSED CIRCULATION :

Most multicellular non-chordates and all chordates possess a circulatory system, in which the blood circulates in closed blood vessels. This is known as closed circulation. Blood is separated completely from other body fluids. A pulsatile heart is connected to two types of blood vessels :

1. **Vessels that carry blood away from the heart :** These vessels are called **efferent vessels** or **arteries**. All arteries, except pulmonary arteries, carry oxygenated blood to the tissues and organs of the body
2. **Vessels that carry blood towards the heart :** These vessels are called **afferent vessels** or **veins**. All veins, except the pulmonary veins carry deoxygenated blood from different tissues and organs to the heart.

Closed circulation is of two types: **single circulation** and **double circulation**.

17.10.1. Single circulation :

As discovered by the British physiologist, **William Harvey (1628)**, the cardio-vascular system forms a circle. The blood pumped out of the heart through one set of vessels (arteries) returns to the heart through a different set of vessels (veins). In single circulation, as **exemplified by cyclostomes** and **fishes**, there is a single circuit of blood flow i.e. the venous blood flowing through the heart returns to the heart as the venous blood again (Fig.17.28). The heart does not contain arterial blood at any point of time.

The heart of cyclostomes and fishes is two-chambered, consisting of an atrium and a ventricle. The deoxygenated blood from all parts of the body is collected through large veins and is drained into the heart. This blood then is carried to the gills for oxygenation and following oxygenation, the blood is supplied to all parts of the body, bypassing the heart. The deoxygenated blood from the tissues and organs is again collected by veins, which is emptied into the heart, thus completing the circuit. The heart, thus, contains deoxygenated blood only and therefore, is known as a **venous heart**.

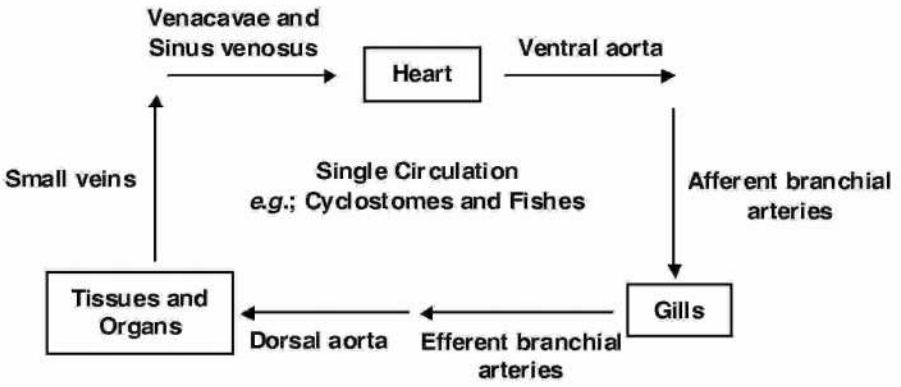


Fig.17.28 : Single circulation in cyclostomes and fishes.

17.10.2. Double circulation :

The heart of vertebrates, above the grade of fishes, is longitudinally divided into two functional halves. Each half contains two chambers: an atrium and a ventricle. An atrium empties the blood into the ventricle of its side only. There is no direct communication between the two atria or the two ventricles. There are two circuits of circulation, such as **pulmonary circulation** and **systemic circulation**. The two circuits are completely separated from each other (Fig. 17.29).

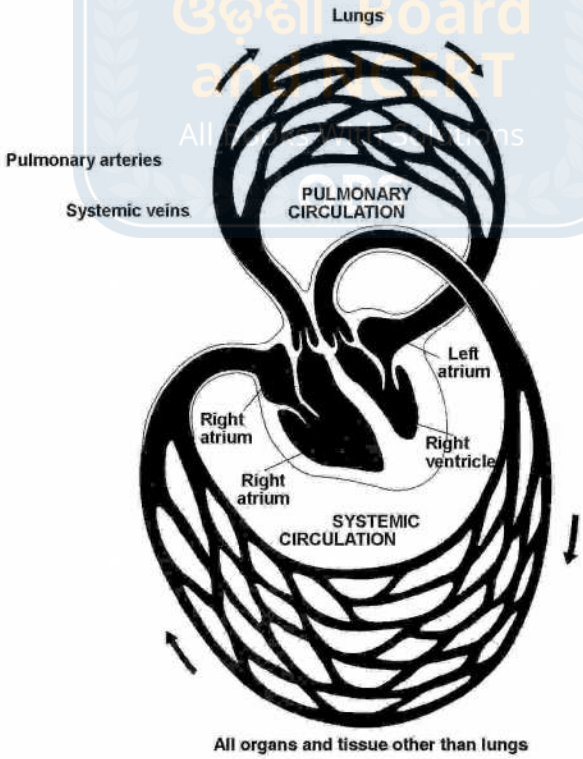


Fig.17.29 : Plan of double circulation in a vertebrate

(a) Pulmonary circulation: The deoxygenated blood from the right ventricle is pumped into the pulmonary arteries. The pulmonary arteries break up into arterioles and then into capillaries in the lung tissue. These capillaries join to form venules and the venules into pulmonary veins, which return the oxygenated blood to the left atrium. Thus, the pulmonary circulation circuit is complete.

(b) Systemic circulation: The left atrium pumps the oxygenated blood into the left ventricle and by the contraction of the left ventricle; this oxygenated blood is pumped into the aorta. The aorta breaks up into arteries, which supply oxygenated blood to all tissues and organs of the body. The arteries break up into arterioles and then into capillaries. The capillaries join forming venules and the venules into veins. All the veins join forming the superior and inferior venacavae. The venacavae finally empty the blood into the right atrium. Thus, the systemic circulation circuit is complete.

17.11. REGULATION OF HEART :

Various intrinsic, neural, and hormonal factors act to influence the rhythm control and impulse conduction within the heart. The rhythmic control of the cardiac cycle and its accompanying heart beat relies on the regulation of impulses generated and conducted within the heart. Regulation of the cardiac cycle is also achieved via the autonomic nervous system. The sympathetic and parasympathetic divisions of the autonomic system regulate heart rhythm by affecting the same intrinsic impulse conducting mechanisms that lie within the heart in opposing ways.

Cardiac muscle is self-contractile because it is capable of generating a spontaneous electrochemical signal as it contracts. This signal induces surrounding cardiac muscle tissue to contract and a wave-like contraction of the heart can result from the initial contraction of a few localized cardiac cells.

The cardiac cycle describes the normal rhythmic series of cardiac muscular contractions. The cardiac cycle can be subdivided into the systolic and diastolic phases. Systole occurs when the ventricles of the heart contract and diastole occurs between ventricular contractions when the right and left ventricles relax and fill. The sinoatrial node (S-A node) and atrioventricular node (AV node) of the heart act as pacemakers of the cardiac cycle.

The contractile systolic phase begins with a localized contraction of specialized cardiac muscle fibers within the sino-atrial node. The S-A node is composed of nodal tissue that contains a mixture of muscle and neural cell properties. The contraction of these fibers generates an electrical signal that then propagates throughout the surrounding cardiac muscle tissue. In a contractile wave originating at the S-A node, the right atrium muscle contracts (forcing blood into the right ventricle) and then the left atrium contracts (forcing blood into the left ventricle).

Intrinsic regulation is achieved by delaying the contractile signal at the atrioventricular node. This delay also allows the complete contraction of the atria so that the ventricles receive

the minimum amount of blood to make their own contractions efficient. A specialized type of neuro-muscular cells, named Purkinje cells, form a system of fibers that covers the heart and which conveys the contractile signal from S-A node (which is also a part of the Purkinje system or subendocardial plexus). Because the Purkinje fibers are slower in passing electrical signals (action potentials) than are neural fibers, the delay allows the atria to finish their contractions prior to ventricular contractions. The signal delay by the AV node lasts about a tenth (0.1) of a second.

The contractile signal then continues to spread across the ventricles via the Purkinje system. The signal travels away from the AV node via the bundle of His before it divides into left and right bundle branches that travel down their respective ventricles.

Extrinsic control of the heart **rate** and rhythm is achieved via autonomic nervous system (ANS) impulses (regulated by the medulla oblongata) and specific **hormones** that alter the contractile and or conductive properties of heart muscle. ANS sympathetic stimulation via the cervical sympathetic chain ganglia acts to increase heart rate and increase the force of atrial and ventricular contractions. In contrast, parasympathetic stimulation via the vagal nerve slows the heart rate and decreases the vigor of atrial and ventricular contractions. Sympathetic stimulation also increases the conduction **velocity** of cardiac muscle fibers. Parasympathetic stimulation decreases conduction velocity.

The regulation in impulse conduction results from the fact that parasympathetic fibers utilize **acetylcholine**, a **neurotransmitter** hormone that alters the transmission of an **action potential** by altering **membrane** permeability to specific ions (e.g., potassium ions [K^+]). In contrast, sympathetic postganglionic neurons secrete the neurotransmitter norepinephrine that alters membrane permeability to **sodium** (Na^+) and **calcium** ions (Ca^{2+}).

The ion permeability changes result in parasympathetic induced hypopolarization and sympathetic induced hyperpolarization.

Additional hormonal control is achieved principally by the adrenal **glands** (specifically the adrenal medulla) that release both epinephrine and norepinephrine into the blood when stimulated by the sympathetic nervous system. As part of the fight or flight **reflex**, these hormones increase heart rate and the volume of blood ejected during the cardiac cycle.

The electrical events associated with the cardiac cycle are measured with an electrocardiogram (ECG). Disruptions in the impulse conduction system of the heart result in arrhythmias.

Variations in the electrical system can lead to serious, even dangerous, consequences. When that occurs an artificial electrical stimulator, called a **pacemaker**, must be implanted to take over regulation of the heartbeat. The small pacemaker can be implanted under the skin near the shoulder and long wires from it are fed into the heart and implanted in the heart

muscle. The pacemaker can be regulated for the number of heartbeats it will stimulate per minute. Newer pacemakers can detect the need for increased heart rate when the individual is under exertion or **stress** and will respond.

17.12. DISORDERS OF CIRCULATORY SYSTEM :

17.12.1. Hypertension :

Hypertension is a sustained blood pressure in excess of the normal range. Hypertension that appers due to diseases is known as **secondary hypertension**. It accounts for only 5%. In over 90% of patients, the cause of hypertension is not known. This type is known as **essential hypertension**. An increased **total peripheral resistance** is the main cause of this condition. Some causes of this type of hypertension are outlined below.

Table - 17.4
Blood Pressure Groups in Adults

Group	Systolic pressure (mm Hg)	Diastolic pressure (mm Hg)
Normal	120	80
Prehypertension	120-139	80-89
Hypertension (Stage I)	140-159	90-99
Hypertension (Stage II)	160 and above	100 and above

1. It is believed that the endothelium of the arteries secretes decreased levels of **nitric oxide** (NO), **a vasodilator** and increased levels of **endothelin**, **a vasoconstrictor**.
2. Elevated levels of **renin**, **a kidney enzyme**, which catalyzes the formation of angiotensin II is another cause of hypertension. It stimulates aldosterone secretion, which promotes salt and water retention by the kidneys, consequently increasing blood volume.
3. High stress, resulting from **sympathetic stimulation**, and high salt intake help in the progression of hypertension.
4. **Arteriosclerosis** leads to the occlusion of the arterial lumen and hence, increases the total peripheral resistance. This leads to the development of hypertension.
5. Finally, dysfunction in the kidneys may lead to a sustained blood pressure and hypertension. The malfunctioning kidneys fail to eliminate salt and water and thereby, increase blood volume and blood pressure.

Effects of hypertension : Hypertension is the cause of many cardio-vascular diseases. Some of these are enlisted below.

1. A sustained blood pressure may result in endothelial damage in the blood vessels of vital organs. This may lead to the formation of a thrombus or clot and this in turn may impair normal blood supply. A prolongation of this may damage the organ.
2. High blood pressure is caused by peripheral resistance and this increases the pressure on the ventricles to eject blood. A sustained action of the ventricles in this manner leads to a progressive weakening of the ventricular muscle. It finally leads to a **congestive heart failure**.
3. High pressure may damage the cerebral blood vessels, which may lead to **cerebro-vascular accident or stroke**.
4. Finally, hypertension contributes to the development of atherosclerosis, which leads to several heart diseases.

Treatment :

(a) Change in the life style : The following changes in the life style are very much essential in keeping the blood pressure within its limits.

1. Getting rid of smoking habit
2. Reducing consumption of alcohol
3. Programmed exercise and reduction in the intake of sodium
4. Eating food that is rich in potassium and supplementing the food with Ca^{2+}

(b) Drug therapy : If a change in the lifestyle does not work, drugs are recommended. However drugs may be taken with the advice of a qualified physician.

1. Diuretic drugs increase urine volume, thus decreasing blood volume and blood pressure.
2. Drugs that block b_1-adrenergic receptors (*e.g.*; **Atenolol**)
3. Angiotensin converting enzyme (ACE) inhibitor inhibits the conversion of angiotensin I to angiotensin II. Angiotensin II is a vasoconstrictor and hence increases the blood volume and pressure (*e.g.*; **Captopril**; **Enalapril**). Angiotensin receptor blockers, unlike ACE inhibitor, allow angiotensin II to be formed, but inhibit the binding of angiotensin II to its receptor (*e.g.*; **Losartan**).

17.12.2. Atherosclerosis :

It is a disease of large and intermediate size arteries in which fatty substances such as cholesterol is deposited on their inner wall. Cholesterol molecules conjugate with plasma proteins and circulate as lipoproteins.

These lipoproteins associate with the membrane of endothelial cells. The trapped molecules trigger the endothelial cells to synthesize cell adhesion molecules, specific for

monocytes. The attached monocytes burrow through the endothelial wall and lie in the smooth muscular layer of the artery (tunica media), where they transform into macrophages. They engulf the associated lipid and become gorged. Such macrophages are known as **foam cells**. Chemotactic factors, released by foam cells recruit more leucocytes perpetuating the state of inflammation. The deposited lipid and macrophages form plaques, known as **atherosclerotic** or **atheromatous plaques** [Fig.17.30 (a) and (b)]. The deposited lipids and trapped macrophages are surrounded by smooth muscle cells, which later undergo calcification. Consequently, the plaque hardens and occludes the arterial lumen. The incidence of atherosclerosis is correlated with the concentration of circulating **low density lipoprotein** (**LDL**), often referred to as **bad cholesterol**. It is also caused by smoking and hypertension. Atherosclerosis is less likely in individuals, who maintain low level of cholesterol in their blood and who have high levels of **high density lipoproteins** [**HDLs** (**good chlesterol**)] in their blood. **Women have a higher level of HDL in their blood and therefore, have a lower risk of getting heart diseases than men.**

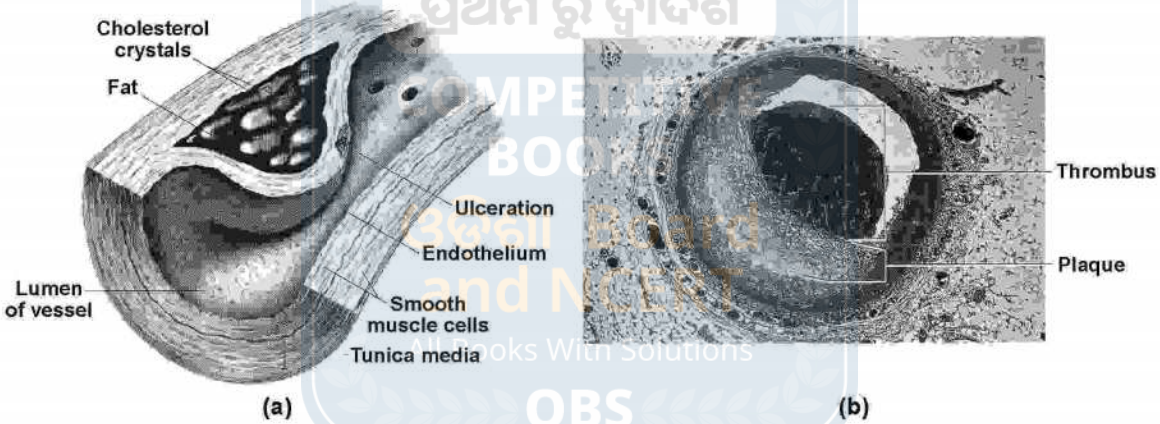


Fig.17.30 : (a) An atherosclerotic plaque in the arterial wall; (b) Cross section of a coronary artery showing an atherosclerotic plaque and a clot in the lumen

Cholesterol, plasma lipoproteins and atherosclerosis : Another major cause of atherosclerosis is the **lack of LDL receptors** or presence of defective receptors on the membrane of liver cells. This situation elevates the level of plasma LDL concentration, which leads to atherosclerosis. This is an **autosomal dominant disorder**, known as **familial hypercholesterolemia**. Normal liver cells do have specific membrane-bound receptors for circulating LDLs. The LDLs bind to their receptors in a species-specific manner and the complexes are engulfed by **receptor-mediated endocytosis**. The cholesterol molecules are released from the LDLs and metabolized. However a mutation in the gene, expressing LDL receptor, causes the formation of a different receptor, which does not bind to LDLs. Consequently, the concentration of circulating LDLs rises leading to atherosclesis and hence to heart diseases. An excessive rise in the level of plasma cholesterol may result in the deposition of cholesterol in the skin and tendons as yellow nodules, known as **xanthomas**.

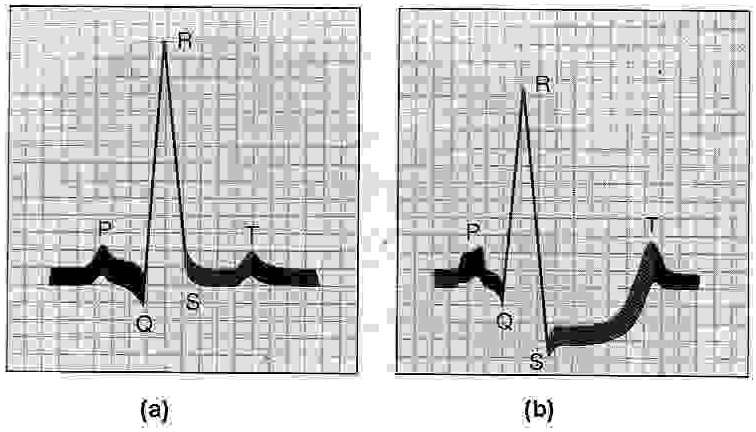


Fig.17.31 : S-T segment in the ECG. (a) Normal S-T segment, (b) Abnormal S-T segment in myocardial ischemia.

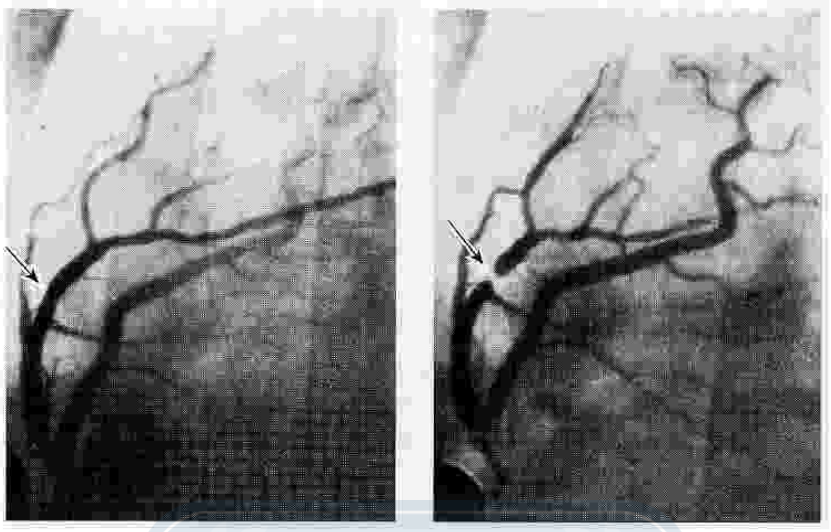
Effects of atherosclerosis :

Atherosclerosis leads to heart diseases, known as **ischemic heart diseases**. When a tissue is deprived of oxygen supply due to inadequate blood flow, it is known as **ischemic**. The most common cause of myocardial ischemia is atherosclerosis of coronary arteries. Myocardial ischemia is associated with increased formation of blood lactic acid by anaerobic respiration. This causes an unbearable pain, known as **angina pectoris**, in the sub-sternal region of the left side (left shoulder and arm). Such people, with angina, take **nitroglycerine** to get a relief from ischemia and pain. It causes **vasodilation**, thus, improving blood supply to the heart.

Statins *is a class of drugs, which inhibits the enzyme, HMG-coenzyme A reductase. This enzyme catalyzes a step in the biosynthesis of cholesterol in the liver cells. Taking the drug, reduces the incidence of atherosclerosis and hence heart diseases.*

If ischemia and anaerobic respiration prolong, the myocardial cells, deprived of oxygen may die. A sudden irreversible injury of this type is referred to as **myocardial infarction** or **heart attack**. The damaged cells can not be repaired nor can these be regenerated. It is detected by the changing pattern of the S-T segment of the electrocardiogram [Fig.17.31 (b)]. The normal pattern is depicted in Fig.17.31 (a).

The diagnosis of myocardial infarction is made by measuring the plasma concentrations of some enzymes, **creatine phosphokinase** (**CPK**) and **lactate dehydrogenase** (**LDH**). For example, the CPK level increases within 3-6 hr after the onset of the symptoms and returns to normal after 3 days. Plasma LDH level reaches a peak within 48-72 hr after onset of the symptoms and remains as such for 11 days. Besides, the plasma concentrations of troponin T and I (muscle proteins) are also elevated. All these may lead to a stoppage of blood supply to the brain which is known as **stroke**.



(a) (b)

Fig.17.32 : Angiogram of the left coronary artery.
(a) Normal; (b) Myocardial ischemia due to a coronary artery block.

Treatment : In the event of the blockage (formation of a clot or thrombus) of the coronary artery, it is important to locate the block and then decide for its clearance. The blockage is visualized by inserting a catheter (plastic tube) into the brachial or femoral artery up to the opening of the coronary artery into the heart and then injecting a radiographic contrast material. Then a photograph is taken. The photograph, known as the **angiogram**, reflects the blockage [Fig.17.32 (b)]. The normal angiogram of the left coronary artery is presented in Fig.17.32 (a).

The blockage is cleared by a technique, called **balloon angioplasty**. An inflatable balloon is used to clear the thrombus. However, **stenosis** (narrowing) may occur again. Therefore, a **cylindrical support** (**stent**) may be inserted to keep the artery open. In case, the blockage is substantial, a **coronary bypass surgery** may be performed.

Another approach is the dissolution of the thrombus by intravenously injecting an agent that produces plasmin from plasminogen. Among these, **streptokinase**, a *Streptococcus* enzyme that converts plasminogen to plasmin, may be injected. Another substance, **tissue plasminogen activator** (**TPA**) may also be injected to dissolve the thrombus.

17.12.3. Arteriosclerosis :

It is a disease where arteries get hardened due to deposition of calcium salts in their wall Calcium salts precipitates with cholesterol forming plaques There plaues make the walls of the arteries hard. Healthy arteries are flexible, strong and elastic. In some cases, the hardened wall may crack making the internal wall rough. This may lead to formation of thrombosis. Arteriosclerosis is an age related disease and may lead to increase in systolic blood pressure. Smoking and obesity are two major factors which may lead to arterioscloresis.

DIFFERENCES BETWEEN TWO WORDS IN PAIRS OF WORDS

Open Circulatory System

1. The blood flows through large open spaces and channels among the tissues, called **lacunae** and **sinuses**.
2. Tissues are in direct contact with the blood.
3. Blood flow is very slow.
4. Exchange of respiratory gases and nutrients occur directly between the blood and the tissues.
5. The blood flow can not be regulated.
   [*e.g.*; Arthropods (crustaceans and insects)]

Closed Circulatory System

1. The blood flows through a closed space, constituted by the heart and walled blood vessels.
2. The blood does not come in direct contact with the tissues.
3. Blood flow is rapid.
4. Respiratory gases and nutrients diffuse through the capillary walls into the tissue fluid, from where they pass on to the tissues.
5. The blood flow is regulated
   (*e.g.*; Annelids; molluscs; echinoderms; and all chordates)

Single Circulation

1. The blood circulates once through the heart *i.e.*, there is a single circuit of circulation.
2. The heart contains **venous blood** only at any pint of time.
3. The heart is two chambered with an atrium and a ventricle.
   (*e.g.*; Cyclostomes and fishes)

Double Circulation

1. The blood circulates twice through the heart *i.e.*, there are two circuits of circulation namely pulmonary and systemic.
2. The heart contains both **venous** and **arterial blood**.
3. The heart is 3-4 chambered with two auricles and a single ventricle or two atria and two ventricles.
   (*e.g.*; All tetrapods)

Blood

1. Blood is a body fluid that circulates in closed blood vessels.
2. It is red in colour due to the presence of an iron containing respiratory pigment, haemoglobin in erythrocytes.
3. All three types of corpuscles, namely erythrocytes (RBC); leucocytes (WBC); and thrombocytes (platelets) are present.
4. The digestion end products, such as monosaccharides and aminoacids are absorbed into the blood.

Lymph

1. Lymph is a tissue fluid that enters into lymphatic vessels and is returned into the blood vascular system through the venous blood.
2. It is colourless due to the absence of erythrocytes (RBC) and hence haemoglobin.
3. Only lymphocytes are present.
4. The digestion end products of lipids, such as fatty acids are absorbed into the lymph.

Plasma	Serum
1. Plasma is the fluid part of the blood, which contains all kinds of organic and inorganic solutes in dissolved state.	1. It is a clear fluid part of the blood that oozes out from an wound following the clot formation.
2. It contains the fibrinogen (the coagulation protein) in a soluble state.	2. It does not contain fibrinogen i.e. the soluble fibrinogen has precipitated out as fibrin mesh following a clot formation.

Erythrocytes (RBCs)	Leucocytes (WBCs)
1. Red in colour due to the presence of iron-containing haemoglobin.	1. Colourless due to the absence of haemoglobin.
2. Most numerous in the blood i.e. 4.5 – 5.5 millions / mm^3 of blood.	2. Least numerous in the blood i.e. 8, 000 – 12, 000 / mm^3 of blood.
3. Anucleate disc-like cells.	3. Nucleated cells.
4. Can't infilter through capillary walls.	4. Can infilter through the capillary walls by **diapedesis**.
5. Confined to blood vessels.	5. Present in the blood as well as the tissue fluid.
6. Carry oxygen from the lungs to the tissues.	6. Evoke an immune response and thus defends the body from external aggression.

Artery	Vein
1. Has a relatively thicker wall and a smaller lumen.	1. Has a relatively thinner wall and a larger lumen.
2. The wall is made up of three layers: outer **tunica adventitia** or **externa**; **middle tunica media**; and **inner tunica intima**.	2. The wall is made up of three layers: outer **tunica adventitia** or **externa**; **tunica media**; and **tunica intima**.
3. Tunica media (smooth muscle layer) is thicker.	3. Tunica media is thinner.
4. Transport blood away from the heart to the lungs and tissues.	4. Transport blood to the heart from the lungs and tissues.
5. Valves are absent.	5. Valves are present periodically.
6. Blood pressure is higher.	6. Blood pressure is lower.
7. Generally lie deep-seated in the body	7. Generally superficially seated.

Neurogenic Heart	Myogenic Heart
1. The heart beat is initiated by a **nerve ganglion**, situated near the heart.	1. The heart beat is initiated by a patch of modified cardiac muscle fibers, constituting a **pacemaker**.
2. The impulse of contraction originates from the nerve ganglion.	2. The impulse of contraction originates from the pacemaker and is transmitted to different parts in a rhythmic manner.
3. The heart normally stops beating after removal from the body.	3. The heart continues to beat for a variable time period following its removal from the body, subject to the condition that it is perfused with normal salaine solution.

Sino-Atria (SA) Node	Atrio-Ventricular (AV) Node
1. The SA node is situated in the wall of the right atrium between the openings of superior and inferior venacavae.	1. The AV node is situated in the wall of the right atrium at the base of the inter-atrial septum.
2. It initiates the heart beat by generating an action potential, which spreads to the entire atrial wall.	2. It is stimulated by the SA node and transmits the waves of excitation to the bundle of His.
3. It generates impulses at the rate of 75 times per min.	3. It generates impulses at the rate of 60 times per min.
4. It is known as the **pace maker**.	4. It is known as the **pace setter**.

Blood Group 'O' (Universal donor)	Blood Group 'AB' (Universal recipient)
1. A person with O blood group can donate blood to person of any blood group.	1. A person with AB blood group can receive blood from a person with any blood group.
2. The serum contains both **anti A** and **anti B antibodies** or **agglutinins**.	2. Serum does not contain anti A and anti B antibodies or agglutinins.
3. The erythrocyte membranes do not contain A or B anitigens or agglutinogens.	3. The erythrocyte membranes contain both A and B antigens or agglutinogens

SAMPLE QUESTIONS

GROUP - A
(Objective-type Questions)

1. Choose the correct answer:

(i) Double circulation is exhibited by:
(a) Rohu (c) Scoliodon
(b) Cockroach (d) Frog

(ii) Which of the following is not a granulocyte:
(a) Neutrophil (c) Eosinophil
(b) Monocyte (d) Basophil

(iii) Serum does not contain:
(a) Fibrin (c) Globulin
(b) Albumin (d) Bilirubin

(iv) Drumstick, representing sex chromatin is present in:
(a) Eosinophil (c) Lymphocyte
(b) Neutrophil (d) Monocyte

(v) Adult haemoglobin (HbA) contains:
(a) Gamma globin chains (c) Epsilon globin chains
(b) Beta globin chains (d) Zeta globin chains

(vi) An amino acid substitution in the beta globin chain causes:
(a) Haemolytic anemia (c) Microcytic anemia
(b) Pernicious anemia (d) Sickle cell anemia

(vii) The presence of a large number of immature leucocytes in the circulation is indicative of :
(a) Leucocytosis (c) Leucopenia
(b) Leukemia (d) Leucomorphosis

(viii) Find the incorrect pair:
(a) Neutrophil – Phagocyte (c) Lymphocyte – Immunoglobulin
(b) Eosinophil – Histamine (d) Monocyte – Macrophage

(ix) Open circulation is exhibited by:
(a) Annelids (c) Arthropods
(b) Vertebrates (d) Protochordates

(x) Myogenic heart is present in:
(a) Annelids (c) Molluscs
(b) Arthropods (d) Vertebrates

(xi) An instrument that measures the blood pressure is known as:
(a) Haemometer (c) Sphygnomanometer
(b) Haemocytometer (d) Haemoglobinometer

(xii) Pacemaker is synonymous with:
(a) SA Node (c) AV Node
(b) Bundle of His (d) Purkinje fibers

(xiii) Find out the correct route of blood circulation:
(a) Venacavae ⟶ Left atrium ⟶ Left ventricle ⟶ Pumonary artery ⟶ Lung ⟶ Pumonary vein ⟶ Right atrium ⟶ Right ventricle ⟶ Aorta
(b) Venacavae ⟶ Right atrium ⟶ Right ventricle ⟶ Pumonary artery ⟶ Lung ⟶ Pumonary vein ⟶ Left atrium ⟶ Left ventricle ⟶ Aorta
(c) Venacavae ⟶ Left atrium ⟶ Left ventricle ⟶ Pumonary vein ⟶ Lung ⟶ Pumonary artery ⟶ Right atrium ⟶ Right ventricle ⟶ Aorta
(d) Venacavae ⟶ Left atrium ⟶ Right ventricle ⟶ Pumonary artery ⟶ Lung ⟶ Pumonary vein ⟶ Left atrium ⟶ Right ventricle ⟶ Aorta

(xiv) Find the incorrect match:
(a) Blood group A – Antigen A on red cell and anti-B antibody in the serum
(b) Blood group B – Antigen B on red cell and anti-A antibody in the serum
(c) Blood group AB – Antigen B on red cell and anti-A antibody in the serum
(d) Blood group O – No antigen A or B on the red cell and both anti-A and anti-B in the serum

(xv) The fourth heart sound is produced by:
(a) Closure of the aortic and pulmonary valves
(b) Closure of the bicuspid and tricuspid valves
(c) Vibration in the ventricular wall during systole
(d) Rapid ventricular filling

(xvi) Which of the following is not a part of the intrinsic blood coagulation pathway:
(a) Tissue thromboplastin (c) Fibrinogen
(b) Prothrombin (d) Ca^{2+}

(xvii) Thalasemia is characterized by:
(a) Globin chains are abnormal in haemoglobin
(b) The structure of heme is altered in haemoglobin
(c) Decreased synthesis of normal globin chains in haemoglobin
(d) Complete absence of globin chains in haemoglobin

(xviii) Complete (third degree) heart block is due to:
- (a) Ventricular fibrillation
- (b) The conduct from the atria to the ventricles is completely interrupted
- (c) The conduct from the atria to the ventricles is partially blocked or slowed
- (d) One branch of the bundle of His is inhibited

2. Answer the following in one word :

(i) The blood-filled space and the blood in cockroach.

(ii) The number of pulsatile chambers in the heart of cockroach.

(iii) The heart of cyclostomes and fishes through which deoxygenated blood always circulates.

(iv) The percentage of erythrocytes in the total volume of human blood.

(v) Swelling and disintegration of erythrocytes in a hypotonic solution.

(vi) Shrinking of erythrocytes in a hypertonic solution.

(vii) Iron is transported in conjugation with a protein carrier in the blood.

(viii) Higher number of erythrocytes than normal in the blood.

(ix) Abnormally lower haemoglobin percentage in the blood.

(x) Lack of ankyrin in the cytoskeleton of erythrocytes causes a hereditary disorder.

(xi) An amino acid substitution in the β-globin chain of the haemoglobin causes a hereditary disorder.

(xii) Expression of abnormal polypeptides in the haemoglobin by mutant genes gives rise to a pathological condition.

(xiii) Decreased synthesis of normal α- and β-globin chains gives rise to a pathological condition.

(xiv) Trans membrane migration of leucocytes into the tissues from the blood vessels.

(xv) The site of maturation of lymphocytes into B-lymphocytes takes place in an organ of bird.

(xvi) An enzyme from the damaged tissue that activates prothrombin into thrombin.

(xvii) An abnormally higher number of thrombocytes in the blood.

(xviii) An abnormally lower number of thrombocytes in the blood.

(xix) The process of formation of erythrocytes in the bone marrow.

(xx) The cytokine, thrombopoietin stimulates a large multinucleate cell to form a large number of platelets

(xxi) The inter-atrial connection in the embryonic heart of human.

(xxii) The footprint of embryonic inter-atrial connection in the inter-atrial septum of the adult.

(xxiii) A vascular connection between the pulmonary trunk and the aorta in the embryonic heart of human.

(xxiv) The outer squamous epithelium layer of the heart.

(xxv) The innermost squamous epithelium layer of the heart.

(xxvi) The tendinous threads attaching the atrio-ventricular valves with the papillary muscles.

(xxvii) The blood pressure is measured by an instrument.

(xxviii) The sound detected by the stethoscope in measuring the blood pressure.

(xxix) A protein that activates inactive plasminogen into active plasmin.

(xxx) The clinical condition, in which the conceived Rh^+ fetus by the Rh^- mother dies.

(xxxi) The trade name of the anti-Rh antibody preparation injected into the Rh^- mother.

(xxxii) The hardening and constriction of large and medium sized arteries due to the deposition of metabolic byproducts on the endothelium.

(xxxiii) The constriction of the lumen of large and medium sized arteries due to deposition of lipids or their derivatives on the endothelium.

(xxxiv) The unbearable pain in the heart due to formation of an excess of lactate in the cardiac muscle due to prolonged ischemia (lack of oxygen).

(xxxv) An irreversible injury followed by death to the myocardial cells due to prolonged ischemia.

(xxxvi) The drug that prevents atherosclerosis by inhibiting an enzyme in the cholesterol biosynthetic pathway in the liver.

(xxxvii) The radiograph that detects blockages in the coronary artery.

(xxxviii) The technique of clearing the blockages in the coronary artery.

(xxxix) A cylindrical support attached to the artery to prevent its narrowing down subsequently.

(xl) Abnormal patterns of electrical conduction in the heart causes abnormal beating.

(xli) A cardiac rate slower than 60 beats/min.

(xlii) A cardiac rate faster than 100 beats/min.

(xliii) The coordinate contraction of myocardial cells at a rate of 200-300/min.

(xliv) The contraction of different groups of myocardial cells at different times.

(xlv) Ventricular fibrillation leads to complete cessation of blood supply to the brain and hence it's functioning.

3. Fill in the blanks with appropriate words:

(i) Blood circulation in human was discovered by _____.

(ii) There are 13 pulsatile chambers in the heart of cockroach. Each chamber opens by apertures, known as _____.

(iii) Two perforated diaphragms divide the haemocoel of cockroach into three sinuses, namely, _____, _____ and _____.

(iv) _____ muscles, attached to the dorsal diaphragm regulate the contraction and relaxation of the heart in cockroach.

(v) In double circulation, there are two circuits. One is pulmonary and the other is _____.

(vi) The average longevity of human erythrocytes is _____ days.

(vii) Human erythrocytes, often, pile up on their lateral sides forming a _____.

(viii) The respiratory pigment in human blood is known as _____.

(ix) Haemoglobin is a conjugate protein consisting of a protein part, _____, conjugated to a non-protein part, _____.

(x) In fetal haemoglobin (HbF), the beta-globin chains are substituted by _____ globin chains.

(xi) Deficiency of Vitamin B_{12} causes _____ anemia.

(xii) Small size of erythrocytes and hence reduced haemoglobin content causes _____ anemia.

(xiii) Excessive destruction of erythrocytes causes _____ anemia.

(xiv) Four oxygen molecules bind to a molecule of haemoglobin one after another forming oxyhaemoglobin. This type of binding is known as cooperative or _____ binding.

(xv) Erythropoiesis is stimulated by a hormone called _____, which is secreted by _____.

(xvi) Increase in the number of leucocytes above normal is known as _____.

(xvii) Decrease in the number of leucocytes below normal is known as _____.

(xviii) Neutrophils turn into _____ at the site of microbial infection.

(xix) Infection by helminth larvae causes a proliferation of a class of leucocytes, called _____.

(xx) _____ and mast cells release _____ at the site of infection, which causes inflammation.

(xxi) _____ infilter through the wall of the blood vessels into the tissues and turn into macrophages.

(xxii) The heart is surrounded by a double-walled membrane, known as _____.

(xxiii) External furrows, marking the internal divisions of the heart are known as _____.

(xxiv) The wall of the heart consists of three layers, such as epicardium, myocardium and _____.

(xxv) The venacavae open into _____ of the heart.

(xxvi) Semilunar valves guard the openings of _____ and _____ trunks.

(xxvii) Hemolysis of red cells results in the formation of ruptured plasma membranes, known as _____.

(xxviii) Crenation results in the formation of shrunken erythrocytes, called _____.

(xxix) The left atrio-ventricular aperture is guarded by a _____ or _____ valve.

(xxx) Muscular bundles, projecting into the cavities of the ventricles constitute _____.

(xxxi) The heart itself is supplied by _____ arteries.

(xxxii) Persons with _____ are treated with digitalis.

(xxxiii) Numerical expression of normal blood pressure of human is _____.

(xxxiv) _____ discovered the ABO blood grouping system.

(xxxv) The AB blood group was discovered by _____ and _____.

(xxxvi) The Rh blood grouping was discovered by _____.

(xxxvii) Persons with _____ blood group are known as universal donors.

(xxxviii) Persons with _____ blood group are known as universal recipients.

(xxxix) The process of forming a clot in the wall of a damaged blood vessel and preventing blood loss is known as _____.

(xl) The endothelial cells secrete _____ and _____, which act as vasodilators and inhibit platelet aggregation.

(xli) The intrinsic pathway of blood clotting is initiated by the exposure of the plasma to negatively charged _____ at the site of blood vessel damage.

(xlii) Extrinsic pathway of blood coagulation is initiated by the release of a tissue enzyme, _____ at the site of tissue damage.

(xliii) The enzyme _____ lyses fibrin mesh.

(xliv) Streptokinase, a bacterial enzyme activates _____ into _____.

(xlv) Heparin, an anticoagulant activates _____.

(xlvi) Haemophilia A, an X-linked recessive disorder, is caused due to the deficiency of a sub-unit of the blood coagulation factor _____. The deficiency in another sub-unit of the same factor causes _____ disease.

(xlvii) Deficiency in the blood coagulation factor IX causes the disease _____.

(xlviii) Defective low density lipoprotein (LDL) receptors on the hepatocyte surface cause an inherited disease, known as _____.

4. Match the words in the Group A with those of Group B to form meaningful pairs of words.

	Group A		Group B
1.	1. Venacavae and coronary sinus	(a)	Left atrio-ventricular aperture
	2. Aortic trunk	(b)	Right atrium
	3. Pulmonary veins	(c)	Left ventricle
	4. Pulmonary trunk	(d)	Right atrio-ventricular aperture
	5. Tricuspid valve	(e)	Right ventricle
	6. Bicuspid (Mitral) valve	(f)	Left atrium
2.	1. End diastolic volume	(a)	The vol. of blood that remains in the ventricles following ventricular systole
	2. Isovolumetric contraction	(b)	The vol. of blood ejected following ventricular systole.
	3. Stroke volume	(c)	The ventricles relax as closed cavities.
	4. End systolic volume	(d)	The ventricles contract as closed cavities.
	5. Isovolumetric relaxation	(e)	The vol. of blood in the ventricles at the end of ventricular diastole.
3.	1. Baroreceptor reflex	(a)	Excretion of more water and sodium
	2. Antidiuretic hormone	(b)	Atrial wall
	3. Atrial stretch reflex	(c)	Regulates blood pressure by vasoconstriction.
	4. Aldosterone	(d)	Aortic arch and carotid sinus
	5. Renin-Angiotensin	(e)	Reabsorption of salt and water by the kidneys
	6. Atrial Natriuretic Peptide	(f)	Reabsorption of water by the kidneys.

GROUP - B
(Short Answer-type Questions)

1. Answer the following in one or a few sentences:

(i) Explain about the transport function of blood.

(ii) What is open circulation? Give an example.

(iii) Why is the heart of cyclostomes and fishes called venous heart ?

(iv) What is systemic circulation ?

(v) What is hematocrit ?

(vi) Why is the colour of the plasma straw yellow ?
(vii) What is a rouleauax? Where it is found ?
(viii) What do you mean by haemolysis ?
(ix) What is an echinocyte ?
(x) What is haemoglobin A ?
(xi) What is fetal haemoglobin ?
(xii) Explain about allosteric binding of oxygen to haemoglobin.
(xiii) What is sickle cell anemia ? How does it differ from haemolytic anemia ?
(xiv) Explain about leucopenia.
(xv) What is thalasemia ?
(xvi) What is diapedesis ?
(xvii) A basophil is functionally related to an areolar connective tissue cell. Name the cell and explain the function.
(xviii) Ennumerate the types of granulocytes and their individual functions.
(xix) Mention the two major functions of lymphocytes.
(xx) What is hematopoiesis? Where does it occur ?
(xxi) Ennumerate why the human heart is myogenic.
(xxii) What is fossa ovalis ?
(xxiii) Why are attrio-ventricular valves called cuspid valves ?
(xiv) What do you mean by action potential ?
(xv) For a moment (0.4 sec), the entire heart is in diastole-explain.
(xvi) What do lubb and dupp signify ?
(xvii) The standard notation of blood pressure (120 / 80 mm Hg) refer to systolic and diastolic pressures of the systemic circulation-Explain.
(xviii) How do antidiuretic hormone (ADH) regulate blood pressure ?
(xix) What is aldosterone ? How it is related to the maintenance of blood pressure ?
(xxx) What is ECG ?
(xxxi) What happens if there is a mismatched blood transfusion ?
(xxxii) What is hemolytic disease of the newborn ?
(xxxiii) What is platelet plug ?
(xxxiv) What is platelet release reaction ?
(xxxv) What is the function of streptokinase ?
(xxxvi) What is EDTA? How does it help in blood preservation ?
(xxxvii) How does heparin act as an anticoagulant ?
(xxxviii) What is arteriosclerosis ?
(xxxix) What is the role of cholesterol in producing atherosclerosis ?

(xl) What is angioplasty ?
(xli) How does tPA help in dissolving a thrombus ?
(xlii) What is bradycardia ?
(xliii) What is lymph? How does it circulate ?

2 Write brief notes on the following :

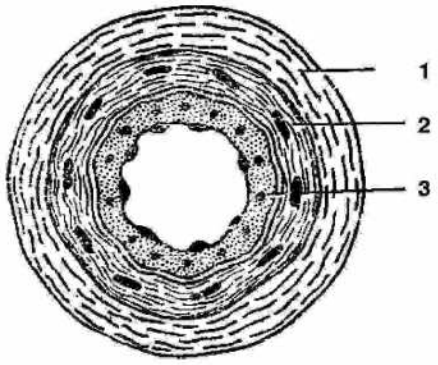
(a) Functions of blood
(b) Agranulocytes
(c) Double circulation
(d) Haemoglobin
(e) Erythrocyte
(f) Anemia
(g) Thalasemia
(h) Erythropoiesis
(i) Bone marrow transplantation
(j) Neurogenic heart
(k) Pacemaker
(l) Artificial pacemaker
(m) Heart sounds
(n) Cardiac output
(o) Electrocardiogram
(p) Agglutination reaction
(q) Anticoagulants
(r) Hemophilia
(s) Hypertension
(t) Ischemic heart disease
(u) Atherosclerosis
(v) Congestive heart failure
(w) Lymphatic system
(x) Myocardial infarction
(y) Blood coagulation
(z) ABO blood groups

3. Differentiate between two words in the following pairs :

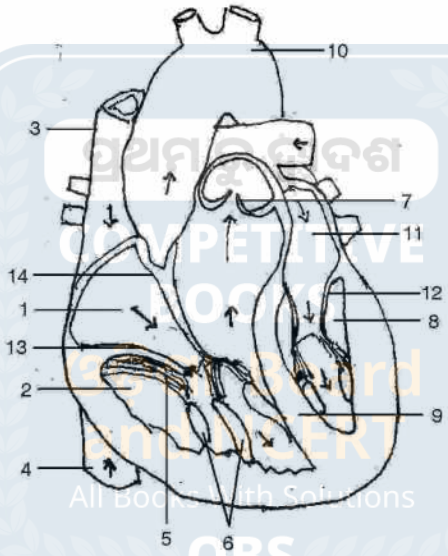
(i) Plasma and Serum
(ii) Blood and Lymph
(iii) Open circulation and Closed circulation
(iv) Single circulation and Double circulation
(v) Haemolysis and Crenation
(vi) Adult haemoglobin and Fetal haemoglobin
(vii) Granulocytes and Agranulocytes
(viii) Sickle cell anemia and Haemolytic anemia
(ix) Pulmonary circulation and Systemic circulation
(x) Bicuspid and Tricuspid valves
(xi) Systole and Diastole
(xii) SA node and AV node
(xiii) Universal donor and Universal recipient
(xiv) Hemophilia A and Hemophilia B
(xv) Haemoglobinopathy and Thalasemia
(xvi) Arteriosclerosis and Atherosclerosis
(xvi) Flutter and Fibrillation

4. Label different parts as numbered in the following figures :

(i)



(ii)



GROUP - C

(Long Answer-type Questions)

1. Describe the constitution and functions of human blood.
2. Describe the structure of human heart and discuss about the mechanism of circulation.
3. Give an account of the conducting tissue of the human heart and describe about the origin and conduction of heart beat.
4. Define cardiac cycle. Describe the events in the cardiac cycle and its regulation.
5. Draw a neat labeled diagram of the longitudinal (vertical) section of human heart (Description not required).

   Draw neat labeled diagrams of the transverse sections of a vein and an artery (Description not required).

❑ ❑ ❑

EXCRETORY PRODUCTS AND THEIR ELIMINATION

CHAPTER 18

Excretion is the process by which waste products of metaboilism are removed from the body. A number of wastes and injurious substances are formed during metabolism. These include carbon dioxide, excess of water and salts, a number of nitrogenous waste products such as ammonia, urea and uric acid and bile pigment, the removal of which is essential for the normal functioning of the organs and organ systems. Excretion also helps in osmo-regulation which is the maintenance of constancy, in particular of sodium chloride that helps in the distribution of body water and its retention and regulation. It also helps to maintain the acid base balance of the body.

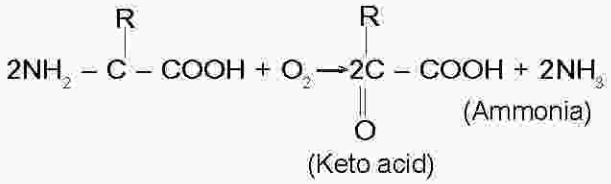
All those organs in which the excretory products are processed, prior to their elimination from the body, are involved in excretion and therefore can be called excretory organs. These include the skin, lungs, liver, alimentary canal and the kidneys. Skin by forming sweat serves to eliminate water, urea and salts that are actively secreted from the capillaries in the blood vessels of the skin, from which the water also evaporates. This helps to loose heat from the body and regulates body temperature. Lungs help to eliminate carbon dioxide that is transported by the blood from the tissues in exchange with Oxygen of the alveoli. Liver forms urea and uric acid from the ammonia by urea and uric acid synthesis and eliminates them from the body by fittering in the kidneys. Liver also forms bile and eliminates through it the bile pigments that originate from the breakdorm of old erythrocytes in the spleen. Alimentary canal eliminates undigested matter in the food and the bile pigments of the bile formed in the liver. Of all these organs, the kidneys are the most important which have been developed by vertebrates especially for the elimination of nitrogenous waste products from the body, which are highly toxic.

18.1. TYPES OF NITROGENOUS EXCRETORY PRODUCT :

Nitrogenous waste products are formed from the breakdown of proteins, nucleic acids and excess aminoacids. The primary product of this breakdown is ammonia. It is produced by deamination of amino acids, a process by which the amino group of the amino acid is removed. Ammonia may be excreted as such, as immediately as possible, or is converted into less toxic urea or the highly insoluble uric acid and then excreted. The exact nature of the nitrogenous excretory product depends on the availability of water in the habitat in which the animal lives, and the extent to which it can control water loss.

18.1.1. Ammonotelism :

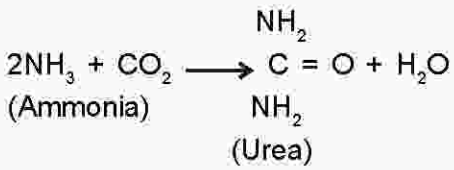
The main source of ammonia in the body tissues is the deamination of excess amino acids. Excess amino acids are not stored to any great extent in the body and are therefore catabolised. Excess amino acids are degraded to their keto acid and ammonia by oxidative deamination. Keto groups are used in catabolism for production of ATP and ammonia excreted out.



Since ammonia is highly toxic, it is removed in the form of dilute solution or simply diffuses out from the body directly. This process of removal of nitrogenous waste material in the form of ammonia from the body is called **ammonotelism** and the animals are called **ammonotelic animals**. Since the process requires large volume of water for removal of ammonia in the form of dilute solution, it is found in aquatic animals like **Protozoa, Sponges, Coelenterates, Prawn, Molluscs, Tadpole of frog, Bony fish, Tailed amphibians** and **Crocodile** etc.

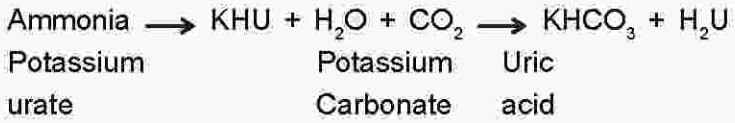
18.1.2. Ureotelism :

In certain animals, ammonia is converted to urea by combining with CO_2 in the liver by a cyclic process called **Ornithine cycle**. Urea is less toxic for the body and is removed in the form of solution. Since urea is less toxic for the body, it can be stored in the body for longer period without any adverse impact. The process by which animals produce urea is called **ureotelism** and the animals are called **ureotelic animals**. Examples - **Mammals, Adult frog** and **Toads, Earthworm when present on land & Cartilaginous fish** etc.



18.1.3. Uricotelism :

In some animals ammonia is converted to uric acid for removal. Uric acid is least toxic and requires very little water for removal as it is insoluble in water.



The process by which animals produce uric acid as waste material is called **Uricotelism** and the animals are called **Uricotelic animals**. It is found in terrestrial animals in which conservation of body water in essential for survival.

Example - **Insects, Snakes, Lizards & Birds** etc.

Human beings excret small quantity of uric acid which is produced from the break down of nucleic acid.

Table - 18.1

Relationship between habitats and excretory products of animals.

Animal	Excretory product	Habitat
Protozoa	Ammonia	Aquatic
Terrestrial insect	Uric acid	Terrestrial
Freshwater bony fish	Ammonia	Aquatic
Marine bony fish	Urea, TMA	Aquatic
Birds	Uric acid	Terrestrial

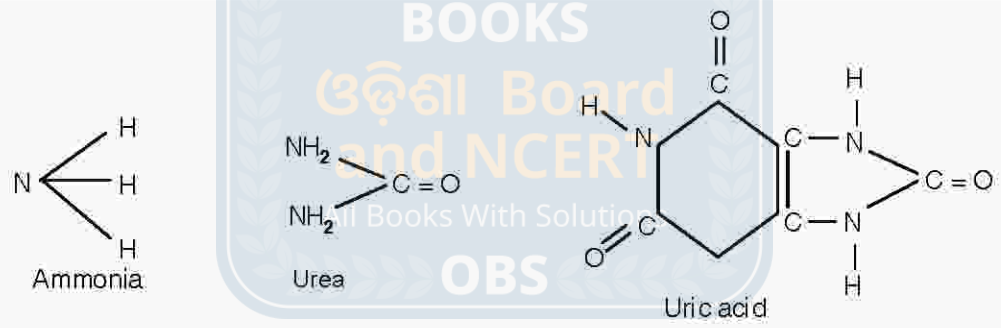


Fig. 18.1 : Molecular structure of the three main nitrogenous excretory products

18.1.4. Other nitrogenous wastes :

(i) Amino acids : Certain molluscs and echinodems excrete aminoacid as the end products of protein digestion and are called **aminotelic animals**, ex- Unio, Limnea, Asterias, and Pentaceros.

(ii) Tri-methyl amine oxide (TMAO) : In marine teleost fish, certain molluscs and crustaceans, the nitrogenous waste is TMAO which is formed from ammonia. The product is soluble in water and less toxic than urea. TMAO is utilised in the body along with urea to maintain osmotic equilibrium with sea water which contains a high concentration of salts and tends to dehydrate the body. It is the excretory product in Octopus, Squid, Copepods, Crabs and Barnacle.

(iii) Guanine : Spiders excrete ammonia in the form of guanine. It is insoluble in water like uric acid.

(iv) Allantoin : Certain organic bases like purine and pyrimidine are excreted in mammals in the form of allantoin.

(v) Creatine, creatinine, - Hippuric acid and Ornithuric acid - are other nitrogenous wastes excreted in animals.

18.2. EXCRETORY SYSTEM IN HUMAN (Fig. 18.2) :

In human beings and other terreestrial vertebrates a number of organs in the body function as excretory organs. Of all these, **kidneys** function as the major excretory and osmo-regulatory organ. Human kidneys are **metanephric** which have the ability to produce urine that is almost five times more connentrated than that of the blood plasma.

A number of metabolic wastes are eliminated by the kidneys from the human body. These include **urea** from **proteins, uric acid from nucleic acids, creatinine** from **muscle,** the end products of haemoglobin breakdown which give urine much of its colour, excess of water, salts and acids and foreign chemicals.

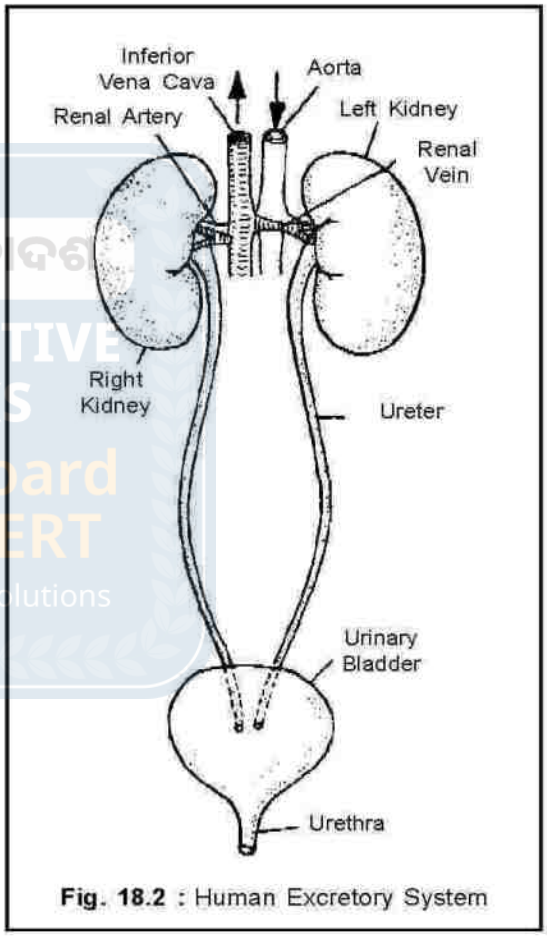


Fig. 18.2 : Human Excretory System

Functions of the kidneys.

1. Regulation of water and inorganic ion balance
2. Removal of metabolic wastes from the body and their excretion in the urine.
3. Acid - base balance of the body and thereby the regulation of the hydrogen ions of body fluids.
4. As a major homeostatic organ, regulation of the chemical composition of the body fluids by the removal of substances which are in excess of immediate requirements including foreign chemicals.
5. Secretion of hormones like erythropoietin which controls erythrocyte production in the body, renin which controls formation of angiotensin that influences blood pressure and sodium balance.

18.2.1. Organs of excretion :

It consists of the following parts :

1. Pair of **Kidneys**
2. Pair of **Ureters**
3. **Urinary bladder**
4. **Urethra**

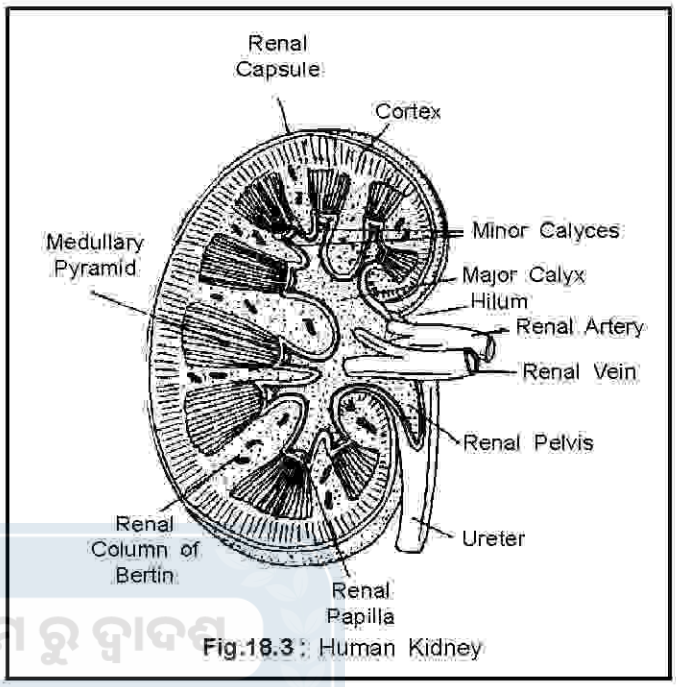


Fig.18.3 : Human Kidney

18.2.1.1. Kidney : A pair of kidneys are located in the anterior part of abdominal cavity, one on each side of the vertebral column. Each kidney is bean shaped of about 10 cm long, 5 cm wide and 2.5 cm thick. They are dark red in colour and each weigh about 150 gms. There is a concavity on the innerside of the kidney called **hilum** or **hilus**. Blood vessles and ureters are attached to kidneys through the hilus. Each kidney receives blood through a single **renal artery** and the filtered blood leaves the kidney through **renal vein**. The kidneys are **retroperitoneal** in position. Left kidney is located slightly higher in position and near to midline than the right kidney. The floating ribs that is, 11th and 12th pairs provide protection to the kidneys Human kidneys are **metanephric** in nature.

18.2.1.2. Ureters : From each kidney comes out a narrow whitish tube through the hilus called **ureter**. It is about 25-30 cm long. Both the ureters run downwards and open to **urinary bladder**. Ureters carry urine from kidneys to urinary bladder. Urine passes through ureters due to peristaltic movements in it.

18.2.1.3. Urinary bladder : It is located in the pelvic cavity and stores the urine. It is muscular and extensible in nature. Internally it is lined by **transitional epithelium** and covered by smooth muscles called **detrusor muscles**. Internally the urinary bladder has a triangular area called **trigone**. It prevents back flow of urine from bladder to ureters.

18.2.1.4. Urethra : It is a tube which removes the urine from the bladder to exterior. The connection between bladder & urethra is guarded by a pair of sphincters. In the males, urethra is a long tube and opens to outside at the tip of the male genital organ, **Penis**. In the females, it is relatively storter in length. Urethra in males carries both urine and semen but in females it carries only urine.

18.3. STRUCTURE OF KIDNEY :

Kidney is covered by a **renal capsule** consisting of fibrous connective tissue. Renal capsule provides protection. Inner to the capsule is a dark region called **cortex**. Below the cortex is present a lighter region called **medulla**.Medulla is divided into 101-5 conical areas called **medullary pyramids** or **renal pyramids** having their broad bases towards the cortex and their narrow tips towards the interior. The distal convoluted tubules of a number of adjacent rephrons open into a common collecting tubule. These tubules traverse through the medulla in the pyramids and opens to **Duct of Bellini.** Ducts of Bellini open to minor calyces which finally open to pelvis.

The functional units of kidney are **nephrons** or **uriniferous tubules.** There are about 10-13 lakhs of nephrons in each kidney. Length of a nephron varies from 45-65 mm.

18.3.1. Structure of a nephron :

Each nephron is a coiled tubule with following regions:-

18.3.1.1. Bowman's capsule : Each rephron begins with a Bowman's capsule which is a double walled sac like structure. Its outer wall consists of flatlened squamous cells and the inner wall consists of **podocytes**. These cells bear distinct finger like processes which entwine around capillaries of glomerulus.

18.3.1.2. Glomerulus : The cavity of Bownman's capsule contains a mass of blood capillaries called **glomerulus**. Blood enters into glomerulus from **afferent arteriole** and comes out through **efferent arteriole.** Glomerulus is the place where the blood is filtered. Bowman's capsule plus glomerulus is called **Malpighian body** and is located in the cortex of the kidney.

18.3.1.3. Neck : Bowman's capsule is followed by neck which has ciliated epithelium.

18.3.1.4. Proximal convoluted tubule (PCT) : It is present behind the neck and is convoluted and forms few coils. It is present in the cortex. The wall of proximal convoluted tubule consists of a single columnar epithelium with **brush border** of **microvilli.**

18.3.1.5. Loop of Henle : It is a narrow U-shaped tubule having a **discending limb** which extends into medulla and an ascending limb which extends back from medulla into cortex.

18.3.1.6. Distal convoluted tubule (DCT) : It is the most distal part of nephron and situated in the cortex. It is also convoluted and forms few coils. The narrow terminal part of each pyramid is known as **renal papilla.** Between the pyramids, the cortex extends into the medulla as **renal columns of Bertini**. The renal pyramids open to 10-15 small tubes called minor calyces (singlular-minor calyx). Minor calyces join to form 2-3 major calyces. The major calyces join to form a large funnel shaped structure called **renal pelvis,** which in turn leaves the kidney through **hilus** and forms the **ureter.**

Malpighian body, proximal and **distal convoluted tubules** of nephrons constitute the **renal cortex**, whereas **loop of Henle, collecting tubules** & **Ducts of Bellini** constitute **renal medulla**.

18.3.2. Types of nephron :

There are two types of nephrons : **Cortical nephrons** and **juxtamedullary nephrons**, which differ in their position and size. **Cortical nephrons** are small sized, found mostly in the cortex, with short loops of Henle, which just extend into the medulla. **Juxtamedullary nephrons** are large sized with long loops of Henle extending deep into the medulla. Such large sized nephrons are specialised for water reabsorption. Under normal conditions of water availability the cortical rephrons deal with the control of blood volume, whereas, when water is in short supply increased water retention occurs through the juxtamedullary nephrons.

18.3.3. Blood supply to the nephron :

Blood to each kidney is supplied by a **renal artery** and is drained by the **renal vein**. Both the blood vessels and the ureter pass through a concavity of the kidney, on the ventral side, called the hilus. Upon entering into the kidney, the renal artery divides into several inter lobular arteries, which finally divide into many **afferent arterioles**.

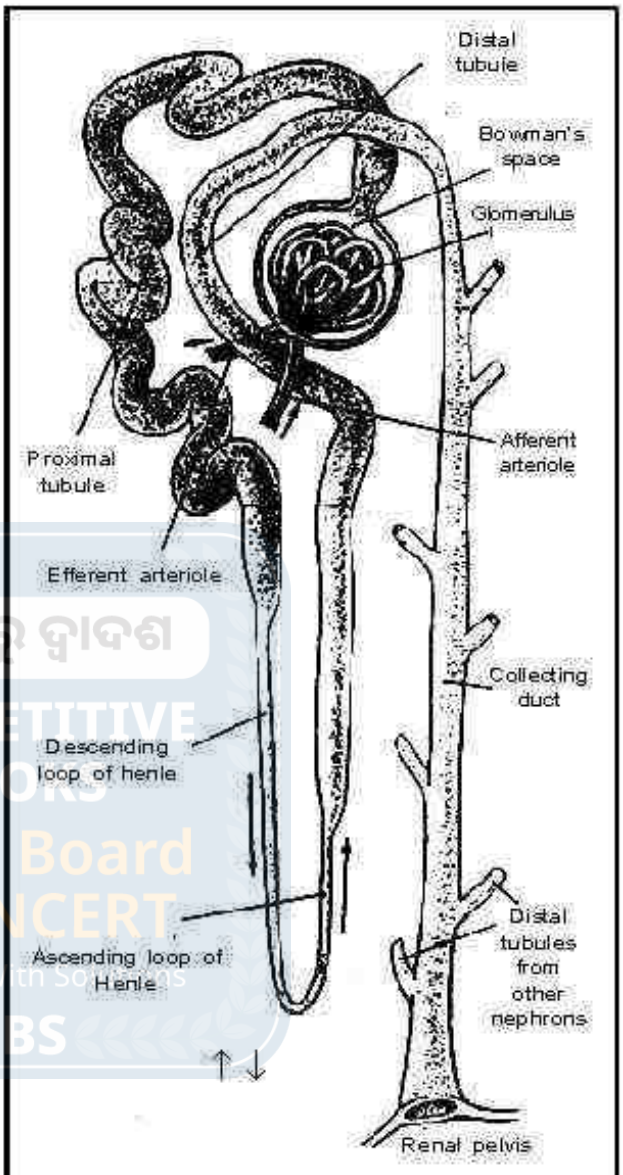


Fig.18.4 : Basic structure of a nephron. The glomerulus consists of the glomerular capillaries and Bowman's capsule. Between the ascending loop of Henle and the distal tubule is a very short tubular segment, called the macula densa.

Each afferent arteriole enters into a glomerulus, and forms a tuft of capillaries. The capillaries reunite to form the **efferent arteriole** which drains the glomerular network. While the blood passes through the glomerular capillaries from the afferent to the efferent the blood is filtered (Afferent means to and efferent means from)

The efferent arteriole again forms a network of peritubular capillaries around the proximal convoluted tubule and the distal convoluted tubule. Long hairpin like loops of blood

vessels are given off from these capillary networks parallel to the 'Henle's loops. These are called **vasa recta**.

18.3.4. Juxtaglomerular apparatus and the secretion of angiotensin :

The ascending limb of Henle's loop passes in between the afferent and efferent arterioles. This short segment of the Henle's loop is known as the macula densa. The macula densa together with granular cells present in the wall of the afferent arteriole form the juxtaglomerular apparatus which is the source of the hormone renin. Renin converts Angiotensinogen to Angiotensin I which is changed to Angiotensin II by an enzyme from the liver. Angiotensin II is a strong stimulator of aldosterone secretion. Aldosterone is the corticosteroid hormone from the adrenal cortex which controls water and Na^+ loss from the body in the urine.

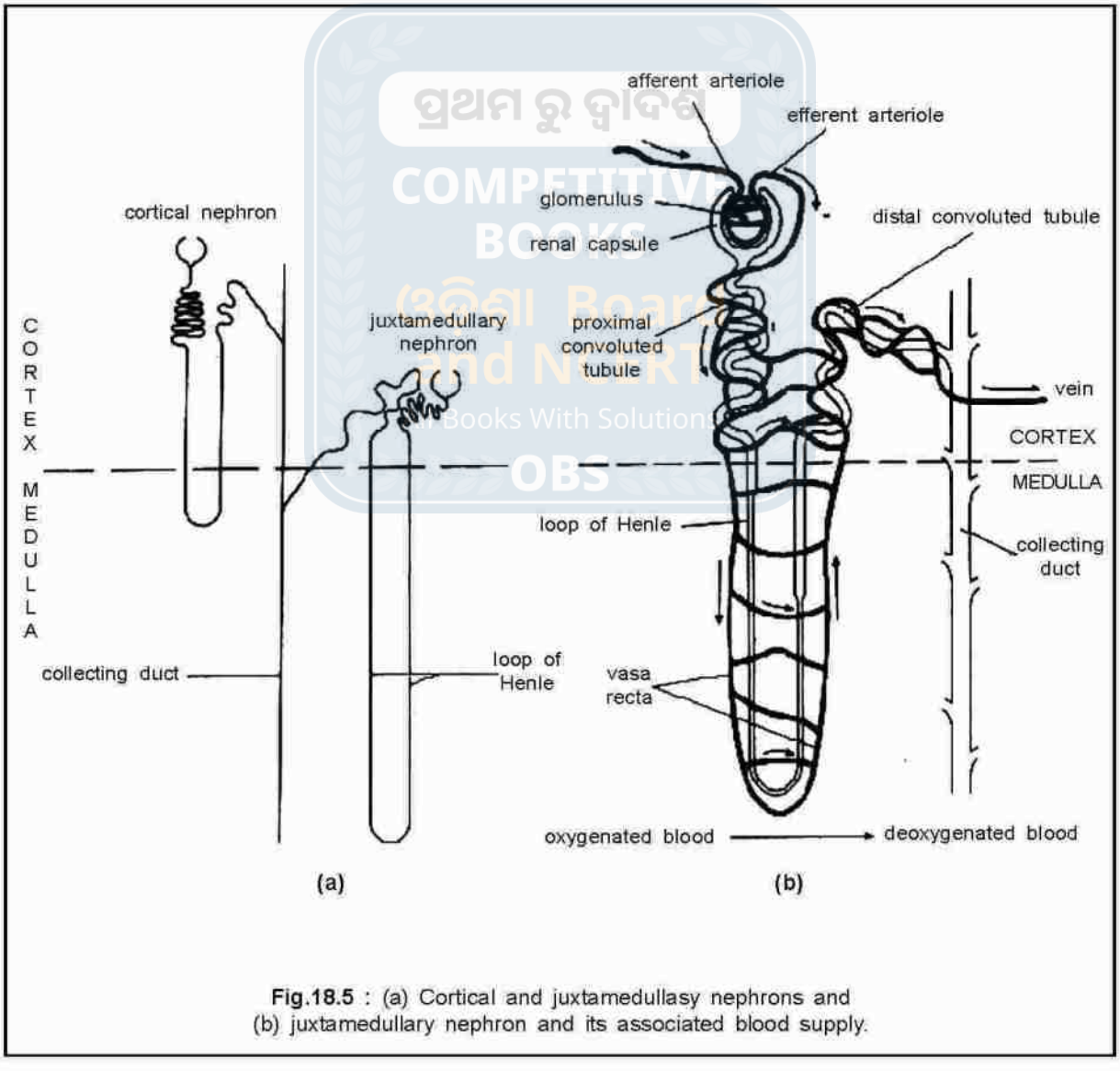


Fig.18.5 : (a) Cortical and juxtamedullasy nephrons and (b) juxtamedullary nephron and its associated blood supply.

18.4. FORMATION OF URINE :

Formation of urine is a complex process consisting of following steps :

(a) Synthesis of urea

(b) Ultrafiltration

(c) Selective reobsorption

(d) Tubular secretion

Of these four steps, the first step has been described below under **ornithine cycle**.

18.4.1. Ultra-filtration :

Ultra-filtration is filtration under pressure which occurs in the glomerulus. This pressure comes from the blood presssure and is called the Net filtration pressure (NFP). Net filtration pressure is the blood pressure (mean systollic pressure inthe glomeruli) minus the osmotic pressure of the blood and the Bowman's capsular pressure.

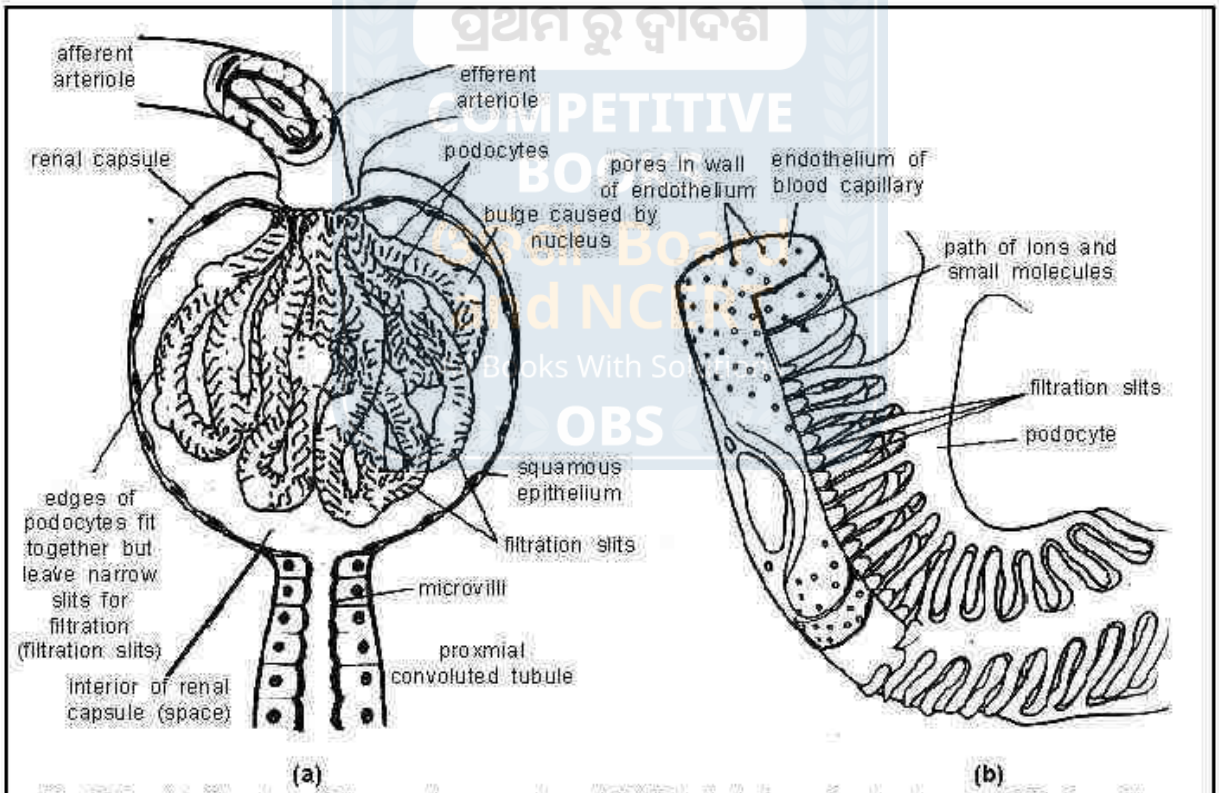


Fig.18.6 : (a) Structure of the renal corpuscle and (b) Detailed view of podocytes and TS of capillary.

(The upper part shows afferent and efferent arterioles. Special epithelial cells called podocytes cover theoutside surfaces of the capillaries of the glomerulus. The capillaries themselves are therefore hidden, although their outline is revealed. (Rather like a glove concealing fingers while revealing their shape. The glove is equivalent to the podocytes and the fingers are equivalent to the capillaries.) The lower part of the diagram shows the start of the proximal convoluted tubule, which has cuboidal epithelial cells with microvilli (a brush border). Note how the podcytes fit together like loosely interlocking fingers, leaving slits through which glomerular filtrate can pass on its way into the renal capsule.)

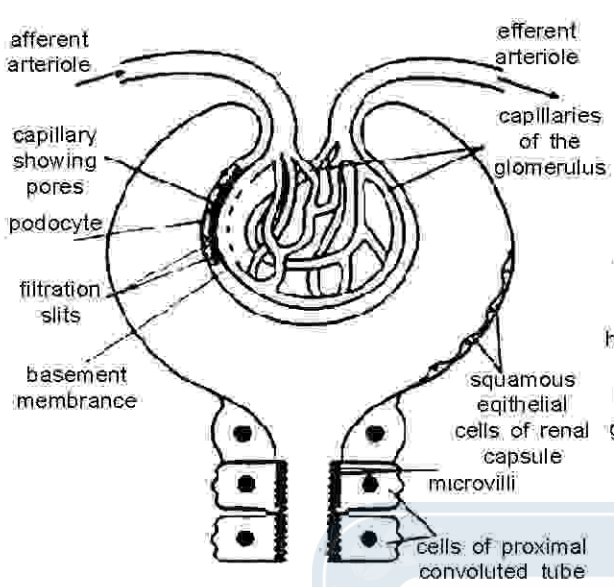


Fig.18.7 : Diagram of a renal corpuscle showing typical cells of the renal capsule.

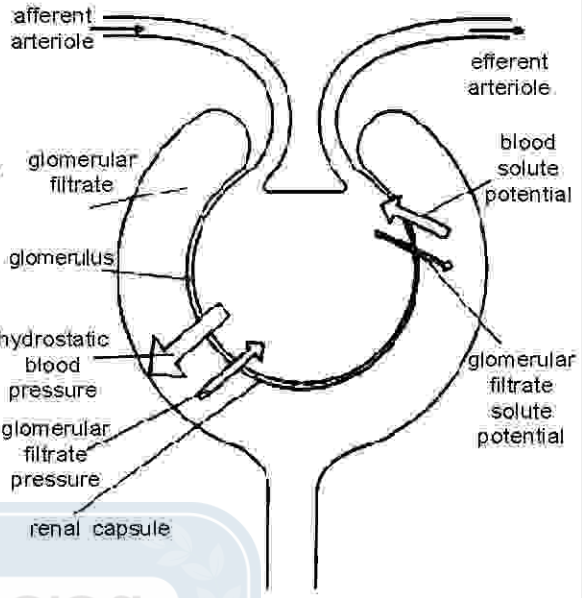


Fig.18.8 : The direction and magnitude of pressures influencing the filtration pressure in the glomerulus.

By the time the blood reaches the glomeruli the mean systollic pressure decreases to its 70 % in the arm i.e. 75 mm Hg opposed by the osmotic pressure of the blood i.e. 30 mm Hg plus the Bowman's capsular pressure i.e. 20 mm Hg.

Net Filtration pressure = Mean systollic pressure in the glomeruli – (Osmotic pressure of the blood + Bowman's capsular pressure)

= 75 mm Hg – (30 mm Hg + 20 mm Hg)

= 75 mm Hg – 50 mm Hg Net filtration pressure = 25 mm Hg The NFP of 25 mm Hg causes filtration in the glomeruli.

Glomerular filtration rate

The quantity of glomerular filtrate formed each minute by both the kidneys is called **glomeralar filtration rate.** It is about 125 ml. So about 180 litres of filtrate is formed per day. But in a normal adult about 1.5 litres of urine is excreted per day. So the rest fltrate is reabserbed in the tubules. GFR is about 1/5th of renal plasma flow.

Nature of the glomeular capillares and filtration :

The glomerulus is a knot of capillaries, the diameter of the capillaries is much less than that of the afferent arteriole that carries blood into it, so that when the blood enters the narrow capillaries, pressure rises. Water and small solute molecules are squeezed out of the capillaries through the simple squamous epithelium of the Bowman's capsule into its interior. Long molecules like the protein as well as the RBC and platelets are left behind in the blood. The structure of the glomerulus and the Bowman's capule is specially adapted for filtration. Filtration takes place through three layers.

1. Endothelium of the glomerular capillaries

2. Basement membrane of the capillaries.

3. Epithelium of the Bowman's capsule : This layer is made up of cells which are highly specialised / modified for filtration; called **podocytes.** (podos meaning foot). Each cell has many foot like extensions which project from its surface. with a diameter of 25 mm. The filtrate can pass through these proes into the cavity of the Bowman's capsule.

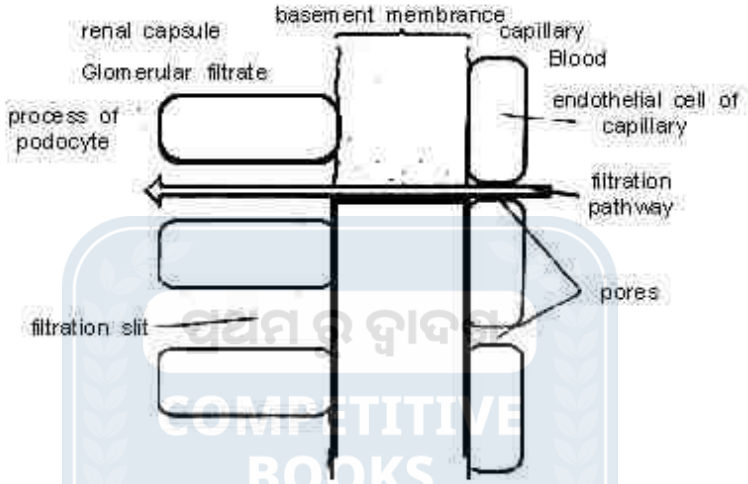


Fig. 18.9 : Diagram showing the path taken by fluid (glomerular filtrate) as it passes from the plasma in a glomerular capillary to the lumen of a renal capsule.

Forces	**mm Hg**
Favouring filtration	
Glomerular capillary blood pressure	75.0
Opposing filtration	
Fluid pressure inBowman's capsule	20.0
Osmotic force (due to proteins) in plasma	30.0
Net filtration pressure	25.0

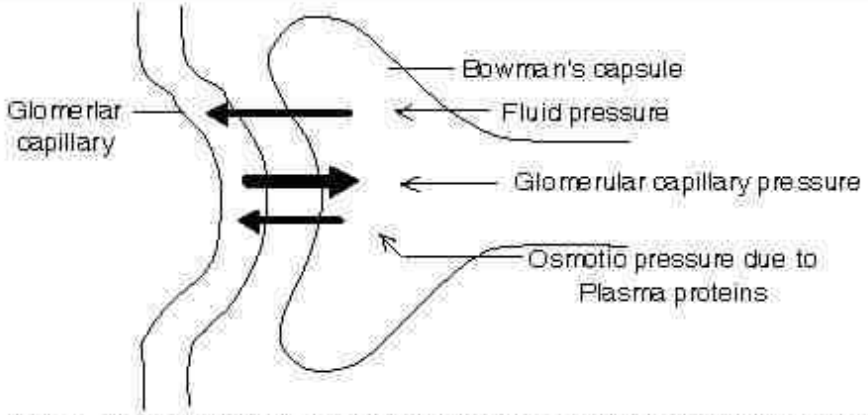


Fig. 18.10 : Pressures operating between glomerular capillary and Bowman's capsule

18.4.2. Selective reabsorption :

Ultrafiltration produces above 125 ml of filtrate per minute, equivalent to 180 liters per day. Since only 1.8 liters of urine is produced each day, about 99% of it is reabsorbed. During ultrafiltration many substances which are useful and vital like sodium, water, glucose, amino acid are reabsorbed while substances like urea, foreign chemicals are not reabsorbed to any great extent. The function of the tubule is to selectively reabsorb substances that are useful and to add certain substances by active secretion to the urine. Formation of urine therefore involves three key processes namely **ultra-filtration, selective reabsorption** and **secretion**. Secretion of Hydrogen ions in exchange with bicarbonate ions or through buffers helps to maintain acid-base balance. The filtrate in the Bowman's capsule is isotonic to blood plasma.

Table - 18.2

Average values for several components that undergo filtration and reabsorption.

Substance	Amount filtered per day/filtering load	Amount excreted per day	Percent reabsorbed
Water L.	180	1.8	99
Sodium g.	630	3.2	99.5
Glucose g.	180	0	100
Urea g.	54	30	44

(a) Proximal convoluted tubule : About 80% of the filtrate is reabsorbed in this region. The brush border of the cells of proximal convoluted tubule helps in the process of reabsorption. This is the place of maximum reabsorption of water and is called obligatory reabsorption. Solutes like glucose, amino acids, vitamins and different salts like chlorides & phosphates of sodium & potassium are reabsorbed by diffusion & active transport. As both water & solutes are reabsorbed, the filtrate remains isolonic to plasma.

(b) The Loop of Henle : The function of the loop of Henle is to conserve water. The longer the loop of Henle, the more concentrated the urine that can be produced. This is a useful adaptation to life on land. Birds and mammals are the only vertebrates which can produce a urine which is more concentrated than the blood and they are the only vertebrates with loops of Henle. The drier the natural habitat of an animal, the longer is its loop of Henle. For example, the beaver, a semi-aquatic mammal, has a short loop of Henle and produces a large volume of dilute urine, whereas, the desert-dwelling kangaroo rat and the jerboa (hopping mouse) have long loops of Henle and produce small volumes of highly concentrated urine. Their urine is 6 to 7 times more concentrated than the human urine and they do not need to drink water. They get enough metabolic water produced during respiration.

The loop of Henle has three distinct regions each with its function-

(i) **Descending limb,** which has thin wall

(ii) **Thin ascending limb,** which is the lower half of the ascending limb and has thin wall like the descending limb

(iii) **Thick ascending limb** -this is the upper half of the ascending limb and has thick wall.

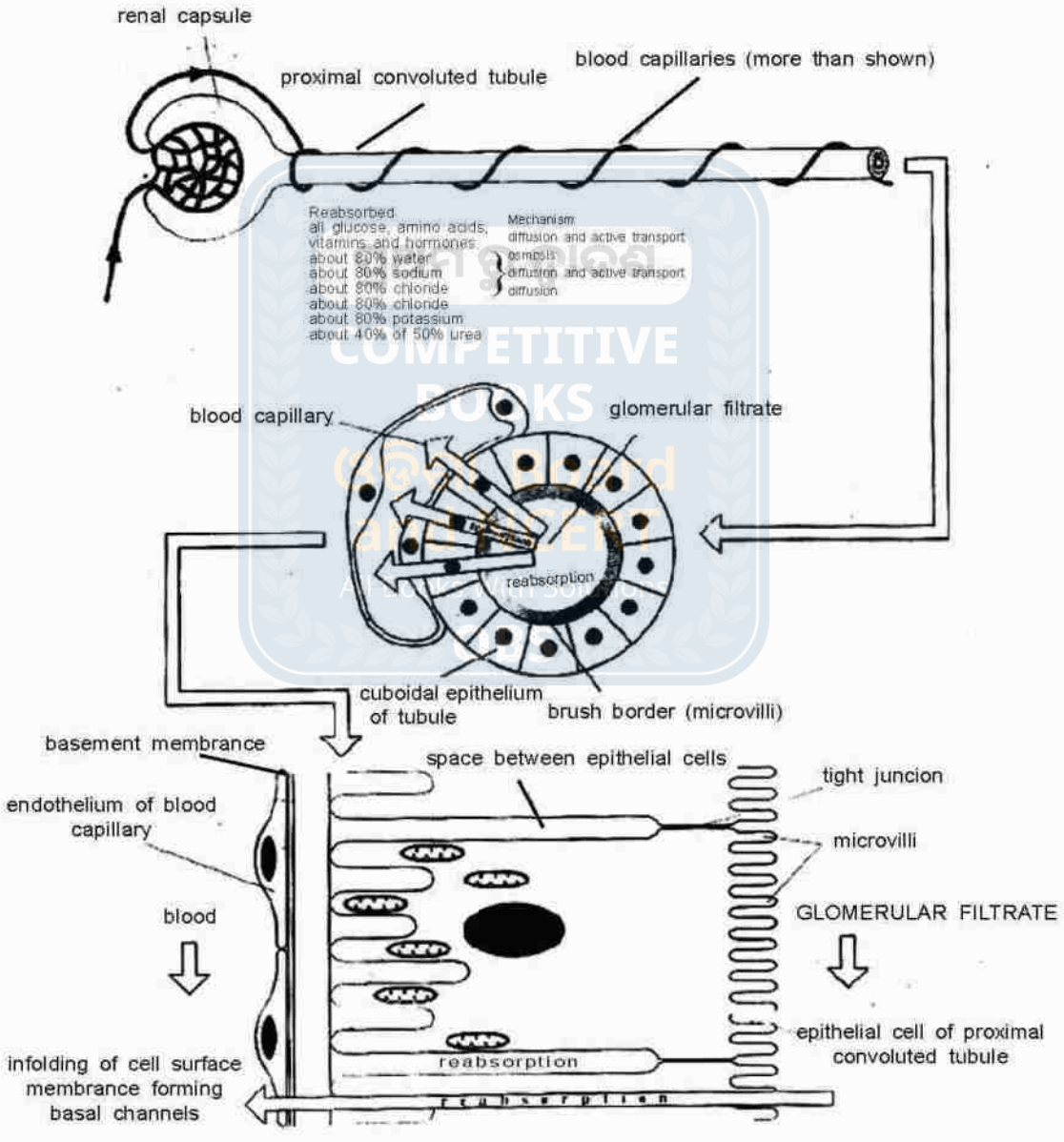


Fig.18.11 : Structure and function of the proximal convoluted tubule

The **descending limb** is permeable to water but not to solutes. As a result the filtrate becomes more concentrated as it moves down along the descending limb of Henle (DLH). So the filtrate becomes **hyperosmotic** to blood plasma. For this reason, **DLH** is called **concentrating segment**.

The ascending loop of Henle (ALH) is permeable to minerals like sodium & potassium salts but impermeable to water. As a result the filtrate becomes gradually dilute and **iso-osmotic** to plasma. So **ALH** is called the diluting segment.

(c) Distal convoluted tubule and collecting duct : In these last parts of the nephron, depending on the body's need for water, absorption of water takes place under the influence of the anti-diuretic hormone (ADH) of the posterior pituitary.

If the body needs to retain more water, as such a need might arise in case we go without water for a long period, more ADH shall be secreted from the posterior pituitary, under the influence of which these regions shall become permeable to water and allow more water reabsorption to take place. This kind of reabsorption of water under ADH influence is known as **facultative reabsorption** of water. Movement of definite amounts of water by osmosis along the osmotic gradient is important in osmo-regulation.

In the deficiency of ADH, more water cannot be reabsorbed in the distal convolution and leads to production of large volume of dilute urine. Loss of water of this kind is called diuresis. Osmoreceptors located in the hypothalamus sense the blood and send appropriate stimuli to the posterior pituitary to control ADH release.

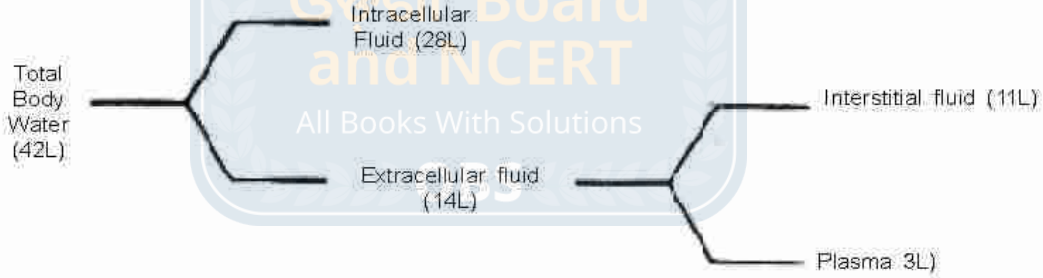


Fig.18.12 : Distribution of body water. The volumes are for a normal 70-kg person. Total body water averages approximately 60 percent of body weight.

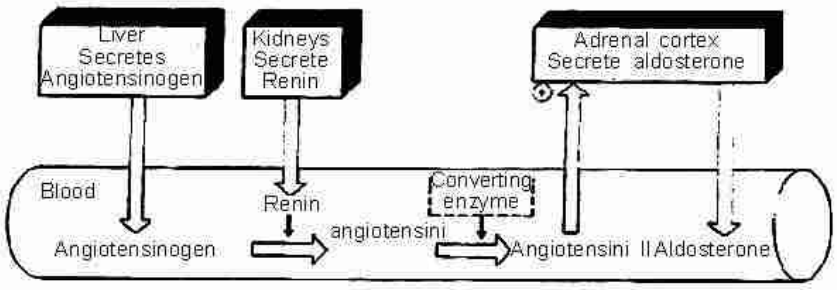


Fig. 18.13 : Summary of the renin-angiotensin-aldosterone system. Converting enzyme islocated on the surface of capillary endothelial cells particularly in the lungs. Renin is the rate-limiting factor in the system.

18.4.3. Tubular secretion :

Cells of uriniferous tubules not only reaborb substances but also remove excretory substances from the blood into the filtrate by tubular secretion. This is a process just opposite to reabsorption. Proximal convoluted tubule secretes uric acid, creatinine, hippuric acid and penicillin drug etc. Hydrogen ions and ammonia are also secreted by the PCT. Urea is secreted by the thin segment of the ascending limb of loop of Henle. The DCT secretes potassium, hydrogen ions, ammonia and HCO^{-3} ions etc. Maximum hydrogen ion secretion occurs in the region of PCT. Secretion of hydrogen ions & ammonia helps to maintain the pH of the blood around 7.3

Table - 18.3

Chemical compositionof Normal urine

Constituent	Daily excretion in grams
water	1200.00
Urea	30.00
Uric acid	0.70
Hippuric acid	0.70
Creatinine	1.20
Oxalic acid	0.02
Allantoin	0.04
Amino acid nitrogen	0.20
Purine bases	0.01
Chloride as NaCl	12.00
Sodium	4.00
Potassium	2.00
Calcium	0.20
Magnesium	0.15
Sulphur, total as S	1.00
Inorg. Sulphates as S	0.80
Neutral Sulphur as S	0.12
Conjugated sulphates as S	0.08
Phosphates as P	1.10
Ammonia	0.70
Sugar	0.00

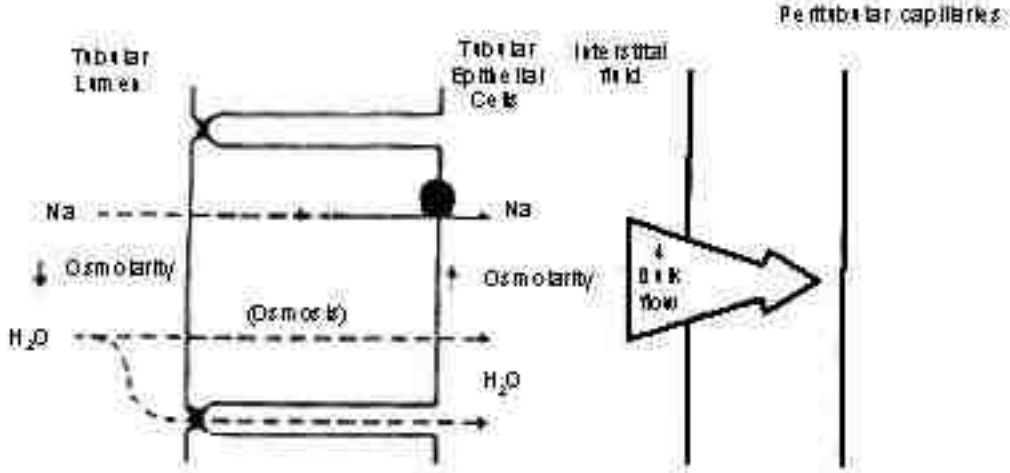


Fig.18.14 : Coupling of water and sodium realsorption. (1) Reabsorption of sodium creates (2) a difference in osmolarity between lumen and interstitial fluid, which causes (3) the osmosis of water in the same direction either through the cell or across the tight junctions. (4) Movement of both solute and water from interstitial fluid into peritubular capillaries occurs by bulk flow.

18.5. ROLE OF KIDNEY IN OSMOREGULATION :

Osmoregulation is the control of water level in the body. When there is excess of water in the body kidney produces large volume of dilute urine and brings the water level to correct position. In the event of deficiency of water, kidney helps to conserve body water by producing small volume of concentrated urine. Kidney produces large quantity dilute urine by reducing tubular reabsorption of water due to absence of ADH.

The ability of the human kidneys to produce a hyperosmotic urine enables the body to survive without water for a long period. The human kidneys can produce a maximal urinary concentration of 1400 m osmol/L., almost five times the osmolarity of the blood plasma; which is 300 m osmol /L. Urea, sulfate, phosphate and other waste products and ions excreted each day amount to approximately 600 m osmol / L. Hence, a minimum volume of water in which the above quantity of solute can be dissolved and excreted in the urine is

$$= \frac{600\,\text{mOsmol/day}}{1400\,\text{mOsmol/L}} = 0.444\ \text{L/day}$$

This volume of urine is known as the 'obligatory water loss'. The loss of this minimal volume of urine contributes to dehydration when a person goes without water for a long period.

Sodium and water usually move together. Whenever, water is lost sodium is lost with it. The major factor determining the rate of tubular reabsorption is **aldosterone.**

The maintenance of the plasma sodium level at a steady state is controlled by the steroid hormone aldosterone from the adrenal cortex which also influences water reabsorption. A decrease in blood sodium leads to a decrease in blood volume because less water enters the blood by osmosis. This in turn reduces blood pressure. The decrease in pressure and volume stimulates a group of secretory cells of the juxtamedullary apparatus situated between the distal convoluted tubule and the afferent arteriole of the glomerulus to secrete a hormone renin. Renin activates a protein angiotensinogen synthesised by liver to angiotensin which is a strong stimulator of aldosterone. Aldosterone is carried by blood to the distal convoluted tubule of the kidney. Here, it stimulates the sodium - potassium pumps in the cells of the tubules resulting in more sodium ions being pumped out of the distal convoluted tubule into the peri-tubula capillaries around it. Potassium moves in the opposite direction.

Aldosterons also stimulates sodium absorption in the gut and decreases loss of sodium in sweat, both these effects tend to raise blood sodium level. This in turn causes more water to enter the blood by osmosis, raising its volume and pressue. This process is called RAAS (Ranin - angiostensin aldosterone system).

Although adlosterone is the most important controller of sodium reabsorption, another peptide hormone known as **atrial natriuretic factor** (ANF) which is synthesised and secreted by cells of cardiac atria. ANF acts on the kidneys to inhibit sodium reabsorption. It also inhibits the secretion of both renin and aldosterone, which results in less sodium reabsorption. Secretion of ANF is increased when there is an excess of sodium in the body; the stimulus being an increase in atrial distension.

18.6. ROLE OF OTHER ORGANS IN EXCRETION :

18.6.1. Role of lungs :

Human lungs eliminate around 18 litres of Co_2 per hour and about 400 ml. of water per day in normal resting condition. Water loss via the lungs is small in hot humid day climate and large in cold dry climates. The rate of ventilation and ventilation pattern (i.e. breathing through mouth or nose) also affect the water loss through the lungs.

18.6.2. Role of skin :

Human skin possesses glands for secreting two fluids on its surface, viz, sweat from sweat glands and sebum from sebaceous glands. Sweat is an agueous fluid (around 99.5% water) containing Nacl, lactic acid, urea, amino acids and glucose. Depending upon activity and temperature, 14 litres sweat per day is formed, whose main function is to cool the body by evaporation. Sebum is a waxy protective secretion to keep the skin oily and this secretion eliminates some lipids, hydrocarbons and fatty acids.

18.6.3. Role of Liver :

Liver is the main site of elimination of cholesterol, bile pigments (bilirubin and biliverdin), inactivated products of steroid hormones, some vitamins and many drugs. Liver secrets these substances in bile, which in turn, carries these materials into the intestine, which are ultimately eliminated with the faeces.

Table - 18.4

Secondary excretory organs and miscellaneous excretory products

Excretory Organs	Procuts eliminated	
	Primary	Secondary
Kidneys	Water, nitrogenous wastes from protein catabolism and inorganic salts	Heat and Carbon dioxide
Lungs	Carbon dioxide	Heat and water
Skin	Carbon dioxide, water, salts and urea	
Alimentary canal	Solid wastes and secretions	Carbon dioxide, water, salts and heat

Abnormal products in the urine :

Glucose - The presence of glucose in the urine is called glycosuria. The most common cause of glycosuria is a high blood sugar level. Kidney tubules fail to reabsorb all this excess quantity of glucose from the glomerular filtrate and some of it is excreted along with urine.

Erythrocytes - The appearance of red blood cells is called haematuria. One cause of haematuria is an acute inflamation of the urinary organs as a result of disease of irritation from kidney stones.

Leucocytes - The presence of leucocytes and other components of pus in the urine, referred to as phyuria indicates infection in the kidney or other urinary organs.

18.7. DISORDERS RELATED TO EXCERTION :

18.7.1. Uremia :

Accumulation of the nitrogenous waste products of metabolism in the blood as a result of the kidneys to excrete them (kidney failure). The effects include nausea, vomiting, oedema, itching, spontaneous bleeding, anaemia, confusion, seizures etc. the uremic syndrome can be defined as the terminal clinical manifestation of kidney failure. It is the signs, symptoms

and results from laboratory tests which result from inadequate excretory regulatory and endocribe function of the kidnesy. Classical signs of uremia are progressive weakness, muscular dystrophy etc.

18.7.2. Renal failure :

Renal failure is a medical condition in which the kidneys fail to adequately filter waste products from the blood. The main forms are acute kidney injury, which is often reversible with adequate treatment and chronic kidney disease, which is often not reversible in both cases, there is usually an underlying cause.

In kidney failure, there may be problems with increased fluid in the body, increased acid levels, raised levels of potassium, decreased level of calcium, increased levels of phosphates, and in later stages in anaemia. Long term kidney problems are associated with increased risk of cardiovascular diseases.

(a) Symptoms :

A High level of urea in the blood, which can result in :

- Vomiting and / or diarrhoea
- Weight loss
- Nocturnal urination
- More frequent urination or in greater amounts than usual
- Blood in the urine
- Pressure or difficulty in urination
- Swelling of the leg, face and hands
- Appetite loss
- Difficulty sleeping

(b) Causes

Acute Kidney injury - It usually occurs when the blood supply to the kidneys is suddenly interrupted or the kidneys become overloaded with toxin. Causes include accidents, injuries or complications from surgery in which kidneys are deprived of normal blood flow for extended periods of time. During overdoses, accidental or from chemical overloads of drugs such as antibiotics or chemotherapy, may also cause the onset of acute kidney injury.

18.7.3. Renal Calculi (Kidney Stone)

A **kidney stone**, also known as renal calculus or rephrolith, is a solid piece of material, which is formed in the kidneys from minerals in urine. If stones grow to sufficient size (usually at least 3 milimeters (0.1 in), they can cause blockage of the ureter. This leads to pain, most commonly begining in the flank or lower back and often radiating to the groin. The associated symptoms are nausea, vomiting, fever, blood in the urine, pus in the urine and painful urination.

Most stones form due to a combination of genetics and environmental factors. The diagnosis is usually based on symptoms, urine testing and medical imaging. High dietary intake of animal protein, sodium, refined sugars, oxalate, grapefruit juice and appljuice may increase the risk of kidney stone formation. The excessive dietary intake of Vitamin-C might increase the risk of calcium oxalate stone formation.

18.7.4. Nephritis :

Nephritis is the inflamation of the kidnesy and may involve the glomeruli, tubules or interstitial tissue surrounding the glomeruli and tubules. It is 2 types

1. Glomerulonephritis is the inflamation of the glomerules
2. Interstitial nephritis is the inflamation of the spaces between renal tubules.

(a) Causes

Nephritis is often caused by infections and toxins, but is most commonly caused by autoimmune disorders that affects the major organs like kidneys.

(b) Mechanism

Nephritis can produce glomerular injury, by disturbing the glomerular structure with inflamatory cell proliferation. As the kidneys inflame, they begin to execrete needed protein form the body into the urine stream. This condition is called proteninuria. Loss of necessary protein due to nephritis can result in several life-threatening symptoms. The most serious complications of nephritis can occur if there is significant loss of the proteins that keep blood from clotting excessively. Loss of these proteins can result in blood clots casing sudden stroke.

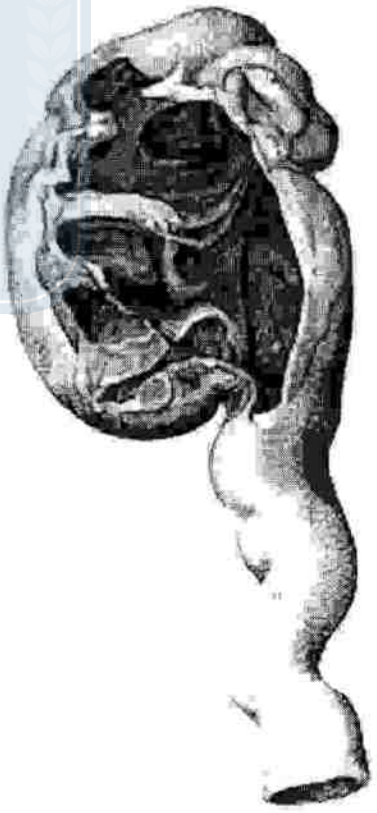


Fig.18.15 : Enlarged Kidney

18.7.5. ADH deficiency and Diabetes insipidus :

It is called antidiuretic hormone or vasopressin. This is secreted by the posterior lobe of pituitary gland. In the presence of ADH the walls of DCT , CT and CD become permeable to water and water is reabsorbed. This causes formation of concentrated urine and conservation of water in the body. More of ADH is secreted during summer season. Reabsorption of water in the presence of ADH is facultative reabsorption. Deficiency of ADH leads to production of large quantity of urine called **Diabetes insipidus.**

Diuretics

Drugs used to increase the volume of urine excreted are known as diuretics. Such agents act by inhibiting the reabsorption of sodium alongwith chloride and / or bicarbonate resulting in increased excretion of these ions. Since water reabsorption is dependent upon sodium reabsorption water reabsorption is also reduced resulting in increased water excretion. Diuretics are used to treat diseases characterised by renal retention of salt and water. Another common use of diuretics is in the treatment of hypertension. The diuretics are classified according to the mechanism by which they inhibit ion reabsorption except for one category of diuretics, the potasium sparing ones, all other diuretics not only increase sodium excretion but also cause increased potassium excretion also, which can be an unwanted side-effect. One category of diuretics blocks the action of aldosterone by competing with its receptors on the tubule cell membrane. There are different categories of diuretics include carbonic anhydrase intibitors, loop diuretics, thiazides, potassium- sparing diuretics that show different mechanisms of action and have different sites of action in the rephron.

18.7.6. Dialysis :

The failing kidneys reach a point when they can no longer excrete water and ions at rates that maintain body balance of these substances nor they can excrete the wastes as fast as they are produced. Dietary changes can minimize these problems but such alternations cannot eliminate these problems. The techniques used to replace the kindney's functions are called dialyses (dialysis sing.) Dialysis means separation of substances using a semi or a selectively permeable membrance.

Dialysis can be of two types, **haemodialysis and peritoneal dialysis**.

(a) Haemodialysis :

This kinds of dialysis involves the use of an artificial membrane in a 'kidney machine'. It functions as an artificial kidney on the same principle as the real kidney. The blood is pumped out of the body, filtered to remove the waste materials, a process called dialysis and then returned. The patient is connected to the machine by inserting a catheter (a hollow tube-like needle) into an artery in the arm or the leg connecting this to a flexible tube leading to the machine and then returning the washed blood into a vein.

The blood is pumped gently out of the artery and returned to the vein. Heparin is added to the blood to prevent clotting. The blood circulates slowly through the dialysis tubing which is an artificial semi-permeable membrane which allows ions, very small molecules and water to diffuse through it. Bloodcells, platelets and protein molecules are too large to escape from the patients blood. The tubing is bathed on the outside by a dialysing solution which has the correct ionic balance, particularly Na^+, K^+, Cl^-,Mg^{++}, Ca^{++} and HCO_3^-; additional nutrients, such as glucose which help to maintain the correct solute potential, the correct pH and buffers maintained at 37^0C. Periodically, the dialysing fluid is removed and replaced by fresh fluid. Unwanted substances are removed, particularly urea and excess sodium and potassium and needed substances are held back. The process is simpler than that of the

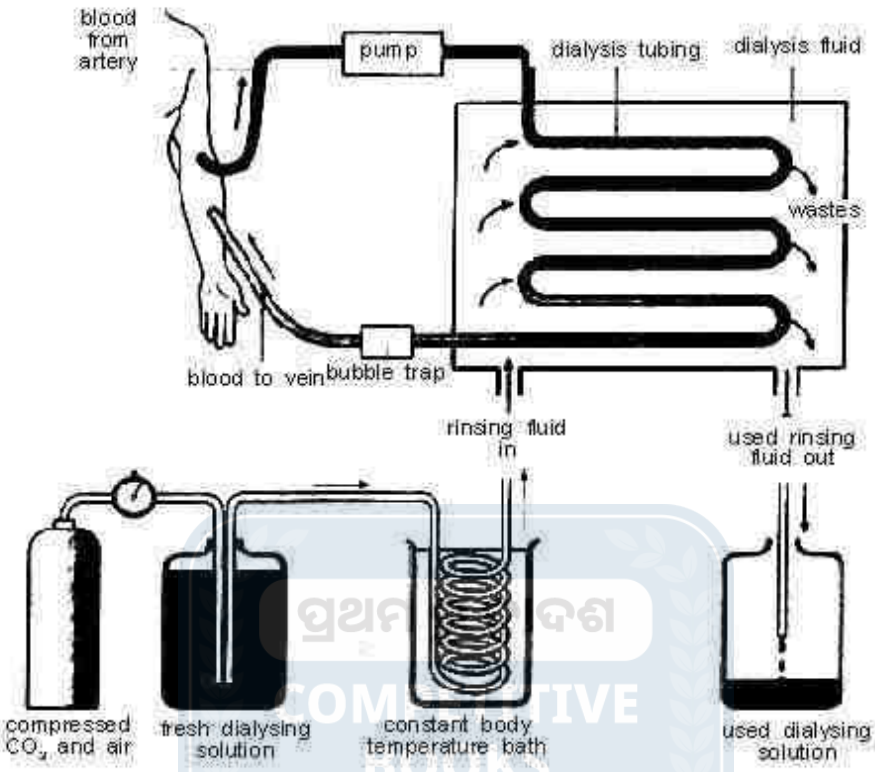


Fig.18.16 : Haemodialysis machine. Blood passes from an artery, through a coiled tube and back into a vein. The tube is a partially permeable membrane and is surrounded by dialysate. Waste products filter out into the dialysate.

real kidney because ultrafiltration does not occur and reabsorption of useful substances is not necessary.

The process takes 6 to 8 hours and is usually done atleast twice a week. Patients with chronic irreversible renal failure require treatment for the rest of their lives or till they receive a kidney transplant. Such patients undergo hemodialysis several times a week, often at home.

(b) Peritoneal Dialysis - use of peritoneum, a natural membrane :

Another way of removing excess substances from the blood is peritoneal dialysis, which uses the lining of the person's own abdominal cavity (peritoneum) as a dialysing membrane. A thin plastic tube is inserted into the abdominal cavity through a small slit in the abdoman wall. The peritoneal membrane which lines the abdominal cavity acts as a dialysing membrane. Dialysing fluid is added to the abdominal cavity through the tube and left for several hours before it is removed. Exchange of material takes place between the tissue fluid in the abdomen and the dialysing fluid. The dialysing fluid is replaced 3 or 4 times a day. In between, the patient can remain mobile and relatively, free to lead a normal life. For this reason, it is described as **continuous ambulatory peritoneal dialysis or CAPD.** Many patients prefer this to haemodialysis in which they have to remain attached to a kidney machine. The method is also cheaper and simpler. The only disadvantage with this method is the risk of infection.

SAMPLE QUESTIONS

GROUP - A

(Objective-type Questions)

1. Choose the correct answer :

(i) The organs of excretion in the cockroach are
(a) Flame cells (b) Green gland
(c) Nephridia (d) Malpighian tubules

(ii) Birds eliminate their nitrogenous wastes in the form of
(a) ammonia (b) urea
(c) uric acid (d) amino acid

(iii) Ornithine cycle occurs in
(a) liver (b) kidney
(c) brain (d) skin

(iv) Ornithine cycles synthesizes
(a) ammonia (b) urea
(c) uric acid (d) Xanthine

(v) What is the main nitrogenous waste product in reptile ?
(a) ammonia (b) urea
(c) uric acid (d) hippuric acid

(vi) Urea is formed from the breakdown of
(a) carbohydrates (b) proteins
(c) fats (d) nucleic acids

(vii) In man, uric acid is formed from the break down of
(a) carbonydrates (b) proteins
(c) fats (d) nucleic acids

(viii) Desert mammals have ——— in their nephrons.
(a) Long loops of Henle (b) long proximal convoluted tubules
(c) long distal convolutions (d) long collecting ducts

(ix) ADH exercises its action on —— part of the rephron.
(a) PCT (b) Henle's loop
(c) DCT (d) glomerulus

(x) Most aquatic animals are
(a) ammonotelic (b) ureotelic
(c) uricotelic (d) aminotelic

(xi) What is diabetes insipidus due to ?
(a) loss of glucose by the urine, (b) deficiency of ADH
(c) deficiency of insulin (d) all of the above

(xii) Which hormone is secreted from juxtaglomerular apparatus of kidney ?
(a) renin (b) angiotensin
(b) adrenalin (d) calcitrol

(xiii) Reabsorption of sodium and chloride occurs in
(a) Ascending limb of Henle'sloop, (b) proximal convoluted tubule
(c) descending limb of Henle's loop (c) Distal convoluted tubule)

(xiv) Human kidney is
(a) pronephric (b) mesonephric,
(c) metanephric (d) opisthonephric

(xv) Longer loop of Henle is meant primarily for increased absorption of
(a) glucose (b) water
(c) potassium (d) aminoacids

GROUP - B
(Short Answer-type Questions)

1. Write briefly on the following (within 50 words each) :

(i) Ammonotelism
(ii) Ureotelism
(iii) Uricotelism
(iv) Role of the Malpighian tubule in the excretion in cockroach.
(v) Structure of the mammalian nephron
(vi) Ultrafiltration
(vii) Selective reabsorption
(viii) Henle's loop
(ix) Counter current mechanism
(x) Kidney as an endocrine organ
(xi) Secretion
(xii) Acid-base balnce
(xiii) Role of liver in excretion
(xiv) Orinithine cycle / Urea cycle
(xv) Dialysis

(xvi) Storage excretion in cockroach

(xvii) Renin - angiotensin system

(xviii) Obligatory water loss

2. Explain the following :

(i) Net filtration pressure

(ii) Glomerular filtration rate

(iii) Obligatory reabsorption of water

(iv) Role of ADH in water reabsorption

(v) Obligatory water loss

(vi) Functions of vasa recta

3. Differnetiate between.

(i) Ammonotelism and Ureotelism

(ii) Ureotelism and Uricotelism

(iii) Cortical nephron and juxamedullary nephron

(iv) Selective reabsorption and secretion

(v) haemodialysis and peritoneal dialysis

(vi) Acute renal failure and chronic renal failure

(vii) Ammonotelism and Aminotelism

(viii) Descending limb of Henle's loop and Ascending limb of Henle's loop

(ix) Obligatory and Facultative rabsorption of water

4. Explain the location of the following :

(i) Renal columns of Bertini

(ii) Duct of Belini

(iii) Macula densa

(iv) Vasa recta

GROUP - C
(Long Answer-type Questions)

1. Give an account of the structure of the human kidney.
2. Give an account of the structure and functions of the human kidney.
3. Give an account of the mechanisms of urine formation.
4. Give an account of the role of the human kidney is osmoregulation.

❑ ❑ ❑

LOCOMOTION AND MOVEMENT

CHAPTER 19

A large number of animals are free moving i.e. they are displaced at will from time to time. **The phenomenon of changing displacement with time is known as locomotion.** The purpose of locomotion is threefold. Firstly, an animal performs locomotion in search of new food source. Secondly, it defends itself from its enemies and inclement weather conditions. It also offends animals of other species and even of its own species to maintain supremacy. Finally, it breeds to give rise to off springs of its own species, which are displaced to another place to avoid overcrowding and shortage of food and shelter. On the contrary, quite a few animals are sedentary i.e. they are attached to a substratum throughout their life. They are not displaced, but exhibit bending and swaying movements only. The disadvantages of becoming sedentary are partly overcome by having free swimming larvae. A larva swims away from its original location, settles down at a new location and undergoes metamorphosis to become sedentary again. A cell, which constitutes the building block of life also exhibits movement. The protoplasm exhibits streaming movement in a defined way. Alternately speaking, where there is life, there is movement. Locomotion is executed by specialized structures. In unicellular organisms, these structures are parts of the same cell i.e. sub-cellular structures and hence, are called **locomotor organelles**. In multicellular animals, these structures are multicellular and therefore, are termed as **locomotor organs**.

19.1. TYPES OF MOVEMENT :

Different types of movements are executed in different animal groups. However, the ones like ciliary, flagellar and muscular are discussed hereunder. Ciliary and flagellar movements are classed under a broader heading, **swimming**. These movements are executed by solitary cells, especially in cilia and flagella bearing protozoa.

19.1.1. Swimming (ciliary and flagellar) Movement :

Protozoa of the classes, Ciliata (e.g. *Paramecium*) and Flagellata (e.g. *Euglena*) execute this of movement. The locomotor organelles are thin and delicate protoplasmic threads, known as cilia and flagella. The microscopic structures of flagellum and cilium are essentially similar except for the size and number. A cilium is shorter and more numerous than a flagellum. The classification of the class, Ciliata is based on the arrangement of cilia. In *Paramecium*, for exmple, cilia are present all over the cell. On the other hand, in *Vorticella*, the cilia are confined the some parts of the cell (Fig. 19.1).

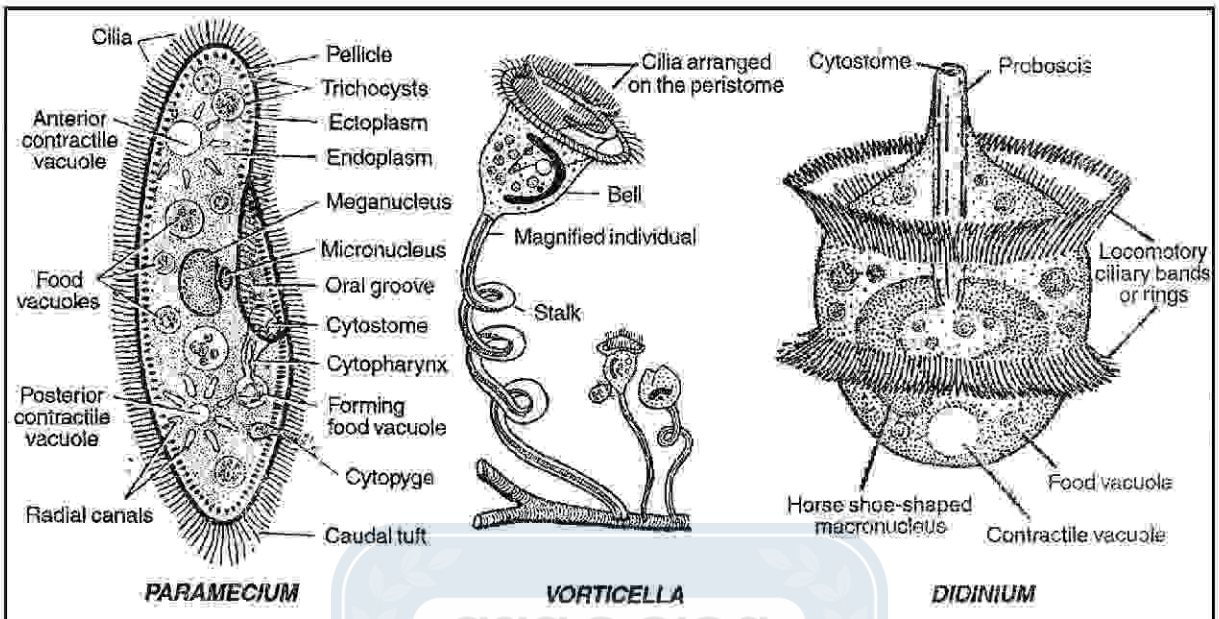


Fig. 19.1 : Three different forms of cilia in the class, Ciliata

Similarly the forms of flagellum are also diverse. There is a single, backwardly directed flagellum in *Euglena*. The number may be two or more, in some reaching a numer of four (e.g.

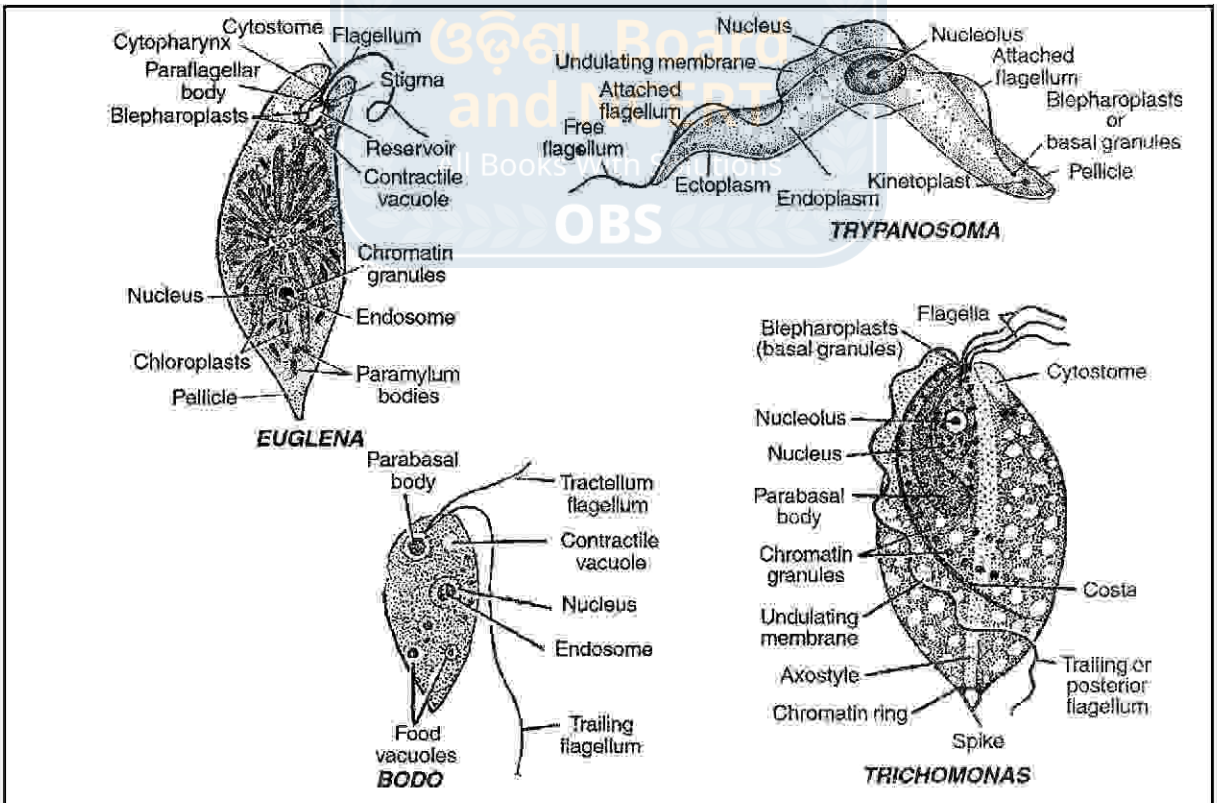


Fig. 19.2 : Different forms of flagella in the class, Flagellata

Trichomonas). In this situation, one flagellum, known as the trailing flagellum is backwardly directed. The rest, known as tactella (singular tactellum) are forwardly directed. In some flagellates (e.g. *Trypanosoma*) the flagellum adhears to the pelliele for most part of its length. When the flagellum undulates, the pellicle is drawn out as an ultra thin membranous structure, known as **undulating membrance** (Fig. 19.2).

19.1.1.1. Structure of flagellum / cilium :

A flagellum or a cilium is a thin and delicate microscopic protoplasmic process protruding from the surface of a cell. In a gross structure, it consists of a fiber-like central axis, called **axoneme**, surrounded by a **protoplasmic sheath**. Electron microscopic structure (Fig.19.3) reveals that the axoneme is made up of a bundle of microtubules in a defined arrangement.

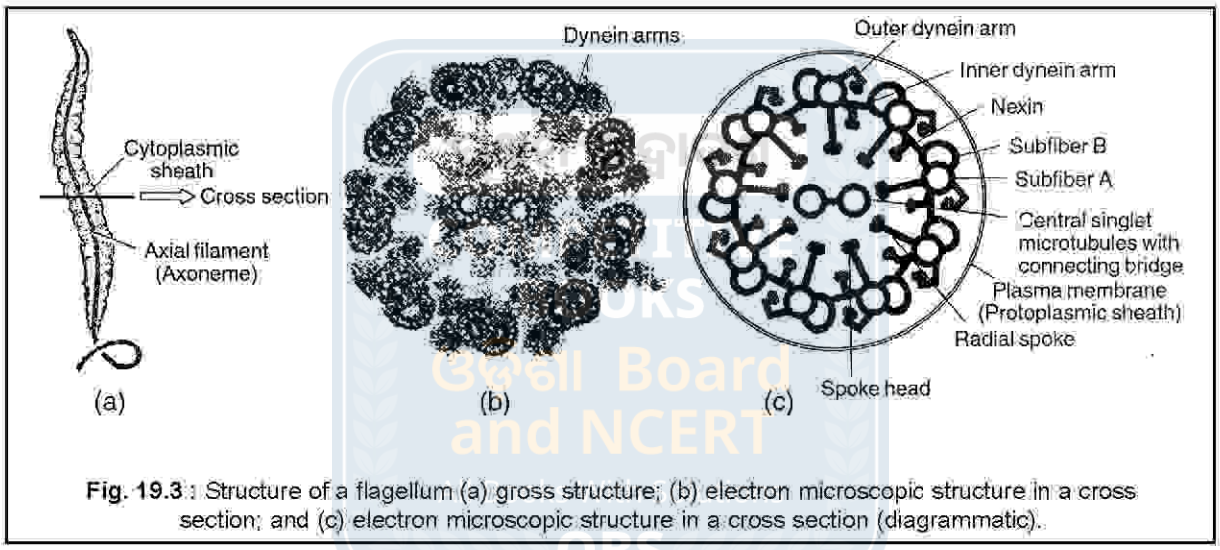


Fig. 19.3 : Structure of a flagellum (a) gross structure; (b) electron microscopic structure in a cross section; and (c) electron microscopic structure in a cross section (diagrammatic).

1. There are two central microtubules surrounded by nine peripheral microtubular bundles. Each peripheral microtubular bundle consists of two closely adhearing microtubules.
2. The central microtubules are known as **singlets**, while the peripheral ones as **doublets**.
3. Each singlet consists of 13 protofilaments.
4. Two singlets are joined by a connecting bridge.
5. Each doublet consists of two closely adhering microtubules, subfiber A and subfiber B. Subfiber A has 13 protofilaments, while subfiber B has 10-11.
6. Subfibers A are joined to the singlets by radial spokes, each terminating in a knob-like spoke head.
7. Doublets are joined by circumferential **nexin protein**. Each subfiber A bears two **dynein protein arms** : an outer and an inner. Each dynein arm ends in a knob-like head.

The dynein arm acts much like the cross bridge of myosin protein filament in a skeletal muscle. It attaches to the subfiber B of the adjacent doublet and slides over it in a similar fashion to that of a sarcomere of the skeletal muscle. Thus, a flagellum / cilium contracts and relaxes alternately and brings about locomotion.

19.1.1.2. Mechanism of flagellar / ciliary locomotion:

The flagella / cilia are contractile protoplasmic threads due to the presence of microtubules. These contract and relax rhythmically in response to external stimuli. This rhythmic beating is known as **undulation.** The flagellum / cilium is held rigidly and bends to one side. Accompanied by bending, undulations pass from the tip to the base. In doing so, it strikes the water like an oar. Mechanical energy is generated, which propels the animalcule a little forward. This stroke is known as **effective stroke** [Figs.19.3 (a) & 19.4 (a)]. Following the completion of the effective stroke, the flagellum / cilium returns back to its normal position in a relaxed manner. This constitutes another stroke, known as **recovery stroke** [Figs.19.3 (b) & 19.4 (b)].

There is a single flagellum in *Euglena*. Therefore, it is propelled forward in a **screwed** or **spiral manner** [Fig.19.6 (a)]. However, in *Paramecium*, there are numerous cilia, arranged in

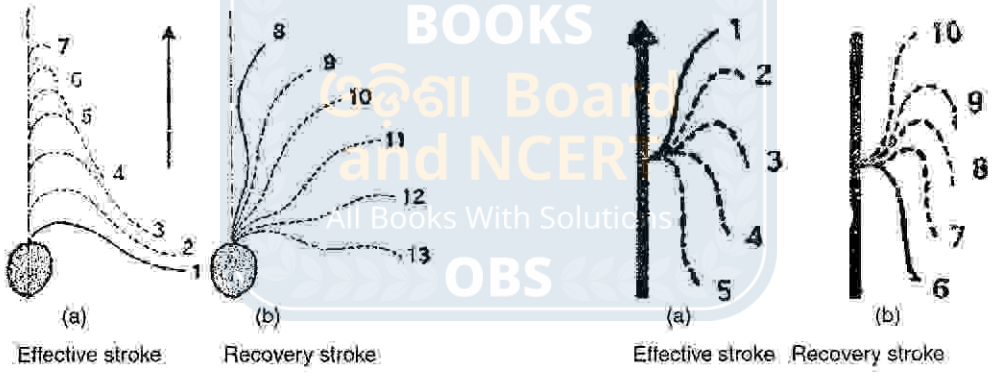


Fig. 19.3 : Undulations of a flagellum in *Euglena*.

Fig. 19.4 : Undulations of a cilium in *Paramecium*.

two rows: transverse and longitudinal. The transverse rows of cilia undulate all at the same time causing a **synchronous rhythm.** Those of tne longitudinal rows undulate at different times) **causing metachronous rhythm** (Fig.19.5).

The beating of the cilia generates mechanical energy, which propels *Paramecium* in a forward direction. Like *Euglena*, it also follows a spiral path, due to the presence of more cilia on

Fig.19.5 : Beating of a longitudinal row of cilia, causing a metachronous rhythm.

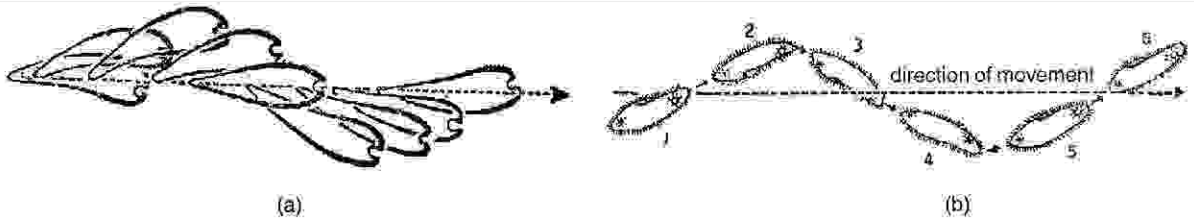


Fig. 19.6 : Patterns of locomotion in (a) *Euglena* and (b) *Paramecium*

the oral groove side [Fig.19.6 (b)]. The **caudal tuft of paramecium** acts as a rudder and helps change the direction as and when necessary.

19.1.2. Muscular movement:

Locomotion in human occurs by the co-ordinated contraction and relaxation of skeletal muscle. A muscle contracts only when it is stimulated by a somatic motor neuron. The axon of neuron makes a special junction at the sarcolemma of a skeletal muscle fiber, known as a **neuro-muscular junction**. The neuron, when stimulated releases a nurotransmitter chemical at the junction. This chemical acts as a signalling substance which brings about changes in the electric potential across the membrane of the muscle fiber. Following this, chemical and physical changes occurr in the fiber, which end up in its contraction. For a better understanding of these changes, it is necessary to have a close look at its structure.

19.2. STRUCTURE OF SKELETAL MUSCLE :

19.2.1. Structure :

Skeletal muscle, as the name indicates, is attached to the elements of the skeletal system, such as bones and cartilages. A skeletal muscle is surrounded by a connective tissue sheath, the **epimysium**. The muscle is made up of bundles of elongated and cylindrical muscle fibers, known as **fasciculi**. Each fasciculus is surrounded by a sheath, known as **perimysium** and each muscle fiber is surrounded by an **endomysium** (Fig.19.7). **A muscle fiber consists of many myofibrils and each myofibril consists of two types of protein myofilaments: actin** and **myosin** (Figs.19.9 and 19.11). A skeletal muscle fiber is a multinucleate elongated cell (**syncytium**) with a surrounding **sarcolemma**. The bulk of the fiber is occupied by **myofibrils**. This results in the displacement of the active sarcoplasm with the nuclei to the peripheral part. Each myofibril is surrounded by an extensive network of endoplasmic reticulum, known as **sarcoplasmic reticulum** and **mitochondria**. The sarcoplasmic reticulum is in the form of tubules, which join to form **terminal cisternae**, present between each anisotropic (A) and isotropic (I) bands. The sarcolemma invaginates between each A and I bands to form a **transverse tubule**. The sarcoplasmic reticulum in the form of tubules and terminal cisternae and transverse tubules constitute a **sarco-tubular system** (Fig.19.8).

19.2.1.1. Structure of myofibril (Fig.19.9) :

In a stained microscopic preparation, the myofibrils are seen to exhibit alternating dark and light bands. The dark staining bands are known as **anisotropic bands** (**A bands**), while the light staining bands are known as **isotropic bands** (**I bands**). A myofibril contains two types of protein myofilaments : **thick filaments (myosin)** and **thin filaments (actin)**. These filaments contribute towards the bulk structure of the myofibril. The filaments are arranged in a periodic manner. This arrangement gives rise to the alternating **A** and **I** bands at regular intervals which imparts a **striated appearance** to the skeletal muscle. The same periodicity is found in all the muscle fibers of a fasciculus, thus giving the muscle a **cross-striated** or **striped appearance** [Figs. 19.10 (a) & (b)].

A thick line called **Z-line** [Z is for a German word, *zwischenschiebe* (*zwischen*, between; *schiebe*, disc)] runs across the middle of each I band. The middle of each A band is traversed by a lighter band called the **H-band** (H is for Hensen, who first described it).

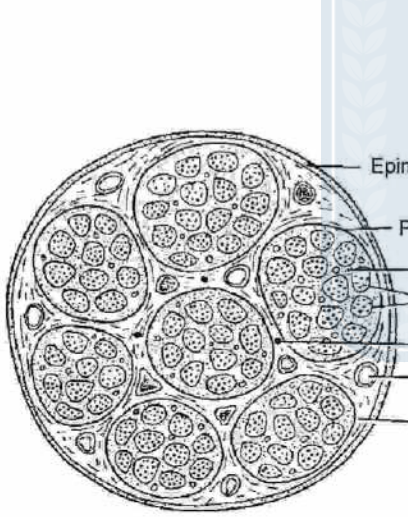


Fig. 19.7 : Three levels of organization (muscle → muscle fiber → myofibril → myofilament) of skeletal muscle with respective connective tissue sheaths.

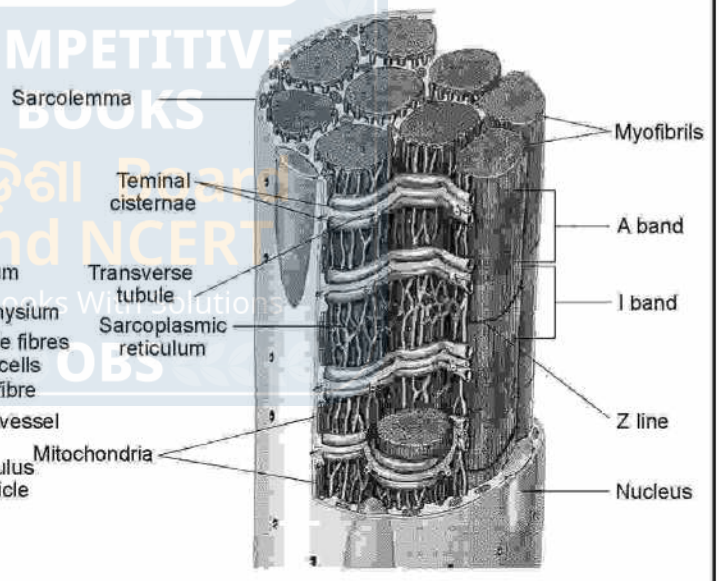


Fig. 19.8 : Organization of myofibrils in a muscle fiber with sarcoplasmic reticulum, terminal cisternae and transverse tubules.

Running through the centre of the H-band, there is a thin **M-band** [M is for a German word, *mittleschiebe* (*mittle*, between; *schiebe*, disc)]. The stretch of the muscle fiber between two Z-lines is called a **sarcomere**. The sarcomere is considered as the **contracting unit** of the muscle fiber. The nerve innervating a muscle enters into it at a place called the **neuro-mascular hilus**.

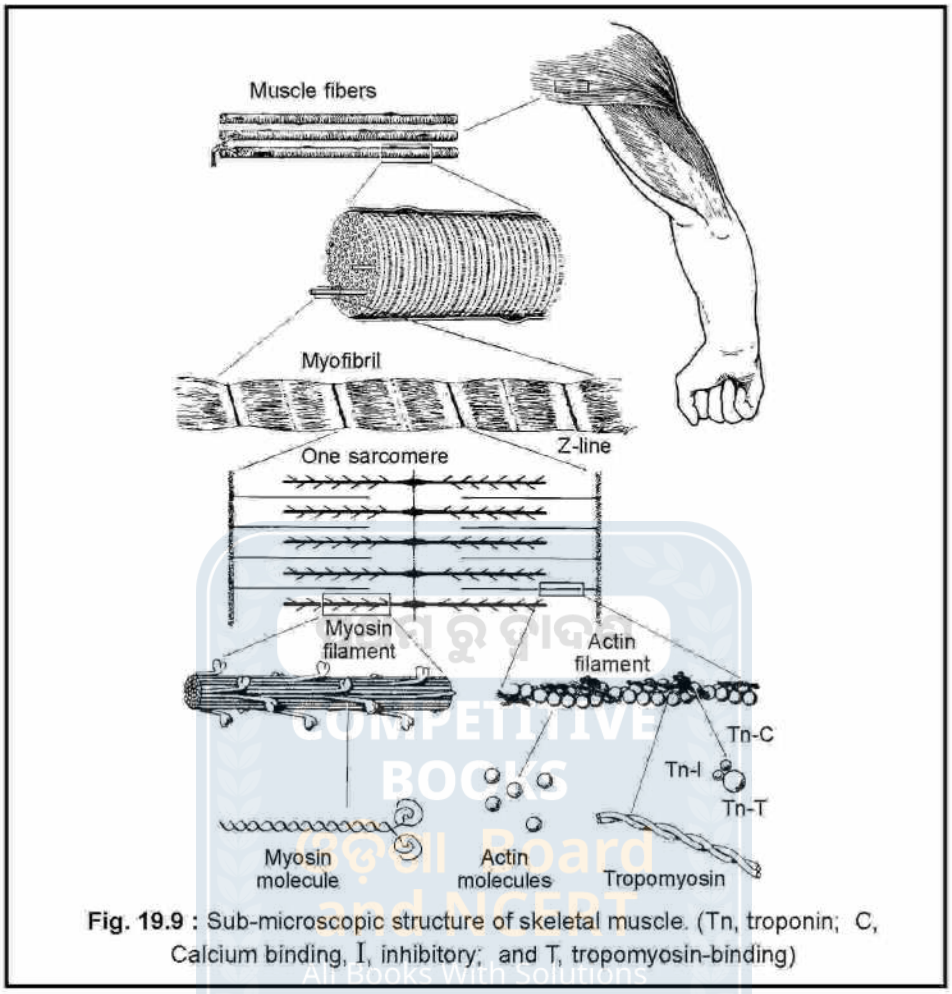


Fig. 19.9 : Sub-microscopic structure of skeletal muscle. (Tn, troponin; C, Calcium binding, I, inhibitory; and T, tropomyosin-binding)

19.2.1.2. Structure of myofilaments (Fig. 19.11) :

Two main types of myofilaments, such as **myosin** and **actin** are present in the myofibril.

Myosin [Fig. 19.11 (c)] **:** A thick or myosin filament consists of several myosin molecules organized into a bundle that gives it a thick filamentous appearance. Each myosin molecule has two **heavy polypeptide chains**, associated with two pairs of **light polypeptide chains**. The heavy chains are helically coiled around each other. At the N-terminus of each heavy chain, the polypeptide is globular forming a **head**. The head has an ATPase activity, which binds to and hydrolyzes ATP to generate mechanical energy during muscle contraction. The myosin molecules are oriented in opposite directions in two halves of the thick filament so that in the middle of the thick filament, there is no head and thus, this part has a lighter band-like appearance, which runs across a muscle fiber. This band has been referred to as the **H-band**. Running through the middle of each H band, there is a relatively thinner M-band or line.

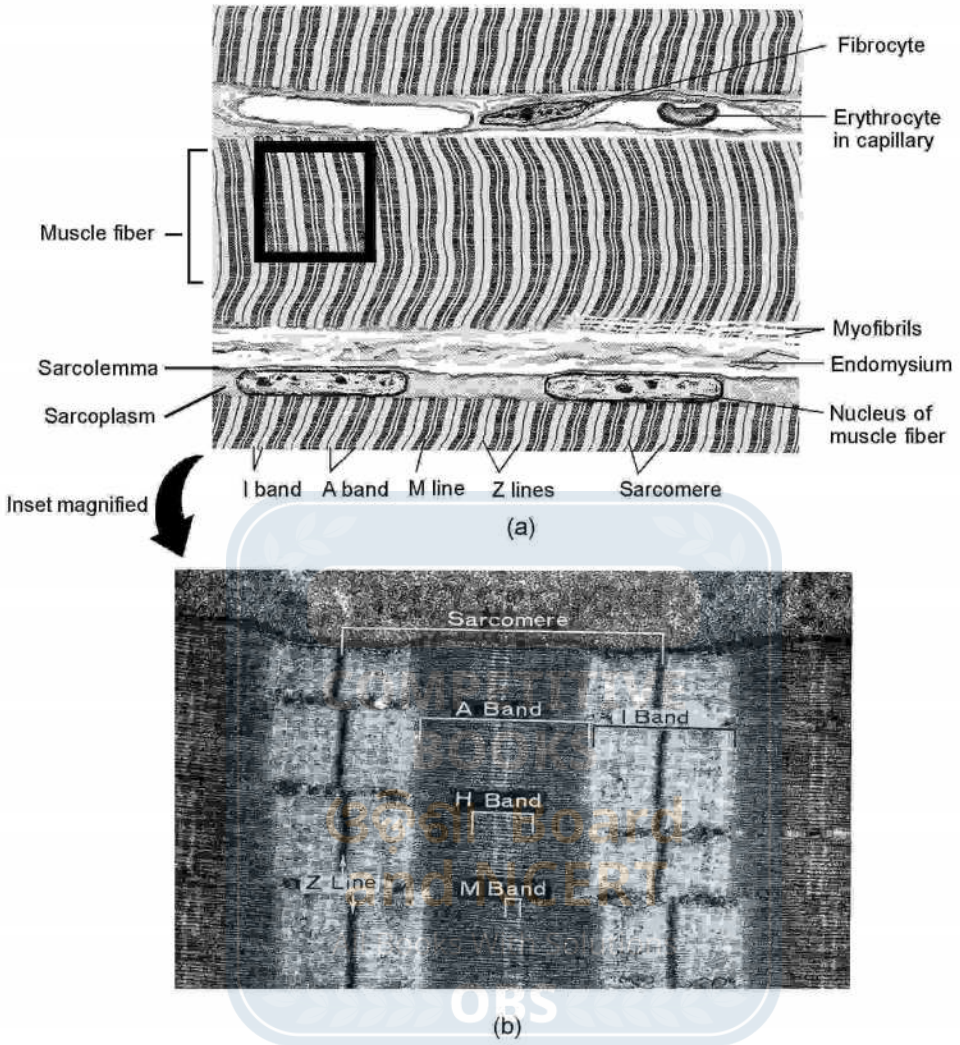


Fig. 19.10 : Structure of a stained muscle fiber. (a) gross structure with alternating A and I bands giving the muscle fiber a striated and striped appearance and (b) magnified view of the inset in (a) revealing the detail structure.

(a) Actin [Fig. 19.11 (b)] **:** A thin or actin filament consists of two actin chains, helically coiled around each other. Each actin chain consists of a linear array of many actin molecules. An actin molecule is a **globular protein** and thus, is known as **globular actin** or **G-actin**. A G-actin molecule has an ATPase ativity and a myosin head binding site. Several G-actins join linearly forming a **fibrous actin** or **F-actin**. Two F-actins helically coil forming an actin filament. During muscle contraction, the myosin heads bind to the G-actin's myosin head binding sites. ATP, bound to the myosin heads are hydrolyzed by the ATPase activity. Mechanical energy is generated, which slides the F-actin and Myosin over each other. Thus the muscle contraction is effected.

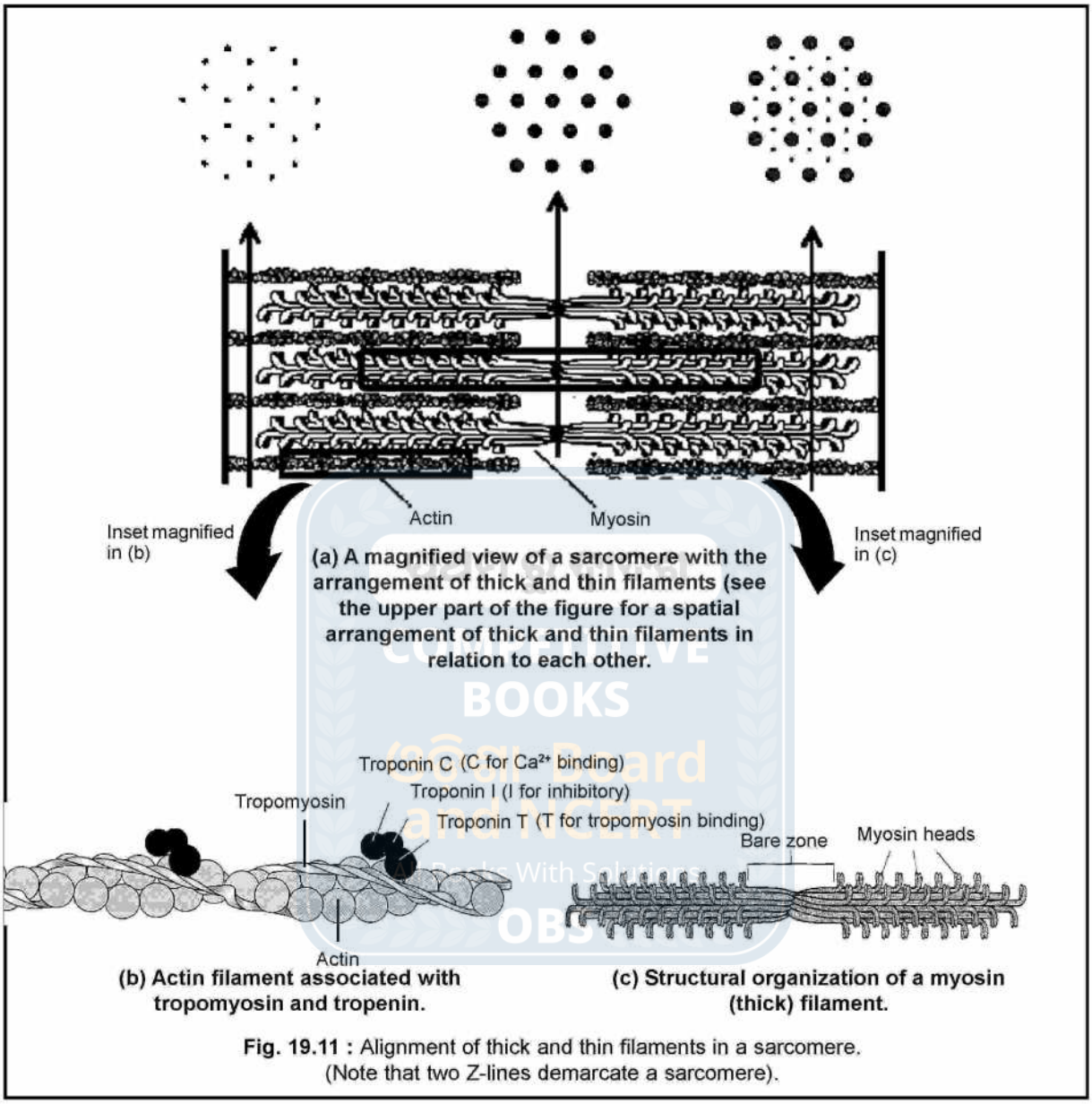


Fig. 19.11 : Alignment of thick and thin filaments in a sarcomere.
(Note that two Z-lines demarcate a sarcomere).

There is a regularity in the arrangement of myosin and actin filaments. A myosin filament is surrounded by six actin filaments [Upper part of Fig. 19.11 (a)]

The actin and myosin filaments are not free floating. The thin filaments are anchored to the Z-line by a protein, called **actinin**. The thick filaments are anchored to the Z-line and M-line by a protein, called **titin** (Fig. 19.12). Two other proteins, known as **troponin** and **tropomyosin** also play an important role in muscle contraction. Troponin is a globular protein consisting of three subunits : TnC (Ca^{2+} binding subunit), TnI (inhibitory subunit) and TnT (tropomyosin-binding subunit). Tropomyosin is a fibrous protein which covers the myosin head binding sites in the actin in a resting muscle fiber. The role of these proteins in muscle

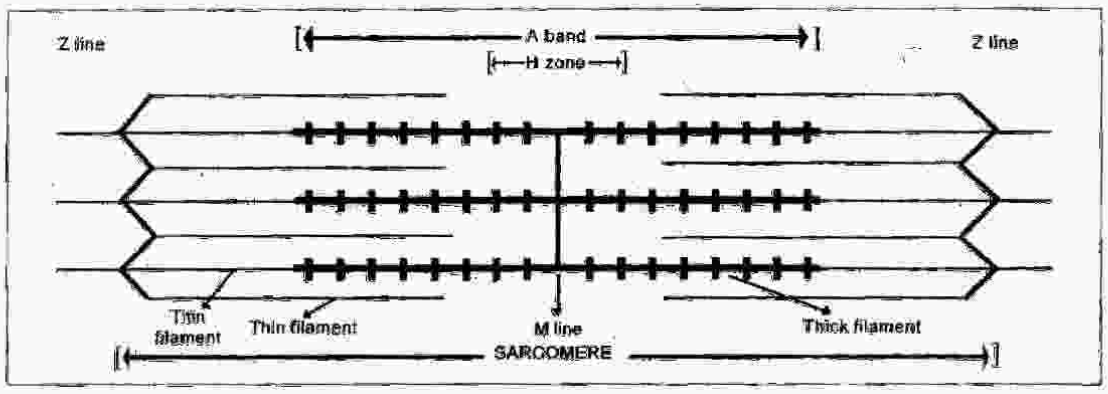


Fig. 19.12 : Organization of a sarcomere with titin filaments anchoring thick (myosin) filaments to Z-lines

contraction is discussed in the section, 19.3.1. at point 2 on locomotion and movement in man. (see the section : on muscle contraction).

19.3. MECHANISM OF MUSCLE CONTRACTION :

The protein myofilaments present in the myofibril form the physical basis of muscle contraction. The actin and myosin filaments slide past over each other to effect the contraction process. Consequently, the sarcomere shortens i.e. the distance between two Z-lines decreases. A close examination reveals that the length of the filaments does not change. The I-bands and H-zones, containing only thin and thick filaments, respectively, get shorter during contraction. The length of A-band remains unaffected [Figs.19.13 (a) & (b)]. The mechanism that explains skeletal muscle contraction is known as **sliding filament mechanism**, proposed by **H. E. Huxley** and **J Hanson**, **A. F. Huxley** and **R. Niedergerke**

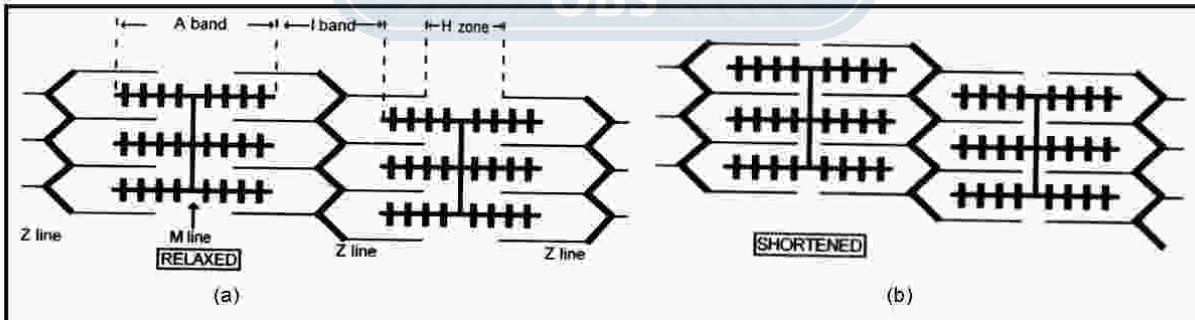


Fig. 19.13 : Shortening of the sarcomere during muscle contraction
(a) sarcomere in resting state and (b) sarcomere following contraction.

19.3.1. Biochemical events during muscle contraction (Fig.19.14) :

1. The muscle contraction is initiated when the axon terminals of an excitatory motor nerve, innervating the muscle is stimulated and then releases a **neurotransmitter** chemical at the nerve-muscle (neuro-muscular) junction. A neurotransmitter is a

chemical signal, which when released changes the electric potential in the sarcolemma of the muscle fibers of the contracting muscle like every other biological membrane. The sarcolemma has a resting electric potential across it. This is known as **resting membrane potential**. Under the influence of the neurotransmitter, the resting membrane potential in a local area of the sarcolemma is reversed. This generates a potential differnece or **action potential (AP)** across the membrane. The generation of an action potential is known as **membrane depolarization**. The AP then propagates to the membrane of the sarcoplasmic reticulum, which causes the calcium ion (Ca^{2+}) channels to open. Consequently Ca^{2+} are released from the sarcoplasmic reticulum lumen into the sarcoplasm. This event initiates the contraction of the muscle fiber. Ca^{2+} will remain in the sarcoplasm as long as the contraction continues. Following an inhibitory stimulus the Ca^{2+} reaccumulate in the sarcoplasmic reticulum by an active transport mechanism. This process is catalyzed by **$Ca^{2+} - M_g^{2+}$ ATpase**. Following a phase of contraction, if the movement of **Ca^{2+}** into the reticulum is inhibited, relaxation doesn't occur. This condition of sustained contraction is known as **contracture**.

2. The released Ca^{2+} bind to the troponin C subunit of troponin. This weakens the binding of troponin I to the actin filament and subsequently, dislodges it. Then the tropomyosin moves laterally, consequently freeing the myosin head binding sites of actin.

3. An ATP binds to the ATP binding site of the myosin head. It is hydrolyzed into ADP and Pi by the ATPase activity. Following the hydrolysis, the myosin head binds to its binding site in each G- actin and forms a cross bridge. The Pi is then released. This causes a conformational change in the myosin, causing the cross bridge to produce a **power stroke**.

4. After the power stroke, the bound ADP is released and a new ATP binds to the myosin head. The release of ADP and binding of another ATP is necessary to break its bond with the actin after the completion of a power stroke.

ATP is required to dislodge ADP. In the absence of ATP, the ADP remains bound to the myosin head. Consequently, the myosin heads remain permanently bound to actin and this means that the muscle is never relaxed. This condition is known as **rigor mortis**. It occurs after death, when there is a complete depletion of ATP and **phosphocreatine**.

19.3.2. Energy sources :

The immediate source of energy for contraction is ATP, produced in carbohydrate, protein and lipid catabolism. However, during heavy exercise, ATP may be used faster than it is produced. A rapid renewal of ATP is extremely necessary to keep the contration process on. Under this situation **phosphocreatine**, a reserve energy currency in mitochondria of

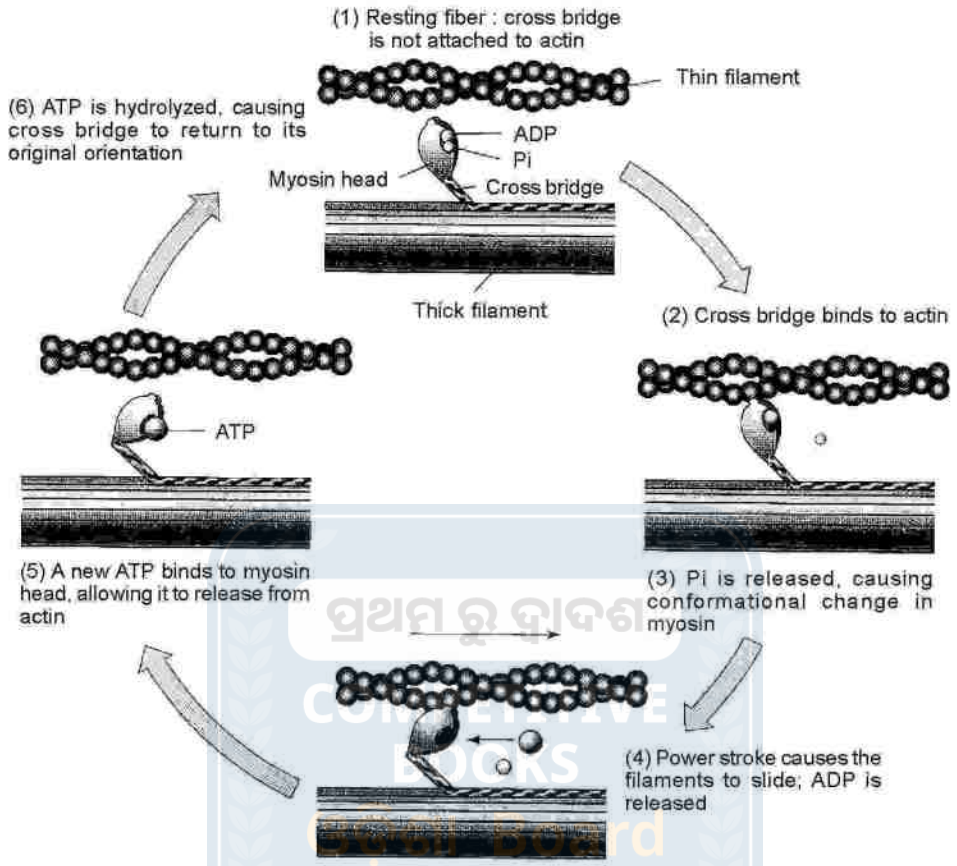


Fig. 19.14 : The cross bridge cycle that causes sliding of myofilaments and hence muscle contraction.

muscle fibers, serves to form ATP. This energy-rich compound transfers its phosphate group to ADP, consequently forming ATP. This phosphate transfer reaction is catalyzed by an enzyme called **creatine kinase**, also called **creatine phosphokinase**, present in the skeletal muscle fiber. When the muscle is at rest, ATP in the mitochondrion transfers its phosphate group to creatine forming phosphocreatine. Thus, there is a build up of phosphocreatine to serve during exigency. Its concentration is more than three times the concentration of ATP in a muscle cell.

Types of skeletal muscle fibers : Skeletal muscle fibers are divided, on the basis of their contraction speed, into **slow twitch** or **type I fibers** and **fast twitch** or **type II fibers**. Slow twich fibers have a rich capillary supply, numerous mitochondria, aerobic respiratory enzymes and a high concentration of **myoglobin**. Myoglobin is a red pigment similar to haemoglobin. It helps deliver oxygen to these fibers. Because of their high myoglobin content, these fibers are also termed as **red fibers** (*e.g.*; soleus muscle of the leg and long muscles of the back). Fast twitch fibers have fewer capillaries and mitochondria than slow twitch fibers. These fibers do not contain as much myoglobin as those of the slow twitch fibers and hence, are termed as **white fibers** (*e.g.*; extra-occular muscles of the eye).

19.3.3. Cori Cycle :

The ATP that drives muscle contraction is generated through oxidative phosphorylation in mitochondria-rich **slow-twich muscle fibers or by catabolism of glucose** into lactic acid in **fast-twich muscle fibers**. (For slow twich and fast twich muscles see the box in the previous page). In heavily exercising slow-twich muscle fibers, the demand of ATP exceeds its supply. In this situation, these fibers produce lactic acid from glucose by lactic acid fermentation (anaerobic respiration). This lactic acid is transported to the liver via the blood Here, it is converted into pyruvic acid and then to glucose by gluconeogenesis. The synthesized glucose returns to the muscle, where it is stored as glycogen during rest or catabolized immediately to generate ATP for muscle contraction. The cycle serves as a means for the replenishment of depleted glycogen in heavily exercising muscle fibers. This two-way traffic between the skeletal muscle and liver is known as **Cori cycle**, (Fig. 19.15), named in the honour of Carl Cori and Gerty Cori, who first described it.

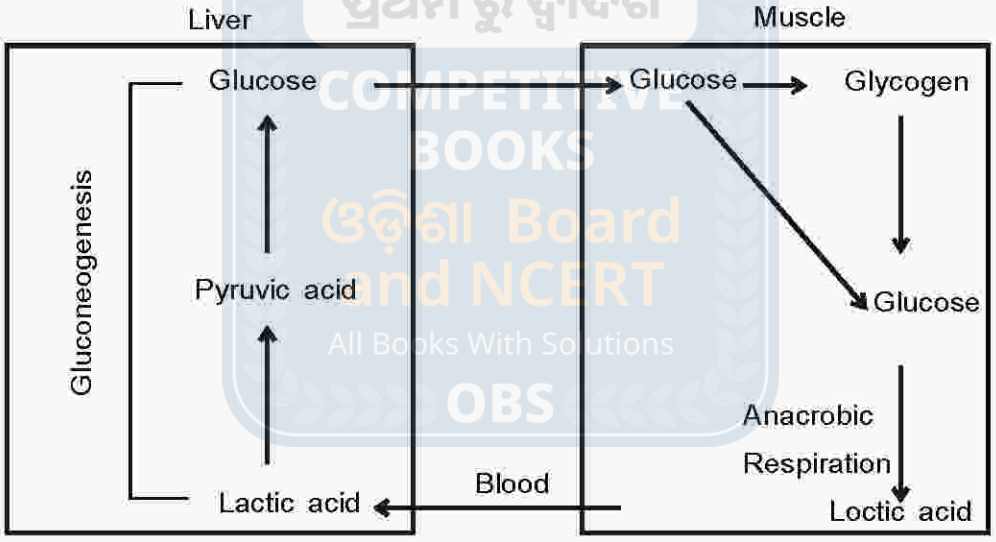


Fig. 19.15 : Cori Cycle (Two-way traffic between skeletal muscle and liver)

19.4. HUMAN SKELETAL SYSTEM :

Human body has a definite shape and an up-right posture. This is possibel due to the presence of an endoskeleton of bones and cartilages. It constitutes the internal supporting frame of the body in human and other vertebrates.

The human body contains 206 bones, which are organized in two groups: **axial skeleton** consisting of the bones of the skull, vertebral column, sternum and ribs and **appendicular skeleton**, consisting of the limb bones and girdles (Fig. 19.16).

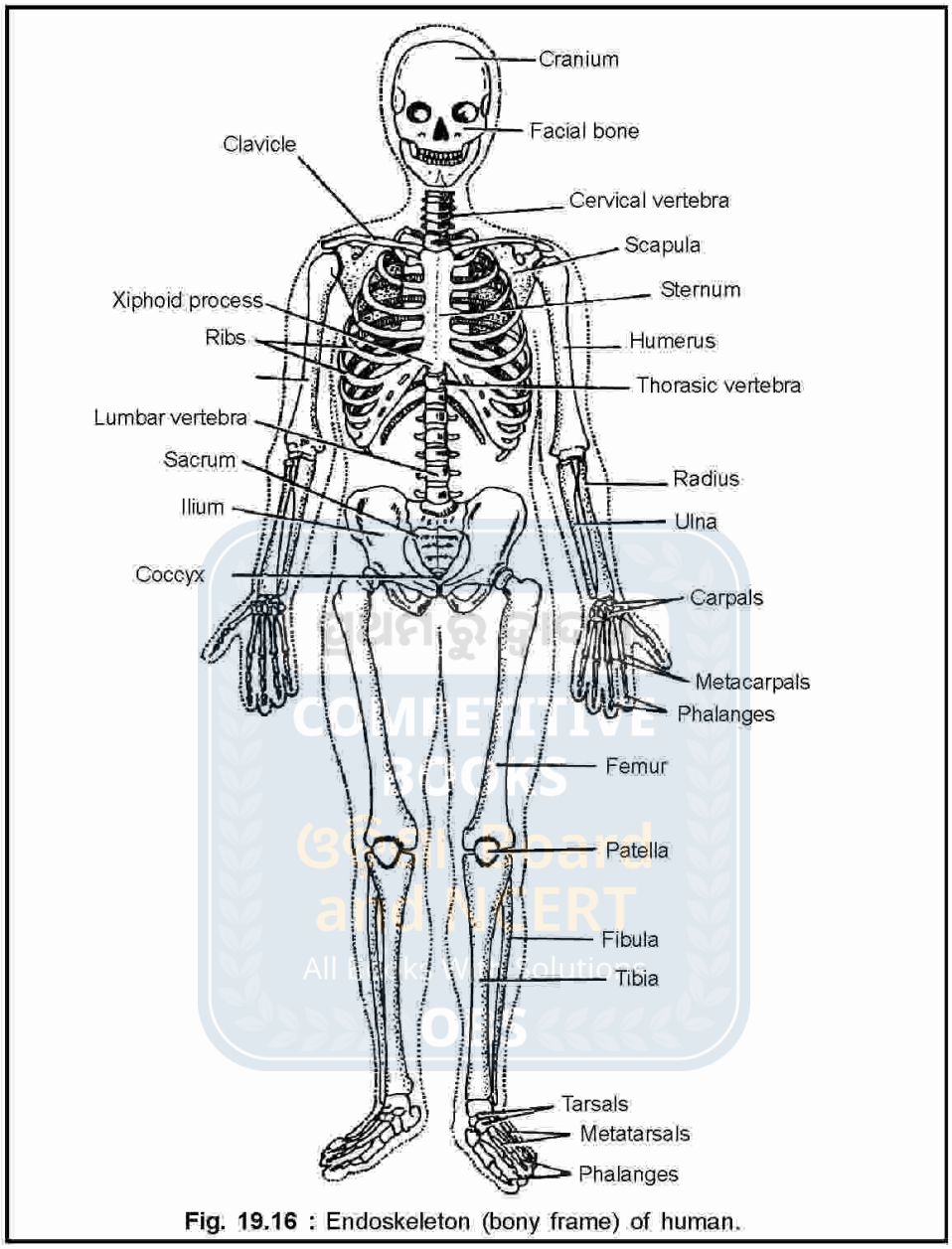


Fig. 19.16 : Endoskeleton (bony frame) of human.

19.4.1. Axial skeleton (Fig 19.17) :

It is named so, because of its presence along the main axis of the body. It has **80 bones**, of which **28 irregular-shaped** including **bones of middle ear** and **brain box** or **cranium** are in the skull and **33 in the vertebral column**. The rest are the ribs and the bones of the sternum.

The vertebral column is made by several vertebrae, articulated with each other linearly forming a flexible column. There are **seven cervical**, **twelve thoracic**, **five lumbar**, **five sacral** (fused to form a **sacrum**), and **four vestigial caudal vertebrae**. The caudal vertebrae,

together, constitute a **coccyx**. The thorax or chest harbours a thoracic cavity, supported by twelve thoracic vertebrae on the dorsal side and twelve pairs of **thoracic ribs**. All the ribs articulate with thoracic vertebrae at the back. However, ten out of the twelve pairs, articulate with the sternum on the ventral side, while 11th and 12th pairs articulate only with the thoracic vertebrae. These do not articulate with the sternum and hence are called **floating ribs**.

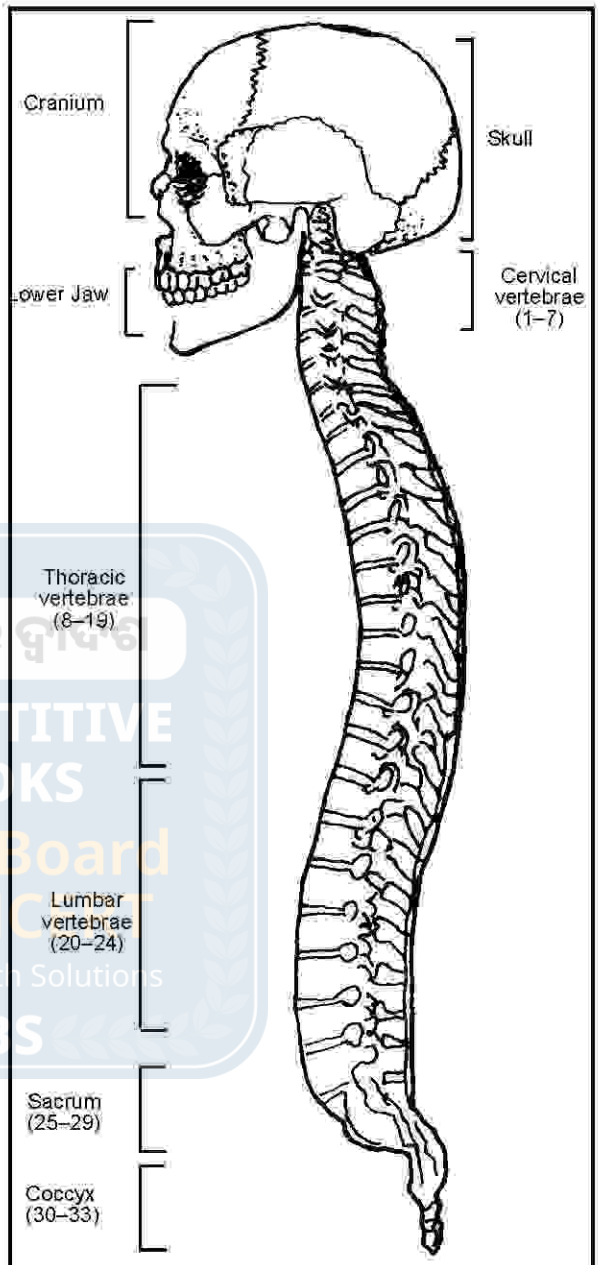


Fig. 19.17 : Axial skeleton (skull and vertebral column) of human.

19.4.2. Appendicular skeleton :

It consists of **126 bones** of the **limbs**, **hip** and the **shoulder**. Limb bones include those of the **fore limbs** (**arms**) and **hind limbs** (**legs**). The bones at the shoulder and hip regions constitute **pectoral** and **pelvic girdles**, respectively. The fore limb bones (Fig. 19.18) are **humerus** (**upper arm**); **radius and ulna** (**fore arm**); **carpals** (**wrist**); **metacarpals**; and **phalanges** (**hand**) in a proximal to distal direction. There are **eight carpals** in the wrist; **five slender metacarpals** and **fourteen phalanges** in the hand. The phalanges are organized into five fingers. There are three phalanges, each in all fingers, than the thumb, which has only two. The proximal end of humerus articulates with the **glenoid cavity** of pectoral girdle in a **ball and socket joint**.

The hind limb bones (Fig. 19.19) are **femur** (**thigh**); **tibio-fibula** (**shank**); and **tarsals**, **metatarsals**, and **phalanges** (**ankle** and **foot**) in a proximal to distal direction. Except the proximal two, the tarsals and all metatarsals and phalanges constitute the foot. There are **seven tarsals**, out of which two proximals constitute the **ankle bone** (astragalus and calcaneum). The tarsals are followed by **five slender metatarsals** and **fourteen phalanges**. The phalanges are organized into five fingers or toes. There are three phalanges, each in all toes, except the big toe, which has only two. The proximal end of femur articulates with the **acetabulum** of the pelvic girdle in the same ball and socket joint as that of the head of humerus.

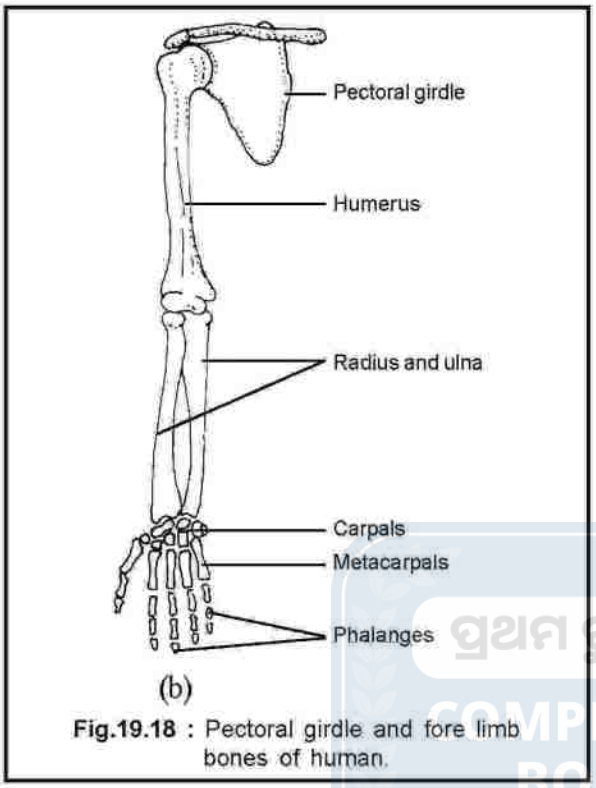


Fig.19.18 : Pectoral girdle and fore limb bones of human.

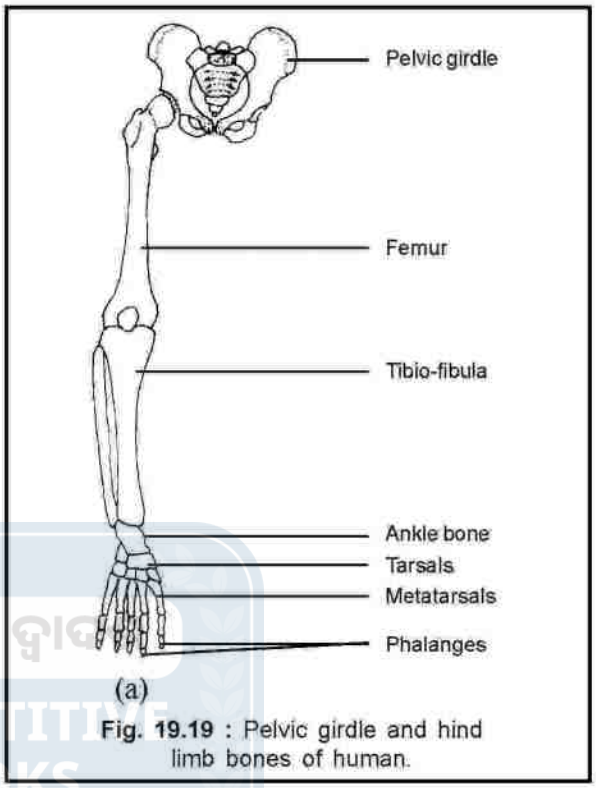


Fig. 19.19 : Pelvic girdle and hind limb bones of human.

19.4.3. Joints :

The skeletal elements articulate with each other in a definite manner and give rise to a flexible frame of the body. The site, where two skeletal elements come together, is known as **a joint**. The degree of free movement of bones is largely determined by the nature of the joints. Two general types of joints have been recognized: **(1) synovial** or **diarthrose [Fig. 19.20 (a)]** and **(2) solid** or **synarthrose [Fig.19.20 (b)]**.

19.4.3.1. Synovial (Diarthrose) joint (Fig. 19.21) :

Each articular surface is covered by a layer of **hyaline cartilage**. Two surfaces are separated by a narrow **articular cavity**. A **joint capsule**, formed by an inner **synovial membrane** and an outer **fibrous membrane**, is present at the place of articulation. The synovial membrane is attached to the margin of each articular surface at the interface between the cartilage and bone. This membrane is vascular and produces a

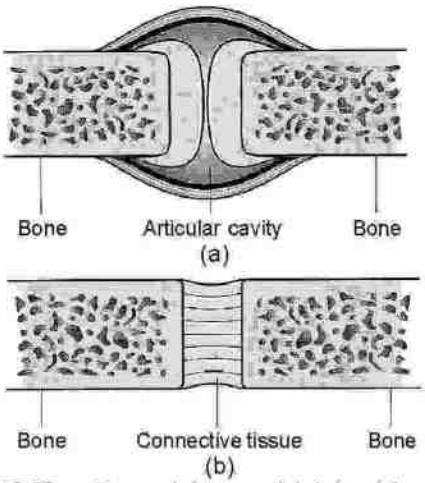


Fig. 19.20 : General types of joints. (a) synovial (diarthrose) and (b) solid (synarthrose).

synovial fluid, which fills in the articular cavity. Synovial fluid is **dialyzed blood plasma**, to which is added **hyaluronic acid** by the synovial membrane. It acts as a lubricant at the articular surface and thus absorbs friction.

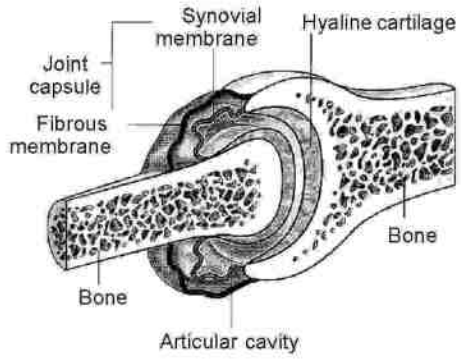


Fig.19.21 : General organization of a synovial joint

The fibrous membrane, consisting of dense connective tissue that surrounds the joint. Parts of the fibrous membrane may thicken to form ligaments. Such ligaments provide additional reinforcements to the joint. Occasionally, **fibrocartilage articular discs**, **fat pads** and **tendons** are enclosed by the articular cavity. These structures act as shock absorbers during the movement of bones at the joint. Based on the axis of movement, these are described as: **(a) uniaxial**, **(b) biaxial**, and **(c) multiaxial**.

(a) Uniaxial : This joint has one degree of freedom i.e. the articulating bones can move in one axis only. It is again classified as: **(i) hinge or ginglymus**, **(ii) pivot or trochoid**, and **(iii) bicondylar joints**. In hinge joint (Fig.19.22), the movement is along a transverse axis. One articular surface is convex and the other concave. The two surfaces are joined by strong collateral ligaments (*e.g.*; interphalangeal joints of fingers and toes; elbow and ankle joints).

In pivot joint, the movement is along a vertical axis. One bone acts as a pivot, on which the other exhibits rotational movement (*e.g.*; atlas-axis joint).

In bicondylar joint, one surface has two contact points known as condyles. The movement is mainly along a transverse axis but partly also along a vertical axis (*e.g.*; knee joint).

(b) Biaxial : The two articulating bones move along transverse and vertical axes. It is classified as: **(i) condylar or ellipsoid**, and **(ii) saddle** joints. In ellipsoid joint, one articular surface is concave, while the other is convex. The convex surface is elliptical in outline (*e.g.*; radio-carpal joint; metacarpo-phalangeal joint; and atlas-occipital condyle joint).

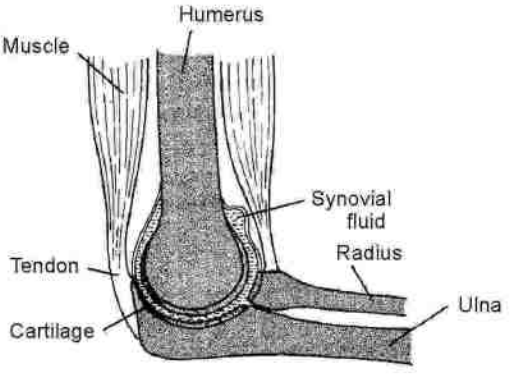


Fig.19.22 : Uniaxial (hinge or ginglymus) joint at the elbow

In saddle joint, the opposing articular surfaces are concave convex in a reciprocal manner. The movement is similar to that of

condylar or ellipsoid joint, however, some degree of rotation is also allowed (*e.g.*; carpo-metacarpal joint of thumb and sternum-clavicle joint).

(c) Multiaxial : The movement is possible along all axes. It includes the only joint i.e. **ball and socket** or **spheroidal joint**. One articular surface is convex, while the other is concave. The concave surface is socket-like, into which articulates the ball-like convex articular surface (Fig.19.23). The movement of one bone takes place along all three independent axes: transverse, antero-posterior, and vertical (*e.g.*; shoulder and hip joints)

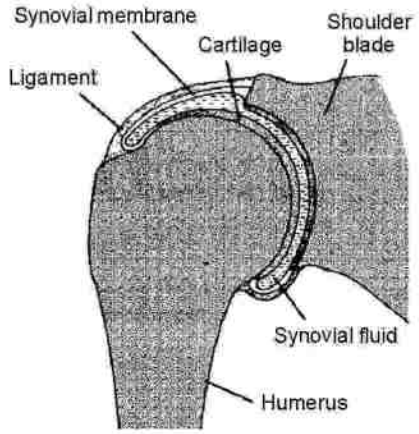


Fig.19.23 : Multiaxial (ball and socket joint at the shoulder)

19.4.3.2. Solid (Synarthrose) joint :

It is a joint between two skeletal elements, connected by **fibrous connective tissue** or **cartilage**, especially, **fibrocartilage**. Movements at these joints are more restricted than at synovial joints. It is of two types: (a) **fibrous** and (b) **cartilaginous**.

(a) Fibrous joints: No movement is allowed at this joint. Fibrous joints include: (i) sutures, (ii) gomphoses, and (iii) syndesmoses.

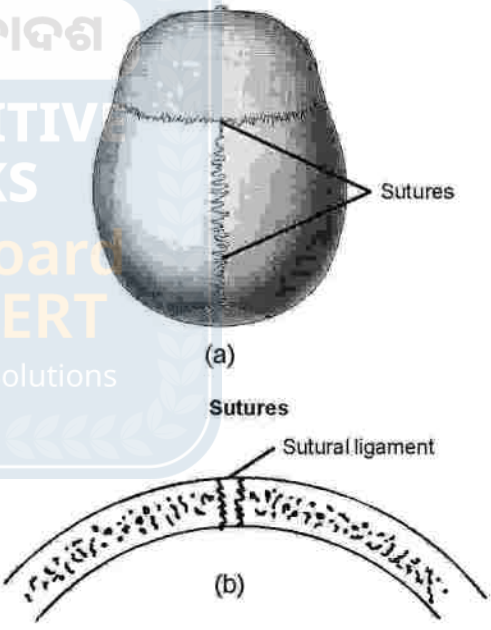


Fig.19.24 : Suture in the skull. (a) Surface view of the skull showing sutures and (b) suture showing a sutural ligament in a section

(i) Sutures (Fig. 19.24) : The adjacent bones are joined by thin layers of connective tissue, called sutural ligaments. (*e.g.*; skull bones)

(ii) Gomphoses (singular; gomphosis) (Fig. 19.25) : It is characterized only in the articulation of the tooth root in the bony socket. Short collagen fibers of the **periodontal ligament** run between the root and the bony socket. (*e.g.*; tooth-socket articulation)

(iii) Syndesmoses (singular; syndesmosis) (Fig. 19.26) : The adjacent bones articulate by a ligament. The radius articulates with the ulna by an **interosseous membrane**. (*e.g.*; radius and ulna articulation)

(b) Cartilaginous joints : A limited degree of movement is allowed at this type of joint. This is of two types: (i) synchondroses and (ii) symphysis.

(i) **Synchondroses (singular; synchondrosis) (Fig. 19.27) :** This type of joint occurs, where two **ossification centres** in a growing bone remain separated by a layer of cartilage. The cartilage keeps adding bony substance to both ends until it is completely ossified. (*e.g.*; a region between the shaft and head of long growing bones)

(ii) **Symphyses (Fig.19.28) :** Two separate bones are connected by a cartilage. (*e.g.*; pubic symphysis and intervertebral disc)

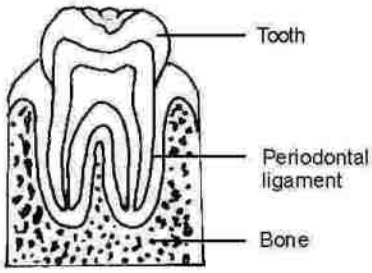


Fig. 19.25 : Tooth-root-bony socket joint.

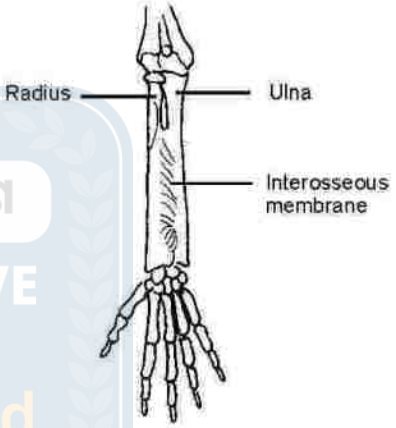


Fig. 19.26 : Radius-ulna joint with an inter-osseus membrane.

19.4.4. Movements at joints :

The entire human body is flexible due to the presence of many joints in the endoskeletal frame. The arms and legs perform more flexible movements in space relative to other parts of the body.

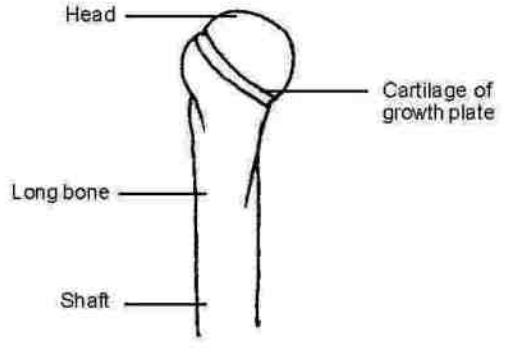


Fig. 19.27 : Growing cartilage at the ossification centre in a long bone

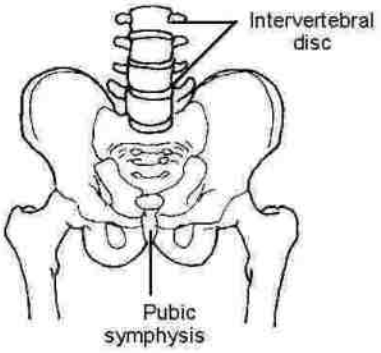


Fig. 19.28 : Symphysis at the pubis joint of the pelvic (hip) girdle and inter-vertebral discs of the vertebral column

19.4.4.1. Movements at joints of the arm :

Unlike the leg, the hand is more mobile for positioning in space. The upper arm is joined to the shoulder at the gleno-humeral (shoulder) joint. The shoulder is suspended from the trunk by muscles. Sliding (protraction and retraction) and rotation of the scapula of the

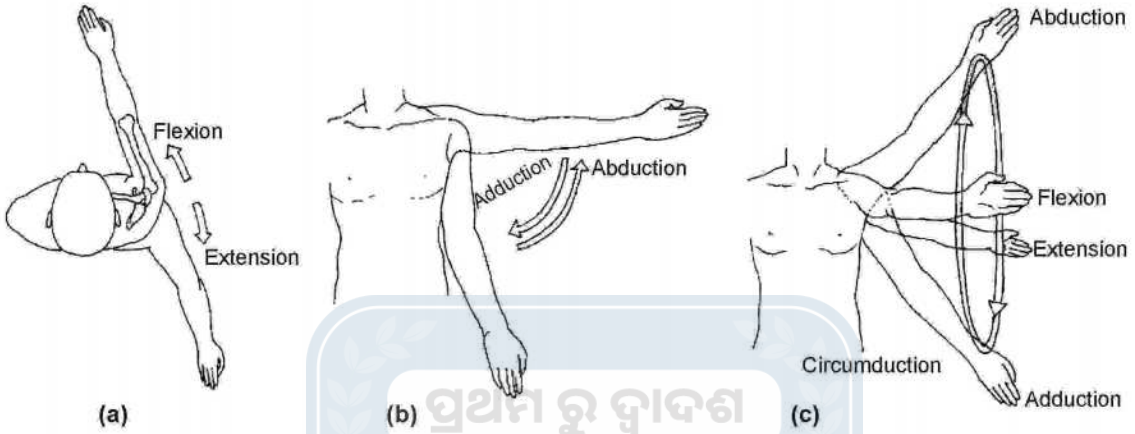


Fig. 19.29 : Different types of movements of the upper arm of the fore limb. (a) Flexion and Extension, (b) Adduction and Abduction and (c) Cicumduction.

peetoral girdle changes the position of the shoulder joint. Consequently, the upper arm moves around three axes. Movements of the upper arm at this joint are flexion, extension, abduction, adduction, medial and lateral rotation and circumduction. (Fig. 19.29)

The major movements at the elbow joint are flexion and extension of the fore arm [Fig. 19.30 (a)] The radius-ulna exhibits medial and lateral rotations [Fig. 19.30 (b). At the distal end, radius is flipped over the ulna by pronation and supination, acquiring palm-posterior and palm-anterior positions respectively [Fig. 19.30 (c)]

At the wrist joint, the hand is abducted, adducted, flexed and extended [Fig. 19.31 (a) & (b)]. Similarly, the fingers exhibit abduction, adduction, flexion and extension at the metacarpo-phalangeal joints (Fig. 19.32).

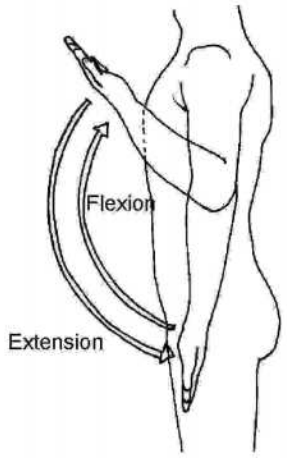


Fig. 19.30 (a) : Flexion and extension at the elbow joint

19.4.4.2. Movements at joints of leg :

The major function of the leg is locomotion. It involves an integration of movements at all joints for an upright posture and displacement with time.

The movements at the hip joint are flexion, extension, abduction, adduction and medial and lateral rotation (Fig. 19.33 and 19.34)

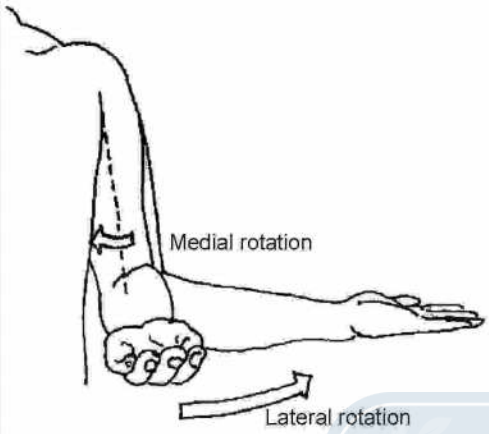


Fig.19.30 (b) : Medial and lateral rotation at the elbow joint

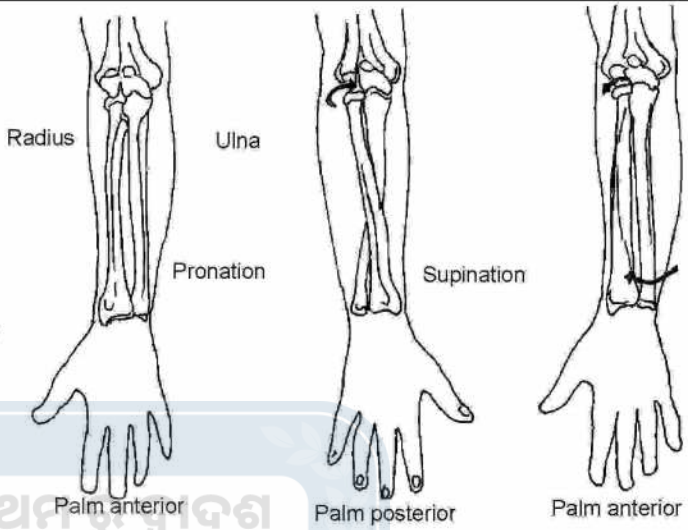


Fig.19.30 (c) : Pronation ans supination at the distal end of radius and ulna.

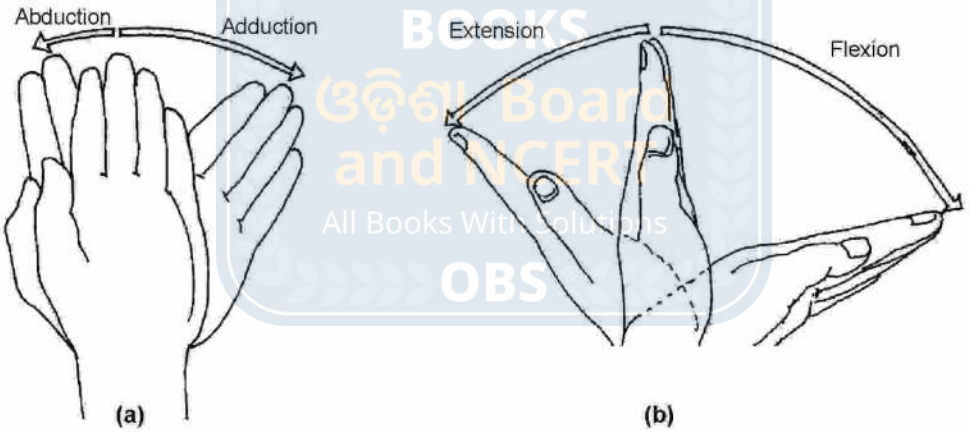


Fig. 19.31 : Movement of bones at the wrist joint.
(a) Abduction and adduction and (b) Extension and flexion

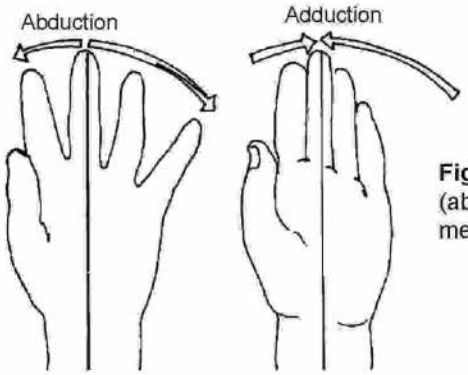


Fig. 19.32 : Movements (abduction and adduction) at metacarpophalangeal joints.

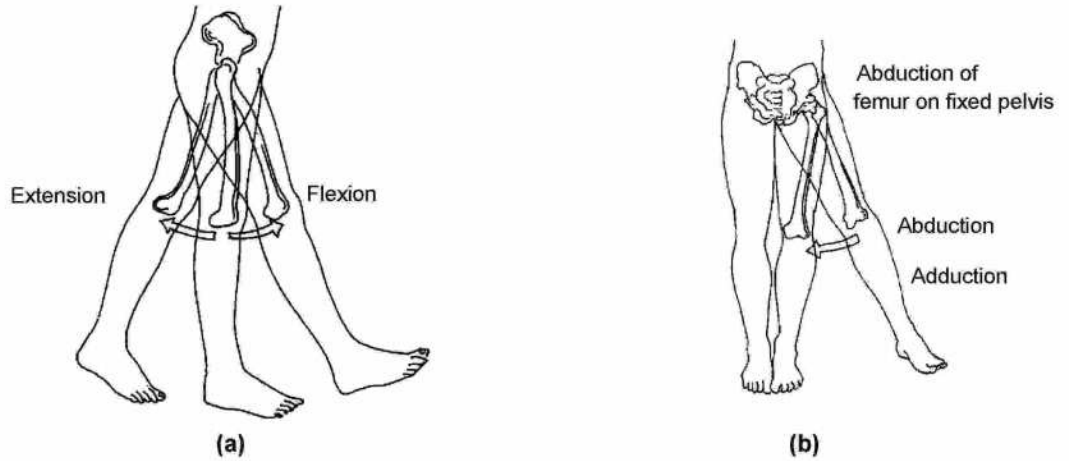


Fig. 19.33 (a), (b) : Movements at the hip joint.
(a) Flexion and extension and (b) Abduction and adduction.

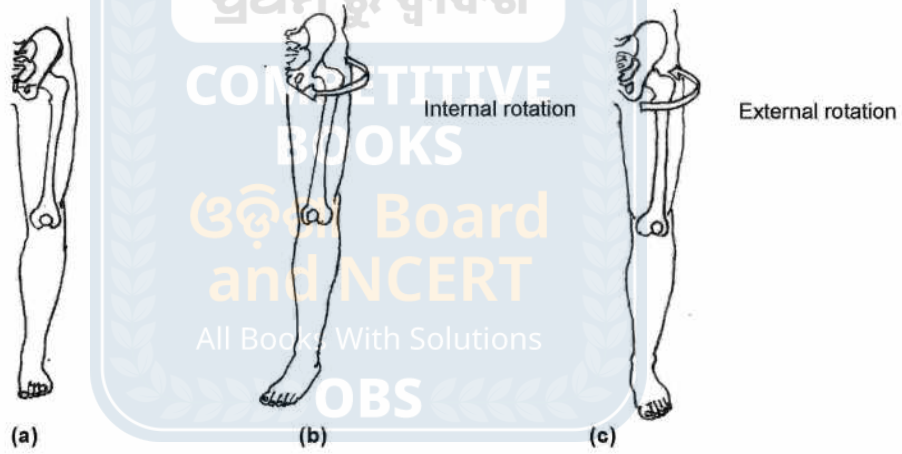


Fig. 19.34 : Movements at the hip joint. (a) Normal position;
(b) Internal rotation; and (c) External rotation

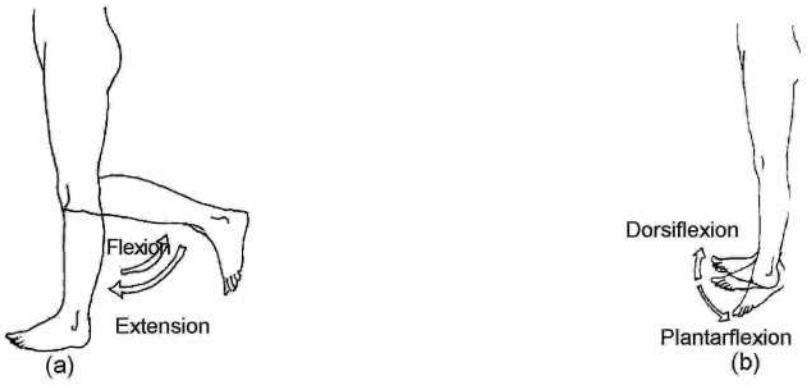


Fig. 19.35 : (a) Movements at the knee joint and (b) Movements at the ankle joint

The movements at the knee joint are flexion and extension [Fig. 19.35 (a)]. Movements at the ankle joint are dorsiflexion (movement of the dorsal side of the foot towards the leg) and plantarflexion [Fig. 19.35 (b)]

19.5. DISORDERS OF MUSCULAR AND SKELETAL SYSTEMS :

19.5.1. Myasthenia gravis :

It is an autoimmune disorder, in which self antibodies are generated against acetylcholine receptors at the neuro-muscular junctions. The consequence is the blockage and destruction of these receptors. The motor nerve fibers fail to transmit the signal to the muscle (effector). This leads to severe muscle weakness.

19.5.2. Tetany :

When a muscle is stimulated rapidly and repeatedly, contraction occurs before it is relaxed. The individual contraction responses fuse into one continuous contraction. This response is known as tetanus. In a complete tetanus, there is no relaxation between periods of contraction and in incomplete tetanus, there are short periods of relaxation between stimuli.

19.5.3. Muscular dystrophy :

Muscular dystrophy refers to a disorganization of the skeletal muscle fibers. The most serious of all dystrophies is Duchenne Muscular Dystrophy (DMD). It is an X-linked dosorder. Persons carrying this disorder die around the age of 30 years. A gene present or X chromosome encodes a protein dystrophin, which is a constituent protein of the cytoskeleton of the muscle fibar. When the gene undergoes a mutation, normal dystropin protein fails to be synthesized. The consequence is that the cytoskeleton becomes abnormal and the musle fibar becomes fragile. Another mild form of the dystrophy is Baker's Muscular Dystrophy. In this case, the dystrophin protein is present, however, its structure is altered.

19.5.4. Arthritis :

Athritis is an inflammatory condition of the joints causing pain and swealling. It is the three types : **rheumatoid arthritis**, **osteoarthritis** and **gout**. The case of gout will be treated separately.

Rheumatoid arthritis is an autoimmune disorder, in which the immune system fails to recognize the self antigens. This pathological condition occurs at synovial joints due to nerve and chronic inflamation. There is a gradual destruction of carlilage and bony material at joints.

Osteoarthritis is a degenerative joint disease, also occuring at synovial joints. The bony and cartilaginous elements at this joint change in structure. Occasionally there are bony outgrowths and cysts at such joints, so that there is a limited movement at such joints. Movements at these joints generate severe and unbearable pain.

19.5.5. Osteoporosis :

This is the most common metabolic bone disorder in elderly people. It is characterized by the loss of minerals and organic matrix from bone, reducing bone mass and density. There is an increase in risk of bone fracture. It occurs in women between their 50s and 60s and in men in 70s. It is more prevalent in women than in men. Although the causes of osteoporosis are not well understood, it is believed that reduced levels of estrogen secretion at menopouse may cause this condition. The withdrawal of estrogen causes increased formation of osteroclasts. There is an imbalance between bone formation and resorption. Therefore, teenage girls are advised to eat more calcium rich food such as milk and other dairy products so as to slow down the progression of osteoporosis.

19.5.6. Gout :

It is yet another form of arthritis. Gout is characterized by an elevated level of uric acid in the body fluid. This causes an excess deposition of insoluble crystals of sodium urate at the joints, especially of the big toe, causing painful inflammation. The most prevalent cause of gout is an improper excretion of uric acid. It may also result from a number of metabolic deficiencies. One well understood cause is the deficiency of an enzyme involved in purin metabolism. This leads to an excess production of uric acid, leading to a syndroms called Lesh-Nyhan syndrome.

SAMPLE QUESTIONS

GROUP - A
(Objective-type Questions)

1. Choose the correct answer

(i) The total no. of bones in human body is
(a) 106 (b) 206
(c) 306 (d) 246

(ii) The contraction of muscle of shotest duration is seen in
(a) Jaw (b) Eye lid
(c) Heart (d) Inlestine

(iii) What is the total number of ribs in human ?
(a) 12 (b) 16
(c) 20 (d) 24

(iv) Which unstriated muscle is entirely involuntary
(a) In the diaphragm (c) At the base of external ear
(b) In the eyelid (d) At the pylorous

(v) Total no. of muscles in human is
(a) 639 (b) 936
(c) 369 (d) 669

(vi) Cori cycle operates within one of the following organs
(a) Liver only (b) Liver and muscle
(c) Muscle only (d) None of these

(vii) One of the following muscles contains myoglobin, stores oxygen and rich in mitochondria
(a) White muscle (b) Red muscle
(c) Both (d) None

(viii) How many vertebrae are present in man?
(a) 33 (c) 31
(b) 32 (d) 30

(ix) Cervical vertebrae are present in
(a) Thorax (b) Neck
(c) Abdomen (d) Tail

(x) Study of muscle is known as
(a) Musculogy (b) Myology
(c) Arthrology (d) Mycology

(xi) Knee joint is a
(a) Ball and socket Joint (c) Hinge Joint
(b) Pivot Joint (d) Bicondylar joint

(xii) Study of joints is called
(a) Osteology (b) Mycology
(c) Arthrology (d) Chondrology

(xiii) Joint between feumur and pelvic girdle is called
(a) Ball and socket Joint (c) Saddle Joint
(b) Pivot Joint (d) Hinge Joint

(xiv) Joint between the lower jaw and skull is called
(a) Gliding (b) Hinge
(c) Perfect (d) Gomphoses

(xv) Which bone is present in pectoral girdle of all mammal
(a) Scapula (b) Ilium
(c) Coracoid (d) Pubis

(xvi) If ossification occurs in a tendon, which bone is formed
(a) Sesamoid bone (c) Membrane bone
(b) Replacing bone (d) Dermal bone

(xvii) Which of the muscles bends the fore arm upward
(a) Biceps (c) Gastrocremius
(b) Triceps (d) Gluteus maximus

(xviii) Which bone is the longest in the body
(a) Fibula (b) Femur
(c) Tibia (d) Ulna

(xix) Which bone of man is not used for protection and support in the body
(a) Stapes (b) Atlas
(c) Ribs (d) Scapula

(xx) The joint between carpals and radius and ulna is called
(a) Condylar Joint (c) Gliding Joint
(b) Immovable Joint (d) Saddle Joint

(xxi) Articulation of odontoid process of axis and atlas vertebrae is an example of
(a) Gliding Joint (c) Pivot Joint
(b) Ball & socket Joint (d) Hinge Joint

(xxii) Articulation of metacarpal of thumb with its carpal is an example of
(a) Saddle Joint (b) Hinge Joint
(c) Pivot Joint (d) Gliding Joint

(xxiii) Articular cavity the pectoral girdle is
(a) Acetabulum (c) Neural canal
(b) Glenoid cavity (d) Foramen of Monro

(xxiv) Name of the joint at acetabulum
(a) Hip Joint (c) Knee Joint
(b) Shoulder Joint (d) Elbow Joint

(xxv) Sutures present between various bones of the skull are
(a) Carlilaginous Joint (c) Hinge Joint
(b) Synovial Joint (d) Fibrous Joint

(xxvi) Number of true ribs and floating ribs are
(a) 6 & 3 (b) 0 & 2
(c) 9 & 4 (d) 20 & 4

(xxvii) Which joint occurs between humerus and radius and ulna
(a) Pivot Joint (c) Sliding Joint
(b) Hinge Joint (d) Ball & Socket Joint

(xxviii) Functions of long bones in mammal is to provide
(a) Support
(b) Support and production of RBCs
(c) Support and production of WBC
(d) Support and production of RBCs and WBCs

(xxix) Epiphyseal plate at the extremity of long bones help in
(a) Elongation of bone
(b) Bone moulding
(c) Bone formation
(d) Formation of Haversian canals

(xxx) Muscle that bends one part over another is
(a) Extensor (b) Flexor
(c) Adductor (d) Abductor

(xxxi) Malleus, incus and stapes occur in
(a) Skull (b) Middle ear
(c) Pectoral girdle (d) Pelvic girdle

2. Express the following statements in one word or more words, wherever necessary.

(i) What is the name of the contractile unit of a skeletal muscle fibre.
(ii) What is myology ?
(iii) Where do you see pivot joint ?
(iv) Give an example of gomphosis.
(v) What is the alternate name of breast bone ?
(vi) In which part of the endo skeleton you come across sutures ?
(vii) What do you call the bones of the wrist ?
(viii) How many lumber vertebrae are there in human ?
(ix) What is a vertebrate limb having five digits known as ?
(x) What is the alternat source of energy in a skeletal muscle ?

3. Fill in the blanks with appropriate words :

(i) _____ muscle contracts during flexon of the elbow joint.
(ii) Hip joint is an example of _____ joint.
(iii) The centrum of mammalian vertebrae is of _____ type.
(iv) Each 'I' band of the muscle fiber contains a dense line at the centre, known as _____.
(v) _____ muscle relaxes the elbow joint.
(vi) A muscle gets fatigued by an accumulation of _____.
(vii) Myoglobin is found in _____
(viii) Knee joint is a _____ type of joint.
(ix) Contraction of _____ muscle helps in lifting heavy weight.
(x) The stretch of a myofibril between two Z-lines is known as _____.
(xi) The shoulder joint is classified as _____ joint.
(xii) Stiffening of the body after death of a person is known as _____.
(xiii) There are _____ number of vertebrae in the human vertebral column.
(xiv) Total number of bones in the human skull are _____.
(xv) Total number of metacarpals in the wrist of man is _____.
(xvi) There are _____ cervical vertebrae in all mammals.

GROUP - B
(Short Answer-type Questions)

1. Answer each within 50 words.

(i) What do understand by a pentadactyl limb ?
(ii) Enlist the constituent parts of the appendicular skeletal system of human.
(iii) Enlist the constituent parts of the axial skeletal system of human.
(iv) What is the role of troponin in muscle contraction ?
(v) What is a synovial joint ? Give two examples
(vi) What is a fibrus joint ? Explain with an example.
(vii) Differentiate between rheumatoid arthrtis and osteoarthritis.
(viii) What are myofilaments ? How many types of myofilaments are present in a myofibril ?
(ix) Describe the role of trrponin and tropomyosin in skeletal muscle contraction.
(x) What is the role of phosphocreatine in the skeletal muscle contraction ?
(xi) What is sarcoplasmic reticulum ? Where it is found and what is its function ?
(xii) What is muscle twich ?
(xiii) What is an antagonistic muscle ?
(xiv) What is synovial fluid ?
(xv) What is the function of supinator muscle ?

2. Differentiate between two words in the following pairs words :

(i) Appendicular skeleton and Axial skeleton
(ii) Synovial joint and Solid joint
(iii) Actin and Myosin
(iv) Rheumatoid asthritis and Osteoarthritis
(v) Red muscle fibers and White muscle fibers
(vi) Biceps and Triceps
(vii) Skeletal muscle and Cardiac muscle
(viii) Involuntary muscle and Voluntary muscle
(ix) Striated muscle and Unstriated muscle.

GROUP - C
(Long Answer-type Questions)

1. Describe the sliding filament theory of skeletal muscle contraction.
2. Draw a neat labeled diagram of a sarcomere of skeletal muscle fiber (No description is necessary)

❑❑❑

NEURAL CONTROL AND COORDINATION

CHAPTER 20

The nervous system along with the endocrine system serves as a communication system of the body. It regulates a majority of internal functions and controls the expression of human behaviour. Human behaviour not only includes such observed acts as smiling, crying moving body parts in response to external stimuli but also many acts, which can't be observed, such as thinking, emotion, learning, memory, etc. Therefore, the nervous system is the one, which coordinates amongst various parts of the body and makes it to function as an integrated whole. The body breaks apart without the proper functioning of this system.

The nervous system is studied from two counts: **structural** and **functional**. Structurally, it consists of two divisions, namely, (1) **central nervous system (CNS)** including the **brain** and the **spinal cord and** (2) **peripheral nervous system (PNS)**, constituted by the **cranial nerves** arising from the brain and **spinal nerves** arising from the spinal cord. The nerves of the PNS travel a long distance as that from the spinal cord to the finger tip and from the brain to the internal organs. Functionally, the system consists of two divisions: **somatic** and **visceral**. In the somatic division, there are innervations of structures like skin and skeletal muscle. It deals with receiving and responding to the information from the external environment. On the contrary, the visceral division innervates body's organ systems and other visceral elements such as smooth muscle and glands. It deals with detecting and responding to information from the internal environment. Hereunder, we are taking up with the structural components and in due course of the discussion, you will be acquainted with the functuional aspects. Prior to it, we present a brief account of the celluar elements of the nervous system.

20.1. NEURAL TISSUE :

The fundamental units of the nervous system are the **nerve cells** or **neurons**. Structurally, a neuron is specialized in having an elongated shape with many processes arising from it. Functionally, it is also specialized in possessing an excitability property unlike a majority of cells. Hence, it has a property of conduction of impulses from one place of the body to the other. These cells help communicate from all parts of the body to the brain and vice versa. The neurons are generally aligned one after the other with specialized junctions known as synapses. That is, one neuron ends and the second begins with a junction, the **synapse**. The means of communication is by generating an **electric potential (impulse)** in one neuron and then transmitting it to the next across a synapse. At the synapse, the electrical impulse turns into a

chemical impulse and again it changes over to an electrical impulse in the next neuron. Thus, the communication by conduction is partly electrical and partly chemical.

20.1.1. Structure of a typical neuron :

Neurons vary considerably in shape, size and other features. However, most of them are built on a common plan. A neuron consists of a **cell body** also known as a **cyton** or **soma** or **perikaryon**. It gives off a variable number of processes called **neurites [Fig. 20.1 (a)]**.

20.1.1.1. Cell Body [Fig. 20.1. (b)] : It contains a mass of cytoplasm surrounding a centrally situated nucleus with a plasma membrane as the limiting membrane. The cytoplasm contains cytoplasmic organelles typical to a cell. The presence of centrioles was debated in the past. However, electronmicroscopic study has revealed the presence of a pair of centrioles. The cytoplasm contains basophilic (stains with basic dyes) granular materials called **Nissl body** or **substance** or **granule**. Electronmicroscopic study has confirmed that Nissl body contains parallel stacks of rough endoplasmic reticulum. The dendrites also contain rough endoplasmic reticulum, while the axon doesn't. However, smooth endoplasmic reticulum is present in all parts of the neuron cytoplasm. Lysosomes are present only in the cell body. Many slender mitochondria are present in the cell body and dendrites. Mitochondria also occur in the axon cytoplasm but are more numerous in the axon terminals. The cytoplasm is traversed by a network of slender fibers called **neurofibrils**. These fibrils are the microfilaments consisting of microtubules.

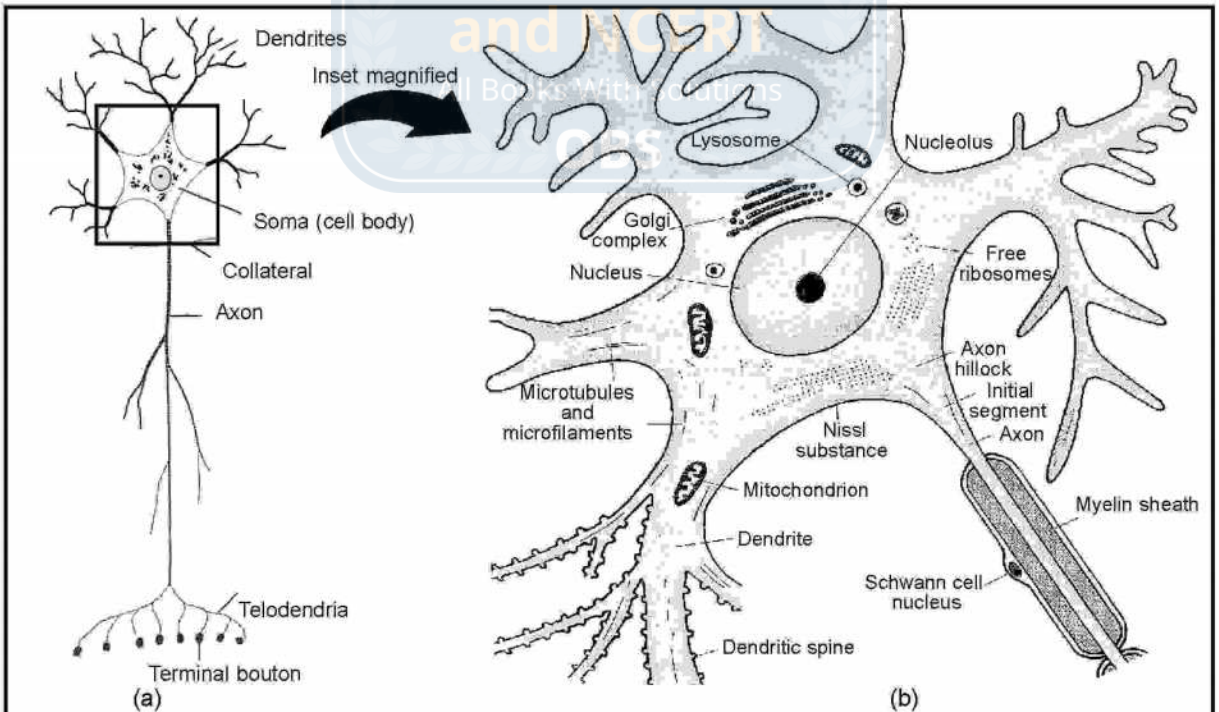


Fig. 20.1 : Structure of a typical neuron. (a) a neuron in the CNS and peripheral ganglion and (b) cell body (magnified)

20.1.1.2. Neurites: The neuritis are of two types: **axon** and **dendrites [Fig. 20.1 (a) and 20.2]**

(a) Axon: The axon is the singular long process, which arises from the cell body and conducts the impulse away from it. It originates from a conical protrusion of the cell body known as **axon hillock**. An axon is of uniform diameter and is devoid of Nissl body. The axons, with the exception of those of the CNS, associate with nonconducting cells called **Schwann cells (Fig. 20.2)**. These cells form and deposit an insulating lipid, known as **myelin** around these axons. **Myelin sheath** or **medullary sheath** forms an insulating sheath around many peripheral nerves and thus protects the adjoining tissues from developing a potential difference during conduction of nerve impulse (Fig. 20.3). A thin layer of Schwann cell cytoplasm persists on the outer side of myelin sheath forming a secondary layer called **neurilemma**. The myelin is deposited in a discontinuous manner around most peripheral nerves. This results in the formation of distinct **nodes** and **internodes** along the length of the axon. The myelin insulated part is the internode, while the myelin free part is the node called **node of Ranvier** (Fig. 20.2). Such myelin encapsulated nerve fibers are known as **myelinated** or **medullated nerve fibers**, while those without myelin sheaths are **unmyelinated** or **nonmedullated nerve fibers**. The axons lying in the CNS are provided with a similar type of sheath by **oligodendrocytes [Fig. 20.2 (above the broken line)]** .

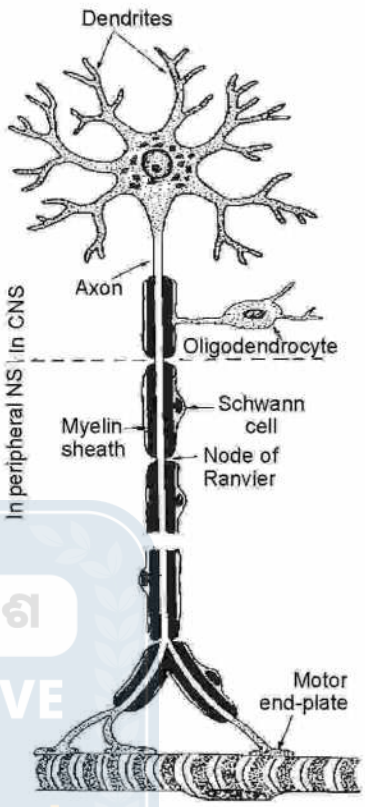


Fig. 20.2 : A neuron exhibiting the structures both of the CNS (see above the broken line) and PNS (see below the broken line).

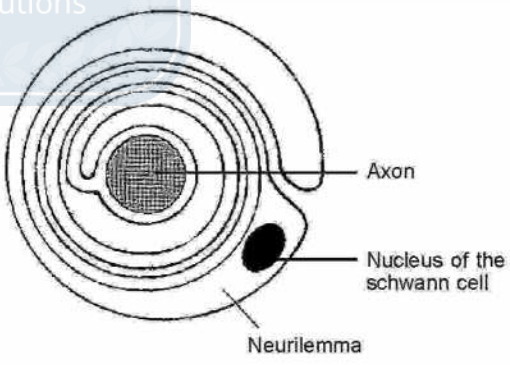


Fig. 20.3 : Mature myelin sheath and neurilemma surrounding a myelinated nerve fiber (axon).

- **Multiple Sclerosis**

  It is a chronic neurodegenerative disease that destroys myelin sheaths of neurons in multiple areas of the CNS. The myelin sheaths harden and become defunct. The consequence is loss of impulse conduction property. It leads to a progressive loss of functions of the CNS. One of the causes of this disease is the destruction of the oligodendrocytes and myelin sheaths by the self immune system. Inflammation occurs, which then leads to demyelination.

The axon may give off variable number of branches. Branches, which arise near the cell body and are perpendicular to the axon are known as **collaterals** [Fig. 20.1 (a)]. At its termination, the axon breaks up into many finer branches called **telodendria** that may end in small swellings known as **terminal boutons**. An axon terminates in either of the two ways. In the CNS, its terminal part forms a junction (synapse) with the dendron of another neuron known as an **interneuron** or **integrator neuron**. Outside the CNS, an axon terminates in an **effector tissue** or organ. The axon terminals are responsible for releasing chemical messengers from the axon. Some neurons release their chemical messengers from a series of bulgings along the axon. These bulging have been termed as **varicosities**.

(b) Dendrites: The many nerve processes, which terminate near the cell body are known as dendrites. Dendrites are shorter in length and are more numerous containing Nissl body. Dendrites carry impulses towards the cell body.

Nonconducting supporting cells in the CNS

- **Neuroglia** are the nonconducting supporting cells of the CNS. In addition to a mechanical support, they provide a suitable environment for optimal functioning of neurons. These are of four types. **astrocytes**, **oligodendrocytes**, **microglia** and **ependymal cells**.
- **Astrocytes:** Nourish neurons
- **Oligodendrocytes:** Form myelin sheaths around axons in the CNS
- **Microglia:** Serve as phagocytes to clear the damaged and injured parts of the CNS.
- **Ependymal cells:** Epithelial cells lining the ventricles of the brain and central canal of the spinal cord. Their cilia help in the streaming movement of the cerebrospinal fluid. Also serve as neural stem cells from which new neurons and neuroglial cells may be formed.

Nonconducting supporting cells in the PNS

- The PNS contains two types of supporting cells: **Schwann cells** and **satellite cells** or **ganglionic gliocytes.**
- **Schwann cell:** Form myelin sheath around axons in the PNS.
- **Satellite cells** or **ganglionic gliocytes:** Support cell bodies of neurons in the ganglia of the PNS.

20.1.2. Classification of neurons:

Neurons are classified both from **structural** and **functional standpoints**.

20.1.2.1. Structural classification (Fig. 20.4) : Neurons are classed as **pseudounipolar**, **bipolar** and **multipolar** from structural view point.

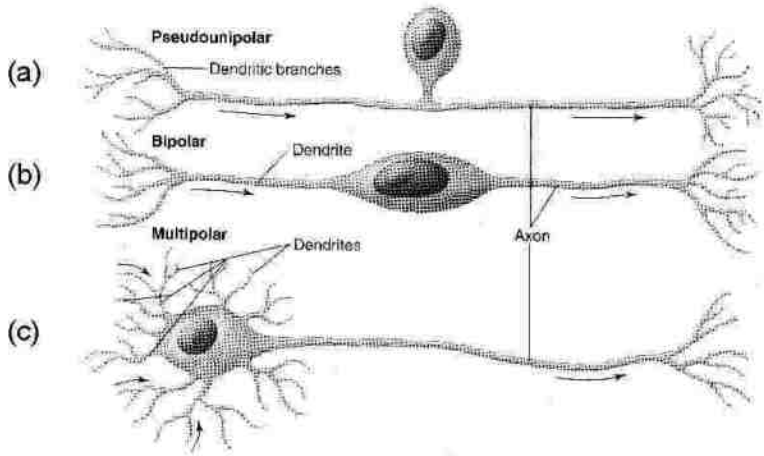


Fig. 20.4 : Structural classification of neurons into (a) pseudo-unipolar; (b) bipolar; and (c) multipolar.

(a) Pseudo-unipolar neuron: A short single process, the axon originates from the cell body and soon after its origin; it bifurcates into a longer peripheral and a shorter central process. The peripheral process ends in a receptor organ, while the shorter central process enters into the CNS, where it forms synapses with other neurons. **Somatic sensory** and **visceral sensory neurons** fall under this category.

(b) Bipolar neuron: A bipolar neuron has two processes, one each at two poles of the cell body. One process is the axon, while the other is a dendron. This type is found in the retina of the eye.

(c) Multipolar neuron: This neuron has several short processes at one pole, while a single long process at the opposite pole. The shorter processes are the dendrites, while the single long process is the axon. This is the most abundant type of neuron in the nervous system

20.1.2.2. Functional classification (Fig. 20.5) : Neurons are of three types, namely **afferent (sensory)**, **efferent (motor)** and **interneurons** or **association neurons** or **integrator neurons**.

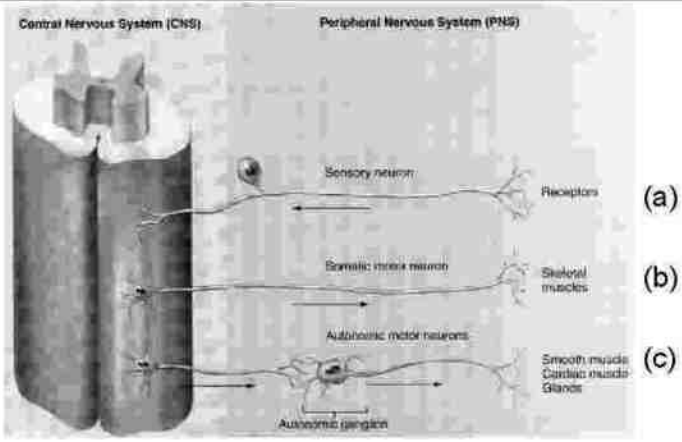


Fig. 20.5 : Functional classification of neurons into (a) somatic and visceral sensory (afferent); (b) somatic motor (efferent); and (c) autonomic motor (efferent).

(a) Afferent neurons: Afferent neurons are also known as **sensory neurons**. These conduct impulse from the tissues and organs **(sensory receptors)** to the CNS. These are pseudounipolar neurons having a single short process, which branches like a 'T' to form a pair of long processes. These processes are two branches of the axon. The relatively longer peripheral process ends in a receptor, while the relatively shorter central process enters the CNS to form synapse with other neurons. The cell body and the longer peripheral process lie outside the CNS.

(b) Efferent neurons: Efferent neurons are also known as **motor neurons**. These conduct impulse from the CNS to the **effector tissues** and organs i.e. muscle and glands. There are two types of efferent (motor) neurons: **somatic** and **autonomic**. The somatic **motor neurons** are responsible for both reflex and voluntary control of skeletal muscle. The cell bodies and dendrites of the somatic motor neurons lie in the CNS, while the axons extend into the voluntary effector tissue (skeletal muscle). The autonomic motor neurons innervate the involuntary effector tissues and organs i.e. smooth muscle, cardiac muscle and glands. The cell bodies of the autonomic motor neurons lie outside the CNS in the autonomic ganglia. There are two types of autonomic motor neurons: **sympathetic** and **parasympathetic**. The autonomic motor neurons with their control centres constitute the **autonomic nervous system (ANS)**.

(c) Interneurons: These are also known as **association** or **integrator neurons**. These connect the afferent and efferent neurons in the CNS. These neurons play an integrative role in the nervous system.

The axons of both afferent and efferent neurons outside the CNS form nerves. An approximate estimate is that for each afferent neuron entering the CNS, there are about 10 efferent neurons and 2,00,000 interneurons. Interneurons account for 99% of all neurons.

20.1.3. Synapse (Fig. 20.6) :

A nerve is a cylindrical conducting structure formed by a bundle of fibers or axons of a group of neurons travelling together to a destination. The neurons are joined end to end or terminate in target tissues or organs forming specialized junctions called **synapses**. Alternately a synapse is a functional junction between a neuron and a second cell. In the CNS, this second cell is always a neuron, while in the PNS, it may either be a neuron or an effector cell within a muscle or gland. When the junction is with an effector cell, it is known as a **myoneural** or **neuromuscular junction**. In a neuron-neuron synapse, the preceding neuron is known as **pre-synaptic**, while the succeeding as **post-synaptic**.

Synapses are of two types: **electrical** and **chemical**. In an electrical synapse, the action potential is conducted from the pre-synaptic membrane to the postsynaptic membrane. The plasma membrane of the pre- and post-synaptic neurons are joined by gap junctions at the synapse. Electrical synapses are rare in mammalian nervous systems. In a chemical synapse, the plasma membranes of the pre and post-synaptic neurons are separated by a gap known as a **synaptic cleft** at the synapse. The terminal part of the pre-synaptic neuron has endings called terminal boutons. These endings store a chemical substance known as **neurotransmitter**

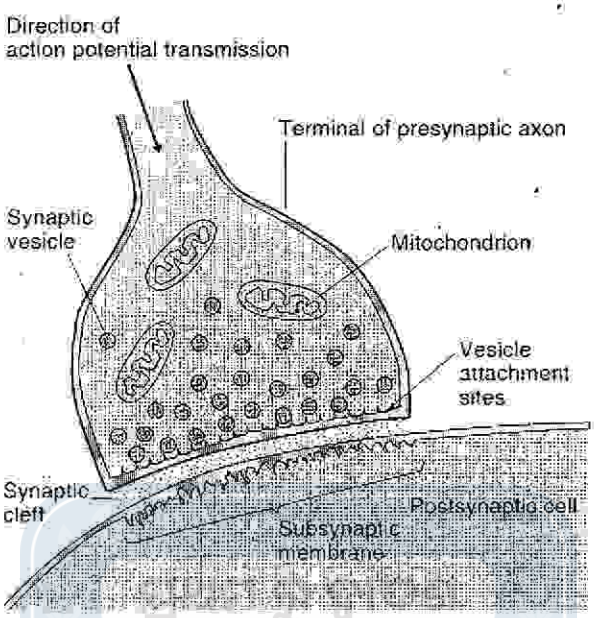


Fig 20.6. Structure of a synapse

in **synaptic vesicles**. On depolarization of the presynaptic neuron membrane at the synapse, the synaptic vesicles fuse with membrane by exocytosis and thus release the neurotransmitter into the synaptic cleft. There are neurotransmitter specific receptors on the postsynaptic neuron membrane. The neurotransmitter molecules bind to their specific receptors and bring about a depolarization of the membrane which propagates in a forward direction.

20.2. THE SYSTEM :

The nervous system, as discussed above, is studied under two heads from structural standpoint: (1) **Central Nervous System (CNS)** consisting of the brain and the spinal cord and (2) **Peripheral Nervous System (PNS)** consisting of the nerves arising from the brain (cranial nerves) and spinal cord (spinal nerves), which innervate all points of the body.

- A group of nerve fibers in the CNS travelling together constitutes a **pathway** or **tract**. When a tract connects the right and left halves, it is a **commissure**. A group of fibers travelling together to the same general destination of the PNS constitutes a **nerve**.
- Groups of cell bodies of neurons in the CNS constitute **nuclei** (**singular: nucleus**)
  Groups of cell bodies in the PNS constitute **ganglia** (**singular: ganglion**).

20.2.1. Central Nervous System (CNS) :

The CNS consists of the brain followed by a spinal cord. Since the brain and spinal cord are made by delicate nervous tissue, there are several degrees of protection to these structures. This system receives inputs from the sensory neurons and directs the activity of the motor neurons innervating muscles and glands. It maintains a state of equilibrium in the internal

environment and guarantees the continued existence of the individual in a changing external environment.

20.2.1.1. Protective Layers of the CNS (Fig. 20.7) : The brain is lodged in a **brain box** or **cranium** formed by several skull bones. Similarly, the spinal cord is present in the neural canal of the vertebral column. Besides the bones, both constituent parts of the CNS are surrounded by three concentric connective tissue layers known as **meninges** (**singular: meninx**). The outermost layer is the **dura mater** consisting of dense fibrous connective tissue. It forms an internal lining of the cranium as well as the neural canal. Inner to the dura mater, there is a more delicate connective tissue layer known as **arachnoid mater**. Inner to the arachnoid mater, there is a delicate connective tissue layer known as **pia mater**. This layer contains numerous blood vessels and directly adhears to the surface of the brain and spinal cord. There is a sub-arachnoid space between the arachnoid mater and pia mater. Fine and delicate collagen and elastic fibers attach the arachnoid mater to the pia mater forming web like **trabeculae**. The sub-arachnoid space is filled with a colourless fluid known as **cerebrospinal fluid** (**CSF**), which acts as a cushion. The ventricles of the brain and the central canal of the spinal cord are also filled with CSF. Following its circulation, it is absorbed and drained into the venous blood by **arachnoid villi**. Fresh CSF is secreted into the space by the **choroid plexuses**.

- **Meningitis:**

  Meningitis is an infection and inflammation of the arachnoid mater and pia mater (leptomeninges) by some bacteria and viruses. Meningococcal bacteria are noteworthy in such an infection. Overwhelming inflammation may lead to cerebral irritation to an extent that may cause sepsis, coma and ultimately death.

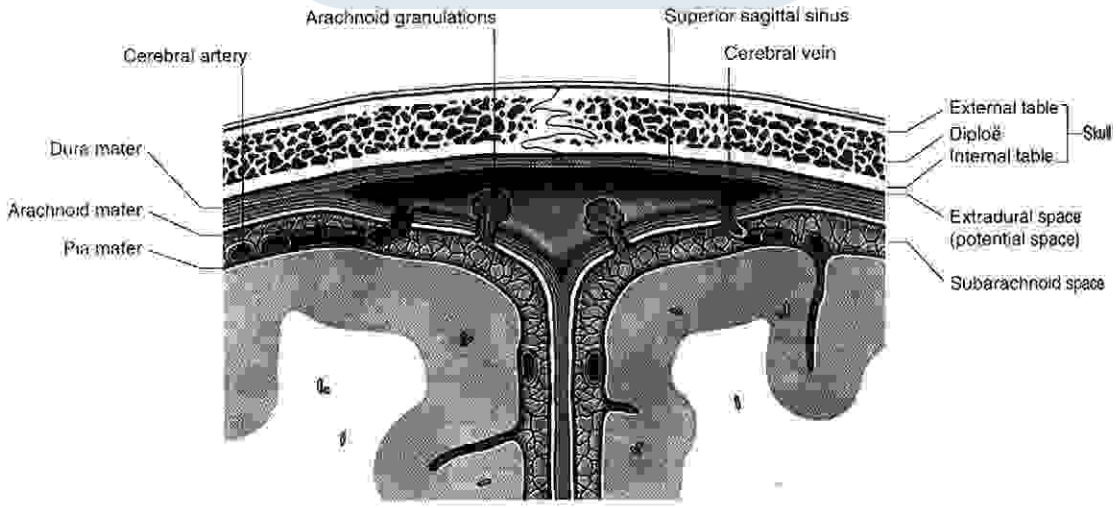


Fig. 20.7 : Protective layers of the brain

- **Hydrocephalus:**

  It is a condition, in which there is a dilation of the ventricles of the brain due to an obstruction in the flow of CSF or overproduction of CSF or failure of its reabsorption. The CSF is secreted by the choroid plexuses. It circulates and reaches the fourth ventricle and passes into the subarachnoid space through foramina. It is then absorbed into the dural venous sinus through the arachnoid granulations. However, sometimes there is a failure of its reabsorption. It is the main cause of hydrocephalus in adults. Another cause is congenital obstruction of the aqueduct of Sylvius, where the CSF fails to pass from the third to the fourth ventricle leading to its failure of reabsorption and hence results in its accumulation and then to hydrocephalus.

20.2.1.2. Brain : During its development, the human brain has three major divisions: **forebrain (posencephalon), mid brain (mesencephalon)** and **hindbrain (rhombencephalon) (Fig. 20.8)**. The forebrain has two divisions, namely **telencephalon**, formed by a pair of **cerebral hemispheres** and a **diencephalon**. The cerebral hemispheres together constitute the **cerebrum**. The midbrain is constituted by **corpora quadrigemina**. The hind brain consists of two divisions such as **metencephalon** and **myelencephalon**. The metencephalon is constituted by **pons** and **cerebellum**., while the myelencephalon consists of **medulla oblongata**. Mid brain, pons and medulla oblongata form the **brain stem**. The adult brain contains an estimated 100 billion (10^{11}) neurons, weighs about 1.5 Kg and receives about 20% of the body's total blood supply.

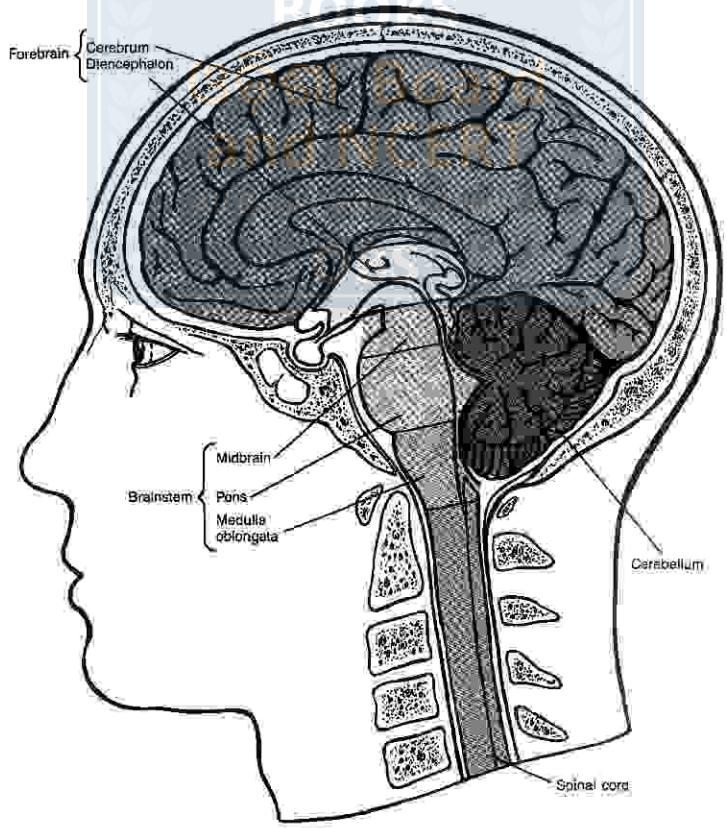


Fig 20.8 : Six divisions of the human brain and the spinal cord.

(a) Forebrain (Prosencephalon): The forebrain is divided into two regions: telencephalon constituted by two cerebral hemisperes (cerebrum) and diencephalon.

(i) Cerebrum (Telencephalon): The cerebrum consists of the right and left cerebral hemispheres, connected internally by a large tract of fibers called **corpus callosum**. The surface of the cerebrum is convoluted by the presence of several projections and depressions, known as **gyri** (**singular: gyrus**) and **sulci** (**singular: sulcus**), respectively. Major sulci, which are deep depressions, divide each cerebral hemisphere into five lobes, namely **frontal**, **parietal**, **temporal**, **occipital** and **insula (Fig. 20.9)**. All lobes except insula are visible from the surface. Insula is present internally and covered by parts of frontal, parietal and temporal lobes. The cerebrum consists of an outer **cerebral cortex** consisting of 2 – 4 mm of **grey matter** with an underlying **white matter** and **subcortical nuclei**. The subcortical nuclei are parts of the grey matter present within the underlying white matter of the cerebral cortex. Predominant among the subcortical nuclei, are the **basal nuclei** or **ganglia**, which regulate voluntary movement and posture and other complex aspects of behavior. Again the most important of the basal nuclei is the **corpus striatum**, consisting of several nuclei, such as **caudate** and **lentiform nuclei**. Lentiform nucleus is constituted by **putamen** and **globus pallidus nuclei**. The degeneration in the caudate necleus causes a dominant neuro-degenerative disorder, **Huntington's Chorea** or **disease**, characterised by rapid and uncontrolled jerky movements. The basal nuclei are involved in the control of voluntary movements.

The grey matter contains cell bodies of neurons and the dendrites while the white matter contains myelinated nerve fibers. Nerve fibers from various places, particularly from the thalamus and brain stem enter the cortex. Some of these convey about changes in the external environment, while others are involved in cortical excitability and arousal.

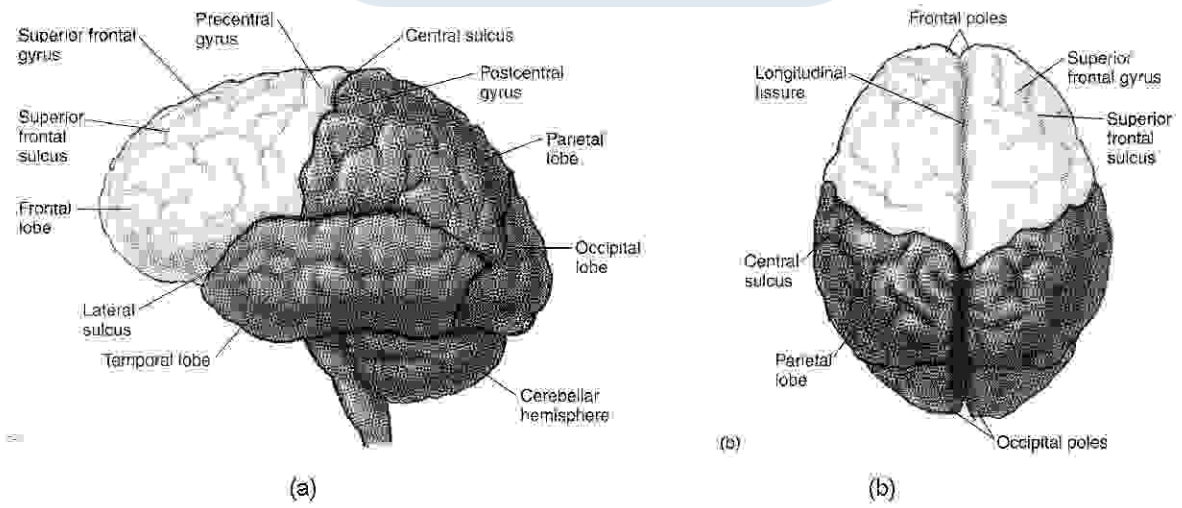
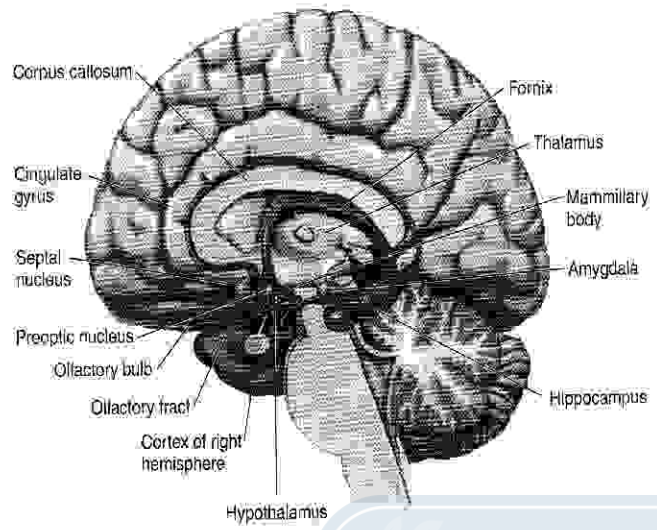


Fig. 20.9 : Lateral view of the brain showing the lobes of cerebral cortex.
(a) Lateral view, (b) Drosal view.



- **Limbic System:**

  Emotional states of a person are controlled by the hypothalamus and limbic system. The limbic system is a group of forebrain nuclei and their fiber tracts, which form a ring around the brain. The system is constituted by cingulate gyrus (a part of the cerebral cortex), amygdala, hippocampus and septal nuclei. Fornix, a fiber tract connects the hippocampus with the mammillary bodies. The hippocampus is a critical part of the brain that is invoved in learning and memory.

There are two forwardly directed **olfactory tracts** on the ventral side of the cerebrum, each ending in an **olfactory bulb**.

(ii) Diencephalon: It is a part of the fore brain consisting of **epithalamus**, **thalamus** and **hypothalamus**. The epithalamus is the dorsal part or roof of diencephalon containing a **choroid plexus** and the **pineal gland** or **epiphysis**. The choroid plexus secretes CSF, while the pineal secretes a hormone called **melatonin**. Melatonin plays a role in the endocrine control of reproduction.

The **thalamus** constitutes 4/5th part of the diencephalon and forms most of the wall of the third ventricle. It consists of paired patches of grey matter positioned below the respective lateral ventricle. It acts as a relay centre through which all sensory information inputs from all parts of the CNS except smell pass to the cerebrum. It is also responsible for relaying neural information outputs. The thalamus also brings about a state of alertness and causes arousal from sleep in response to an appropriate sensory stimulus.

The floor of diencephalon specializes as the **hypothalamus**. Although it is small, it regulates important functions like hunger and thirst. It also regulates sleep, wakefulness, sexual arousal and performance and such emotional behaviours like anger, fear, pain and pleasure. In its regulation of emotion, it works together with the limbic system. Hypothalamus acts as body's **thermostat** i.e. it regulates body temperature. The anterior hypothalamus contains bilateral **suprachiasmatic nuclei**, which are believed to regulate body's **circadian** or **daily rythms**. The hypothalamus evaginates downward as a stalk known as the **infundibulum**. The tip of the infundibulum specializes as **posterior pituitary** or **neurohypophysis**. An **anterior pituitary** or **adenohypophysis** is associated with the posterior pituitary. Both constitute the **pituitary gland** or **hypophysis**. It is an important endocrine gland that regulates many target endocrine glands and othe vital body functions.

- **The Brain Stem :**

  The brain stem literally means stalk of the brain. It is constituted by mid brain, pons and medulla oblongata. It acts as a relay centre for sensory and motor pathways. A mass of loosely arranged cell bodies and axons, known as reticular formation run through the brain stem. The reticular formation establishes a communication network between the spinal cord and cerebrum. Information between the brain stem and cerebellum is established by three large bundles of nerve fibers known as cerebellar peduncles. Thus, it receives and integrates the information inputs from all parts of the CNS and dispatches instruction outputs.

- **Blood Brain Barrier :**

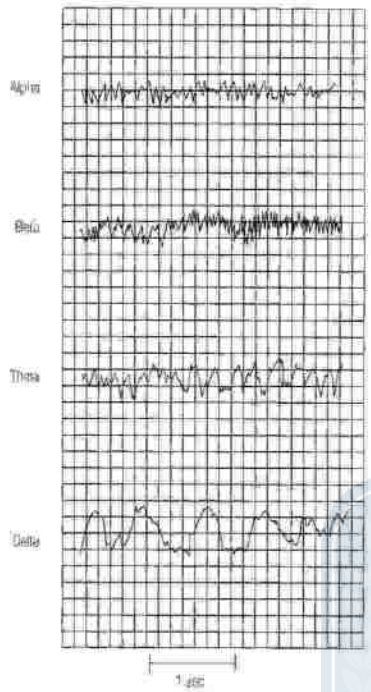
  Unlike in most other organs, the brain capillaries do not have pores for free exchange of materials between the blood and extracellular fluid of the neural tissue. The endothelial cells are present in close adherence to each other with tight junctions. The endothelial cells with their tight junctions stand as a barrier, known as blood brain barrier. The barrier prevents free exchange between the two environments.

  The barrier presents difficulty in chemotherapy and treating patients with DOPA, suffering from Parkinson's disease, since DOPA cannot cross the barrier. Such patients are administered with Levo-DOPA (L-DOPA), a precursor of DOPA. This precursor can cross the barrier into the neural tissue. Since all antibiotics cannot cross this barrier, antibiotics only that can cross the barrier are used in treating patients with meningitis.

(b) Midbrain (Mesencephalon) : The midbrain or mesencephalon is situated between the diencephalon and pons. It consists of four rounded elevations on its dorsal surface. These elevations constitute **corpora quadrigemina**. The two upper elevations are known as **superior colliculi, which** are involved in visual reflexes. The lower two, the inferior colliculi are relay centres for auditory information. The midbrain also contains the **cerebral peduncles, red nucleus** and **substantia nigra**.

- **Cerebral Stroke:**

  A cerebral stroke is a cardiovascular accident, in which there is an interruption in the normal blood supply to the brain. It results in sub-normal or no functioning of the brain depending on the degree of stroke. It is of two types: ischemic and hemorrhagic. In ischemic type, the normal blood flow is prohibited by the formation of an atherosclerotic plaque in the carotid artery, which supplies the brain, while hemorrhagic stroke is caused by the rupture of blood capillaries due to hypertension or an accident. The risk factors for stroke are those of cardiovascular diseases such as diabetes mellitus and hypertension and smoking. Stroke is a neurological emergency. It requires an early diagnosis to decide on the course of action of a treatment.



● **Electroencephalogram (EEG):**

The electric potential created at the dendrites and cell bodies of neurons of the cerebral cortex produce electric current that can be measured by placing electrodes on the scalp. The recorded electric current constitutes an electroencephalogram (EEG). There are four types of EEG patterns:

Alpha waves: These waves are emitted from parietal and occipital regions when a person is relaxed in an awakened state with both eyes closed. Such waves indicate happiness. The frequency is 10-12 cycles per second in an adult, while 4-7 cycles per second in a child under the age of 8 years.

Beta waves: Strong beta waves are generated from the frontal region. These waves have lower amplitude and higher frequency than the alpha waves. It indicates that a person is attentive and is thinking hard about something. The frequency is 13-25 cycles per second.

Theta waves: These waves are emitted from the temporal and occipital lobes. These occur at a frequency of 5-8 cycles per second and are common in infants. The emission in adults indicate a severe emotional stress.

Delta waves: These waves are emitted from the cerebral cortex and have a frequency of 1-5 cycles per second, which are common during sleep in an adult and awake infants. The emission of these waves in an awake adult suggests brain damage.

(c) Hindbrain (Rhombencephalon) : The hindbrain or rhombencephalon consists of two divisions: metencephalon and myelencephalon. The metencephalon is constituted by pons and cerebellum, while mylencephalon consists of medulla oblongata.

(i) Pons (Metencephalon) : It is a bulged part of the brain present on the lower side between the midbrain and medulla. It has both surface fibers and deeper fibers. The surface fibers connect the cerebellum, while deeper fibers, both sensory and motor, connect the midbrain with the medulla. It has several nuclei associated with trigeminal (V), abducens (VI), facial (VII), and vestibulo-cochlear (VIII) cranial nerves. Many other nuclei are associated with such regions of the medulla regulating breathing. These nuclei are the respiratory control centres in the pons.

(ii) Cerebellum (Metencephalon) : Next to the cerebrum, cerebellum is the complex regulatory centre of the brain. **It is also the second largest part of the brain, the first being the cerebrum.** It contains around 100 billion neurons. It is made up of three lobes, namely an **upper vermis** and two **lateral cerebellar hemispheres**. The cerebellum has an outer convoluted layer known as the **cerebellar cortex**. It consists of outer grey matter and an underlying white matter. Fibers from the cerebellum pass through the red nucleus of the thalamus to the cerebral cortex. Other tracts connect the cerebellum with the pons, medulla oblongata and spinal cord. The pair of fiber tracts, which connects the cerebellum with the brain stem is known as **cerebellar peduncles**. It receives several inputs from the receptor of joints, tendons and skeletal muscle. Working together with the basal nuclei and motor areas of the cerebral cortex, it coordinates

movements. Damage to the cerebellum produces **ataxia**, i.e. lack of coordination in speed and direction of movement. The speech is also affected like those of intoxicated persons.

- **Parkinson's Disease:**

  It is a neurodegenerative disease, next to Alzheimers disease in frequency. There is a degeneration of dopaminergic neurons in the substantia nigra of the midbrain. These neurons send fibers to the corpus striatum of the basal nucleus (a large mass of subcortical neuronal cell bodies) . These cell bodies initiate skeletal muscle movement. Their degeneration expresses symptoms, such as muscle tremors and rigidity, difficulty in initiating movements and speech and other severe motor problems. The patients are often treated with L-DOPA and monoamine oxidase inhibitors in an attempt to increase the dopaminergic transmission.

- **Alzheimer's Disease:**

  It is the most frequently occurring neurodegenerative disease in the human population. It is associated with a progressive loss of memory (senile dementia) and mental deterioration. Lesions develop in the brain due to the deposition of dense extracellular insoluble proteins called amyloid beta proteins. Twisted fibrils called neurofibrillar tangles are formed within the decaying neurons. It is also associated with the degeneration of cholinergic neurons, which terminate in the hippocampus and cerebral cortex. The patients are currently treated with cholinesterase inhibitors in an attempt to increase cholinergic transmission in the brain. Another combination of treatment in practice is by vitamin E and other antioxidants, which would reduce oxidative stress.

(iii) Medulla Oblongata (Myelencephalon) : Simply known as medulla, it is a part of the brain between the anteriorly situated pons and spinal cord behind. All ascending and descending fiber tracts that communicate between spinal cord and brain pass through it. Many such fiber tracts of the left side cross over to the right and vice versa through elevated triangular structures called **pyramids**. The left side of the brain receives sensory information from the right side of the body, while the right from the left. Similarly, the right side of the brain controls motor activities of the left side of the body and vice versa. Cranial nerves VIII, IX, X, XI and XII arise from the medulla. The medulla contains groups of neurons implicated in the **regulation of breathing** and **cardiovascular functions**. The respiratory centre of the medulla acts in close cooperation with those present in the pons.

(d) Ventricles of the brain (Fig. 20.10) : The brain is a hollow structure, each segment of it having a cavity known as a **ventricle**. All the ventricles are continuous with each other. The ventricle continues into the spinal cord as a **central canal**. The ventricles of the brain and the central canal of the spinal cord are filled with circulating cerebrospinal fluid. The ventricles are as follows: