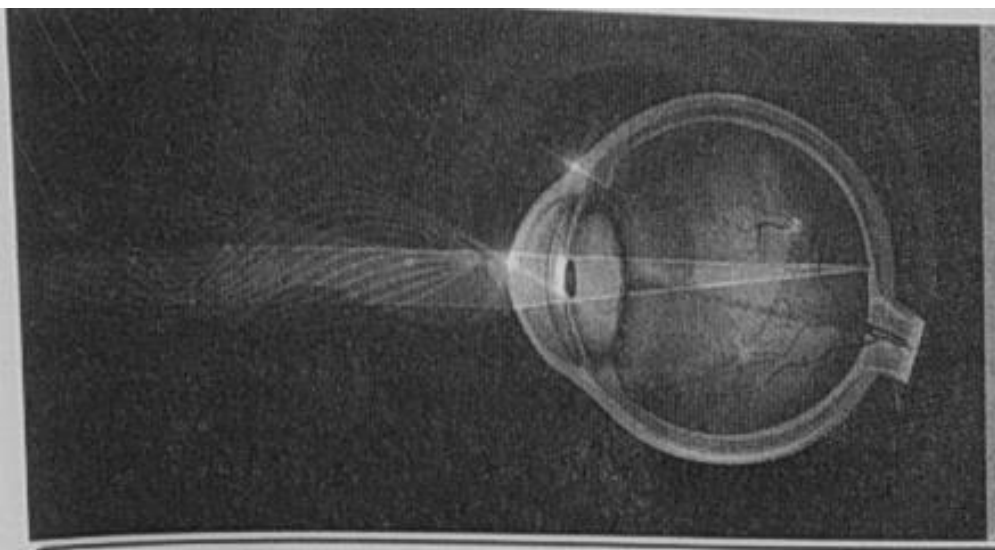


UNIT-II

MUSCLE AND NERVOUS SYSTEM

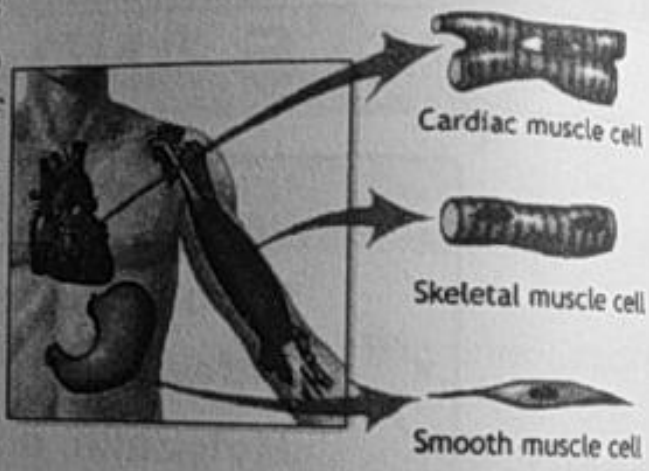
Learning Objectives :

- ✓ Histology of different types of muscles
- ✓ Ultrastructure of Skeletal muscles
- ✓ Molecular and chemical basis of muscle contraction
- ✓ Structure of Neuron
- ✓ Resting membrane potential / Origin of action potential
- ✓ Propagation of action potential across the myelinated and unmyelinated nerve fibres.
- ✓ Types of Synapse, Synaptic transmission
- ✓ Neuromuscluar Junction
- ✓ Reflex action and its types, Reflex Arc
- ✓ Physiology of hearing and physiology of vision

INTRODUCTION

The muscular system is the biological system of humans that produces movement. The muscular system, in vertebrates, is controlled through the nervous system, although some muscles, like cardiac muscle, can be completely autonomous. Its function is to produce force and cause motion, either locomotion or movement within internal organs. Much of muscle contraction occurs without conscious thought and is necessary for survival, like the contraction of the heart or peristalsis, which pushes food through the digestive system. Voluntary muscle contraction is

used to move the body and can be finely controlled, such as movements of the finger or gross movements that of the biceps and triceps. Muscle is composed of muscle cells (sometimes known as "muscle fibres"). Within the cells are myofibrils; myofibrils contain sarcomeres which are composed of actin and myosin. Muscle cells are bound together by perimysium into bundles called fascicles. These bundles are then grouped together to form muscle, and is lined by epimysium. Skeletal muscle, which involves muscles is connected by tendons to processes of the skeleton. In contrast, smooth muscle occurs at various scales in almost every organ, from the skin (in which it controls erection of body hair) to the blood vessels and digestive tract.



There are approximately 640 skeletal muscles in the human body. Muscle comprises the largest group of tissue in the body, accounting for approximately half of the body's weight. Contrary to popular belief, the number of muscle fibres cannot be increased through exercise; instead the muscle cells simply get bigger. There are three basic types of muscles in the body (smooth, cardiac, and skeletal). In skeletal muscle, contraction is stimulated at each cell by nervous impulses that releases acetylcholine at the neuromuscular junction, creating action potentials along the cell membrane.

Neurons are highly specialized cells for the processing and transmission of cellular signals. With the variety of functions performed by neurons in different parts of the body, a wide diversity in the shape, size, and electrochemical properties of neurons are found. The soma (cell body) is the central part of the neuron. It contains the nucleus. The dendrites of a neuron are cellular extensions with many branches, and is referred to as a dendritic tree. This is where the majority of input to the neuron occurs. The axon is a fine, cable-like projection which carries nerve signals away from the soma.

The part of the axon where it emerges from the soma is called the'axon hillock'. While the axon and axon hillock are generally involved in information outflow, this region can also receive input from other neurons as well. The axon terminal is a specialized structure at the end of the axon that is used to release neurotransmitter chemicals and communicate with target neurons. The longest axon of a human motor neuron can be over a meter long, reaching from the base of the spine to the toes. Sensory neurons have axons that run from the toes to the dorsal columns, over 1.5 meters in adults. Giraffes have single axons several meters in length running along the entire length of their necks.

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CHAPTER-1

HISTOLOGY OF DIFFERENT TYPES OF MUSCLES

INTRODUCTION

In higher animals contractile cells called myocytes occur in the body to perform different modes of movements and locomotion. Muscle cells or myocytes are specialized for contractile ability. Muscle cells or myocytes are organized to form a special tissue called muscle tissue. **Muscle tissue** is a soft tissue that composes muscles in animal bodies, and gives rise to muscles' ability to contract.

A wide variety of muscle types are present in the animal body to meet the wide variety of functions including movement of an animal through its environment, maintenance of body posture, circulatory movements, gastro-intestinal tract movements, movement along the reproductive tract and so forth.

Muscle tissue varies with function and location in the body. They are classified by three different methods, based on different factors.

I. Depending upon the presence or absence of striations.
II. Depending upon the control.
III. Depending upon the situation.

DEPENDING UPON STRIATIONS

Depending upon the presence or absence of cross striations, the muscles are divided into two groups: 1. Striated muscle, 2. Non-striated muscle.

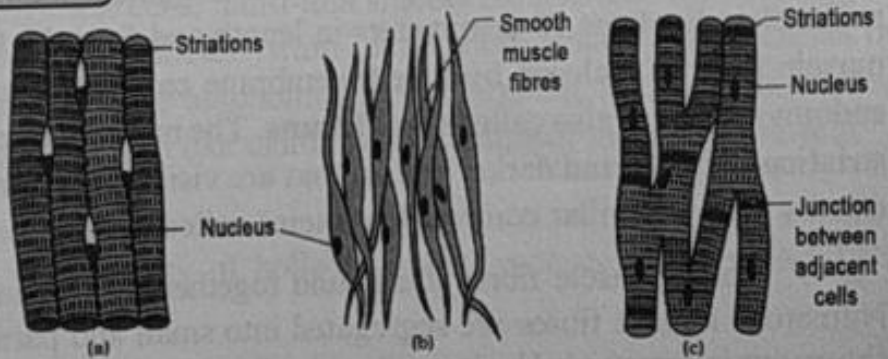

Fig. 1.1 a. Skeletal muscle tissue , b. Smooth muscle tissue , c. Cardiac muscle tissue

1.Striated Muscle : Striated muscle is the muscle which has a large number of cross-striations (transverse lines). Skeletal muscle and cardiac muscle belong to this category. Cardiac muscle, is sometimes known as semi-striated.

2.Non-striated Muscle : Muscle which does not have cross-striations is called non-striated muscle. It is also called plain muscle or smooth muscle. It is found in the wall of the visceral organs.

DEPENDING UPON CONTROL

Depending upon control, the muscles are classified into two types: 1. Voluntary muscle 2. Involuntary muscle.

1.Voluntary Muscle: Voluntary muscle is the muscle that is controlled by the will of the animal. Striated or skeletal muscle only contracts voluntarily, upon influence of the central nervous system.

2.Involuntary Muscle: Muscle that cannot be controlled by the will is called involuntary muscle. Smooth and cardiac muscle contracts involuntarily, without conscious intervention. These muscle types may be activated both through interaction of the CNS as well as by receiving innervation from autonomic nerves or endocrine (hormonal) activation.

DEPENDING UPON SITUATION

Depending upon situation, the muscles are classified into three types: 1. Skeletal muscle, 2. Smooth muscle, 3. Cardiac muscle

1. SKELETAL MUSCLE (STRIATED MUSCLE)

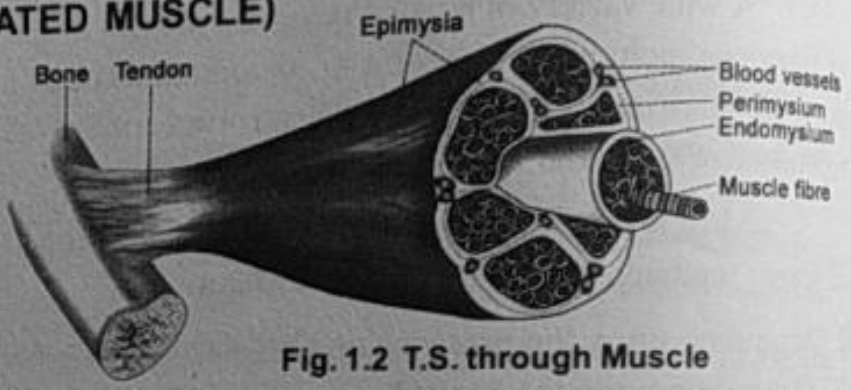

Fig. 1.2 T.S. through Muscle

Skeletal muscle is situated in association with bones forming the skeletal system. It is used to effect skeletal movement such as locomotion and to maintain posture. An average adult male is made up of 42% of skeletal muscle and an average adult female is made up of 36% (as a percentage of body mass). Skeletal muscles always remain arranged in the form of bundles of individual muscle fibres. A striated or skeletal muscle fibre (myocytes) is an elongated multinucleate cell ranging from several millimeters to about 10 centimeters in length and from 10 to 100 micrometers in width. Each muscle fibre is enclosed by a cell membrane called plasma membrane, that lies beneath the endomysium. It is also called **sarcolemma**. The myofibres are oriented vertically; the horizontal striations (lighter and darker bands) that are visible result from differences in composition and density of myofibrillar contractile proteins called myofilaments within the cells.

These muscle fibres are bound together by a connective tissue called **endomysium**. Numerous muscle fibres are segregated into small and parallel bundles called **fasciculi**. Each fasciculus is surrounded by large strands of connective tissue called **perimysium**. Blood capillary and nerve fibres are present in the perimysium. All the fasciculi in a single striated muscle is surrounded by another connective tissue membrane called **epimysium**. These muscles are supplied by somatic nerves. Skeletal muscles are anchored to the bones by the tendons. Cytoplasm of the muscle is known as sarcoplasm.

Structures embedded within the sarcoplasm are: 1. Nuclei, 2. Myofibril, 3. Golgi apparatus, 4. Mitochondria, 5. Sarcoplasmic reticulum, 6. Ribosomes, 7. Glycogen droplets, 8. Occasional lipid droplets.

The short dark patches to the side of the myofibres are cell nuclei.Each muscle fibre has got one or more nuclei. In long muscle fibres, many nuclei are seen. Nuclei are oval or elongated and situated just beneath the sarcolemma. Usually in other cells, the nucleus is in the interior of the cell. All organelles of muscle fibre have same functions as those of other cells.

Function

1.They carry out movements of the body, 2.They support the body, 3.Aids in bone movement, 4. Assists with the movement of cardiovascular and lymphatic vessels through contractions, 5. Protection of internal organs and contributing to joint stability, 6. They maintain the posture of the body.

2. SMOOTH MUSCLE

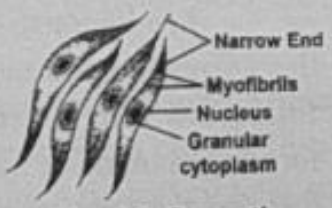

Fig. 1.3 Smooth Muscle fibres

These muscles are also called unstriated muscles. Smoot muscles are neither striated nor under voluntary control. They are foun within the walls of organs and structures such as the oesophagu stomach, intestines, bronchi, uterus, urethra, bladder, blood vessels, an the arrector pili in the skin. It is also called visceral muscle as it is situate in association with viscera. The smooth muscle fibres taper at both ends and do not show striation. They are thin, spindle-shaped, uninucleate and undivided. Cell junctions hold them together and they are bundled together in a connective tissue sheath. Sarcoplasm contains longitudinal but somewhat scattered myofibrils.

Smooth muscles can be divided into two subgroups: **single unit** (unitary) and **multi unit**. **Single unit** smooth muscle cells can be found in the gut and blood vessels. Because these cells are linked together by gap junctions, they are able to contract as a syncytium or contract together as a single unit. Single-unit smooth muscle cells contract myogenically, which can be modulated by the autonomic nervous system.

Unlike single-unit smooth muscle cells, multi-unit smooth muscle cells are found in the muscle of the eye and in the base of hair follicles. Multi-unit smooth muscle cells contract by being separately stimulated by nerves of the autonomic nervous system. As such, they allow for fine control and gradual responses, much like motor unit recruitment in skeletal muscle.

Function

It is responsible for the contractility of hollow organs, such as blood vessels, the gastrointestinal tract, and the bladder.

3. CARDIAC MUSCLE (MYOCARDIUM)

Found only in the heart, is a striated muscle similar in structure to skeletal muscle but not subject to voluntary control. Cardiac muscle cells are joined end to end. The resulting fibres are branched and interconnected to form complex networks. Each cell has a single nucleus. The muscle cells are shorter, thicker, cylindrical, nucleated, branched and remain covered by sarcolemma. At its end, where it touches another cell, there is a specialized intercellular junction called an **intercalated disc**, which occurs only in cardiac tissue. As a matter of fact, the intercalated discs represent the cell membranes that separate individual cardiac muscle cells from each other. The cardiac muscle cells are so tightly bound that when one of the cells become excited, the action potential spreads to all of them through their lattice work. Cardiac muscle is controlled involuntarily for pumping blood through the heart chambers into the blood

vessels. There are two types of cardiac muscle cells: autorhythmic and contractile. Autorhythmic muscle cells do not contract, but instead set the pace of contraction for other cardiac muscle cells, which can be modulated by the autonomic nervous system. In contrast, contractile muscle cells constitute the majority of the heart muscle and are able to contract.

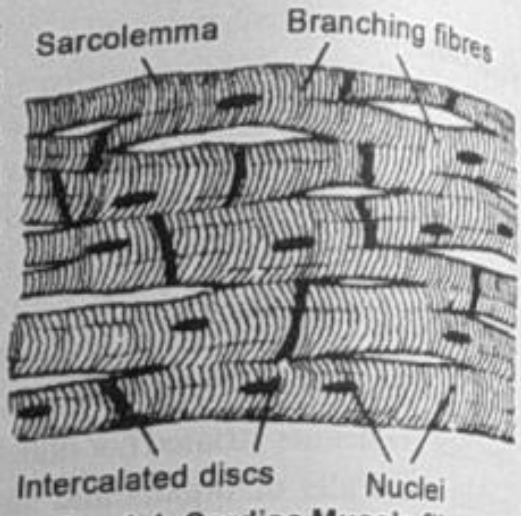

Fig. 1.4 Cardiac Muscle fibres

In addition to the cardiac muscles associated with the auricles and ventricles special conductive muscle fibres are also present. These include **nodal fibres** forming S-A node and A-V node, **transitional fibres** forming the inter-nodal connecting fibres and **Purkinje fibres** found associated with the walls of ventricles. The conductive tissue of heart contracts feebly because it contains few contractile fibrils, but provide rapid conduction of impulses through the heart.

Function

Cardiac muscle is the muscle of the heart. It is self-contracting, autonomically regulated and must continue to contract in rhythmic fashion for the whole life of the organism. Hence it has special features.

EXERCISE

A. Fill in the blanks:

1. Striated muscle is differentiated from that of non-stiated muscle on the basis of presence of _____
2. The muscle type found in the wall of alimentary canal is _____.
3. Mucle fibre is enclosed by a cell membrane is called _____.
4. Cytoplasm of the muscle cell is known as _____.

Answer : 1. Cross-striations, 2. Smooth muscle, 3. Sarcolemma, 4. Sarcoplasm

B. Give one word answer.

1. Muscle with branched muscle fibres.
2. The muscle that works in rhythmic fashion.

Answer : 1. Cardiac muscle, 2. Cardiac muscle / myocardium

C. Answer in two to three sentences each.

1. Single unit smooth muscle, 2. Multi unit smooth muscle, 3. Intercalated disc

D. Anwer in 75 words.

1. Cardiac muscle, 2. Fasciculi, 3. Smooth muscle.

E. Answer within 500 words.

1. Give an account of histology of different types of muscle in the body.
2. Describe the histology of skeletal muscle and cardiac muscle.

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CHAPTER-2

ULTRA STRUCTURE OF SKELETAL MUSCLES

INTRODUCTION

All skeletal muscles are composed of numerous muscle fibres bound together by connective tissue. The fibres lie parallel to each other and range from 10 to 100 μm in diameter (1 μm = 1 millionth of a meter). In most skeletal muscles, each fibre extends the entire length of the muscle.

Each muscle fibre is a multinucleate cell which was formed during embryonic development from the fusion of a large number of mononuclear myoblasts. Each muscle fibre is surrounded by a plasma membrane called the *sarcolemma* which contains a typical cytoplasm called *sarcoplasm*. The sarcoplasm contains numerous mitochondria, many nuclei, proteins, enzymes, glycogen, lipid droplets, a small Golgi body and sarcoplasmic reticulum.

FINE STRUCTURE OF SKELETAL MUSCLE FIBRE

Further magnification reveals that each muscle fibre is made up of numerous longitudinal, parallel, slender subunits called ***myofibrils***. Each muscle fibre contains several hundred to several thousand myofibrils. Myofibrils are specialized contractile elements having a diameter of about 1 – 2 μm. They constitute 80% of the volume of the muscle fibre.

Sarcotubular system: Sarcotubular system is a system of membranous structures in the form of tubules in the sarcoplasm of the muscle fibre. It surrounds the myofibrils embedded in the sarcoplasm. Sarcotubular system is formed mainly by two types of structures: 1. T-tubules, 2. L-tubules or sarcoplasmic reticulum.

1. T-Tubules: T-tubules or transverse tubules are formed by the invagination of the sarcolemma. These tubules penetrate all the way from one side of the muscle fibre to another side. Because of their origin from sarcolemma, the T-tubules open to the exterior of the muscle cell allowing the ECF to run through their lumen.

Function of T-Tubules: T-tubules are responsible for rapid transmission of impulse in the form of action potential from sarcolemma to the myofibrils. Since T-tubules are the continuation of sarcolemma, the action potential passes through them and reaches the interior of the muscle fibre rapidly.

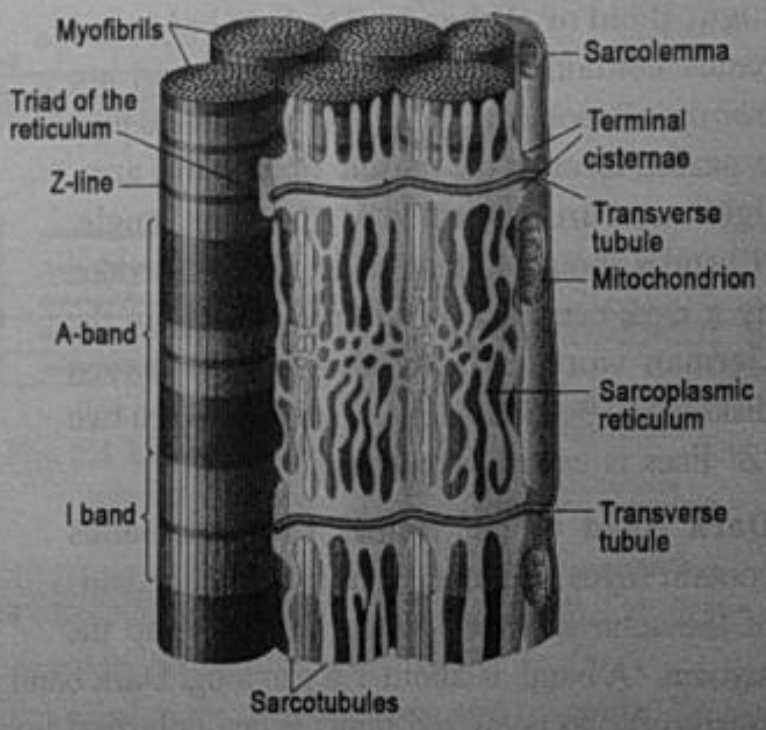

Fig. 2.1 Detailed structure of skeletal Muscle

2. L-Tubules or **Sarcoplasmic Reticulum:**

L-tubules or longitudinal tubules are the closed tubules that run along the axis of the muscle fibre, forming sarcoplasmic reticulum. These tubules form a closed tubular system around each myofibril and do not open to exterior like T-tubules. L-tubules correspond to the endoplasmic reticulum of other cells. At regular intervals, the L-tubules dilate to form a pair of lateral sacs called terminal cisternae. Each pair of terminal cisternae is in close contact with T-tubule. The T-tubule along with the cisternae on either side is called the triad of skeletal muscle. In human skeletal muscle, the triads are situated at the junction between 'A' band and 'I' band. Calcium ions are stored in L-tubule and the amount of calcium ions is more in cisternae.

Function of L-Tubules: L-tubules store a large quantity of calcium ions. When action potential reaches the cisternae of L-tubule, the calcium ions are released into the sarcoplasm. Calcium ions trigger the processes of muscle contraction.

The myofibrils further consist of two kinds of even smaller structures called ***myofilaments***. Each myofibril is composed of about 1500 adjacent *myosin filaments* and 3000 *actin filaments,* which are large polymerized protein molecules that are responsible for the actual muscle contraction.

The myofibrils have a striated appearance because conspicuous cross striations divide it into alternating **light** and **dark** bands. The light bands are called ***I bands*** because they are *isotropic* to polarized light. The dark bands are called ***A bands*** because they are *anisotropic* to polarized light.

The levels of organization in a skeletal muscle: Muscle → Muscle fibre → Myofibril → Thick & thin filaments → Myosin & actin

Light Band or 'I' bands: The light bands or I bands contain only actin filaments and are *isotropic* to polarized light. When polarized light is passed through the muscle fibre at this area, light rays are refracted at the same angle. 'I'band is about 1 μm long. The I band is divided by a dark central Z-band or Z-line (from the German word zwischenscheibe = between disks). The portion of myofibril in between two 'Z' lines is called **sarcomere**.

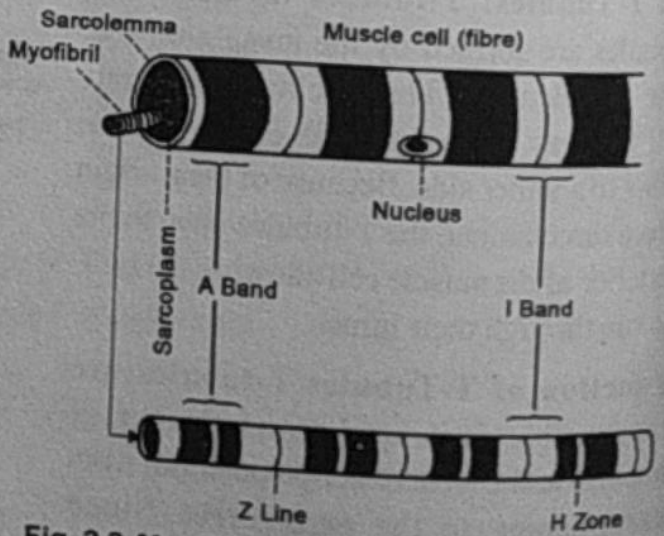

Fig. 2.2 Myofibril showing A Band and I Band

Dark Band or 'A' Band: The dark bands contain myosin filaments, as well as the ends of the actin filaments where they overlap the myosin. 'A'band is about 1.6 μm long. Dark band is called 'A' (anisotropic) band because it is anisotropic to polarized light. When polarized light is passed through the muscle fibre at this area, the light rays are refracted at different directions. Dark band is also called 'Q' disk

(Querscheibe = cross disk). In the middle of 'A' band, there is a light area called 'H' zone (H = Henson – discoverer). In the middle of 'H' zone lies the middle part of myosin filament. This is called 'M' line (in German-mittel = middle). 'M' line is formed by myosin binding proteins.

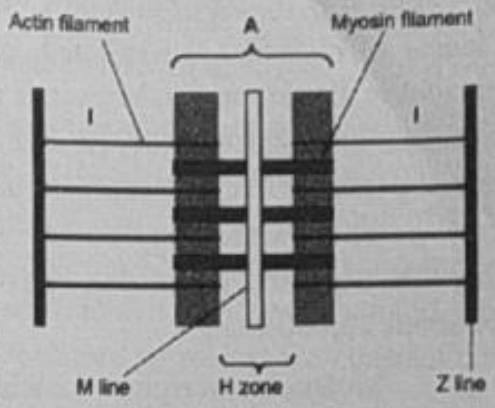

Fig. 2.3 Sarcomere

Sarcomere: Each sarcomere extends between two 'Z' lines of myofibril. Thus, each myofibril contains many sarcomeres arranged in series throughout its length. When the muscle is in relaxed state, the average length of each sarcomere is 2 to 3 μ. Sarcomere is defined as the structural and functional unit of a skeletal muscle. It is also called the basic contractile unit of the muscle.

ELECTRON MICROSCOPIC STUDY OF SARCOMERE

Electron microscopic studies reveal that the sarcomere consists of many thread-like structures called myofilaments. Myofilaments are of two types: 1. Actin filaments 2. Myosin filaments.

1. Actin Filaments: Actin filaments are the thin filaments with a diameter of 20 Å and a length of 1 μ. These filaments extend from either side of the 'Z' lines, run across 'I' band and enter into 'A' band up to 'H' zone.

2. Myosin Filaments: These are thick filaments with a diameter of 115 Å and a length of 1.5 μ. These filaments are situated in 'A' band.The myosin filament is composed of multiple myosin molecules, each having a molecular weight of about 480,000. Small projections from the sides of the myosin filaments are *cross-bridges*. It is the interaction between these cross-bridges and the actin filaments that causes contraction.

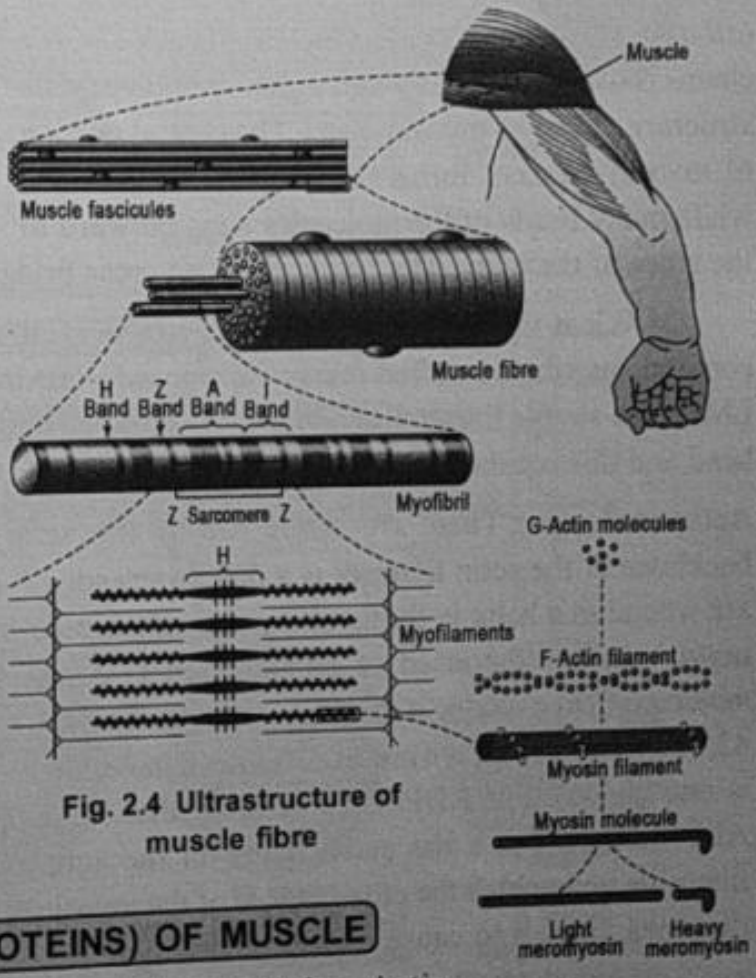

Fig. 2.4 Ultrastructure of muscle fibre

CONTRACTILE ELEMENTS (PROTEINS) OF MUSCLE

Myosin filaments are formed by *myosin* molecules. Actin filaments are formed by three types of proteins called *actin, tropomyosin* and *troponin*. These four proteins together constitute the contractile proteins or the contractile elements of the muscle.

Myosin molecule : Each myosin filament consists of about 200 myosin molecules. Though about 18 classes of myosin are identified, only myosin II is present in the sarcomere. Myosin II is a globulin with a molecular weight of 480,000. The *myosin molecule* is composed of six polypeptide chains—two *heavy chains*, each with a molecular weight of about 200,000, and four *light chains* with molecular weights of about 20,000 each.

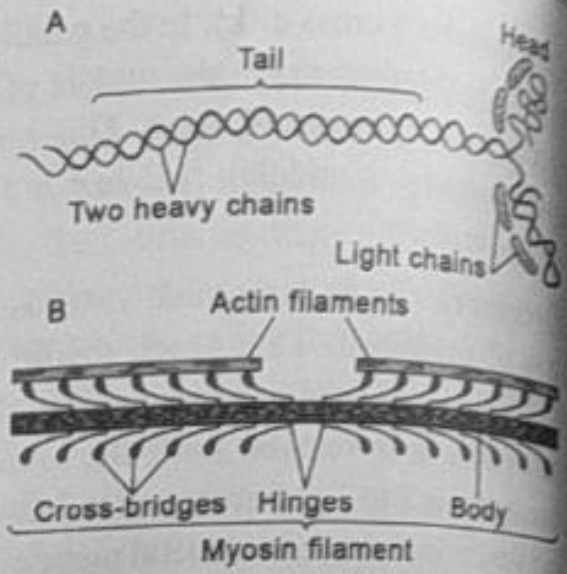

Fig. 2.5 A - Myosin molecule
B - Myosin filament

Molecular weight of each heavy chain is 200,000 (2 × 200,000 = 400,000). Molecular weight of each light chain is 20,000 (4 × 20,000 = 80,000). Thus, total molecular weight of each myosin molecule is 480,000 (400,000 + 80,000). The length of the molecule is 1500 A° and its diameter is 20-40 A°. The two heavy chains wrap spirally around each other to form a double helix, which is called the *tail* of the myosin molecule. One end of each of these chains is folded bilaterally into a globular polypeptide structure called as myosin *head.* The central portion of myosin filament forms the *body* of the filament, while many heads of the molecules hang outward to the sides of the body. The heads establish cross bridges between the thick and thin filaments.

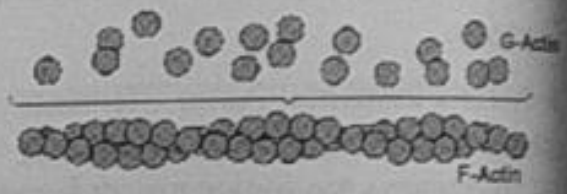

Fig. 2.6 Actin Filament

When the myosin molecule is treated with enzyme **trypsin,** it separates into two components, the so called *heavy meromyosin* (HMM) and *light meromyosin* (LMM). The LMM is a simple linear strand and constitutes the tail region. The HMM have a large globular head and this region contains all the enzymatic and actin binding activity of the molecule.

Actin molecule: There are about 300 to 400 actin molecules in each actin filament. The backbone of the actin filament is a double stranded *F-actin protein molecule.* The two strands are wound in a helix in the same manner as the myosin molecule. Each strand of the double *F-actin* helix is composed of polymerized *G-actin molecules*, each having a molecular weight of about 42,000. Attached to each one of the G-actin molecules is one molecule of ADP. It is believed that these ADP molecules are the active sites on the actin filaments with which the crossbridges of the myosin filaments interact to cause muscle contraction.

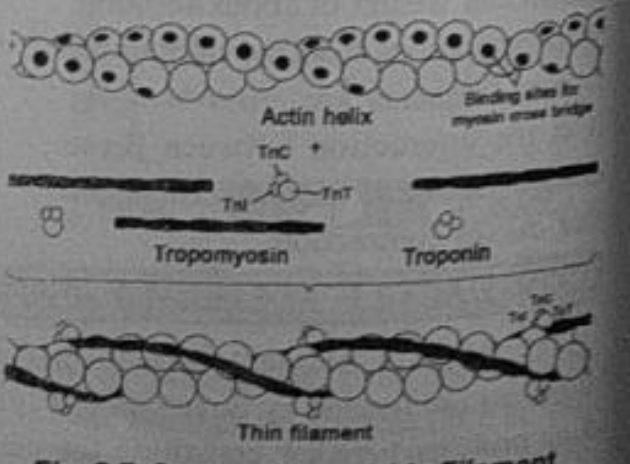

Fig. 2.7 Composition of thin Filament

Tropomyosin Molecules : About 40 to 60 tropomyosin molecules are situated along the double helix strand of actin filament. These molecules are wrapped spirally around the sides of the F-actin helix.

Each molecule of tropomyosin has a molecular weight of 70,000. In the resting state, the tropomyosin molecules lie on top of the active sites of the actin strands, so that attraction cannot occur between the actin and myosin filaments to cause contraction.

Troponin : Attached intermittently along the sides of the tropomyosin molecules are still other protein molecules called *troponin*. These are actually complexes of three loosely bound protein subunits, each of which plays a specific role in controlling muscle contraction. One of the subunits (troponin I) has a strong affinity for actin, another (troponin T) for tropomyosin, and a third (troponin C) for calcium ions. This complex is believed to attach the tropomyosin to the actin.The strong affinity of the troponin for calcium ions is believed to initiate the contraction process.

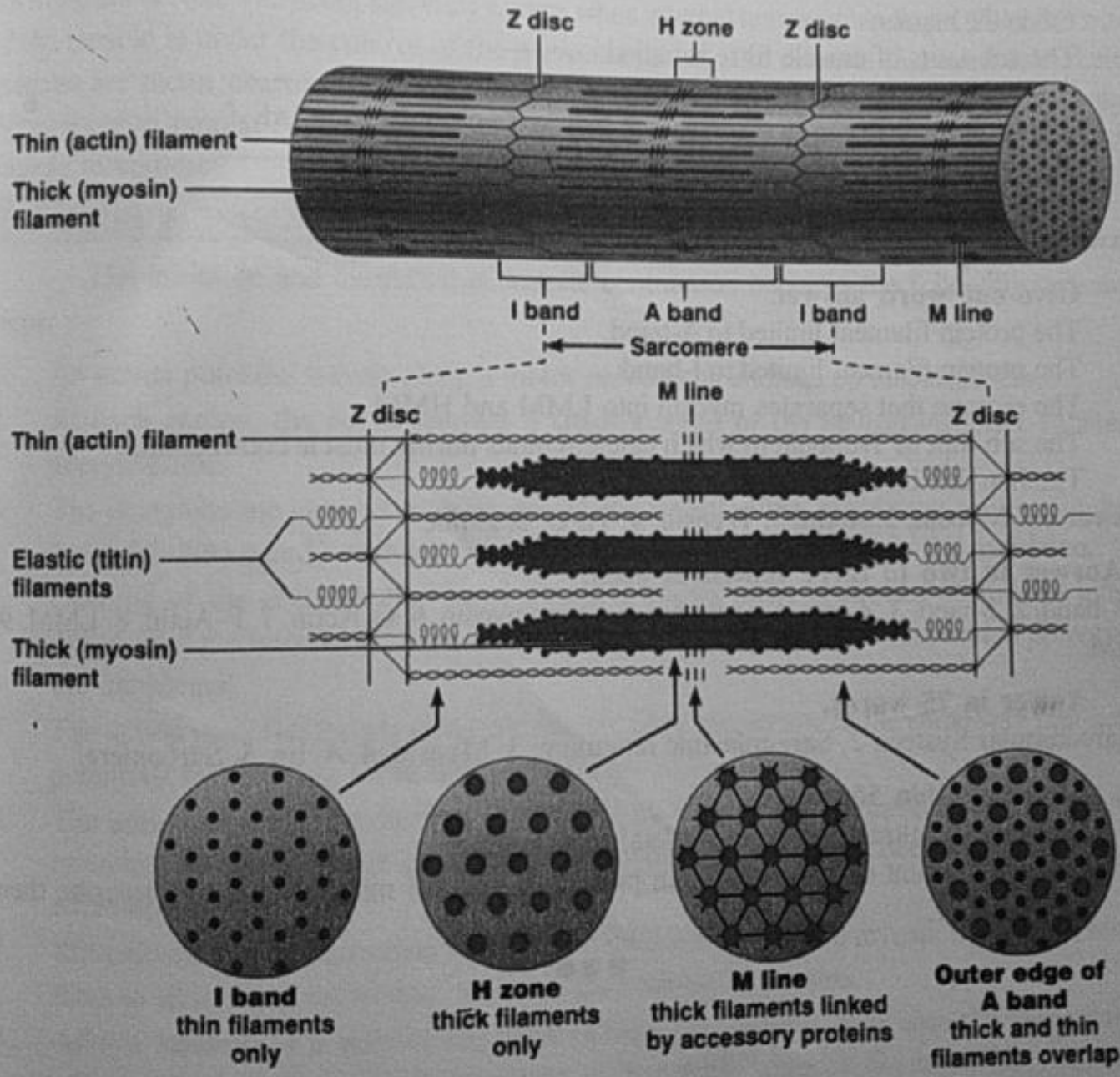

Fig. 2.8 Ultra structure of Myofilament showing arrangement of filaments at different regions of the sarcomere.

OTHER PROTEINS OF THE MUSCLE

In addition to the contractile proteins, the sarcomere contains several other proteins such as: 1. *Actinin*, which attaches actin filament to 'Z' line. 2. *Desmin*, which binds 'Z' line with sarcolemma. 3. *Nebulin*, which runs in close association with and parallel to actin filaments. 4. *Titin*, a large protein connecting 'M' line and 'Z' line. Each titin molecule forms scaffolding (framework) for sarcomere and provides elasticity to the muscle. When the muscle is stretched, the titin unfolds itself. However, if the stretching is more, it offers resistance and protects the sarcomere from overstretching. 5. *Dystrophin*, a rod-shaped large protein that connects actin filament to dystroglycan. Dystroglycan is a transmembrane protein, present in the sarcolemma.

EXERCISE

A. Fill in the blanks:

1. The sub-units of muscle fibre is called ———.
2. The light area present in the middle of A-band is called ———.
3. The segment between two adjacent Z-line in a myofibril is called ———.
4. The number of polypeptide chain that constitute myosin is ———.
5. Each Troponin molecule is composed of ——— sub-units.

Answer : 1. myofibril, 2. H-Zone, 3. Sarcomere, 4. Six, 5. Three

B. Give one word answer.

1. The protein filament limited to A-band.
2. The protein filament limited to I-band.
3. The enzyme that separates myosin into LMM and HMM
4. The sub-unit of Troponin to which calcium binds during muscle contraction.
5. The line that bisects I-band.

Answer : 1. Myosin, 2. Actin, 3. Trypsin, 4. Tn-C, 5. Z-line

C. Answer in two to three sentences each.

1. A-band, 2. I-band, 3. Z-line, 4. Troponin, 5. Tropomyosin, 6. G-Actin, 7. F-Actin, 8. LMM, 9. HMM

D. Anwer in 75 words.

1. Sarcotubular System, 2. Sarcoplasmic reticulum, 3. Myosin, 4. Actin, 5. Sarcomere.

E. Answer within 500 words.

1. Describe the ultrastructure of skeletal muscle fibre.
2. Give an account of muscle protein present in skeletal muscle fibre and describe their arrangement.

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CHAPTER-3

MOLECULAR AND CHEMICAL BASIS OF MUSCLE CONTRACTION

INTRODUCTION

The muscular system is one of the most versatile systems in the body. The muscular system contains the heart, which constantly pumps blood through the body. The muscular system is also responsible for involuntary (e.g. breathing) and voluntary (e.g. walking, picking up objects) actions. The muscles in our body contract, which increases body heat when environment is cold. The act of shivering occurs when internal temperature drops. The contraction of the muscle is under the control of the nervous system. The neurons that innervate skeletal muscles are motor neurons which establish a neuro-muscular junction at the point of contact. When a nerve impulse reaches the neuro-muscular junction action potential is set in that cause muscle to contract.

GENERAL MECHANISM OF MUSCLE CONTRACTION

The initiation and execution of muscle contraction occur in the following sequential steps.

1. An action potential travels along a motor nerve to its endings on muscle fibres.
2. At each ending, the nerve secretes a small amount of the neurotransmitter substance acetylcholine.
3. The acetylcholine acts on a local area of the muscle fibre membrane to open multiple "acetylcholine gated" channels through protein molecules present in the membrane.
4. Opening of the acetylcholine-gated channels allows large quantities of sodium ions to diffuse into the interior of the muscle fibre membrane. This initiates an action potential at the membrane.
5. The action potential travels along the muscle fibre membrane in the same way that action potentials travel along nerve fibre membranes.
6. The action potential depolarizes the muscle membrane, and it causes the sarcoplasmic reticulum to release large quantities of calcium ions that have been stored within this reticulum.
7. The calcium ions initiate attractive forces between the actin and myosin filaments, causing them to slide along each other, which is the contractile process.
8. After a fraction of a second, the calcium ions are pumped back into the sarcoplasmic reticulum by a Ca^{++} membrane pump, and they remain stored in the reticulum until a new muscle action potential comes along. This removal of calcium ions from the myofibrils causes the muscle contraction to cease.

MOLECULAR MECHANISM OF MUSCLE CONTRACTION

The mechanism of muscular contraction involves formation of actomyosin complex. It includes three stages: 1. Excitation-contraction coupling. 2. Role of troponin and tropomyosin. 3. Sliding mechanism.

1. **Excitation-contraction coupling :** It is the process that occurs in between the excitation and contraction of the muscle. When an impulse arrives at the neuromuscular junction, action potential is generated in the muscle fibre. Action potential spreads over sarcolemma and into the muscle fibre through the 'T' tubules. The 'T' tubules are responsible for the rapid spread of action potential into the muscle fibre. When the action potential reaches the cisternae of 'L' tubules, these cisternae are excited. The calcium ions stored in the cisternae are released into the sarcoplasm. The calcium ions from the sarcoplasm move towards the actin filaments to produce the contraction. Thus, the calcium ion forms the basis of excitation-contraction coupling.

2. **Role of Troponin and Tropomyosin :** Normally, the head of myosin molecules has a strong tendency to get attached with active site of F actin. However, in relaxed condition, the active site of F actin is covered by the tropomyosin. Therefore, the myosin head cannot combine with actin molecule. Large number of calcium ions, which are released from 'L' tubules during the excitation of the muscle, bind with troponin C. The loading of troponin C with calcium ions produces some change in the orientation of troponin molecule. It in turn, pulls tropomyosin molecule away from F actin. Due to the movement of tropomyosin, the active site of F actin is uncovered and exposed. Immediately the head of myosin gets attached to the actin leading to muscle contraction.

3. **Sliding Mechanism :** Sliding mechanism explains how the actin filaments slide over myosin filaments and form the actomyosin complex during muscular contraction. It is also called **ratchet theory** or **walk along theory**. It was independently developed by Andrew F. Huxley and Rolf Neidergerke and by Hugh Huxley and Jean Hanson in 1954. Myosin, which has ADP and inorganic phosphate bound to its nucleotide binding pocket binds to the newly uncovered binding sites on the thin filament. Myosin is now bound to actin in the strong binding state forming a cross bridge between the myosin and actin. Each cross bridge from the myosin filaments has got three components namely, a hinge, an arm and a head.

After binding with active site of F actin, the myosin head is tilted towards the arm so that the actin filament is dragged along with it. This tilting of head is called power stroke. The release of ADP and inorganic phosphate are tightly coupled to the power stroke. In other words the energy for movement of myosin head (power stroke) is obtained by breakdown of adenosine triphosphate (ATP) into adenosine diphosphate (ADP) and inorganic phosphate (Pi).

After tilting, the head immediately breaks away from the active site and returns to the original position. When head is tilted, the ADP and Pi are released and a new ATP molecule binds with head. ATP binds to myosin, allowing it to release actin and break the cross bridge (a lack of ATP makes this step impossible, resulting in the rigor state characteristic of rigor mortis).

The myosin then hydrolyzes the ATP and uses the energy to move into the "cocked back" conformation. The cocked myosin head now contains ADP + P_i.

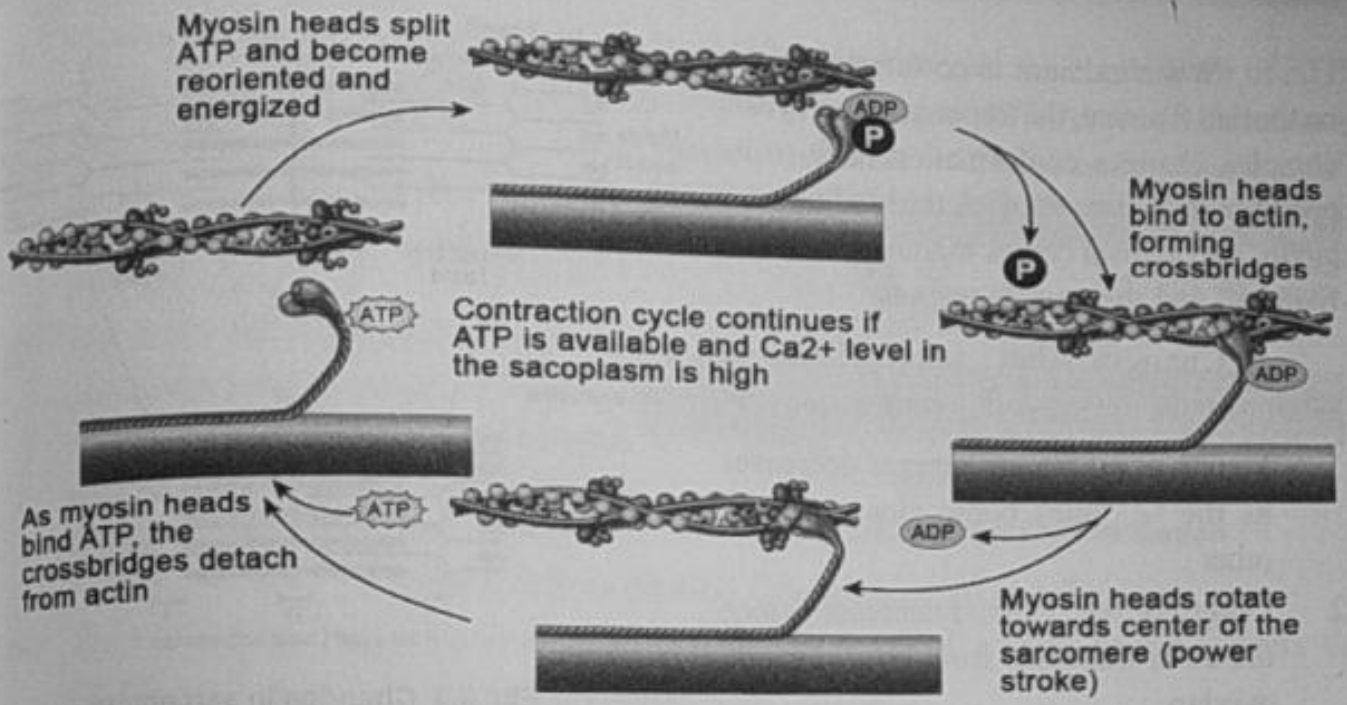

Fig. 3.1 Sliding mechanism of muscle contraction

Now, it combines with a new active site on the actin molecule. After attachment to the actin filament, the release of the inorganic phosphate (P_i) initiates the power stroke as the myosin head pushes the actin filament past. At the end of the power stroke, ADP is released from the myosin head, and it is maintained in the rigor state until ATP binds again. And, tilting movement occurs again. Thus, the head of cross bridge bends back and forth and pulls the actin filament towards the centre of sarcomere. In this way, all the actin filaments of both the ends of sarcomere are pulled. This process is repeated until the muscular contraction is completed. The steps are repeated as long as ATP is available and calcium is freely bound within the thin filaments. In general, evidence indicates that each skeletal muscle myosin head moves 10–12 nm each power stroke.

Formation of actomyosin complex results in contraction of the muscle. The actin filaments from opposite ends of the sarcomere approach each other, so the 'H' zone becomes narrow. The two 'Z' lines come closer with reduction in length of the sarcomere. However, the length of 'A' band is not altered, but, the length of 'I' band decreases. When the muscular contraction becomes severe, the 'H' zone disappears.

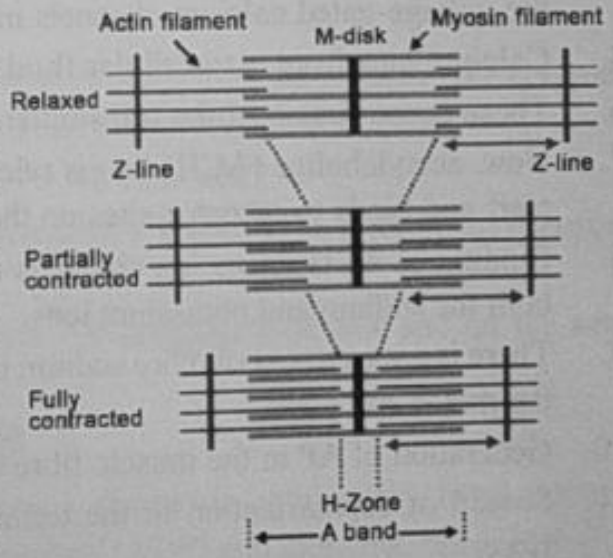

Fig. 3.2 Changes during muscle contraction

The last phase is relaxation which returns the muscle to resting length. Acetylcholine (ACh) ceases being released across the neuromuscular junction because nerve signals stop arriving. Calcium is reabsorbed by the sarcoplasmic reticulum, and when the terminal cisternae no longer receive an action potential they will no longer release calcium. Finally, the calcium dissociates from troponin.

When calcium is no longer present on the thin filament, the troponin-tropomyosin complex changes conformation back to its previous state so as to block the binding sites again. The myosin ceases binding to the thin filament, and the muscle relaxes.

Changes that take place in sarcomere during muscular contraction are:

1. Length of all the sarcomeres decreases as the 'Z' lines come close to each other .
2. Length of the 'I' band decreases since the actin filaments from opposite side overlap.
3. 'H' zone either decreases or disappears. 4. Length of 'A' band remains the same.

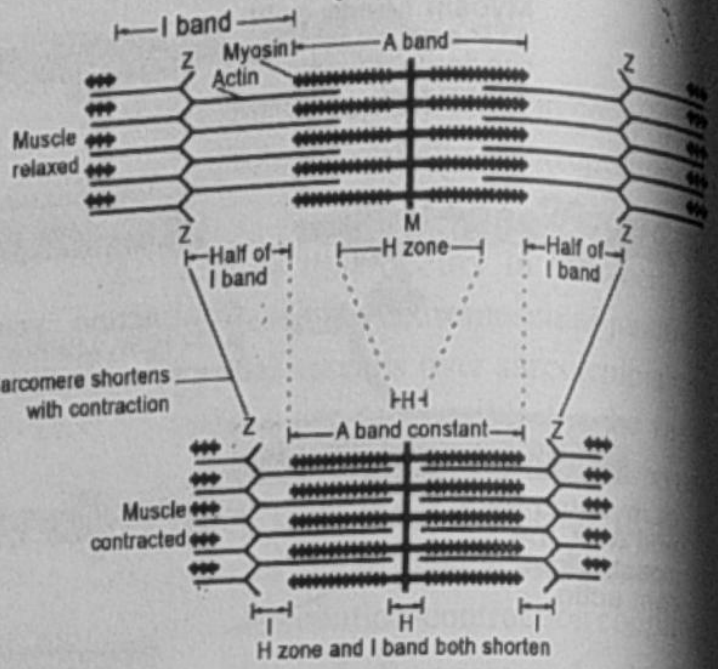

Fig. 3.3 Changes in sarcomere

CHEMICAL BASIS OF MUSCLE CONTRACTION

1. In muscle contraction the cross bridges play an important role and in fact the sliding movement is mediated by the bridges.
2. Under resting condition, the actin and myosin filaments remain relaxed and the cross bridges are held apart.
3. Stimulation of motor nerve produces an action potential which reaches the neuro-muscular or myo-neural junction.
4. The nerve membrane located at the neuro-muscular junction is depolarized thereby opening the voltage-gated calcium channels in the membrane of axon terminal.
5. Calcium ions from extracellular fluid (ECF) enter the axon terminal.
6. These cause fusion of the transmitter vesicles with the nerve membrane and its rupture.
7. Now, acetylcholine (ACH) that is released from the ruptured vesicles diffuses across the cleft and binds to receptor sites on the motor end plate membrane.
8. Binding of ACH opens ion channels in the end plate membrane to allow the passage of both the sodium and potassium ions.
9. There is a movement of more sodium in than potassium out, producing a depolarization of the motor end plate.
10. Generation of AP in the muscle fibre spreads inwards along the T-tubules.
11. Spread of depolarization to the terminal cisternae cause the release of Ca^{2+} in muscle fibre.
12. Increase in Ca^{2+} concentration in the intracellular fluid cause it to diffuse into the thin filaments.
13. Ca^{2+} bind with the calcium binding subunit of troponin causing tropomyosin to move away exposing the binding sites for myosin heads on actin.

14. Myosin head contains ATP and an enzymatic site that catalyses the break down of ATP.
15. Before myosin head attaches to the actin filament, splitting of ATP occurs on the myosin molecule.
16. Breakdown of ATP produces ADP and inorganic phosphate along with chemical energy.
17. The ADP and inorganic phosphate generated remain bound to myosin however the chemical energy released is transferred to myosin producing an energized form of myosin.

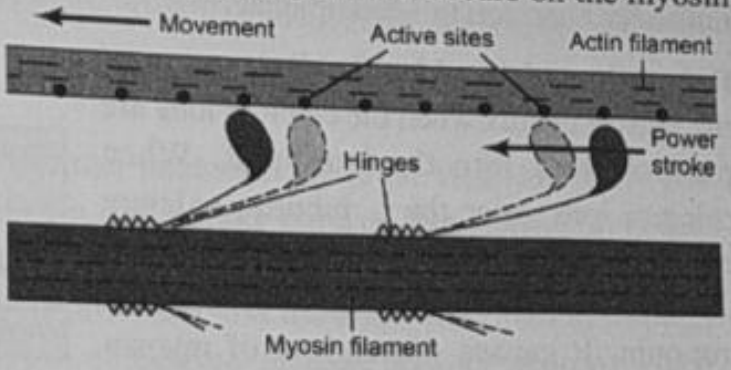

Fig. 3.4 Cross bridge formation

$$\text{Myosin} + \text{ATP} \rightarrow \text{Myosin (energized)} + \text{ADP} + P_i$$

18. The binding of the energized myosin to actin by means of a cross bridge triggers the discharge of the energy stored in myosin.
19. The energy released is now responsible for the generation of a force that causes movement of the cross bridge. ADP and inorganic phosphate are now released from myosin.

$$\text{A} + \text{Myosin (energized)} + \text{ADP} + P_i \rightarrow \text{A-Myosin (energized)} + \text{ADP}$$
$$\rightarrow \text{A-Myosin} + \text{ADP} + P_i + \text{(energy)}$$

20. The release of Pi, initiates the power stroke, followed by release of ADP. This is accompanied by a large conformational change in the head of myosin in relation to its tail, pulling actin about 10 nm toward the center of the sarcomere. This is the power stroke.
21. The myosin is now in a so-called low-energy state, indicated as actin-myosin.
22. During contraction, the myosin cross bridge binds very firmly to actin, and this actin-myosin link has to be broken at the end of the bridge cycle in order to form a new cross bridge.
23. Another molecule of ATP binds to the myosin head, forming an actin-myosin-ATP complex. Myosin-ATP has a low affinity for actin, and actin is thus released.

$$\text{A-Myosin} + \text{ATP} \rightarrow \text{A} + \text{Myosin-ATP}$$

24. The free myosin bridge now once again splits its bound ATP thereby re-forming the energized state of myosin.
25. Now once again the energized state of myosin can reattach to a new site on the actin filament and carry out the process.

ENERGY FOR MUSCLE CONTRACTION

Energy for movement of myosin head (power stroke) is obtained by breakdown of adenosine triphosphate (ATP) into adenosine diphosphate (ADP) and inorganic phosphate (Pi). Head of myosin has a site for ATP. Actually the head itself can act as the enzyme ATPase and catalyze the breakdown of ATP. Even before the onset of contraction, an ATP molecule binds with myosin head. When tropomyosin moves to expose the active sites, the head is attached to the active site. Now ATPase cleaves ATP into ADP and Pi, which remains in head itself. The

energy released during this process is utilized for contraction. When head is tilted, the ADP and Pi are released and a new ATP molecule binds with head. This process is repeated until the muscular contraction is completed.

Relaxation of the Muscle: Relaxation of the muscle occurs when the calcium ions are pumped back into the L tubules. When calcium ions enter the L tubules, calcium content in sarcoplasm decreases leading to the release of calcium ions from the troponin. It causes detachment of myosin from actin followed by relaxation of the muscle. The detachment of myosin from actin obtains energy from breakdown of ATP. Thus, the chemical process of muscular relaxation is an active process although the physical process is said to be passive.

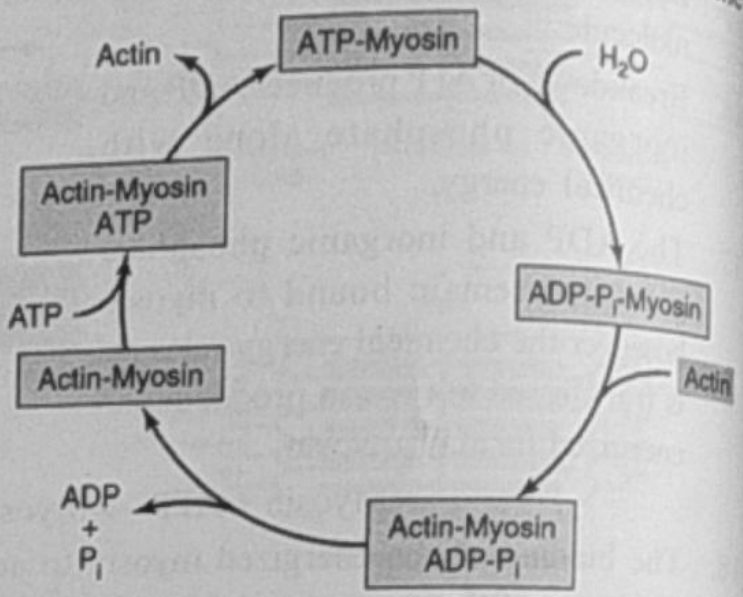

Fig. 3.5 Cyclic representation of Association and Dissociation of Actin & Myosin

EXERCISE

A. Fill in the blanks:

1. The inorganic ion responsible for muscle contraction is ———.
2. During muscle contraction Ca++ are released from ———.
3. The band that show no change in its length during muscle contraction is ———.
4. The band that decreases in length during muscle contraction is ———.
5. Energy from muscle contraction is obtained from ———.

Answer : 1. Ca++, 2. L-tubules, 3. A-band, 4. I-band, 5. ATP

B. Give one word answer.

1. The system in muscle cell where Ca++ are stored.
2. The protein sub-unit to which Ca++ binds prior to muscle contraction.
3. The site on F-Actin masked by Tropomyosin.
4. The protein part that masks the active site on F-Actin.
5. The theory that best explains muscle contraction.
6. The state when the cross bridges are not broken.

Answer : 1. L-tubule, 2. Troponin-C, 3. Active site, 4. Tropomyosin, 5. Sliding mechanism theory/Rachet theory, 6. Rigor mortis

C. Answer in two to three sentences each.

1. L-tubule, 2. Cross bridge, 3. Rigor mortis, 4. Acto-myosin complex,

D. Anwer in 75 words.

1. Energy for muscle contraction, 2. Role of Calcium in muscle contraction, 3. Power stroke, 4. Change in Sarcomere during muscle contraction, 5. Sliding mechanism.

E. Answer within 500 words.

1. Describe the molecular mechanism of muscle contraction.
2. What is muscle contraction? Explain the chemical basis of muscle contraction alongwith the energetics.

●●●

CHAPTER-4

STRUCTURE OF NEURON

INTRODUCTION

The term *neuron* was coined by the German anatomist Heinrich Wilhelm Waldeyer. Neurons are the core components of the brain and spinal cord of the central nervous system (CNS), and of the ganglia of the peripheral nervous system (PNS). A **neuron** (also known as **nerve cell**) is an electrically excitable cell that processes and transmits information through electrical and chemical signals. Specialized types of neurons include: sensory neurons which respond to touch, sound, light and all other stimuli affecting the cells of the sensory organs that then send signals to the spinal cord and brain, motor neurons that receive signals from the brain and spinal cord to cause muscle contractions and affect glandular outputs.

Definition: Neuron or nerve cell is defined as the structural and functional unit of nervous system. Neuron is similar to any other cell in the body, having nucleus and all the organelles in cytoplasm. However, it is different from other cells by two ways:

1. Neuron has branches or processes called axon and dendrites.
2. Neuron does not have centrosome. So, it cannot undergo division.

STRUCTURE

A typical neuron consists of a cell body (soma), dendrites, and an axon. Dendrite and axon form the processes of neuron. Dendrites are short processes and the axons are long processes. Dendrites and axons are usually called nerve fibres. Nerve fibres are often bundled into fascicles, and in the peripheral nervous system, bundles of fascicles make up nerves (like strands of wire make up cables).

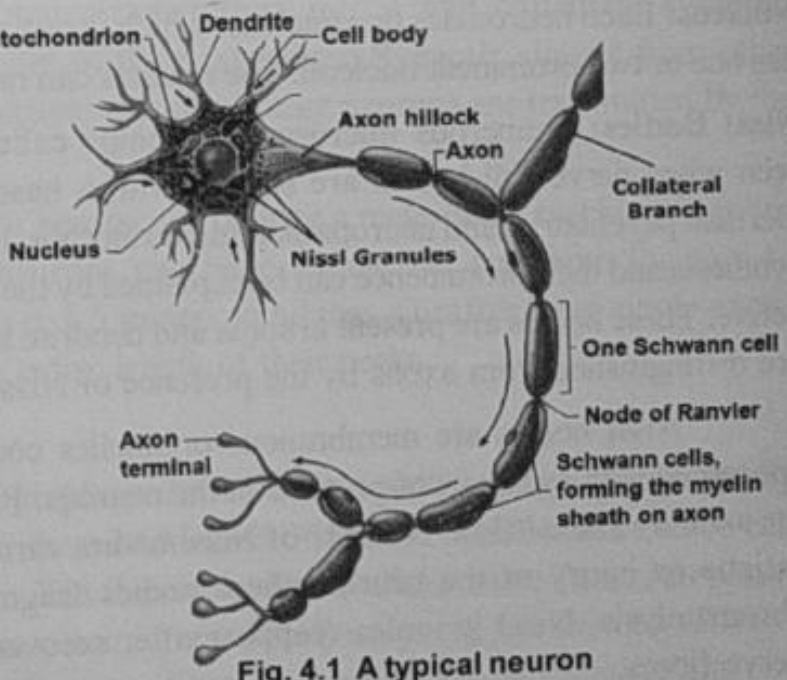

Fig. 4.1 A typical neuron

- ✓ Dendrites are thin structures that arise from the cell body, often extending for hundreds of micrometres and branching multiple times, giving rise to a complex "dendritic tree".
- ✓ An axon is a special cellular extension (process) that arises from the cell body at a site called the axon hillock and travels for a distance, as far as 1 meter in humans or even more in other species.

✓ The cell body of a neuron frequently gives rise to multiple dendrites, but never to more than one axon, although the axon may branch hundreds of times before it terminates.

ANATOMY OF A MULTIPOLAR NEURON

A neuron is a specialized type of cell found in the bodies of all eumetozoans. Only sponges and a few other simpler animals lack neurons. The body's neurons, plus the glial cells that give them structural and metabolic support, together constitute the nervous system. A typical neuron is divided into three parts: the soma or **cell body, dendrites,** and **axon**. There are no neurons that lack a soma, but there are neurons that lack dendrites, and others that lack an axon. Like all animal cells, the cell body of every neuron is enclosed by a plasma membrane, a bilayer of lipid molecules with many types of protein structures embedded in it.

1. NERVE CELL BODY

Nerve cell body is also known as soma or perikaryon. As it contains the nucleus, most protein synthesis occurs here. It is irregular in shape; the axon and dendrites are filaments that extrude from it. Like any other cell, it is constituted by a mass of cytoplasm called neuroplasm, which is covered by a cell membrane. The cytoplasm contains a large nucleus, nissl bodies, neurofibrils, mitochondria and Golgi apparatus. Nissl bodies and neurofibrils are found only in nerve cell and not in other cells. The axon and dendrites are processes that extrude from it. Nerve cell body does not contain centrosome. So, the nerve cell cannot multiply like other cells.As it contains the nucleus, most protein synthesis occurs here.

Nucleus: Each neuron has one nucleus, which is centrally placed in the nerve cell body. Nucleus has one or two prominent nucleoli. The nucleus can range from 3 to 18 micrometers in diameter.

Nissl Bodies: Numerous microscopic clumps called **Nissl substance** (or Nissl bodies) are seen when nerve cell bodies are stained with a basophilic ("base-loving") dye. Named after German psychiatrist and neuropathologist Franz Nissl (1860–1919), they are involved in protein synthesis and their prominence can be explained by the fact that nerve cells are very metabolically active. These bodies are present in soma and dendrite but not in axon and axon hillock. Dendrites are distinguished from axons by the presence of Nissl granules under microscope.

Nissl bodies are membranous organelles containing ribosomes. So, these bodies are concerned with synthesis of proteins in the neurons. Proteins formed in soma are transported to the axon by axonal flow. Number of Nissl bodies varies with the condition of the nerve. During fatigue or injury of the neuron, these bodies fragment and disappear by a process called chromatolysis. Nissl granules reappear after recovery from fatigue or after regeneration of nerve fibres.

Neurofibrils: Presence of neurofibrils is another characteristic feature of the neurons.The cell body of a neuron is supported by a complex mesh of structural proteins called neurofilaments, which are assembled into larger neurofibrils. Neurofibrils are thread-like structures present in the form of network in the soma and the nerve processes. The neurofibrils consist of microfilaments and microtubules.

Mitochondria: Mitochondria are present in soma and in axon. As in other cells, here also mitochondria form the powerhouse of the nerve cell, where ATP is produced.

Golgi Apparatus: Golgi apparatus of nerve cell body is similar to that of other cells. It is concerned with processing and packing of proteins into granules.

2. DENDRITE

The dendrites of a neuron are cellular extensions with many branches. Dendrite is the branched process of neuron and it is branched repeatedly. This overall shape and structure is referred to metaphorically as a dendritic tree. Dendrites typically branch profusely, getting thinner with each branching, and extending their farthest branches a few hundred micrometers from the soma. Dendrite may be present or absent. If present, it may be one or many in number. Dendrite has Nissl granules and neurofibrils. Dendrite transmits impulses towards the nerve cell body. Usually, the dendrite is shorter than axon.

3. AXON

Axon is the longer process of nerve cell. Each neuron has only one axon. The axon leaves the soma at a swelling called the **axon hillock**, and can extend for great distances, giving rise to hundreds of branches. Length of longest axon is about 1 meter. Unlike dendrites, an axon usually maintains the same diameter as it extends. Axon is devoid of Nissl granules. Axon transmits impulses away from the nerve cell body. The end of the axon has branching terminals (axon terminal) that release neurotransmitters into a gap called the synaptic cleft between the terminals and the dendrites of the next neuron.Synaptic signals from other neurons are received by the soma and dendrites; signals to other neurons are transmitted by the axon.

The longest axon of a human motor neuron can be over a meter long, reaching from the base of the spine to the toes. Sensory neurons can have axons that run from the toes to the posterior column of the spinal cord, over 1.5 meters in adults. Giraffes have single axons several meters in length running along the entire length of their necks.

Internal Structure of Axon

Axon has a long central core of cytoplasm called axoplasm. Axoplasm is covered by membrane called axolemma. Axolemma is the continuation of the cell membrane of nerve cell body. Axoplasm along with axolemma is called the axis cylinder of the nerve fibre. Axoplasm contains mitochondria, neurofibrils and axoplasmic vesicles. Because of the absence of Nissl bodies in the axon, proteins necessary for the nerve fibres are synthesized in the soma and not in axoplasm. After synthesis, the protein molecules are transported from soma to axon, by means of axonal flow. Some neurotransmitter substances are also transported by axonal flow from soma to axon.

Some neurons also contain pigment granules, such as neuromelanin (a brownish-black pigment that is byproduct of synthesis of catecholamines), and lipòfuscin (a yellowish-brown pigment), both of which accumulate with age.

Properties of Neuron

- All neurons are electrically excitable, maintaining voltage gradients across their membranes by means of metabolically driven ion pumps, which generate intracellular-Vs-extracellular concentration differences of ions such as sodium, potassium, chloride, and calcium.
- Neurons do not undergo cell division. In most cases, neurons are generated by special types of stem cells.
- Astrocytes are star-shaped glial cells that have also been observed to turn into neurons by virtue of the stem cell characteristic pluripotency.
- Neurons are highly specialized for the processing and transmission of cellular signals.
- In humans, neurogenesis largely ceases during adulthood; but in two brain areas, the hippocampus and olfactory bulb, there is strong evidence for generation of substantial numbers of new neurons.

ORGANIZATION OF NERVE

Each nerve is formed by many bundles or groups of nerve fibres. Each bundle of nerve fibres is called a fasciculus.The whole nerve is covered by tubular sheath called epineurium. Each fasciculus is covered by perineurium and each nerve fibre (axon) is covered by endoneurium.

Non-myelinated Nerve Fibre : Nerve fibre is said to be non-myelinated when it is not covered by myelin sheath. The nerve fibre lacks a myelin sheath.

Myelinated Nerve Fibre : Nerve fibre which is insulated by myelin sheath is called myelinated nerve fibres.

MYELIN SHEATH

Myelin sheath is a thick lipoprotein covering that insulates the myelinated nerve fibre. Myelin sheath is not a continuous sheath. It is absent at regular intervals. The area where myelin sheath is absent is called **node of Ranvier**. Segment of the nerve fibre between two nodes is called internode. Myelin sheath is responsible for white color or white matter of nerve fibres. Myelin sheath is formed by concentric layers of proteins, alternating with lipids. The lipids are cholesterol, lecithin and cerebroside (sphingomyelin).

Formation of Myelin Sheath – Myelinogenesis

Formation of myelin sheath around the axon is called the **myelinogenesis**. It is formed by **Schwann cells** in neurilemma. It starts at 4th month of intrauterine life and is completed only in the second year after birth. Before myelinogenesis, Schwann cells of the neurilemma are very close to axolemma, as in the case of unmyelinated nerve fibre. Schwann cells wrap up and rotate around the axis cylinder in many concentric

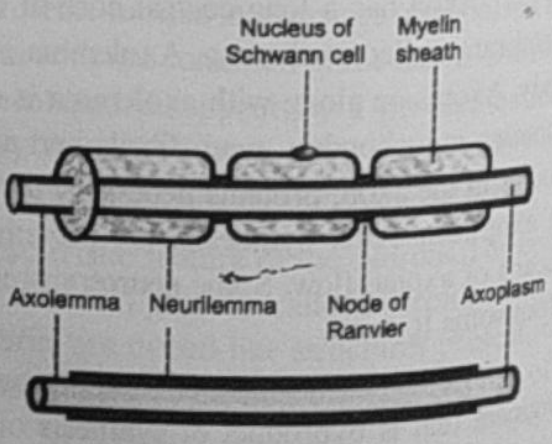

Fig. 4.2 Myelinated nerve

layers. The concentric layers fuse to produce myelin sheath but cytoplasm of the cells is not deposited. Outermost membrane of Schwann cell remains as neurilemma. Nucleus of these cells remains in between myelin sheath and neurilemma.

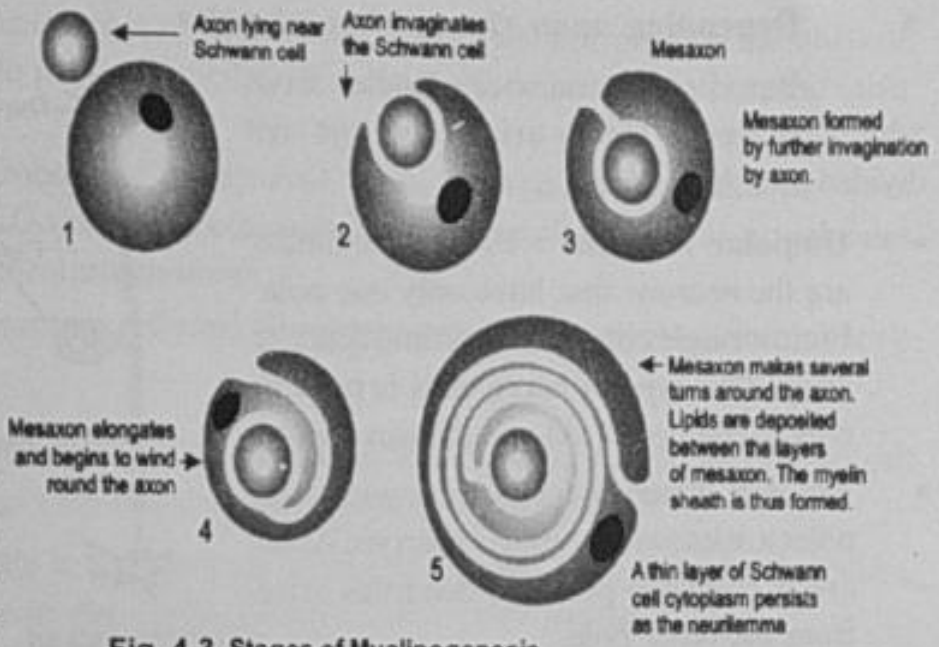

Fig. 4.3 Stages of Myelinogenesis

Functions of Myelin Sheath

1. **Faster conduction:** Myelin sheath is responsible for faster conduction of impulse through the nerve fibres. In myelinated nerve fibres, the impulses jump from one node to another node adding to the rapid mode of conduction. This type of transmission of impulses is called saltatory conduction.

2. **Insulating capacity:** Myelin sheath has a high insulating capacity. Because of this quality, myelin sheath restricts the nerve impulse within single nerve fibre and prevents the stimulation of neighboring nerve fibres. In general the myelin sheath does not allow the movement or influx of ions through them.

NEURILEMMA

Neurilemma is a thin membrane, which surrounds the axis cylinder. It is also called neurilemmal sheath or sheath of Schwann. It contains Schwann cells, which have flattened and elongated nuclei. One nucleus is present in each internode of the axon. Nucleus is situated between myelin sheath and neurilemma. In non-myelinated nerve fibre, the neurilemma surrounds axolemma continuously. In myelinated nerve fibre, it covers the myelin sheath. At the node of Ranvier (where myelin sheath is absent), neurilemma invaginates and runs up to axolemma in the form of a finger-like process. In non-myelinated nerve fibre, the neurilemma serves as a covering membrane. In myelinated nerve fibre, it is necessary for the formation of myelin sheath (myelinogenesis).

CLASSIFICATION OF NEURON

Neurons exist in a number of different shapes and sizes and can be classified by their morphology and function. The anatomist Camillo Golgi grouped neurons into two types; type I with long axons used to move signals over long distances and type II with short axons, which can often be confused with dendrites.Neurons are classified by three different methods.

A. Depending upon the number of poles
B. Depending upon the function
C. Depending upon the action on other neurons
D. Depending upon the neurotransmitter type

A. Depending upon the number of poles

Based on the number of poles from which the nerve fibres arise, neurons are divided into three types:

- **Unipolar Neurons :** Unipolar neurons are the neurons that have only one pole. From a single pole, both axon and dendrite arise. This type of nerve cells is present only in embryonic stage in human beings.
- **Bipolar Neurons:** Neurons with two poles are known as bipolar neurons. Axon arises from one pole and dendrites arise from the other pole.
- **Multipolar Neurons:** Multipolar neurons are the neurons which have many poles. One of the poles gives rise to axon and all other poles give rise to dendrites.

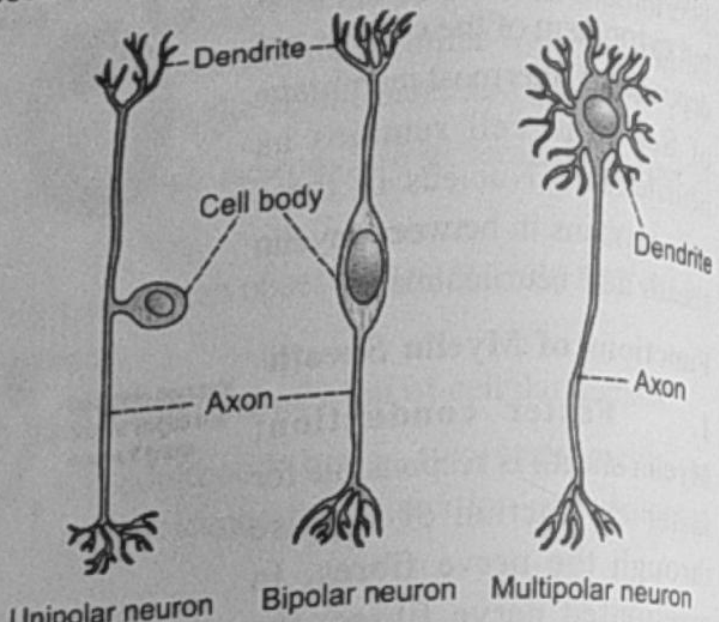

Fig. 4.4 Types of Neuron

B. Depending upon the function

On the basis of function, neurons are classified into three types:

- **Motor or efferent neurons :** Motor or efferent neurons are the neurons which transmit signals from the central nervous system to peripheral effector organs like muscles, glands, blood vessels, etc.
- **Sensory or afferent neurons :** Sensory or afferent neurons are the neurons which carry the sensory impulsesfrom tissues and organs to central nervous system.
- **Interneurons:** Interneurons connect neurons within specific regions of the central nervous system.

C. Depending upon the action on other neurons

A neuron affects other neurons by releasing a neurotransmitter that binds to chemical receptors.The effect upon the postsynaptic neuron is determined not by the presynaptic neuron or by the neurotransmitter, but by the type of receptor that is activated. Receptors can be classified broadly as ***excitatory*** (causing an increase in firing rate), ***inhibitory*** (causing a decrease in firing rate), or ***modulatory*** (causing long-lasting effects not directly related to firing rate).

D. Depending upon the neurotransmitter type

- Cholinergic neurons — Acetylcholine is released from presynaptic neurons into the synaptic cleft.
- GABAergic neurons — Gamma aminobutyric acid is released from presynaptic neurons into the synaptic cleft. GABA is one of two neuroinhibitors in the CNS, the other being Glycine.

- Glutamatergic neurons — Glutamate is released from presynaptic neurons into the synaptic cleft. Glutamate is one of two primary excitatory amino acid neurotransmitter, the other being Aspartate.
- Dopaminergic neurons — Dopamine is released. Loss of dopamine neurons has been linked to Parkinson's disease. Dopamine is connected to mood and behavior, and modulates both pre and post synaptic neurotransmission.
- Serotonergic neurons — Serotonin is released. Serotonin can act as excitatory or inhibitory.

FUNCTION

- Neurons communicate with one another via synapses, where the axon terminal of one cell impinges upon another neuron's dendrite, soma or, less commonly, axon.
- Neurons such as Purkinje cells in the cerebellum can have over 1000 dendritic branches, making connections with tens of thousands of other cells; other neurons.
- Synapses can be excitatory or inhibitory and either increase or decrease activity in the target neuron.
- In a chemical synapse, the neurotransmitters diffuse across the synaptic cleft and activate receptors on the postsynaptic neuron.
- The number of neurons in the brain varies dramatically from species to species. One estimate puts the human brain at about 100 billion (10^{11}) neurons and 100 trillion (10^{14}) synapses. A lower estimate (published in 2009) is 86 billion neurons, of which 16.3 billion are in the cerebral cortex, and 69 billion in the cerebellum.

NERVE REGENERATION

It has been demonstrated that neurogenesis can sometimes occur in the adult vertebrate brain, a finding that led to controversy in 1999. However, later studies suggest that this process occurs only for a minority of cells. It is often possible for peripheral axons to regrow if they are severed. Recent studies have also shown that the body contains a variety of stem cell types that have the capacity to differentiate into neurons.

DEMYELINATION

Demyelination is the act of demyelinating, or the loss of the myelin sheath insulating the nerves. When myelin degrades, conduction of signals along the nerve can be impaired or lost, and the nerve eventually withers. This leads to certain neurodegenerative disorders like multiple sclerosis and chronic inflammatory demyelinating polyneuropathy.

NEUROLOGICAL DISORDERS

Alzheimer's disease (AD), also known simply as *Alzheimer's*, is a neurodegenerative disease characterized by progressive cognitive deterioration together with declining activities of daily living and neuropsychiatric symptoms or behavioral changes. The early symptom is loss of short-term memory (amnesia), that becomes steadily more pronounced with illness progression, with relative preservation of older memories. As the disorder progresses, cognitive (intellectual)

impairment extends to the domains of language (aphasia), skilled movements (apraxia), and recognition (agnosia), and functions such as decision-making and planning become impaired.

Parkinson's disease (PD), also known as *Parkinson disease*, is a degenerative disorder of the central nervous system that often impairs the sufferer's motor skills and speech. Parkinson's disease belongs to a group of conditions called movement disorders. It is characterized by muscle rigidity, tremor, a slowing of physical movement (bradykinesia), and in extreme cases, a loss of physical movement (akinesia). The primary symptoms are the results of decreased stimulation of the motor cortex by the basal ganglia, caused by insufficient formation and action of dopamine.

Myasthenia gravis is a neuromuscular disease leading to fluctuating muscle weakness and fatigability during simple activities. Weakness is typically caused by circulating antibodies that block acetylcholine receptors at the post-synaptic neuromuscular junction, inhibiting the stimulative effect of the neurotransmitter acetylcholine. Myasthenia is treated with immunosuppressants, cholinesterase inhibitors and, in selected cases, thymectomy.

EXERCISE

A. Fill in the blanks:

1. The cell that bears processes is called ———.
2. The smaller processes present in the cell body of a neuron is called ———.
3. Nissl body are only found in ——— cells.
4. The axon of a neuron arises from ———.
5. Myelin sheath is laid down by ——— cell.

Answer : 1. Neuron, 2. Dendrite, 3. Nerve, 4. Axon-hillock, 5. Schwann

B. Give one word answer.

1. Cell that do not undergo cell division.
2. Cytoplasm of axon.
3. Covering sheath of nerve.
4. Chemical substance produced by terminal end of neuron.

Answer : 1. Neuron, 2. Axoplasm, 3. Epineurium, 4. Neurotransmitter,

C. Answer in two to three sentences each.

1. Neuron, 2. Axon-hillock, 3. Bipolar neuron, 4. Nissl bodies, 5. Node of Ranvier, 6. Sensory neuron, 7. Motor neuron, 8. Inter neuron.

D. Anwer in 75 words.

1. Myelinated nerve fibre, 2. Schwann cell, 3. Non-Myelinated nerve fibre

E. Answer within 500 words.

1. Describe the structure of a typical neuron.

●●●

CHAPTER-5

RESTING MEMBRANE POTENTIAL / ORIGIN OF ACTION POTENTIAL

INTRODUCTION

For the nervous system to function, neurons must be able to send and receive signals. These signalling properties are possible because each neuron has a charged cellular membrane (a voltage difference between the inside and the outside), and the charge of this membrane can change in response to neurotransmitter molecules released from other neurons and environmental stimuli. To understand how neurons communicate, one must first understand the basis or "resting" membrane charge. When subjected to an external stimuli, the membrane depolarization occurs with the origin of Action Potential.

DEFINITION

All cells under resting conditions have a potential difference across their plasma membranes with the inside of the cell negatively charged with respect to the outside. This potential is the **resting membrane potential**. By convention, extracellular fluid is assigned a voltage of zero, and the polarity (positive or negative) of the membrane potential is stated in terms of the sign of the excess charge on the inside of the cell. For example, if the intracellular fluid has an excess of negative charge and the potential difference across the membrane has a magnitude of 70 mV, we say that the membrane potential is - 70 mV.

The relatively static membrane potential of quiescent cells is called the resting membrane potential. The human organism is composed of multiple cells, all of them with different components and therefore with different resting membrane potentials. Some of these cells are excitable (e. g.: cells; neurons; muscle fibres), generating an action potential when subjected to an external stimulus, causing its membrane depolarization.

Resting membrane potential may be characterized as:

- the unequal distribution of ions on the both sides of the cell membrane of quiescent cells;
- the membrane potential that would be maintained if there weren't any stimuli or conducting impulses across it;
- a *negative value*, which means that there is an excess of negative charge inside of the cell, compared to the outside.

The **resting membrane potential (RMP)** is due to changes in membrane permeability for potassium, sodium, calcium, and chloride, which results from the movement of these ions across it. In order to understand the mechanism that maintain the RMP in a neuron, we should understand the nature of nerve membrane and the ion channel / gated channel that function to maintain the membrane potential.

Nature of Nerve Membrane

The membrane of a nerve fibre separates the intracellular fluid from the extracellular fluid. Both intracellular fluid and extracellular fluid have widely different ionic concentrations. The cytoplasm inside the neuron is rich in **K+ but low in** Cl-. Similarly the extracellular fluid is rich in Na+, Cl- and bicarbonate ions. However, because of the presence of a large number of non-diffusible negatively charged proteins, organic phosphate and sulphate, inside of the nerve membrane becomes electronegative while the outside becomes electropositive.

Ion Channels

The lipid bilayer membrane that surrounds a neuron is impermeable to charged molecules or ions. To enter or exit the neuronal membrane, ions must pass through special proteins called ion channels that span the membrane. Ion channels have different configurations: **open**, **closed**, and **inactive**. Some ion channels need to be activated in order to open and allow ions to pass into or out of the cell. These ion channels are sensitive to the environment and can change their shape accordingly. Ion channels that change their structure in response to voltage changes are called voltage-gated ion channels. Voltage-gated ion channels regulate the relative concentrations of different ions inside and outside the cell.

RESTING MEMBRANE POTENTIAL

The difference in total charge between the inside and outside of the cell is called the **membrane potential**. A neuron at rest is negatively charged.The inside of a cell is approximately 70 millivolts more negative than the outside (–70 mV). This voltage called the resting membrane potential; is caused by differences in the concentrations of ions inside and outside the cell. If the membrane were equally permeable to all ions, each type of ion would flow across the membrane and the system would reach equilibrium. Because ions cannot simply cross the membrane at will, there are different concentrations of several ions inside and outside the cell.The difference in the number of positively charged potassium ions (K^+) inside and outside the cell dominates the resting membrane potential.

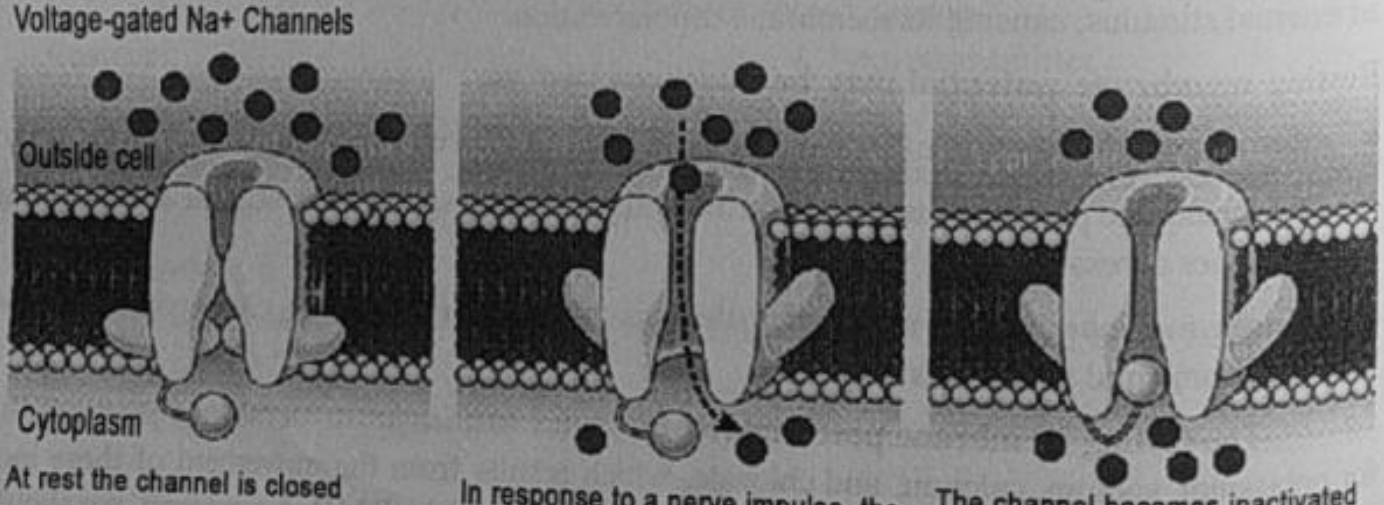

Fig. 5.1 Voltage-gated Na+ Channel

In neurons K+ and organic anions are typically found at a higher concentration within the cell than outside, whereas Na+ and Cl- are typically found in higher concentrations outside the cell. This difference in concentrations of ions across the membrane provide a gradient for them to flow down when their channels are open. At rest, most neurons are permeable to K+, Na+ and Cl-, as such they will all readily flow down their concentration gradients, with K+ (high conc. inside) moving out of the cells and Na+ and Cl- (high conc. outside) moving into the cell. However the main factor that determines the RMP is the difference in permeability of K+ and Na+ resulting in slightly more net K+ diffusion (from inside of the neuron to the outside) than Na+ diffusion in the reverse direction. This cause a difference in polarity along the membrane.

Creation and maintenance of RMP

i) Membrane selectivity : It is the difference of permeabilites between different ions

ii) Leakage channels: The negative resting membrane potential is created and maintained by increasing the concentration of cations outside the cell relative to inside the cell. In neurons, potassium ions are maintained at high concentrations within the cell while sodium ions are maintained at high concentrations outside of the cell. The negative charge within the cell is created by the cell membrane being more permeable to potassium ion movement than sodium ion movement. The cell possesses potassium and sodium leakage channels that allow the two cations to diffuse down their concentration gradient.

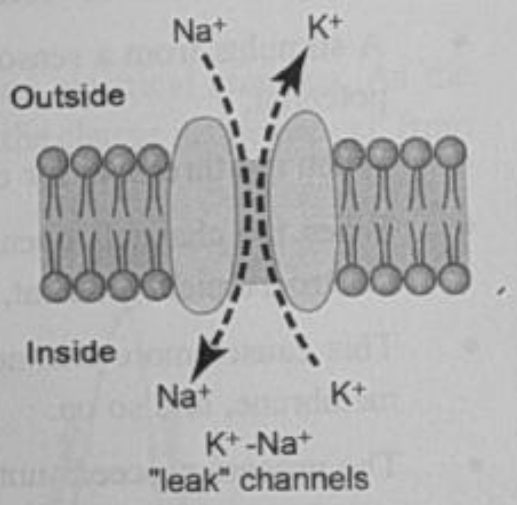

Fig. 5.2 Leak channel

However, the neurons have far more potassium leakage channels than sodium leakage channels. Therefore, potassium diffuses out of the cell at a much faster rate than sodium leaks in. Because more cations are leaving the cell than are entering, this causes the interior of the cell to be negatively charged relative to the outside of the cell.

iii) Na^+/K^+ ATPase pump: The actions of the sodium potassium pump help to maintain the resting potential, once established. Recall that sodium potassium pumps brings two K^+ ions into the cell while removing three Na^+ ions per ATP consumed. As more cations are expelled from the cell than taken in, the inside of the cell remains negatively charged relative to the extracellular fluid. These concentration gradients are maintained by the action of the **Na+/K+ ATPase** via active transport. The *Na^+/K^+ ATPase pump* creates a concentration gradient by moving $3Na^+$ out of the cell and $2K^+$ into the cell. Na^+ is being pumped out and K^+ pumped in against their concentration gradients. Because this pump is moving ions against their concentration gradients, it requires energy. This unequal distribution of Na+ and K+ on the two sides of the membrane creates the resting membrane potential.

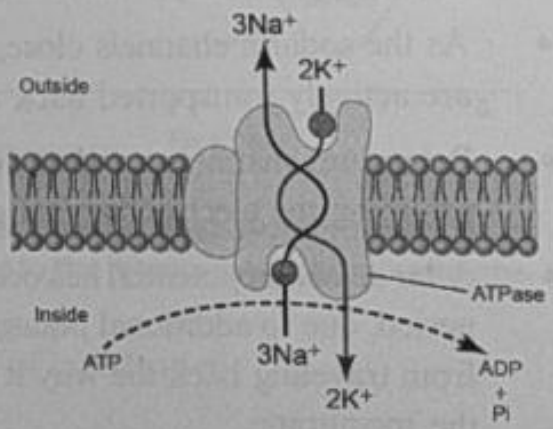

Fig. 5.3 $Na^+ - K^+$ Pump

ORIGIN OF ACTION POTENTIAL

In physiology, an **action potential** is a short-lasting event in which the electrical membrane potential of a cell rapidly rises and falls. It is defined as a brief change in the voltage across the membrane due to the flow of certain ions into and out of the neuron. Action potentials in neurons are also known as "**nerve impulses**" or "spikes".

What is action potential?

An action potential (AP) is the mode through which a neuron transports electrical signals. Action potentials are generated by special types of voltage-gated ion channels embedded in a cell's plasma membrane. These channels are shut when the membrane potential is near the resting potential of the cell, but they rapidly begin to open if the membrane potential increases to a defined threshold value.

Steps in generation of Action potential

- A stimulus from a sensory cell causes the target cell to depolarize to reach the threshold potential.
- When the threshold for excitation is reached Na^+ channel opens.
- When the channels open, they allow an inward flow of sodium ions, which changes the electrochemical gradient, which in turn produces a further rise in the membrane potential.
- This causes more channels to open, producing a greater electric current across the cell membrane, and so on.
- The process proceeds until all of the available ion channels are open, resulting in a large upswing in the membrane potential.
- The rapid influx of sodium ions causes the polarity of the plasma membrane to reverse, and the ion channels then rapidly inactivate.
- Now peak action potential is reached.
- As the sodium channels close, sodium ions can no longer enter the neuron, and then they are actively transported back out of the plasma membrane.
- Potassium channels are then activated, and there is an outward current of potassium ions, returning the electrochemical gradient to the resting state.
- After an action potential has occurred, there is a transient negative shift, called the refractory period, due to additional potassium currents. This mechanism prevents an action potential from traveling back the way it just came. This state is called the hyperpolarized state of the membrane.

Formation of an action potential

The formation of an action potential can be divided into five steps. (1) A stimulus from a sensory cell causes the target cell to depolarize toward the threshold potential. (2) If the

threshold of excitation is reached, all Na+ channels open and the membrane depolarizes. (3) At the peak action potential, K+ channels open and K+ begins to leave the cell. At the same time, Na+ channels close. (4) The membrane becomes hyperpolarized as K+ ions continue to leave the cell. The hyperpolarized membrane is in a refractory period and cannot fire. (5) The K+ channels close and the Na+/K+ transporter restores the resting potential.

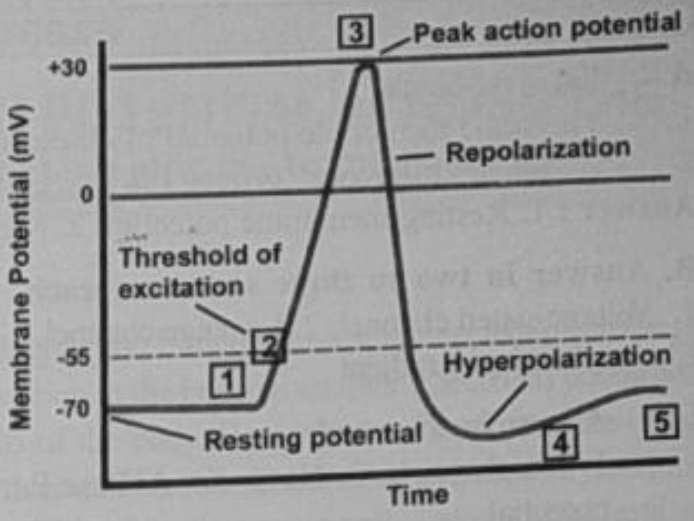

Fig. 5.4 Formation of Action Potential

Depolarization vs Action Potential

An action potential begins at the axon hillock as a result of **depolarization**. During **depolarization** voltage gated sodium ion channels open due to an electrical stimulus. As the sodium rushes back into the cell the positive sodium ions reverse the charge inside the cell from negative to positive.Once the cell has been depolarised the voltage gated sodium ion channels close. The raised positive charge inside the cell causes potassium channels to open, K+ ions now move down their **electrochemical gradient** out of the cell. As the K+ moves out of the cell the membrane potential falls and starts to approach the resting potential. Typically, repolarization overshoots the resting membrane potential, making the membrane potential more negative. This is known as **hyperpolarization.**

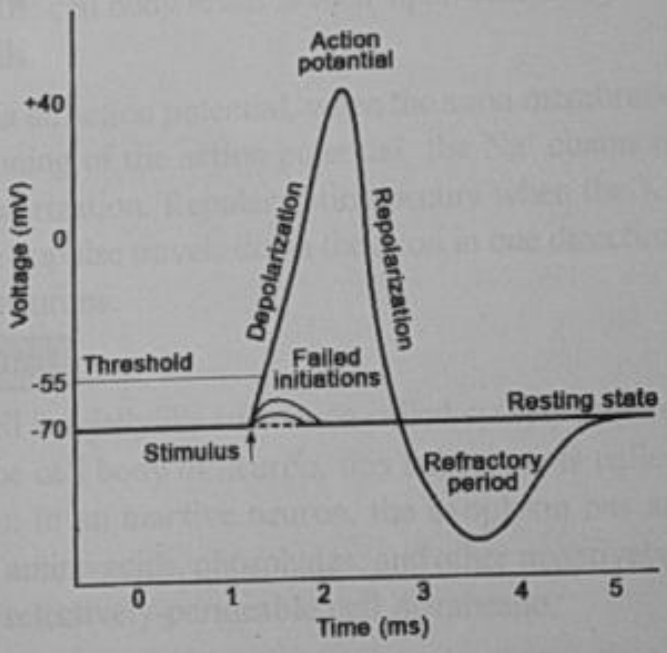

Fig. 5.5 Phases of an Action Potential in relation to the membrane voltage over time

Refractory Period

Every action potential is followed by a **refractory period.** This period occurs as once the sodium channels close after an AP, they enter an inactive state during which they cannot be reopened regardless of the membrane potential. Slowly the sodium channels come out of inactivation.

All or nothing

If a threshold is reached, then an action potential is produced with maximum response. Action potentials will only occur if a threshold is reached, as such they are described as "**all or nothing**".

CHAPTER-6

PROPAGATION OF ACTION POTENTIAL ACROSS THE MYELINATED AND UNMYELINATED NERVE FIBRES

INTRODUCTION

The human nervous system contains roughly 100 billion neurons, connected in elaborate networks that transmit information from one location in the body to another. Electrical potentials exist across the membranes of virtually all cells of the body. However, nerve and muscle cells, are capable of generating electrochemical impulses at their membranes that are used to transmit signals along the nerve or muscle membranes. This phenomenon is called excitability and is defined as the physiochemical change that occurs in a tissue when stimulus is applied. Stimulus is defined as an external agent, which produces excitability in the tissues.

Information travels through a neuron in the form of an electrical impulse, called an action potential. Action potentials are unidirectional, self-propagating changes in ion concentration over the plasma membrane. Dendrites receive inputs from other cells and conduct signals towards the cell body. Axons conduct signals away from the cell body towards their tips, where they are then passed on to other neurons or to muscle cells.

Signals are transmitted along a neuron via an action potential, when the axon membrane rapidly depolarizes and repolarizes. At the beginning of the action potential, the Na^+ channels open and Na^+ moves into the axon, causing depolarization. Repolarization occurs when the K^+ channels open and K^+ moves out of the axon. The impulse travels down the axon in one direction only, to the axon terminal where it signals other neurons.

ELECTRICAL PROPERTIES OF NEURONS

Enclosed within the membrane of any cell is a jellylike substance called cytoplasm that contains both inorganic and organic matter. In the cell body of neuron, this substance is called cytoplasm, but in the axon it is called axoplasm. In an inactive neuron, the axoplasm has an overall negative charge. This is because proteins, amino acids, phosphates, and other negatively-charged entities inside the cell cannot cross the selectively-permeable cell membrane.

Two types of positively-charged ions, potassium (K^+) and sodium (Na^+), can cross the cell membrane through selective ion channels. Normally there are more potassium ions inside the cell than outside, whereas there are more sodium ions outside the cell than inside. To combat the dissipation of the concentration of these ions, a chemically driven pump works to move sodium out of the cell and potassium into the cell.

Action potential

In physiology, an **action potential** is a short-lasting event in which the electrical membrane potential of a cell rapidly rises and falls. In neurons, they play a crucial role in cell-to-

cell communication. Action potentials in neurons are also known as "**nerve impulses**". Action potentials are generated by special types of voltage-gated ion channels embedded in a cell's plasma membrane. These channels are shut when the membrane potential is near the resting potential of the cell, but they rapidly begin to open if the membrane potential reaches a well defined threshold value. When the channels open, they allow an inward flow of sodium ions, which reverse the polarity of the plasma membrane. This then causes more channels to open, producing a greater electric current across the cell membrane, and so on. The process proceeds until all of the available ion channels are open, resulting in a large upswing in the membrane potential. After a while the sodium channels close, sodium ions can no longer enter the neuron, and then they are actively transported back out of the plasma membrane. Potassium channels are then activated, and there is an outward current of potassium ions, returning the electrochemical gradient to the resting state.

Transmission of nerve impulse within a neuron (in one direction only, from dendrite to axon terminal) is carried out by the opening and closing of voltage-gated ion channels, which cause a brief reversal of the resting membrane potential to create an action potential. As an action potential travels down the axon, the polarity changes across the membrane. Once the signal reaches the axon terminal, it stimulates other neurons.

CONDUCTION ALONG AN UNMYELINATED NERVE FIBRE

The action potential travels down the axon as the membrane of the axon depolarizes and repolarizes. As an action potential travels down the axon, there is a change in polarity across the membrane. At the beginning of the action potential, the Na^+ channels open and Na^+ moves into the axon, causing depolarization.

Repolarization occurs when the K^+channels open and K^+ moves out of the axon. This creates a change in polarity between the outside of the cell and the inside.

When a nerve is stimulated the resting potential changes. The rapid change in polarity that moves along the nerve fibre is called the "action potential." This moving change in polarity has several stages:

i) Depolarization

When a strong stimulus reaches a nerve it cause change in membrane permeability. The permeability of the nerve membrane to Na+ increases and the ions rush to the inside of the membrane. The inward flow of sodium ions, changes the electrochemical gradient, which in turn produces a further rise in the membrane potential. This then causes more channels to open, producing a greater electric current across the cell membrane, and so on.

As additional sodium rushes in, the membrane potential actually reverses its polarity so that the outsideof the membrane is negative relative to the inside. Thus the membrane become depolarized. The following series of event takes place:

- The nerve cells maintain a voltage difference across the plasma membrane, known as the **membrane potential**.

- Each excitable patch of membrane has two important levels of membrane potential: the resting potential, which is the value the membrane potential maintained as long as nothing perturbs the cell.
- At the axon hillock of a typical neuron, the resting potential is around –70 millivolts (mV) and the threshold potential is around –55 mV.
- Synaptic inputs to a neuron cause the membrane to depolarize .
- Action potentials are triggered when enough depolarization accumulates to bring the membrane potential up to threshold.
- When an action potential is triggered, the membrane potential abruptly shoots upward and then equally shoots back downward, often ending below the resting level, where it remains for some period of time.

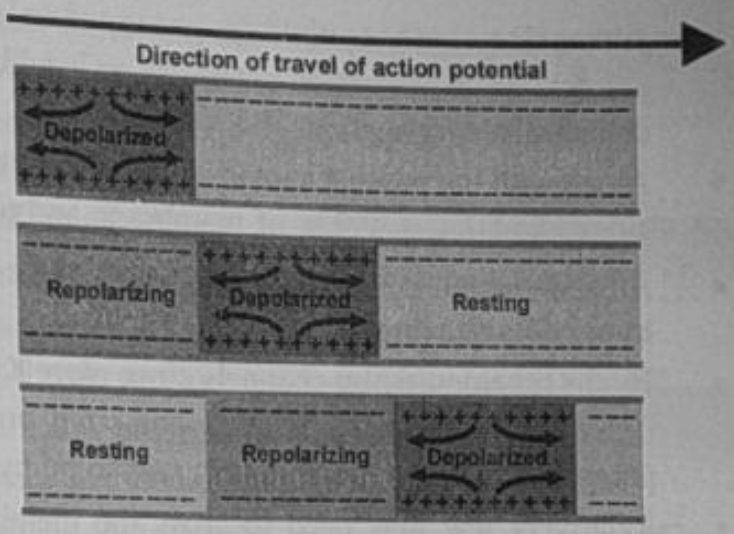

Fig. 6.1 Phase of Depolarization and Repolarization

ii) Repolarization

The rapid influx of sodium ions causes the polarity of the plasma membrane to reverse followed by inactivation of these ion channels. The downswing is caused by the closing of sodium ion channels and the opening of potassium ion channels. As the sodium channels close, sodium ions can no longer enter the neuron, and then they are actively transported back out of the plasma membrane. Potassium channels are then activated, and there is an outward current of potassium ions, returning the electro-chemical gradient to the resting state. This expulsion acts to restore the localized negative membrane potential of the cell (about – 65 or – 70 mV is typical for nerves). The following series of events occur :

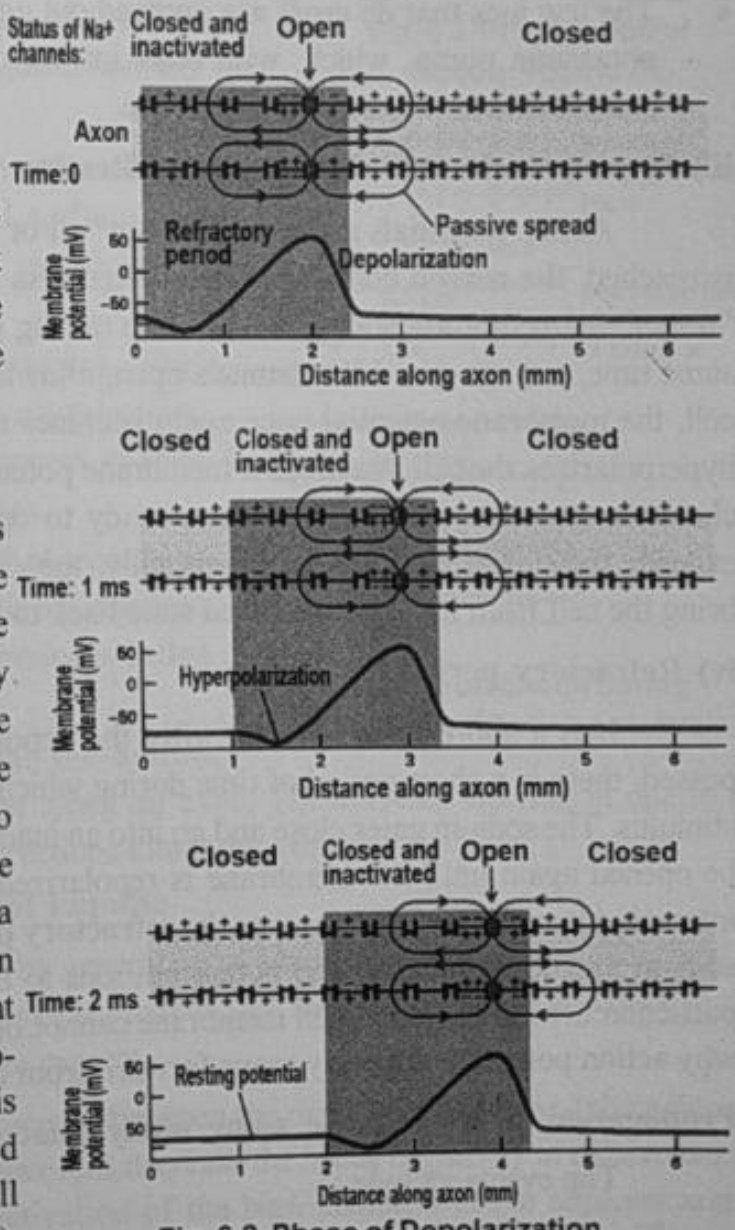

Fig. 6.2 Phase of Depolarization and Repolarization (Graphical representation)

- Although action potentials are generated on patches of excitable membrane, the resulting currents do trigger action potentials on neighboring stretches of membrane, precipitating a domino-like propagation.
- Along with the passive spread of electric potentials, action potentials are generated a new along excitable stretches of membrane and propagate without decay.
- After an action potential has occurred, there is a transient negative shift, called the after **hyperpolarization**.
- By the time potassium channels close more K+ have moved out of the cell than is actually necessary to establish original polarized potential. It further decreases the membrane potential. Thus the membrane is said to be hyperpolarized (about –80mV).
- Relatively few ions need to cross the membrane for the membrane voltage to change drastically. The ions exchanged during an action potential, therefore, make a negligible change in the interior and exterior ionic concentrations.
- The few ions that do cross are pumped out again by the continuous action of the sodium–potassium pump, which, with other ion transporters, maintains the normal ratio of ion concentrations across the membrane.

iii) Hyperpolarization and Return to Resting Potential

Action potentials are considered an "all-or nothing" event. Once the threshold potential is reached, the neuron completely depolarizes. As soon as depolarization is complete, the cell "resets" its membrane voltage back to the resting potential. The Na^+channels close and at the same time, voltage-gated K^+ channels open, allowing K^+ to leave the cell. As K^+ ions leave the cell, the membrane potential once again becomes negative. The diffusion of K^+ out of the cell hyperpolarizes the cell, making the membrane potential more negative. At this point, the sodium channels return to their resting state, ready to open again if the membrane potential again exceeds the threshold potential. Eventually, the channels closed and the Na^+/K^+ transporter, bring the cell from its hyperpolarized state back to its resting membrane potential.

iv) Refractory period

It is a short period of time after the depolarization stage. After a nerve impulse has passed, there is a short period of time during which the nerve is not able to respond to another stimulus. The sodium gates close and go into an inactive conformation. The sodium gates cannot be opened again until the membrane is repolarized to its normal resting potential. This brief interval of inexcitability is known as the **refractory period**. The sodium-potassium pump returns sodium ions to the outside and potassium ions to the inside. During the refractory phase this particular area of the nerve cell membrane cannot be depolarized. This refractory area explains why action potentials can only move forward from the point of stimulation.

Propagation of the Impulse along unmyelinated nerve

The events include :

- The action potential generated at the axon hillock propagates as a wave along the axon.
- It excites adjacent portions of the membrane resulting in propagation of the action potential.

- The excited nerve develops a **local circuit** of current flow between the depolarized and the resting membrane.
- The currents flowing inwards at a point on the axon during an action potential spread out along the axon, and depolarize the adjacent sections of its membrane.
- In this way more areas on the membrane becomes depolarized and the process of depolarization occur in one direction or both directions along the nerve fibre.
- Initially, a threshold stimulus creates an action potential. As the nerve fibre depolarizes, it triggers an increase in permeability of the sodium ion channels that causes sodium channels to open and sodium ions go into the nerve cell and reverse polarity. This action potential is going to be conducted along the length of the fibre by causing the next adjacent **voltage-gated** sodium ion channels to open.
- So as we go from left to right, sodiums are entering the cell due to these voltage-gated sodium ion channels opening up and meanwhile, to the left of it, the potassiums are going out.
- As the potassium ions go out, it repolarizes. This idea of sodium coming in and potassium going out, is going to repeat constantly so it appears to keep moving the electricity through the fibre.
- Once an action potential has occurred at a patch of membrane, the membrane patch needs time to recover before it can fire again. This period is called refractory period.
- The refractory period ensures that the action potential moves in only one direction along an axon. The currents flowing in due to an action potential spread out in both directions along the axon.

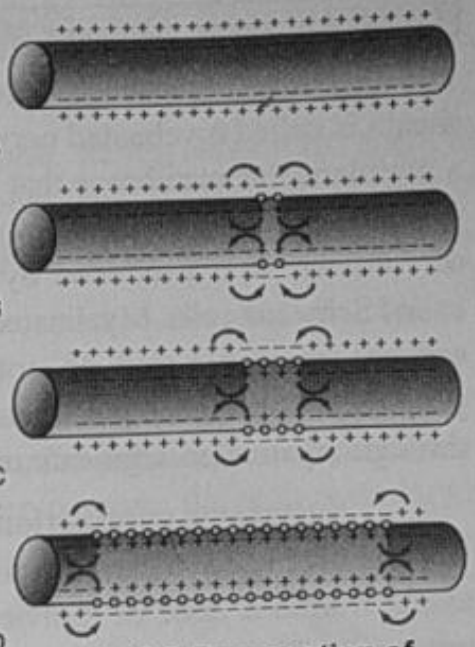

Fig. 6.3 Propagation of Action Potential

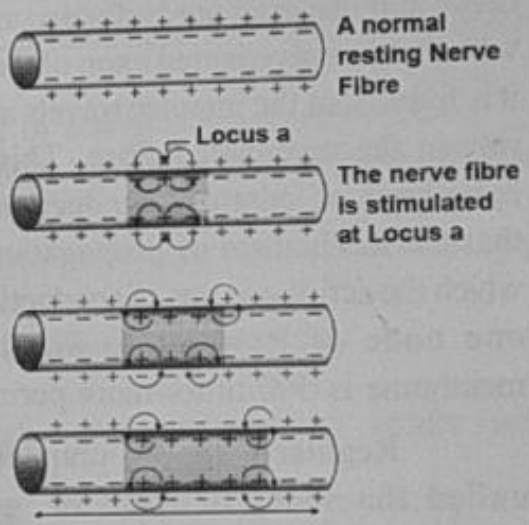

Fig. 6.4 Local circuit during propagation of Action potential

Local Circuit Theory of Propogation of impulse

The propagation of the impulse is by generation of Local Circuit Currents. The flow of current is from the activated locus to the adjacent inactivated loci on either side and back to the activated locus which acts as a sink of the current.

The local circuit of current flow occurs between the depolarized area and the adjacent resting membrane area. The influx of the Na+ ions decrease the inside negativity of the axolemma and initiate an AP which results in an activation of the Na+ channels in the adjacent areas, leading to its propagation in both the directions. The AP travel in both directions away from the site of stimulation and even along all branches of a nerve fibre to depolarize the entire membrane.

CONDUCTION ALONG MYELINATED NERVE FIBRE

Nerve fibre which is insulated by myelin sheath is called myelinated nerve fibres.Myelin is a multilamellar membrane that enwraps the axon in segments separated by intervals known as nodes of Ranvier. It is produced by specialized cells called Schwann cells. Myelinated sections of axons are not excitable and do not produce action potentials. Thus action potentials cannot propagate through myelinated segments of the axon.

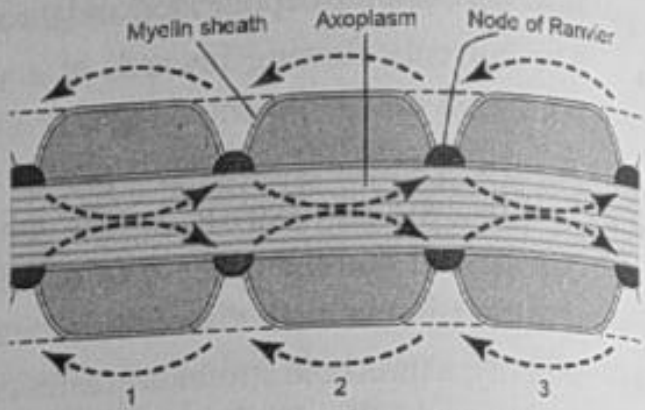

Fig. 6.5 Saltatory conduction along a myelinated axon

Saltatory conduction (from the latin word saltaire which means to jump or leap) is the propagation of action potentials along myelinated axons from one node of Ranvier to the next node, increasing the conduction velocity of action potentials. The uninsulated nodes of Ranvier are the only region along the axon where ions are exchanged. When the velocity of propagation of a nerve impulse in an unmyelinated axon is compared with that in a myelinated axon of the same diameter, it is found that the impulse travels at a much greater rate in the myelinated fibre. This has led to the hypothesis of saltatory conduction which suggest that the mechanism of propagation is different in which the active process of conduction 'jumps' from one node of Ranvier to another where the membrane is 500 times more permeable.

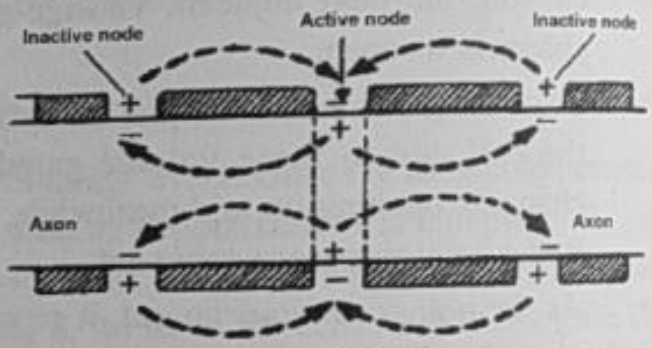

Fig. 6.6 Flow of electrical current during Saltatory conduction.

Regularly spaced unmyelinated patches, called the nodes of Ranvier, generate action potentials. Myelin prevents ions from entering or leaving the axon. As a general rule, myelination increases the conduction velocity of action potentials and makes them more energy efficient. The ionic current from an action potential at one node of Ranvier provokes another action potential at the next node; this apparent "hopping" of the action potential from node to node is known as saltatory conduction.

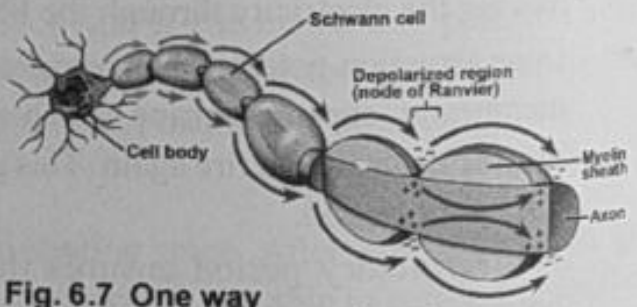

Fig. 6.7 One way transmission of nerve impulse in myelinated nerve fibre

Mechanism

- Myelinated axons only allow action potentials to occur at the unmyelinated nodes of Ranvier.
- Myelin acts as an insulator that prevents current from leaving the axon.
- It is by this restriction that saltatory conduction propagates an action potential along the axon of a neuron at rates significantly higher than without the myelination of the axon. The velocity in unmyelinated nerve fibre ranges from 0.5 to 2.4 m/sec., whereas in myelinated nerve fibre it ranges from 3 to 120 m/sec..

- This rapid conduction of electrical signal reaches the next node and creates another action potential. In this manner, saltatory conduction allows electrical nerve signals to be propagated long distances at high velocity without any degradation of the signal.

Energy efficiency

In addition to increasing the speed of the nerve impulse, the myelin sheath helps in reducing energy expenditure over the axon membrane as a whole. This is because the amount of sodium and potassium ions that need to be pumped to bring the concentrations back to the resting state following each action potential is decreased.

All-or-none principle

All-or-none law states that when a nerve is stimulated by a stimulus it gives maximum response or does not give response at all. The amplitude of an action potential is independent of the amount of current that produced it. In other words, larger currents do not create larger action potentials. Therefore, action potentials are said to be all-or-none signals, since either they occur fully or they do not occur at all. Greater intensity of stimulation does not produce a stronger signal but can produce a higher frequency of firing.

EXERCISE

A. Fill in the blanks:

1. The voltage difference across the plasma membrane of a neuron is called ———.
2. The jumping of the action potential from node to node in a myelinated nerve fibre is called ———.
3. The minimum potential value to which the membrane potential must reach before opening the ion channel is called ———.

Answer : 1. Membrane potential, 2. Saltatory conduction, 3. Threshold potential

B. Give one word answer.

1. The short lasting event in which the electrical membrane potential of a cell rapidly rises and falls.
2. The cells that form myelin sheath across nerve fibre.
3. The resting potential value of a typical neuron.

Answer : 1. Action potential, 2. Schwann cell, 3. –70 mV.

C. Answer in two to three sentences each.

1. Depolarization, 2. Refeactory period, 3. Hyperpolarization, 4. 'All or nothing' rule, 5. Threshold potential

D. Anwer in 75 words.

1. Action potential, 2. Local circuit theory, 3. Saltatory conduction.

E. Answer within 500 words.

1. What is action potential ? Describe the mechanism of propagation of action potential across the unmyelinated nerve fibre.
2. What is saltatory conduction ? Explain the mechanism along a myelinated nerve fibre and add a note on its energy efficiency.

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CHAPTER-7

SYNAPSE, TYPES OF SYNAPSE, SYNAPTIC TRANSMISSION

INTRODUCTION

Neurons form elaborate networks through which nerve impulses (action potentials) travel. Neurons receive information from sensory organs, send information to motor organs, or share information with other neurons. Each neuron has as many as 15,000 connections with other neurons. Neurons do not touch each other; instead, neurons interact at close contact points called synapses. The word synapse is derived from the Greek word *synapsis* meaning conjunction. Sir Charles Sherrington (1861 – 1954) first applied the term synapse to the junctional points between two neurons.

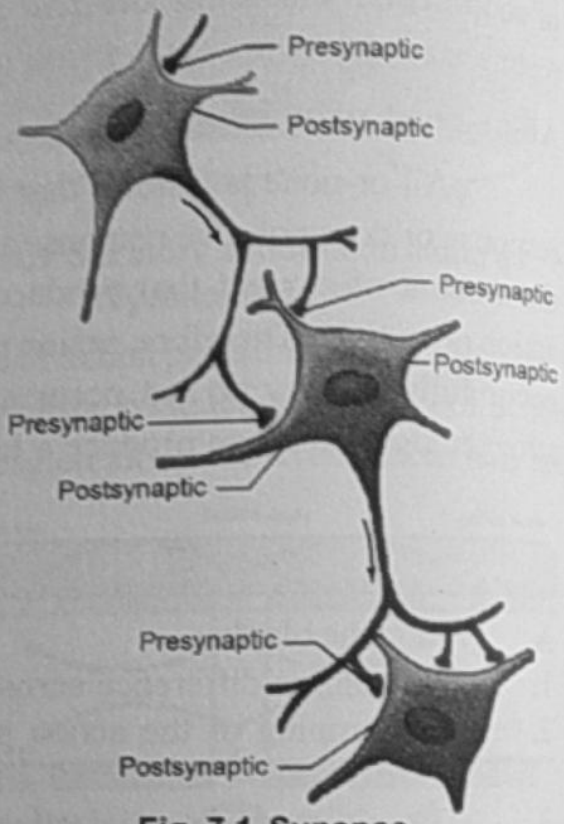


Fig. 7.1 Synapse

Definition : The synapse is an area of functional contact between one neuron and another for the purpose of transferring information. It is the junction between two neurons. It is only a physiological continuity between two nerve cells.

SYNAPSE STRUCTURE

A typical synapse consists of a minute bulbous expansion of a nerve terminal called a **presynaptic knob** lying close to the membrane of a dendrite. As many as 10,000 to 200,000 synaptic knobs also called presynaptic terminals lie on the surfaces of the dendrites and soma of the motor neuron, about 80 percent of them on the dendrites and only 20 percent on the soma. The presynaptic terminals show varied anatomical forms, but most resemble small round or oval knobs and, therefore, are sometimes called terminal knobs, boutons, or synaptic knobs.The cytoplasm of the pre synaptic knob contains mitochondria, smooth endoplasmic reticulum, microfilaments and numerous synaptic vesicles. The part of the synapse that belongs to the initiating neuron is called the ***presynaptic membrane or*** presynaptic terminal.The part of the synapse that belongs to the receiving neuron

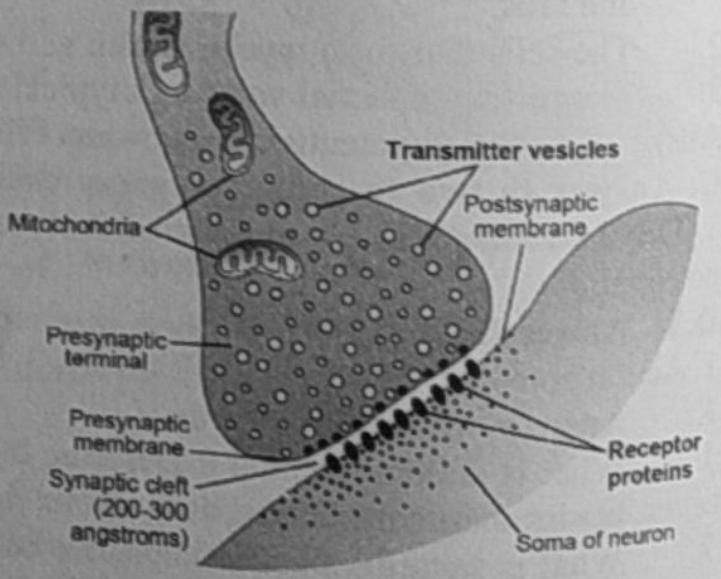


Fig. 7.2 Ultrastructure of Synapse

is called the ***postsynaptic membrane***.These two membranes do not fuse with each other but remain separated by a gap, the **synaptic cleft**. It is about 200 Å across.The presynaptic terminals has two internal structures important to the excitatory or inhibitory function of the synapse: the **transmitter vesicles** or **synaptic vesicle**and the **mitochondria**.

Each synaptic vesicle contains neurotransmitter (chemical substance) responsible for the transmission of the nerve impulse across the synapse. The neurotransmitter substance, when released into the synaptic cleft, either excites or inhibits the postsynaptic neuron.The mitochondria provide adenosine triphosphate (ATP), which in turn supplies the energy for synthesizing new transmitter substance.The post synaptic membrane contains large protein molecules which act as receptor sites for neurotransmitter and numerous channels and pores. These receptor proteins respond to chemical stimulation and inhibition.

When an action potential spreads over a presynaptic terminal, depolarization of its membrane causes a small number of vesicles to empty into the cleft. The released transmitter in turn causes an immediate change in permeability characteristics of the postsynaptic neuronal membrane,and this leads to excitation or inhibition of the postsynaptic neuron.

Common neurotransmitters include: Acetylcholine, Dopamine, Norepinepherine (noradrenaline), Serotonin

TYPES OF SYNAPSE

According to nature of connections the synapses are of following types:

i) **Axo-dendritic synapse :** A synapse between the axon of one neuron and dendrite of the other. This type of synapse is found in the cerebellum.

ii) **Axo-axonic synapse :** A synapse between axon of one neuron and axon of another neuron is known as Axo-axonic synapse.

iii) **Axo-somatic synapse :** A synapse between axon of one neuron and cell body of another neuron is known as axo-somatic synapse. In the cerebellum the axons of basket cell form connection with the cell body (cytons) of Purkinje cells.

iv) **Dendro-dendritic synapse :** A synapse between dendrites of two different neurons is known as dendro-dendritic synapse.

v) **Soma-somatic synapse :** It is the most primitive type of synapse which is developed between the cytons of different neurons.

The human nervous system uses a number of different neurotransmitter and neuroreceptors, and they don't all work in the same way. On this basis synapses are classified into 5 types:

i) **Excitatory Ion Channel Synapses :** These synapses have neuroreceptors that are sodium channels. When the channels open, positive ions flow in, causing a local depolarization and making an action potential more likely. Typical neurotransmitters are acetylcholine, glutamate or aspartate.

ii) **Inhibitory Ion Channel Synapses :** These synapses have neuroreceptors that are

chloride channels. When the channels open, negative ions flow in causing a local hyperpolarization and making an action potential less likely. So with these synapses an impulse in one neurone can inhibit an impulse in the next. Typical neurotransmitters are glycine or GABA.

iii) **Non Channel Synapses :** These synapses have neuroreceptors that are not channels at all, but instead are membrane-bound enzymes. When activated by the neurotransmitter, they catalyse the production of a "messenger chemical" inside the cell, which in turn can affect many aspects of the cell's metabolism. These synapses are involved in slow and long-lasting responses like learning and memory. Typical neurotransmitters are adrenaline, noradrenaline, dopamine, serotonin, endorphin, angiotensin, and acetylcholine.

iv) **Neuromuscular Junctions :** These are the synapses formed between motor neurones and muscle cells. They always use the neurotransmitter acetylcholine, and are always excitatory.

v) **Electrical Synapses :** In these synapses the membranes of the two cells actually touch or make physical contact. This allows the action potential to pass directly from one membrane to the next. They are very fast, found only in the heart and the eye.

Depending upon the mode of transmission across the synapse, synapse are of two kinds:

i) **Chemical Synapse :** In a chemical synapse pre-synaptic neuron releases a chemical (neurotransmitter) from synaptic vesicles into the synaptic cleft which binds to receptors on the post-synaptic side of the synaptic cleft. This causes depolarization of the post-synaptic cell membrane and transmission of impulse across the synapse. It is the most common type of synapse. Later the transmitter is cleared from the synapse by enzymes to terminate its action.

ii) **Electrical Synapse :** An electrical synapse is an electrical link between two adjacent neurons that is formed between pre-synaptic and post-synaptic neurons. The gap junction is much narrower than that of chemical synapse. The gap junctions are juxtaposed so that as the action potential reaches the end of the axon, the depolarization continues across the postsynaptic neuron directly. Electrical synapse is very fast and bi-directional (mostly allow impulse transmission in either direction).

Properties of Synapse

- Impulse is transmitted in one direction across the synapse. Presynaptic neuron → Post synaptic neuron.
- Synapse act as relay station as it is the site where impulses are received and discharged.
- A synaptic delay of 0.5 millisecond is required for the transmission of impulse across the synapse.
- During continuous muscular activity, synapse becomes the seat of fatigue. Fatigue at synapse is due to the depletion of neurotransmitter substance, acetylcholine.
- Summation is an important characteristic of synapse. It means adding up of the effects of multiple impulses at the synapse. It is of two types: **Spatial summation** occurs when many presynaptic terminals are stimulated simultaneously. **Temporal summation** occurs when one presynaptic terminal is stimulated repeatedly. Both spatial summation and temporal summation play an important role in facilitation of response.

SYNAPTIC TRANSMISSION

When a nerve impulse travelling along an efferent peripheral nerve reaches the synaptic terminals it produces a characteristic response in the effector tissue. However, evidence suggests that the impulse is conveyed to the effector organs by the release of chemical transmitters (neurotransmitters) into the synaptic cleft. Generally mammals use chemical means to trasmit information.

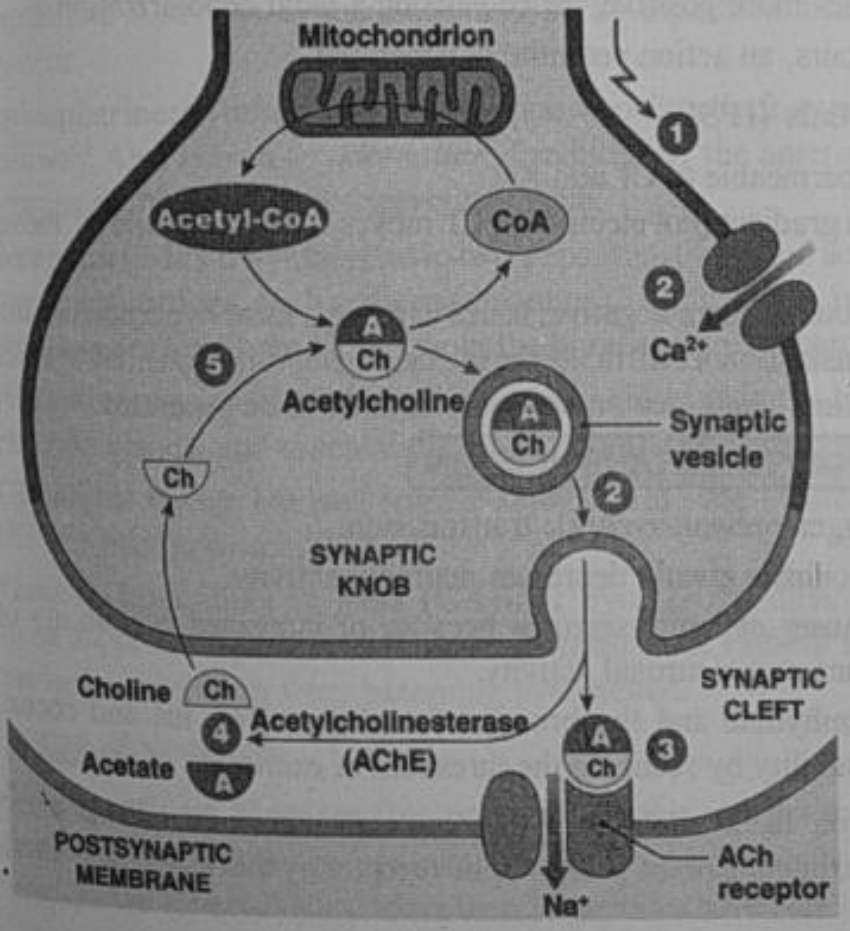
The process of chemical transmission across synapses was studied by Henry Dale (1936). A brief description of the mechanism of synaptic transmission is given below:-

(i) When an impulse arrives at a presynaptic knob, it depolarizes the presynaptic membrane resulting in the opening of voltage gated calcium channels. These calcium channels allow large numbers of calcium ions from the synaptic cleft to enter the cytoplasm of the presynaptic knob. The calcium ions that enter the presynaptic terminal bind with special protein molecules on the inside surface of the presynaptic membrane, called **release sites**.

(ii) The calcium ions cause the movement of the synaptic vesicles to the surface of the knob. The synaptic vesicles are fused with the presynaptic membrane and get ruptured (exocytosis) to discharge their contents (neurotransmitter) into the synaptic cleft.

(iii) The quantity of transmitter substance that is released into the synaptic cleft is directly related to the number of calcium ions that enter.

(iv) The synaptic vesicles then return to the cytoplasm of the synaptic knob where they are refilled with neurotransmitter.



1. Action potential depolarizes the synaptic knob.
2. Ca^{++} enter and after a brief period, ACh is released into the synaptic cleft. (Exocytosis)
3. ACh binds to receptor on the post-synaptic membrane causing depolarization.
4. Depolarization ceases as ACh is degraded into acetate and choline by Acetylcholine esterase.
5. Synaptic knob takes choline from the synaptic cleft to use for the synthesis of new ACh molecules.

Fig. 7.3 Events that occur at a Cholinergic synapse

(v) The neurotransmitter in the synaptic cleft binds with protein receptor molecules on the post synaptic membrane. This binding action changes the membrane potential of the postsynaptic membrane, opening channels in the membrane and allowing sodium ions to enter the cell.

(vi) This causes the depolarization and generation of action potential in the post synaptic membrane. Thus the impulse is transferred to the next neuron.

(vii) When the local depolarization on the post synaptic membrane (synaptic potential) reaches a certain magnitude it fires off an action potential in the next neuron or in the effector cell.

(viii) Having produced a change in the permeability of the post synaptic membrane the neurotransmitter is immediately removed from the synaptic cleft. In the case of cholinergic synapses, acetylcholine (ACh) is hydrolysed by an enzyme acetylcholin esterase (AChE) which is present in high concentration at the synapse.

(ix) The products of the hydrolysis are acetate and choline which are reabsorbed into the synaptic knob where they are resynthesized into acetylcholine, using energy from ATP.

(x) The time period from neurotransmitter release to receptor channel binding is less than a millionth of a second.

Postsynaptic stimulation

Once the postsynaptic ion channel is opened, whether directly or indirectly, the effect can be either excitatory (depolarizing) or inhibitory (hyperpolarizing).

Excitatory Postsynaptic Potentials (EPSP)

- Excitatory ion channels are permeable to Na^+ and K^+
- More Na^+ moves into the cell than K^+
- The inside of the cell becomes more positive, hence causing a local depolarization.
- If enough depolarization occurs, an action potential is generated.

Inhibitory Postsynaptic Potentials (IPSP)

- Inhibitory ion channels are permeable to Cl^- and K^+
- Because of the concentration gradient (not electrical), Cl^- moves into the cell and K^+ moves out of the cell
- The inside of the cell thus becomes more negative, hence causing a local hyperpolarization
- The hyperpolarization will make it more difficult for the cell membrane potential to reach threshold, thereby making it less likely that an action potential will be generated

FACTORS AFFECTING SYNAPTIC TRANSMISSION

Hypoxia: Non-availability of oxygen prevent synaptic transmission.

Acidosis: A fall in blood pH or acidosis greatly depresses neuronal activity.

Alkalosis: A rise in blood pH causes epileptic seizures because of increased excitability of neurons. Thus alkalosis greatly increases neuronal activity.

Drugs: Drugs like caffeine, theophylline and theobromine found in coffee, tea and cocoa, respectively increase neuron excitability by reducing the threshold of excitation of neurons.

Synaptic transmission relies on the availability of the neurotransmitter; the release of the neurotransmitter by exocytosis; the binding of the postsynaptic receptor by the neurotransmitter;

the functional response of the postsynaptic cell; and the subsequent removal or deactivation of the neurotransmitter.

NEUROTRANSMITTER

Neurotransmitters are signaling molecules released by a neuron (the presynaptic neuron), that bind to and activate the receptors of the postsynaptic neuron. Synthesis of the neurotransmitter occurs in the neuron itself.

There are two classes of neurotransmitters:

i. **Small molecules**, such as acetylcholine (ACh) or dopamine that are packaged in small vesicles.

ii. **Large molecules** made up of chains of amino acids that are packaged in large vesicles.

Small Molecules

Acetylcholine (ACh): It is the excitatory transmitter. Uses *choline* as a precursor, obtained from external food sources. Used at neuromuscular junctions as an excitatory neurotransmitter to influence muscle activation. Acetylcholine is the transmitter substance of the cholinergic effector organs.

Dopamine: Synthesized from the amino acid tyrosine. Generally involved in regulatory motor activity. Involved in mood, sensory perception, and attention. Schizophrenics have too much dopamine, patients with Parkinson's Disease have too little.

Norepinepherine: Also known as *noradrenaline*. Synthesized directly from dopamine, and forms the direct precursor to epinepherine. Used in the CNS by neurons that project in the cortex, cerebellum, and spinal cord; as such has many uses including sleep / wakefulness regulation. Activates sympathetic and parasympathetic neurons in the Autonomic Nervous System.

Epinepherine: Synthesized from tyrosine, and directly from norepinepherine in the biosynthetic pathway. Also known as *adrenaline*. Produced by the adrenal medulla. Activates sympathetic neurons in the Autonomic Nervous System.

Serotonin (5-HT): Synthesized in two steps from the amino acid tryptophan. Regulates complex cognitive functions, such as sleep (dreaming), eating, mood, pain regulation. Neurons which use serotonin are distributed throughout the brain and spinal cord.

Histamine: Synthesized from the amino acid histidine. Used in control of smooth muscle, exocrine glands, and vasculature. Used during inflammatory reactions.

Glutamate (Glu): Derived from α-ketoglutarate.Glutamate is the most important excitatory (EPSP) neurotransmitter.

Gamma-Aminobutyric Acid (GABA): Synthesized directly from glutamate. GABA is the most important inhibitory (IPSP) neurotransmitter. Present in high concentrations in the CNS, preventing the brain from becoming overexcited.

Large Molecules

Neuropeptides: They are first processed in the endoplasmic reticulum (ER) and are moved to the Golgi apparatus before being secreted as large vesicles and transported down the axon in preparation for exocytosis. More than 50 peptides have been isolated in nerve cells. For example,

- ✓ *Substance P* and *enkephalins*: Active during inflammation and pain transmission in the PNS.
- ✓ *Endorphins*: Endogenous opiates which cause euphoria, suppress pain, or regulate responses to stress.

They can also act as neuromodulators, affecting the amount of neurotransmitter released

Neurotransmitter Deactivation

If neurotransmitters were continually present in the synaptic cleft, the postsynaptic channels would be continually stimulated and the membrane potential would not be able to become stable. There are three ways in which neurotransmitter is deactivated:

1. ***Degradation***: Enzymes located in the synaptic cleft break down the neurotransmitter into a substance which has no effect on the receptor channel
2. ***Reuptake***: The neurotransmitter can reenter the presynaptic cell through channels in the membrane.
3. ***Autoreceptors***: Receptors for a particular neurotransmitter are located on the presynaptic membrane that act like a thermostat. When there is too much neurotransmitter released in the synapse, it decreases the release of further neurotransmitter when the action potential arrives at the presynaptic membrane.

EXERCISE

A. Fill in the blanks:

1. The functional contact between two neurons is called ———.
2. The space between pre-synaptic and post-synaptic membrane is called ———.
3. The protein receptor on post-synaptic membrane to which neurotransmitter attaches is called ———.

Answer : 1. Synapse, 2. Synaptic cleft, 3. Receptor protein

B. Give one word answer.

1. Types of synapse between axon of one neuron and dendrite of another.
2. Synapse type where chemical substance is released into the synaptic cleft.
3. The enzyme that degrades neurotransmitter Acetylcholine.

Answer : 1. Axodendritic synpase, 2. Chemical synapse, 3. Acetylcholinesterase

C. Answer in two to three sentences each.

1. Excitatory synapse, 2. Inhibitory synapse, 3. Synaptic vesicles, 4. Synaptic cleft, 5. Cholinergic synapse, 6. Acetylcholine.

D. Anwer in 75 words.

1. Neurotransmitter, 2. Structure of Synapse, 3. Types of synapse.

E. Answer within 500 words.

1. What is synapse ? Discuss the events that occur during synaptic transmission.
2. What is synapse ? Describe the ultra structure of axo-somatic synapse.

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CHAPTER-8

NEUROMUSCULAR JUNCTION

INTRODUCTION

An action potential in the plasma membrane of a skeletal muscle fibre is the signal that triggers contraction. Stimulation of the nerve fibres to a skeletal muscle is the only mechanism by which action potentials are initiated in this type of muscle. The nerve cells whose axons innervate skeletal muscle fibres are known as motor neurons or somatic efferent neurons. The axons of motor neurons are myelinated and are therefore able to propagate action potentials at high velocities, allowing signals from the central nervous system to be transmitted to skeletal muscle fibres with minimal delay.

Upon reaching a muscle, the axon of a motor neuron divides into many branches, each branch forming a single junction with a muscle fibre. A single motor neuron innervates many muscle fibres, but each muscle fibre is controlled by a branch from only one motor neuron. A motor neuron plus the muscle fibres it innervates is called a motor unit. When an action potential occurs in a motor neuron, all the muscle fibres in its motor unit are stimulated to contract.

The region of the muscle fibre plasma membrane that lies directly under the terminal portion of the axon is known as the motor end plate.The junction of an axon terminal with the motor end plate is known as a neuro muscular junction.

Definition: A **neuromuscular junction** (or **myoneural junction**) is a chemical synapse formed by the contact between a motor neuron and a muscle fibre. It is at the neuromuscular junction that a motor neuron is able to transmit a signal to the muscle fibre, causing muscle contraction.

STRUCTURE

The nerve cells whose axons innervate skeletal muscle fibres are known as motor neurons. Upon entering a skeletal muscle, each nerve fibre (axon) divides into many terminal branches. Each terminal branch innervates one muscle fibre through the neuromuscular junction. The structure of neuromuscular junction can be described under:

Axon Terminal and Motor Endplate: Terminal branch of nerve fibre is called axon terminal. When the axon comes close to muscle fibre, it loses the myelin sheath and thus the axis cylinder is exposed. The portion of the axis cylinder or terminal neuron is expanded like a bulb, which is called **motor endplate**. The plate invaginates into the muscle fibre but lies outside the muscle fibre membrane. Axon terminal contains mitochondria and synaptic vesicles. Synaptic vesicles contain the neurotransmitter substance, acetylcholine (Ach). Mitochondria contain ATP, which is the source of energy for the synthesis of acetylcholine.

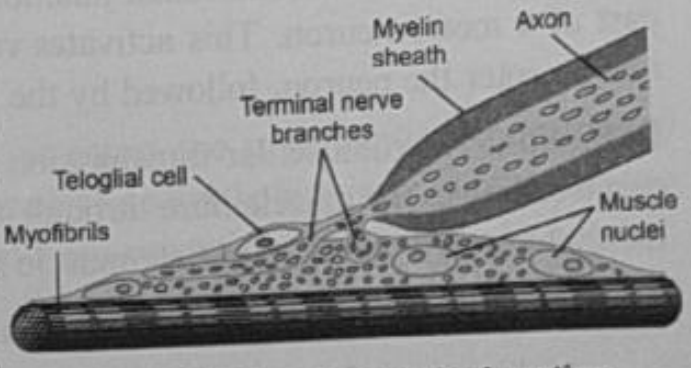

Fig. 8.1 Neuromuscular junction

Synaptic trough: Motor endplate invaginates inside the muscle fibre and forms a depression, which is known as synaptic trough or synaptic gutter. The membrane of the muscle fibre below the motor endplate is thickened.

Synaptic Cleft: Membrane of the nerve ending is called the presynaptic membrane. Membrane of the muscle fibre is called postsynaptic membrane. Space between these two membranes is called synaptic cleft. Synaptic cleft contains basal lamina, a thin layer of matrix through which the extracellular fluid diffuses.

Subneural Clefts: Postsynaptic membrane is the membrane of the muscle fibre. It is thrown into numerous folds called subneural clefts. Postsynaptic membrane contains the receptors called nicotinic acetylcholine receptors.

The **neuromuscular junction** differs from chemical synapses between neurons. Presynaptic motor axons stop 30 nanometers from the sarcolemma. This 30-nanometer space forms the synaptic cleft through which signalling molecules are released. The sarcolemma has invaginations called post-junctional folds, which increase the surface area of the membrane exposed to the synaptic cleft. These post- junctional folds form what is referred to as the motor end plate, which possess nicotinic acetylcholine receptors (nAChRs) at a density of 10,000 receptors/ micrometer^2 in skeletal muscle.

The presynaptic axons form bulges called presynaptic terminals that project into the postjunctional folds of the sarcolemma. The presynaptic terminals have active zones that contain synaptic vesicles. When impulse arrives these vesicles can fuse with the presynaptic membrane and release ACh molecules into the synaptic cleft via exocytosis.

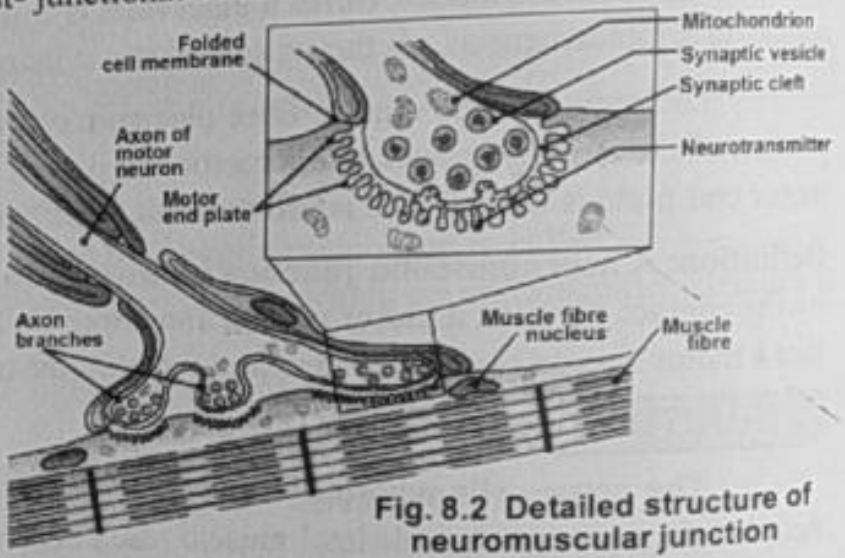

Fig. 8.2 Detailed structure of neuromuscular junction

NEUROMUSCULAR TRANSMISSION

The neuromuscular junction is where a neuron activates a muscle to contract. Synaptic transmission at the neuromuscular junction occurs when an action potential reaches the terminal part of a motor neuron. This activates voltage-dependent calcium channels to allow calcium ions to enter the neuron, followed by the release of neurotransmitter substances.

Definition: Neuromuscular transmission is defined as the transfer of information from motor nerve ending to the muscle fibre through neuromuscular junction. It is the mechanism by which the motor nerve impulses initiate muscle contraction.

Events During Neuromuscular Transmission

A series of events take place during neuromuscular transmission. The events are: 1. Release of acetylcholine, 2. Action of acetylcholine, 3. Development of endplate potential, 4. Development of miniature endplate potential, 5. Deactivation of acetylcholine.

1. Release of acetylcholine

When action potential reaches axon terminal, it opens the voltage-gated calcium channels in the membrane of terminal neuron. Calcium ions from extracellular fluid (ECF) enter the axon terminal and bind to synaptic vesicles. This binding triggers vesicle fusion with the cell membrane and subsequent release of neurotransmitter into the synaptic cleft, a process known as exocytosis. Each vesicle contains about 10,000 acetylcholine molecules. And, at a time, about 300 vesicles open and release acetylcholine.

2. Action of acetylcholine

In the synaptic cleft, acetylcholine molecules bind to acetylcholine receptors, present in the postsynaptic membrane and form acetylcholine-receptor complex. This complex increases the permeability of postsynaptic membrane for sodium by opening the ligand-gated sodium channels. Sodium ions enter and depolarize the muscle fibre, causing a cascade that eventually results in muscle contraction. In other words, sodium ions alter the resting membrane potential and develops the electrical potential called the endplate potential.

3. Development of endplate potential

Endplate potential is the change in resting membrane potential when an impulse reaches the neuromuscular junction. Resting membrane potential at neuromuscular junction is –90 mV. When sodium ions enter inside, slight depolarization occurs up to –60 mV, which is called endplate potential.

4. Development of miniature endplate potential

Miniature endplate potential is a weak endplate potential in neuromuscular junction that is developed by the release of a small quantity of acetylcholine from axon terminal. And, each quantum of this neurotransmitter produces a weak miniature endplate potential. Miniature endplate potential cannot produce action potential in the muscle. When more and more quanta of acetylcholine are released continuously, the miniature endplate potentials are added together and finally produce endplate potential resulting in action potential in the muscle.

5. Deactivation of acetylcholine

Acetylcholine released into the synaptic cleft is destroyed very quickly, by the enzyme, acetylcholinesterase. Rapid destruction of acetylcholine has got some important functional significance. It prevents the repeated excitation of the muscle fibre and allows the muscle to relax.

Reuse of acetylcholine:

The degraded product of neurotransmitter re-enters the presynaptic axon terminal where it is reused. Acetylcholinesterase splits (degrades) acetylcholine into inactive choline and acetate. Choline is taken back into axon terminal from synaptic cleft by reuptake process. There, it is reused in synaptic vesicle for synthesis of a new acetylcholine molecule.

NEUROMUSCULAR BLOCKERS

Neuromuscular blockers are the drugs, that prevent transmission of impulses through the neuromuscular junctions. These drugs are used widely during surgery and trauma care.

Neuromuscular blockers used during anesthesia relax the skeletal muscles and induce paralysis so that surgery can be conducted with less complication. Some important neuromuscular blockers, that are commonly used in clinics and research are:

1. Curare:

Curare prevents the neuromuscular transmission by combining with acetylcholine receptors. So, the acetylcholine cannot combine with the receptors. And, the endplate potential cannot develop. Since curare blocks the acetylcholine receptors, it is called receptor blocker.

2. Bungarotoxin

Bungarotoxin is a toxin from the venom of deadly snakes. It affects the neuromuscular transmission by blocking the acetylcholine receptors.

3. Succinylcholine and Carbamylcholine

These drugs block the neuromuscular transmission by acting like acetylcholine and keeping the muscle in a depolarized state. Since these drugs are not destroyed by cholinesterase, the muscle remains in a depolarized state for a long time.

4. Botulinum Toxin

Botulinum toxin is derived from the bacteria *Clostridium botulinum*. It prevents release of acetylcholine from axon terminal into the neuromuscular junction.

Drugs Stimulating Neuromuscular Junction

Neuromuscular junction can be stimulated by some drugs like neostigmine, physostigmine and diisopropyl fluorophosphate. These drugs inactivate the enzyme, acetyl cholinesterase. The acetylcholine is not hydrolyzed. This leads to repeated stimulation and continuous contraction of the muscle.

EXERCISE

A. Fill in the blanks:

1. The contact between a motor neuron and a muscle fibre is called _____.
2. The post-junctional fold in a neuromuscular junction is called _____.

Answer : 1. Neuromuscular junction, 2. Motor end plate

B. Give one word answer.

1. The neuron that innervate skeletal muscle.
2. The bulb like expanded structure of terminal neuron at neuromuscular junction.

Answer : 1. Motor neuron, 2. Mortor end plate

C. Answer in two to three sentences each.

1. Motor end plate, 2. Sub-neuron cleft, 3. Synaptic trough.

D. Anwer in 75 words.

1. Neuromuscular junction, 2. Neuromuscular blocker

E. Answer within 500 words.

1. What is neuromuscular junction ? Describe the structure and enumerate the events that occur during stimulation of skeletal muscle.

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CHAPTER-9

REFLEX ACTION AND ITS TYPES, REFLEX ARC

INTRODUCTION

Reflex activity is the response to a peripheral nervous stimulation that occurs without our consciousness. It is a type of protective mechanism and it protects the body from irreparable damages. For example, when hand is placed on a hot object, it is withdrawn immediately. When a bright light is thrown into the eyes, eyelids are closed and pupil is constricted to prevent the damage of retina by entrance of excessive light into the eyes.

REFLEX ACTION

A reflex action, also known as a reflex, is an involuntary and nearly instantaneous movement or action by an effector organ in response to a stimulus. When a person accidentally touches a hot object, he automatically jerkhis hand away without thinking. A reflex does not require any thought input.

The path taken by the nerve impulses in a reflex is called a reflex arc. In higher animals, most sensory neurons do not pass directly into the brain, but synapse in the spinal cord. This characteristic allows reflex actions to occur relatively quickly by activating spinal motor neurons without the delay of routing signals through the brain. The brain also receive sensory input while the reflex action occurs.

The steps carried out during reflex action when a person suddenly steps on a sharp object.

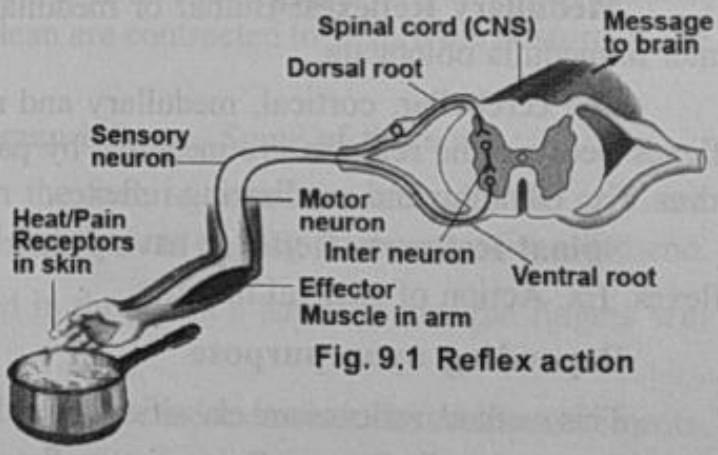

Fig. 9.1 Reflex action

- Pain stimulus arrives at the site of injury which activates the receptor at the site.
- Sensory neuron is activated that transmits the stimulus to CNS (Spinal Cord).
- The information (pain stimulus) is processed in CNS.
- Simultaneously the information is relayed to the brain by collateral nerves.
- After processing in the CNS the motor neuron supplying to the effector (muscles) is activated.
- The effector muscles contract thereby pulling away the organ or receptor from the source of stimulus.

TYPES OF REFLEX

Reflexes are classified by five different methods depending upon various factors.

1. Whether inborn or acquired reflexes

i) Inborn Reflexes or Unconditioned Reflexes : Unconditioned or inborn reflexes are the natural reflexes, which are present since the time of birth. Such reflexes do not require previous learning, training, conditioning or past experiences with a particular type of stimulus. Best example is the secretion of saliva when a drop of honey is kept in the mouth of a newborn baby for the first time. The baby does not know the taste of honey, but still saliva is secreted. Another example is that the pupil of our eyes automatically expand in darkness and contract in light.

ii) Acquired Reflexes or Conditioned Reflexes : Conditioned or acquired reflexes are reflexes, which an individual learns from previous experiences with similar stimulus. These reflexes are not inborn but, acquired after birth. These are the reflexes that are developed after conditioning or training. For example, a dog may begin to salivate with smell of food because the dog has learnt to associate the smell with the food. Another example is the secretion of saliva by sight, smell, thought of a known edible substance.

2. Depending upon situation

In this method, reflexes are classified depending upon the situation of the center.

i) Cerebellar Reflexes: Cerebellar reflexes are the reflexes which have their center in cerebellum.

ii) Cortical Reflexes: Cortical reflexes are the reflexes that have their center in cerebral cortex.

iii) Midbrain Reflexes: Midbrain reflexes are the reflexes which have their center in midbrain.

iv) Medullary Reflexes: Bulbar or medullary reflexes are the reflexes which have their center in medulla oblongata.

The cerebellar, cortical, medullary and midbrain reflexes are together called cranial reflexes because the reflexes are mediated by pathways situated in the brain and the cranial nerves. Ex. Blinking and swallowing reflexes.

v) Spinal Reflexes: Reflexes having their center in the spinal cord are called spinal reflexes. Ex. Action of skeletal muscles.

3. Depending upon purpose

This method, reflexes are classified depending upon the purpose (functional significance).

i) Protective Reflexes: Protective reflexes are the reflexes which protect the body from harmful stimuli. These reflexes are also called withdrawal reflexes or flexor reflexes. Withdrawal of body from a hot object after touching unknowingly.

ii) Antigravity Reflexes: Antigravity reflexes are the reflexes that protect the body against gravitational force. These reflexes are also called the extensor reflexes because, the extensor muscles contract during these reflexes resulting in extension at joints.

4. On the basis of number of synapse

Depending upon the number of synapse in reflex arc, reflexes are classified into two types:

i) **Monosynaptic Reflexes:** When a reflex arc consists of only two neurons (one sensory and one motor) with one synapse between them, it is known as monosynaptic reflex. Ex. Patellar (Knee-jerk) Reflex.

ii) **Polysynaptic Reflexes:** Reflexes having more than one synapse in the reflex arc are called polysynaptic reflexes. Ex. A limb can move in opposite directions because muscles work in pairs, an extensor and a flexor.

5. **Whether somatic or visceral reflexes**

i. **Somatic Reflexes:** Somatic reflexes are involved in the reflex control of skeletal muscles and there are many different types of somatic reflexes like scratching reflexes, withdrawal reflexes, stretch reflexes and tendon reflexes. A few of these will be covered in the section below.

ii. **Visceral or Autonomic Reflexes:** Autonomic reflexes control and regulate **smooth muscle cells, cardiac muscle cells** and **glands**. In general these reflexes contain the same basic components as somatic reflexes but difference is that autonomic reflexes have the ability to stimulate as well as inhibit the smooth muscle or gland.

Tendon Reflexes: In certain instances, muscle contractions is so powerful that the tendon either breaks or detaches or have a similar effect. Tendon reflexes is designed to prevent tendon damage from occurring. The result of this reflex arc is that if the sensory neurons detect tendon stretch that is excessive, the muscle will relax to reduce the load on the tendon.

Stretch Reflexes : It is performed totally unconsciously. Stretch reflexes have been included here as they play an important role in posture and balance of animals. During locomotion the body of the animal will regularly lean laterally as the limbs move. The stretch reflex ensures that the contra-lateral muscles to the side of the lean are contracted to ensure the posture of the body is brought back into a neutral position.

Many reflexes are only observed in **human infants**. Some of these are :

i) **Asymmetrical tonic neck reflex**:When the face is turned to one side, the arm and leg on the side to which the face is turned extend and the arm and leg on the opposite side bend.

ii) **Grasp reflex**: When an object is placed in the infant's hand / palm, the fingers will close and they will grasp it.

iii) **Moro reflex**: When the body contracts in response to loud noises or sudden movements.

iv) **Sucking**: When an item is placed by the infants mouth it will begin sucking on it.

v) **Tonic labyrinthine reflex**: When the head of the infant is tilted back while he/she is lying on his/her back, it causes the back to stiffen and arch backwards. It also causes the legs to straighten, stiffen, and push together, causes the arms to bend at the elbows and wrists, and causes the hands to become fisted.

PROPERTIES OF REFLEXES

1. **One way conduction** : During any reflex activity, impulses are transmitted in only one direction through the reflex arc. The impulses pass from receptors to center and then from center to effector organ.

2. **Reaction time** : Reaction time is the time interval between application of stimulus and the onset of reflex. It depends upon the length of afferent and efferent nerve fibres, velocity of impulse through these fibres. Synaptic delay is the delay at the synapse.

3. **After discharge** : It is the continuation of response for some time even after cessation of stimulus. When a reflex action is elicited continuously for sometime and then the stimulation is stopped, the reflex activity continues for sometime even after the stoppage of the stimulus. It is because of the discharge of impulses from the centre even after stoppage of stimulus.

4. **Rebound phenomenon** : Reflex activities can be forcefully inhibited for some time. However, when the inhibition is removed, the reflex activity becomes more forceful than before inhibition. It is called rebound phenomenon. Reason for this state is not known.

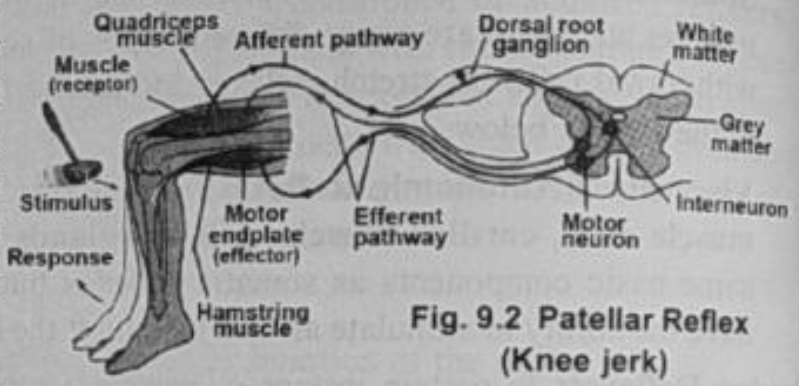

Fig. 9.2 Patellar Reflex (Knee jerk)

5. **Fatigue** : When a reflex activity is continuously elicited for a long time, the response is reduced slowly and at one stage, the response does not occur. This failure to elicit response to the stimulus is called fatigue.

Example:

Patellar (Knee-jerk) Reflex : When the patellar tendon is tapped with a reflex hammer just below the knee, the patellar reflex is initiated which instantaneously stretches the quadriceps muscle and excites a dynamic stretch reflex that causes the lower leg to "jerk" forward. The tap creates an action potential in a muscle fibre in quadriceps. This action potential travels to the L3 and L4 nerve roots of the spinal cord through sensory axon. The action potential then travels onto a motor neuron which conducts an efferent impulse back to the quadriceps, causing its contraction. This contraction, coordinated with the relaxation of the antagonistic flexor hamstring muscle causes the leg to kick. It is an example of monosynaptic reflex as there are no interneurons in the pathway.

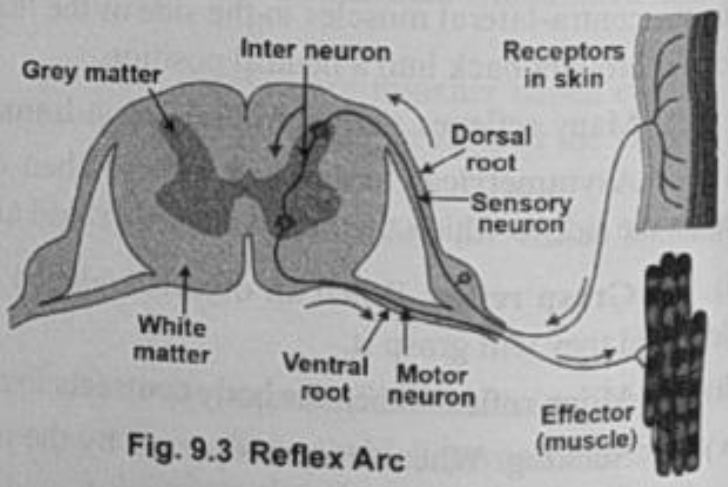

Fig. 9.3 Reflex Arc

REFLEX ARC

A **reflex arc** is a neural pathway that controls a reflex action. It is the pathway followed by sensory nerve in carrying the sensation from receptor organ to spinal cord and then the pathway followed by motor nerve in carrying the order from spinal cord to effector organ during a reflex action. In higher animals, most sensory neurons do not pass directly into the brain, but synapse in the spinal cord. This allows faster reflex action to occur.

A simple reflex arc includes the following five components:

1. **Somatic receptor:** Receptor is the organ, which receives the stimulus. When receptor is stimulated, impulse is generated in afferent nerve.
2. **Sensory neuron :** Sensory neuron transmits sensory impulses from the receptor to the the spinal cord.
3. **Center :** The nerve impulse reaches the axon endings and the synapse. The impulse is then initiated in the second neuron in the integrating centre. Center receives the sensory impulses and in turn, generates appropriate motor impulses. The impulse proceeds along the connector neuron and initiates impulse in the motor neuron. Center is located in the brain or spinal cord.
4. **Motor neuron :** Motor neuron transmits motor impulses from the center to the effector organ.
5. **Effector Organ :** The motor neuron terminates in the effector organ which responds to the impulse. Effector organ may be muscle or gland where the activity occurs in response to stimulus.

Reflex Arc chain : In higher vertebrates a single stimulus may produce several simple reflexes which may involve more than one reflex arc. Ex. If a person burns his finger he will remove his hand in a jerk. Simultaneously he will also behave and react in different ways which involves a number of reflex arcs. This occurs due to the fact that a single sensory neuron have synaptic connections with other neurons thus eliciting several reflexes. Similarly, a single motor neuron may have synaptic connections with several neurons, thus several stimuli in different parts of the body may elicit response. Thus most reflex actions are usually complex and involve a chain of reflex arcs.

TYPES OF REFLEX ARCS

There are two types of reflex arcs : **Autonomic reflex arc**, affecting inner organs, and the **Somatic reflex arc**, affecting muscles.

i) Autonomic Reflexes : Visceral or autonomic reflexes are the reflexes, where a part of reflex arc is formed by autonomic nerve fibres. These reflexes involve participation of smooth muscle or cardiac muscle. Visceral reflexes include pupillary reflexes, gastrointestinal reflexes, cardiovascular reflexes, respiratory reflexes, etc. Some reflexes like swallowing, coughing or vomiting are visceral reflexes. However, these reflexes also involve participation of skeletal muscles.

ii) Somatic Reflexes : Somatic reflexes are the reflexes, in which the reflex arc is formed by somatic nerve fibres. These reflexes involve the participation of skeletal muscles.

iii) Monosynaptic reflex arc : When a reflex arc consists of only two neurons, one sensory neuron, and one motor neuron, it is defined as monosynaptic. Monosynaptic refers to the presence of a single chemical synapse. In the case of peripheral muscle reflexes (patellar reflex), stimulation to the muscle results in the contraction of the effector muscle.

iv) **Polysynaptic reflex arc :** In polysynaptic reflex arc, one or more interneurons connect afferent (sensory) and efferent (motor) neuron. For example, the withdrawal reflex is a spinal reflex intended to protect the body from damaging stimuli. It causes the stimulation of sensory, association, and motor neurons.

EXERCISE

A. Fill in the blanks:

1. Secretion of saliva by sight of food is —— reflex.
2. Expansion of eye pupil in darkness is —— reflex.
3. The information received by receptor during reflex action is processed in ———.

Answer : 1. Acquired / conditioned, 2. Inborn / unconditioned, 3. CNS

B. Give one word answer.

1. An involuntary movement by an effector organ in response to a stimulus.
2. The path taken by the nerve impulse in a reflex action.

Answer : 1. Reflex action, 2. Reflex arc

C. Answer in two to three sentences each.

1. Acquired reflex, 2. Inborn reflex, 3. Monosynaptic reflex, 4. Polysynaptic reflex, 5. One way conduction, 6. Autonomic reflex

D. Anwer in 75 words.

1. Reflex action, 2. Reflex act, 3. Patellar reflex

E. Answer within 500 words.

1. What is reflex action ? Describe the phenomenon taking a suitable example.
2. What is reflex arc ? Describe the types of reflex arc along with its mode of action.

●●●

CHAPTER-10

PHYSIOLOGY OF HEARING AND VISION

INTRODUCTION

To maintain a normal life all animals along with human beings must adapt effectively to its fluctuating or changing environment. Therefore a continuous flow of information of the change, must reach the CNS to make suitable adjustments or changes in order to adapt according to the need of the moment. Nature has designed specialized cells to perceive fluctuating conditions outside or inside the body. These specialized cells are called **receptors**. All receptor cells of the body are supplied with nerve fibres of afferent or sensory nature.

The most familiar receptors are the photoreceptors, phonoreceptors, olfactoreceptors, gustatoreceptors and tangoreceptors. In addition numerous other receptors are also present in the body. The receptors found outside the body are called external receptors. These receptors receive informations from external environment. Ex. Photoreceptors (Eye), Phonoreceptors (Ear), Gustatoreceptor(Tongue), Olfactoreceptor (Nose),Tangoreceptor (Skin). The receptors found inside the body are called internal receptors. Thesereceptors receive informations from internal environment. Ex. Statoreceptors (Equilibrium), internal receptors within the body for hunger, thirst etc.

Most receptors are more or less diffused over a large area. However, those receptors which are localized are the special sensory receptors, which include eyes, ears etc.

PHYSIOLOGY OF HEARING

Ears are the organs of hearing and balance. They are divided into three parts: **external, middle, and inner ears.** The external and middle ears are involved in hearing only, whereas the inner ear functions in both hearing and balance. The external ear includes the auricle (pinna) and the external auditory meatus. The external ear terminates medially at the eardrum, or tympanic membrane. The middle ear is an air-filled space within the temporal bone, which contains the auditory ossicles. The inner ear consists of interconnecting fluid-filled tunnels and chambers within the temporal bone.

Auditory structures and their functions : The mammalian ear is differentiated into three parts : **External, Middle** and **Inner ear.**

i) External Ear

It is not found in non-mammalian vertebrates. It consists of a skin-covered flap known as the pinna, which leads into the ear canal or external auditory meatus. Pinna is absent in prototherians and marine mammals. It is made up of elastic cartilage, and in man has very little

mobility. From the external ear, there leads a narrow tube that passes down to the tympanic membrane. The narrow tube termed as **external auditory meatus**, is about 25 mm long in human being, and is situated in the temporal bone.

Fine hairs and ceruminous glands (which secrete cerumen or ear-wax) are found in the outer part. Accumulation of wax prevents conduction of sound. The ear canal terminates at the eardrum, which forms the boundary between the external ear and the middle ear. The external ear is responsible for collecting airborne sounds. The tympanic membrane or ear drum is a delicate membrane (about 1.0 cm in diameter) that separates auditory meatus from the middle ear. Tympanic membrane vibrates under the influence of sound waves that enter the auditory meatus.

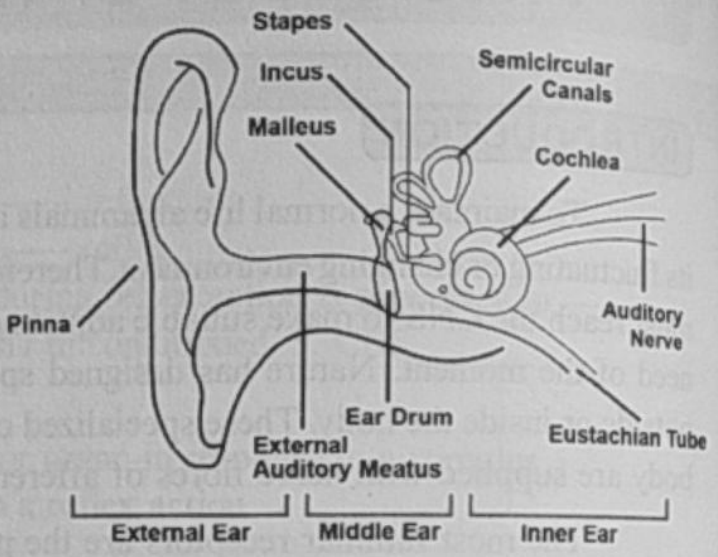

Fig. 10.1 Internal Structure of Human ear

The external ear has two key functions. Firstly, the resonances of the external ear, increase the sound pressure at the eardrum by as much as 20 dB, which, contributes to the listener's hearing sensitivity. Secondly, interaction of sound waves with the external ear provides information on the location of sound sources.

Some mammals, such as cats and bats, can independently alter the shape and orientation of their pinnae. Dogs tend to raise their pinnae. Cats direct their ears toward the source of environmental sounds. In bats, pinna movements are additionally thought to play an important role in echolocation.

ii) Middle Ear

It is well developed in birds and mammals. It is the region between tympanic membrane and two openings, the **round** and **oval** windows, that separate it from the inner ear. The ear drum is concave towards the outer surface and convex towards inner. The air-filled cavity of the middle ear also called tympanic cavity, has two openings for air passages. One passage opens into the the mastoid process of the temporal bone. The other passage, the auditory or eustachian tube, opens into the pharynx and equalizes air pressure between the outside air and the middle ear cavity. If the air pressure is not equalized, the tympanic membrane may rupture. Unequal pressure between the middle ear and the outside environment can distort the eardrum, and make hearing difficult.

The middle ear contains three small bones or auditory ossicles: the *malleus* (hammer), *incus* (anvil), and *stapes* (stirrup), which transmit vibrations from the tympanic membrane to the oval window. The handle of the malleus is attached to the inner surface of the tympanic membrane, and vibration of the membrane causes the malleus to vibrate as well. Malleus, articulates with the incus. Incus, in turn is attached to the stapes, the base of which carries a

foot plate that fits into the **oval window** or **fenestra ovalis**. The three ossicles act as a lever system performing an amplification function.

Auditory ossicles

Auditory ossicles are the three miniature bones, which are arranged in the form of a chain, extending across the middle ear from the tympanic membrane to oval window. Auditory ossicles are: i. Malleus ii. Incus iii. Stapes.

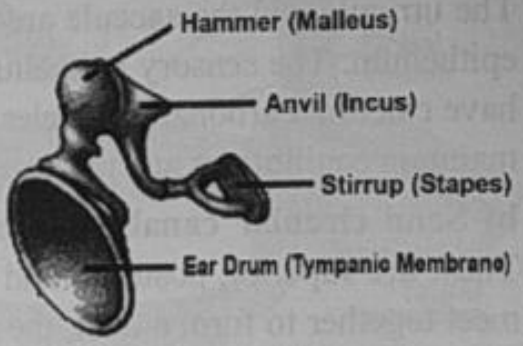

Fig. 10.2 Tympanic membrane & Ear Ossicles

a) Malleus : Malleus, otherwise called hammer has a handle, head and neck. Handle is called manubrium and it is attached to tympanic membrane. Neck extends from handle to the head. Head articulates with the body of incus.

b) Incus : Incus is also known as anvil. Incus has a body, one long process and one short process. Anterior surface of the body articulates with the head of malleus. The short process is attached to a ligament. Tip of the long process articulates with the stapes.

c) Stapes : Stapes is also called stirrup. It is the smallest bone in the body. It has a head, neck, anterior crus, posterior crus and a footplate. Head articulates with incus. Footplate fits into oval window.

Eustachian tube

Eustachian tube is the canal extending from the middle ear to nasopharynx. It forms the passage of air between middle ear and atmosphere. So, the pressure on both sides of tympanic membrane is equalized.

iii) Inner Ear

The internal ear or membranous labyrinth is a membranous structure that remains lodged within a bony labyrinth of temporal bone. The tunnels and chambers inside the temporal bone are called the bony labyrinth. The membranous labyrinth is a similarly shaped set of membranous tunnels and chambers situated inside the bony labyrinth. In other words the membranous labyrinth fits exactly in the bony labyrinth. It consists the sense organs of hearing and equilibrium. Sense organ for hearing is the cochlea and the sense organ for equilibrium is the vestibular apparatus.

The membranous labyrinth is filled with a clear fluid called **endolymph**, and the space between the membranous and bony labyrinth is filled with a fluid called **perilymph**. The bony labyrinth is divided into three regions: ***cochlea***, ***vestibule***, and ***semicircular canals***. The four major divisions of membranous labyrinth are

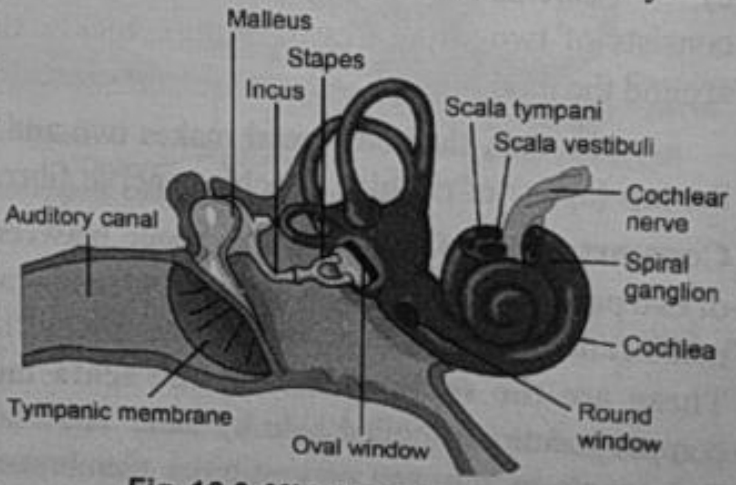

Fig. 10.3 Middle and Inner Ear

cochlear duct, suspended in the cochlea, the ***utricule*** and ***saccule***, suspended in the vestibule, and the ***semi-circular ducts*** suspended in semi circular canals. The vestibule and semicircular canals are involved in balance whereas the cochlea is involved in hearing.

a) Vestibule : The vestibular apparatus constitutes two parts, the **utriculus** and the **sacculus**. The utricule and the saccule are two bag like structures, internally lined with sensory cubical epithelium. The sensory epithelium is produced into sensory patches called **maculae**. Maculae have calcium carbonate particles known as **otoconia** embedded in a protein matrix. It helps to maintain equilibrium and posture of the animal.

b) Semi circular canals : Three semi circular canals arise from the vestibular apparatus. These are superior, posterior and lateral semi circular canals. The superior and posterior canals meet together to form a duct, the **crus commune**. Remaining canal ends into an ampulla placed above the utriculus. Ampulla contains the sensory patches called **cristae**. It is called **crista ampullaris**. It consists of a ridge, lined by epithelial cells along with sensory cells and supporting cells. Sensory cells bear small cilia (**stereocilia**) and a large cilium called the **kinocilium** embedded in a gelatinous membrane called the **cupula**.

Maintenance of equilibrium by Vestibule and Semi-circular canal

Vestibular apparatus : The vestibular apparatus respond to the pull of gravity, rotation movements and body posture. Its receptors detect both the position of the head and body in relation to the pull of gravity and sudden change in the displacement of the body. When body is suddenly displaced, the otoconia fall in an opposite direction on the hair cells. The hair cells then send impulses to the brain about the position of the head and body in space. Vestibular information are used for two purposes: to keep the eyes fixed on a point despite changes in the position of the head and to maintain the body in an upright position.

Semi circular canals : The semi circular canals respond to the rotation movements of the body. Whenever movements of the body stop, or start or accelerate or decelerate or there is a change in the direction, the endolymph moving through the semi circular canals deflects the **cupula** thereby stimulating the hair cells of **crista**. The stimulus regarding velocity and direction of the moving body, is then conveyed to the brain.

c) Cochlea : Cochlea is a coiled structure like a snail's shell (cochlea = snail's shell). It consists of two structures: Central conical axis called **modiolus** and Bony canal, that winds around the modiolus.

In man, the bony canal makes two and a half turns, starting from the base and ends at the top (apex) of cochlea. Cochlear nerve fibres pass and enter the modiolus at the base.

Compartments of cochlea: The space between the membranous and bony labyrinth consists of two parallel tunnels: the scala vestibuli and scala tympani. Two membranous partitions, basilar membrane and vestibular membrane divide the canal of cochlea into **three** compartments. These are the **scala vestibuli**, the **scala media**, and the **scala tympani**. All the three compartments are coiled side by side. The scala vestibuli and scala media are separated by **Reissner's membrane** or vestibular membrane while the scala media and scala tympani are separated by **basilar membrane**. All the three compartments are filled with fluid. The scala

vestibuli and the scala tympani are the **perilymph** -filled spaces between the walls of the bony and membranous labyrinths. Scala media is filled with **endolymph**. The **perilymph** present within scala vestibuli and the scala tympani can easily move between the two canals through a small opening called **helicotrema**.

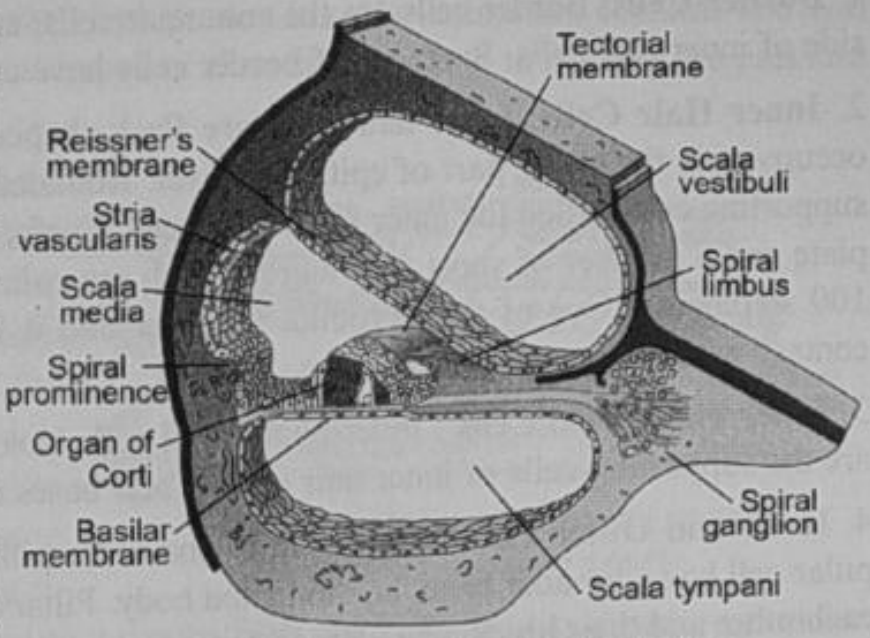

Fig. 10.4 Compartments of Cochlea

i. **Scala vestibuli :** Scala vestibuli lies above scala media. It arises from **oval window** (fenestra vestibuli), which is closed by the footplate of stapes. It follows the bony canal up to its apex. At the apex, it communicates with the scala tympani through a small canal called helicotrema.

ii. **Scala tympani :** Scala tympani lies below scala media. It is parallel to scala vestibuli and ends at the **round window**. Round window is closed by a thin membrane known as secondary tympanic membrane.

iii. **Scala media :** Scala media is otherwise called cochlear duct. It is a triangular compartment enclosed by basilar and vestibular membranes. It ends blindly at the apex and at the base of cochlea. On the upper surface of the basilar membrane, epithelial cells are arranged in the form a special structure called the **organ of Corti**.

Organ of Corti : Organ of Corti is the receptor organ for hearing. It rests upon the basilar membrane extending throughout the cochlear duct, except for a short distance on either end. It contains supporting epithelial cells and specialized sensory cells called hair cells, which have hairlike projections at their apical ends. The tips of the hairs are embedded within an acellular gelatinous shelf called the **tectorial membrane**, which is attached to the organ of Corti. The hair cells in the human ear is estimated to be from 13,000 to 54,000 in number, each one with perhaps 40 cilia projecting into the endolymph.

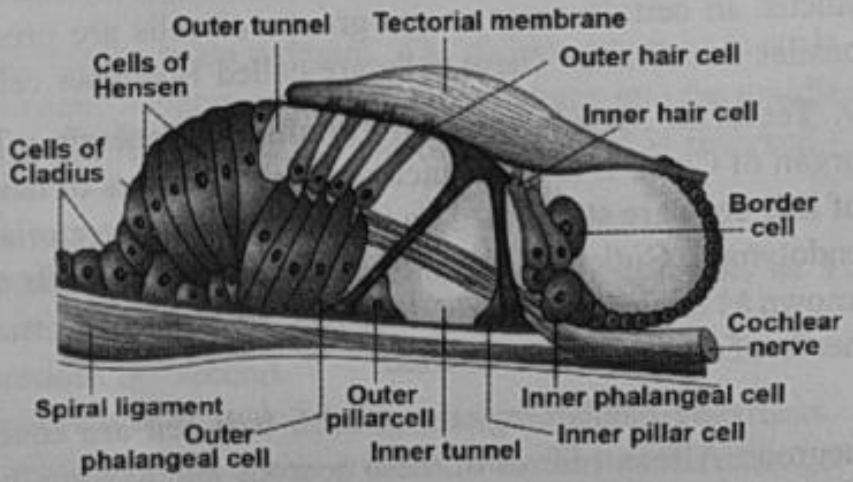

Fig. 10.5 Organ of Corti

Cells constituting organ of Corti : 1. Border cells 2. Inner hair cells 3. Inner phalangeal cells 4. Inner pillar cells and Outer pillar cells 5. Deiters cells 6. Outer hair cells 7. Cells of Hensen 8. Cells of Claudius 9. Tectorial membrane and lamina reticularis.

1. **Border Cells**: Border cells are the columnar cells, arranged in a single layer along the inner side of inner hair cells. Surfaces of border cells have cuticle.

2. **Inner Hair Cells**: Inner hair cells are flask-shaped cells arranged in a single row. They occupy only the upper part of epithelial layer. Rounded base of each cell rests on the adjacent supporting cells called the inner phalangeal cell. Surface of the inner hair cell bears a cuticular plate and a number of short stiff hairs, which are called **stereocilia**. Each hair cell has about 100 stereocilia. One of the sterocilia is larger and it is called **kinocilium**. Stereocilia are in contact with the tectorial membrane.

3. **Inner Phalangeal Cells** : Inner phalangeal cells look like the finger bones, phalanges. They are the supporting cells of inner hair cells. Their bases rest on the basilar membrane.

4. **Inner and Outer Pillar Cells :** Inner and outer pillar cells are called rods of Corti. Each pillar cell has a broader base, an elongated body. Pillars of inner and outer cells slope towards each other and their heads articulate to form series of arches, which enclose a triangular tunnel called tunnel of Corti.

5. **Deiters Cells :** Deiters are the supporting cells of outer hair cells. Deiters cell is the tall columnar cell. It sends stiff processes upward between the hair cells, to form the part of lamina reticularis.

6. **Outer Hair Cells :** Outer hair cells are the columnar cells occupying the superficial part of epithelium of organ of Corti. Their bases are supported by Deiters cells.

7. **Cells of Hensen :** These are tall columnar cells forming the outer border cells of organ of Corti. These cells are arranged in several rows on basilar membrane. The space between Deiters cells and cells of Hensen is called outer tunnel.

8. **Cells of Claudius:** Cells are cuboidal in nature and line the lower surface of external spiral sulcus. In certain areas, some groups of cells are present between the cells of Claudius and basilar membrane. These cells are called Boettcher cells.

9. **Tectorial Membrane and Lamina Reticularis :** Tectorial membrane forms the roof of organ of Corti. It is in contact with the processes of hair cells. It is assumed that the processes of hair cells are stimulated by the movements of tectorial membrane, in relation to vibrations in endolymph. Cuticular plates of all the supporting cells collectively form a reticular membrane, known as lamina reticularis. It covers the organ of Corti. It has rows of holes, through which the heads of hair cells are inserted.

The basilar regions of each hair cell are covered by synaptic terminals of sensory neurons. Afferent fibres of these neurons join to form the cochlear nerve. This nerve then joins the vestibular nerve to become the vestibulocochlear nerve (VIII), which traverses the internal auditory meatus and enters the cranial vault.

MECHANISM OF HEARING

1. During the process of hearing, ear converts energy of sound waves into action potentials in auditory nerve fibres. This process is called sound transduction. External ear directs the sound waves towards tympanic membrane. Sound waves travel through external auditory meatus

and produce vibrations in the tympanic membrane. Vibrations set up in tympanic membrane are transmitted through the malleus, incus and reach the stapes. It causes to and fro movement of stapes against oval window and against perilymph present in scala vestibuli of cochlea. The oval window bulges inward and pushes the perilymph of the scala vestibuli to develop the pressure waves.

Since more force is required to cause vibration in a liquid (perilymph) than required in air, the vibrations reaching the perilymph must be amplified as they cross the middle ear. The footplate of the stapes and its annular ligament, which occupy the oval window, are much smaller than the tympanic membrane. This size difference cause the mechanical force of vibration to be amplified about 20-fold as it passes from the tympanic membrane → ossicles → oval window.

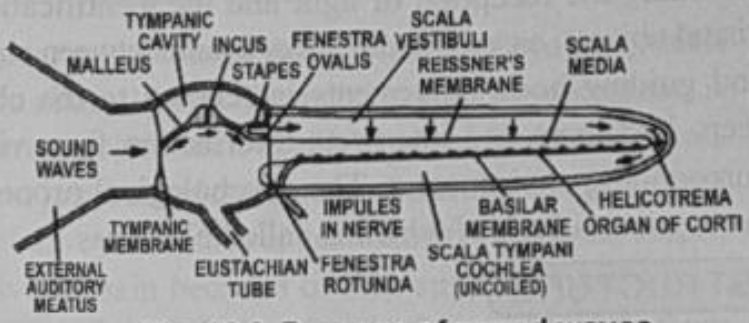

Fig. 10.6 Passage of sound waves through cochlear canals

2. As the stapes vibrates, it produces waves in the perilymph of the scala vestibuli. The waves travel to the apex of the cochlea. Vibrations of the perilymph are transmitted through the thin vestibular membrane and cause simultaneous vibrations of the endolymph. Vibration of the endolymph causes vibration of basilar membrane. Waves in the perilymph of the scala vestibuli are also transmitted through the helicotrema and into the scala tympani. When basilar membrane vibrates, the hair cells of the organ of Corti are moved against the tectorial membranes, which remains stationary. The striking of hair cells stimulates nerve and generate action potential which is transmitted by vestibulo-cochlear nerve to the temporal lobe of the cerebral cortex. The transmission occurs by electrical excitation through electrical synapses rather than by neurotransmitters. In the cerebral cortex the information is interpreted to hear the sound.

3. The basilar membrane also bulges into the scala tympani. The sudden pressure in scala tympani pushes the perilymph towards the round window causing it to bulge back into the middle ear. As the sound wave subsides, the stapes moves backward and the procedure is reversed.

SOME FACTS ABOUT HEARING

- Vibration of the round window membrane is important to hearing because it acts as a mechanical release for waves from within the cochlea.
- Man can hear 16,000 to 20,000 vibrations per second.
- Injury or disease of the auditory system cause eiher conduction, nerve or central deafness.
- Conduction deafness may be due to foreign bodies, wax and otic infection which damage the ear drum or ossicles.
- In case of nerve deafness, there may be degeneration of hair cells in the organ of Corti or damage to the cochlear nerve.
- Central deafness is caused by damage to central auditory pathways or to the primary auditory cortex.

PHYSIOLOGY OF VISION

Fig. 10.7 Human Eye

The **visual system** is the part of the central nervous system which gives organism its ability to process visual detail. The visual system carries out complex tasks, including the reception of light and the identification of visual objects; assessing distances to and between objects; and guiding body movements in relation to the objects seen. It detects and interprets information from visible light to build a representation of the surrounding environment. The psychological process of visual information is known as visual perception, a lack of which is called blindness.

STRUCTURE

The adult human eye ball is nearly a spherical structure, with a diameter of about 24 mm. Eyeball is made up of two segments, an anterior part and a posterior part. Anterior part forms one sixth of the eyeball which is exposed. Posterior part forms five sixth of the eyeball and is protected by the orbit into which it fits. Posterior wall of this part is lined by the light-sensitive structure called retina.

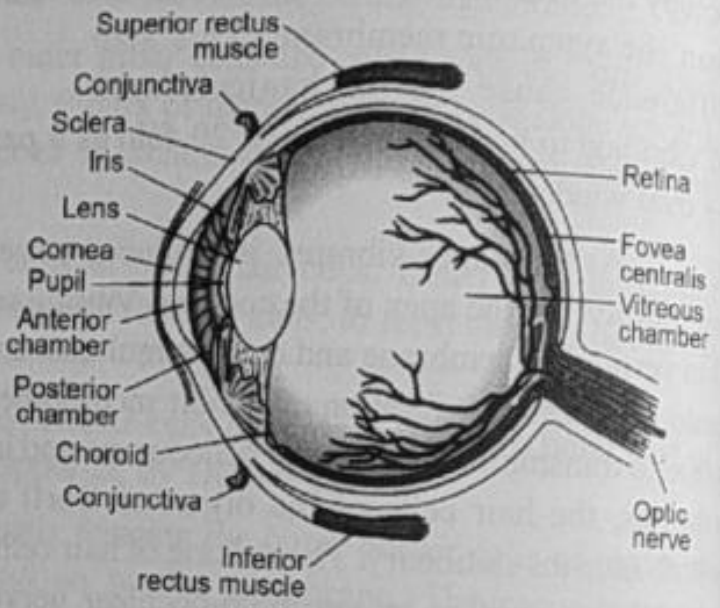

Fig. 10.8 Structure of Human Eye

Anatomy of the eye ball

The eyeball is situated in a bony cavity known as orbital cavity or eye socket. A thick layer of areolar tissue is interposed between bone and eyeball. It serves as a cushion to protect the eyeball from external force. Eye balls are held within the orbit by the ocular muscles. These constitute four **recti** and two **oblique** muscles. Wall of the eyeball is composed of three layers. These are :

A. Outer layer, which includes cornea and sclera.

B. Middle layer, which includes choroid, ciliary body and iris.

C. Inner layer, the retina.

A. Outer layer : Outer layer preserves the shape of the eyeball. Posterior five sixth of this coat is opaque and is called the **sclera**. Anterior one sixth is transparent and is known as **cornea**.

i) Sclera : It is the outermost covering of the eye, made of tough white collagen fibrous tissues and elastic fibres. It covers posterior five sixth of the eye and is opaque. Anteriorly it is continuous with cornea which is transparent. Sclera is non-cellular and non-vascular in nature, hence

called **white of the eye**. Due to the non-vascular nature, corneal transplant is without any risk of tissue rejection. Posterior part of sclera, where it is pierced by the optic nerve is thin. At the junction of sclera and cornea, the **canal of Schlemm** drains out the fluid called aqueous humour into blood.

Sclera maintains the shape of the eye ball and also protects it. It supports the inner layers of the eye ball and provide surface for attachment of extra ocular muscle.

ii) Cornea : Cornea is the transparent convex anterior portion of the outerlayer of eye ball,which covers the iris and pupil. Diameter of cornea is about 12mm. Though cornea is transparent, it does not appear transparent. It appears in different colors such as blue, brown, grey and black. It is because of the color of iris, which is present just behind the cornea. Sclera overlaps cornea at its periphery and appears in front as white of the eye. Cornea is very sensitive to pain, touch, pressure and cold. Center of cornea is sensitive to pain because of rich supply of free nerve endings. Normally, cornea is not vascularized. Therefore, it derives its nourishment mainly from aqueous humor.

B. Middle layer : Middle layer surrounds the eye ball completely, except for a small opening in front known as pupil. This layer comprises of three structures: **Choroid**, **Ciliary body** and **Iris**. Together they are called **uveal tract**.

i) Choroid : Choroid is the thin vascular layer of eyeball situated between outer sclera and inner retina. It is composed of connective tissue fibres and pigment cells. Pigments are black brown or bluish in colour, making the inside of the eye dark to prevent internal reflection. It forms posterior five sixth of middle layer. Choroid is extended anteriorly up to the insertion of ciliary muscle. Choroid is separated from sclera by perichoroidal space.

ii) Ciliary Body : Ciliary body is the thickened anterior part of middle layer of eye, situated between choroid proper and iris. It is composed of smooth muscles. It is vascular and pigmented like the choroid layer. It protrudes into the cavity of the eyeball in the form of a **ciliary process**. Ciliary processes are the finger-like projections from the ciliary body. The epithelial cells of the ciliary process secretes aqueous humor (watery fluid) which maintains shape of the eye and also provides nourishment to the cornea. There are about 70 ciliary processes. Suspensory ligaments from the lens are attached to the ciliary body.

iii) Iris: Behind the cornea, the choroid extends to form the **iris diaphragm**. The oval muscular iris diaphragm is a coloured curtain-like structure, located in front of the

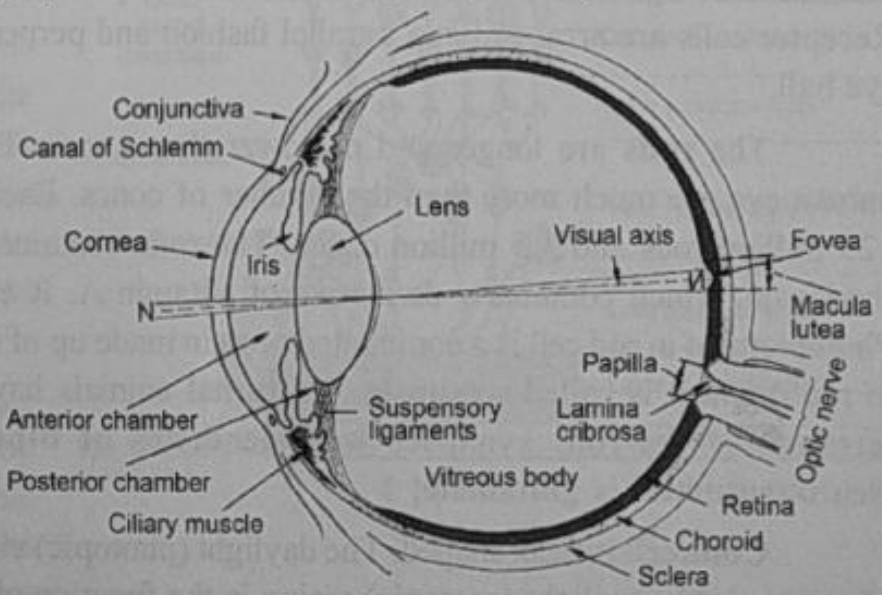

Fig. 10.9 V.S. of Human Eye

lens. The diaphragm is centrally perforated to form a circular opening called pupil. The diameter of the pupil is autonomically controlled by two sets of muscles called the **circular sphincters** and **radial dilators**. These muscles increase or decrease the diameter of pupil and regulate the amount of light entering the eye. Thus, iris acts like the diaphragm of a camera.

Lens: The lens is a transparent, biconvex and elastic structure situated behind the pupil. It is crystalline, avascular and receives its nutrition mainly from the aqueous humor. It is circular and about 1 cm in diameter (human). Lens is supported by the suspensory ligaments which are attached to ciliary body. Lens refracts light rays and helps to focus the image of the objects on retina.

C. Inner layer or Retina : Retina is a delicate light-sensitive membrane that forms the innermost layer of eyeball. Posteriorly it is continuous with the optic nerve. Opposite to the entrance of optic nerve there exist a circular area known as **optic disc**. Retina extends from the margin of optic disk to just behind ciliary body. Retina consists of photosensitive cells for vision. Optic disc is insensitive to light as it is devoid of photosensitive cells (Rods and Cones). It is also called blind spot. At the posterior pole of the eye lateral to the blind spot, a yellowish pigmented spot called **macula lutea or yellow spot** is present. It has a central pit called the **fovea centralis**. The fovea is a portion of the retina where only the cones are densely packed. It is the point where the visual acuity (resolution) is the greatest. Structurally, retina is made up of 10 layers of cells. These layers from outside → inside constitute:

i) Pigmented epithelium : It is the outermost layer situated adjacent to choroid. Contains nucleus and pigment granules. Protoplasmic extensions from the cells pass between rods and cones. Pigment epithelial layer absorbs light and prevents its reflection. If light rays are reflected by retina, image becomes blurred. Epithelial cells store vitamin A (retinol) and remove the debris from rod cells and cone cells by phagocytic action.

ii) Layer of rods and cones : Layer of rods and cones lies next to pigmented layer. Rods and cones are the light-sensitive portions of visual receptor cells, namely **rod** cells and **cone** cells. Receptor cells are arranged in a parallel fashion and perpendicular to the inner surface of the eye ball.

The **rods** are longer and narrower than cones. The number of rods present in the human eye are much more than the number of cones. Each human retina comprises roughly 125 million rods and 5.5 million cones. The rods containa photosensitive pigment called the rhodopsin, which contains a derivative of Vitamin A. It enables animals to see in the dark. Photopigment in rod cell is a conjugated protein made up of a protein and chromophore. Protein in rod pigment is called **scotopsin**. Nocturnal animals have more number of rods. Synaptic terminal of the rods synapses with dendrites of **bipolar cells** and horizontal cells. Neurotransmitter is **glutamate**.

Cone cell is flask shaped. The daylight (photopic) vision and colour vision are functions of **cones** andthe twilight (scotopic) vision is the function of the rods. Shape and length of the cone vary in different parts of the retina. Photosensitive pigment in cone cells is of three types,

namely **porphyropsin**, **iodopsin** and **cyanopsin**. Photopigment in cone cell is a conjugated protein made up of a protein and chromophore. Protein part is called **photopsin**, which is different from **scotopsin**, the protein part of rhodopsin. Only one of these pigments is present in each cone.

However, chromophore of cone pigment is the retinal that is present in rhodopsin. In the human eye, there are three types of cones which possess their own characteristic photopigments that respond to red, green and blue lights. The sensations of different colours are produced by various combinations of these cones and their photopigments. When these cones are stimulated equally, a sensation of white light is produced. Neurotransmitter is glutamate.

iii) Outer limiting membrane : Outer limiting membrane is a thin layer, formed by the Muller fibres.

iv) Outer nuclear layer : It is formed by the fibres and granules of rods and cones. Granules of rods and cones contain nucleus.

v) Outer plexiform layer : Outer plexiform layer is formed by terminal fibres of rods and cones and dendrites from bipolar cells, situated in the inner nuclear layer.

vi) Inner nuclear layer : Inner nuclear layer contains bipolar cells. Axons of bipolar cells synapse with dendrites of ganglionic cells in the inner plexiform layer. Dendrites synapse with fibres of rods and cones in the outer plexiform layer.

vii) Inner plexiform layer : Inner plexiform layer of retina consists of synapses between dendrites of ganglionic cells and axons of bipolar cells. It also contains processes from amacrine cells.

viii) Ganglionic cell layer : Multipolar cells are present in this layer. Some cells are large and are called giant ganglion cells. Other cells are smaller called ganglion cells. Axons from ganglion cells form the optic nerve. Dendrites of ganglion cells synapse with axons of bipolar cells in the inner plexiform layer. Retinal blood vessels are also present in this layer.

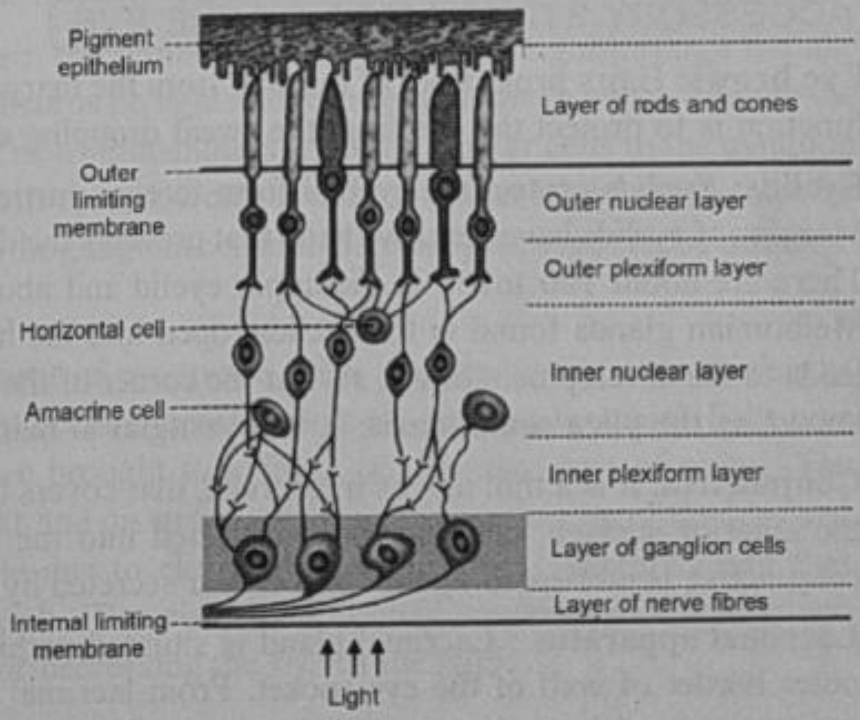

Fig. 10.10 Layers of Retina

ix) Layer of optic nerve fibres : Layer of nerve fibres is formed by non-myelinated axons of ganglionic cells. After taking origin, the axons run horizontally to a short distance and then converge towards the optic disk and form the optic nerve. Retinal blood vessels are also present in this layer.

x) Inner limiting membrane : Internal limiting membrane is the innermost layer of retina and it separates retina from the vitreous body.

Optic nerve : The information about the image via the eye is transmitted to the brain along the optic nerve. The optic nerves leave the eye and the retinal blood vessels enter it at a point slightly above the posterior pole of the eye ball. Populations of ganglion cells in the retina send information to the brain through the optic nerve. Another population sends information to the superior colliculus of the midbrain, which help in controlling eye movements as well as other motor responses.

INTRAOCULAR FLUID

Intraocular fluid is the fluid within the eyeball. It is responsible for the maintenance of shape and nourishment. Intraocular fluid is of two types: 1. Vitreous humor, 2. Aqueous humor.

1. Vitreous humor : Vitreous humor is a viscous and gelatinous fluid present behind lens, in the space between lens and retina. It is composed of 99 % of water, collagenous fibrils, mucopolysaccharides and hyaluronic acid. The jelly is condensed to form a membrane called the vitreous membrane. At the centre of the vitreous body runs an oblique hyaloid canal joining the blind spot with the centre of the posterior surface of the lens. Vitreous humor helps to maintain the shape of eyeball and maintain intra ocular pressure.

2. Aqueous humor: Aqueous humor is a thin fluid that fills the space between lens and cornea. This space is divided into anterior and posterior chambers by iris. Both the chambers communicate with each other through pupil. Aqueous humor is secreted by the capillaries of the ciliary process. It contains Vit-C, amino acids and glucose. It provides nourishment to cornea and lens. Aqueous humor maintains intra ocular pressure and the shape of the eye ball.

ACCESSORY STRUCTURES OF THE EYE

Eye brows: Hairs project out of the skin from the margin of the eye to form the eyebrows. Its function is to protect the eye from the sweat dropping down the forehead.

Eyelids: Eyelids protect the eyeball from foreign particles and cut off the light during sleep. Margins of eyelids have sensitive hairs that prevents the dust particles from reaching the eyeball. There are about 100 to150 in the upper eyelid and about 50 to 75 hairs in the lower eyelid. Meibomian glands found in the eyelids, open into the hair follicles. Infection of these glands leads to the development of **eye sty**. At the corner of the eyeball is a short reddish flap of skin, known as the **plica semilunaris**. It is a vestigial in man.

Conjunctiva: It is a thin mucus membrane, that covers the exposed part of eye. After covering the anterior surface, conjunctiva is reflected into the inner surfaces of eyelids. Surface of conjunctiva is lubricated by thin film of tear secreted by lacrimal gland.

Lacrimal apparatus : Lacrimal gland is situated within the bone shelter forming upper and outer border of wall of the eye socket. From lacrimal gland, tear flows over the surface of conjunctiva and drains into nose via lacrimal ducts and nasolacrimal duct. Due to its continuous washing and lubrication, the conjunctiva is kept moist and is protected from infection. Tear also contains lysozyme that kills bacteria.

MECHANISM OF IMAGE FORMATION

- Light entering the eye is refracted as it passes through the cornea. It then passes through the pupil (controlled by the iris) and is further refracted by the lens.
- The light rays coming from an object pass through the cornea, aqueous humor, pupil, lens and vitreous humor to fall on the retinal layer.
- The cornea and lens act together as a compound lens to project an inverted image onto the retina.
- The light rays in visible wavelength focussed on the retina generate potentials (impulses) in rods and cones.
- The photosensitive compounds (photopigments) in the human eyes is composed of **opsin** (a protein) and **retinal** (an aldehyde of vitamin A).
- Light induces dissociation of the retinal from opsin resulting in changes in the structure of the opsin.
- This causes membrane permeability changes. As a result, potential differences are generated in the photoreceptor cells.
- This produces a signal that generates action potentials in the ganglion cells through the bipolar cells.
- These action potentials (impulses) are transmitted by the optic nerves to the **visualcortex** area of the brain, where the neural impulses are analysed and the image formed on the retina is recognised based on earlier memory and experience.
- Although 130 million photo-receptors absorb light, roughly 1.2 million axons of ganglion cells transmit information from the retina to the brain.

Diurnal/Nocturnal Adaptation in eye : The retina adapts to change in light through the use of the rods. In the dark, the rhodopsin absorbs no light and releases glutamate which inhibits the bipolar cell. This inhibits the release of neurotransmitters from the bipolar cells to the ganglion cell. When there is light present, glutamate secretion ceases thus no longer inhibiting the bipolar cell from releasing neurotransmitters to the ganglion cell and therefore an image can be detected.

ACCOMMODATION

Accommodation is the adjustment of eye to see either near or distant objects clearly. The human eyes possess great power of accommodation. It is the process by which light rays from near objects or distant objects are brought to a focus on sensitive part of retina. The animals are able to see objects both near and distant by changing the convexity of the lens and hence its focal length. This is possible due to elastic property of lens. Another event that supports accommodation is the iris muscle. The iris muscle control the amount of light which enters through the pupil by increasing or decreasing the size of the pupil.

PHOTOCHEMISTRY

The visual pigments associated with rods and cones are composed of a protein, called **opsin** bound to a chromatophore, the **retinaldehyde (retinene)**. Photo pigment, **rhodopsin**

present in rods is sensitive to black, grey and white colours. Cones have a different pigment called **iodopsin**, which is sensitive to bright light as well as colours.

In dim light, the rhodopsin of rods dissociates into opsin and retinene. In darkness, again the retinene and opsin associate to form rhodopsin. During the process of splitting, the rods are excited and transmit signals through their terminal bulbs to the central nervous system. Periodic blinking of eye probably provides the light and dark stimulus to the eye, as a result of which the breaking down of rhodopsin and its resynthesis becomes possible. When a person suddenly moves out of bright light into dark, he is not able to see things clearly for a few minutes. This is so because resynthesis of rhodopsin takes some time. Similarly, when one goes out of a dark room to outside he remains blind and blink for a few minutes. This is due to the fact that the rhodopsin is not completely bleached.

DEFECTS OF VISION

The eye with normal refractive power is called **emmetropic** eye and the condition is called **emmetropia**. Any deviation in the refractive power from normal condition is called **ametropia** and the eye is called **ametropic eye**. Ametropia is of two types: 1. Myopia 2. Hypermetropia.

1. Myopia : It is otherwise called short sightedness because the person can see near objects clearly but not the distant objects. In normal state, the far point is infinite. In myopia, the far point is not infinite but it is at a definite distance.

Cause : This is caused due to an abnormally long eye ball. However lens is usually normal. The image is brought to focus a little in front of retina. Light rays, after coming to a focus, disperse again so, a blurred image is formed upon retina.

Correction: The myopic eye is corrected by using a biconcave lens.

2. Hypermetropia : It is otherwise known as long sightedness because the person can see the distant objects clearly but not the near objects.

Cause : Hypermetropia is caused due to an abnormally long eye ball. The refractive power of lens is normal. The light rays are brought to a focus behind retina. Light rays are not converged so a blurred image of near objects is formed. It is common in old age also.

Correction : Hypermetropia is corrected by using biconvex lens.

Anisometropia : Anisometropia is the condition in which the two eyes have unequal refractive power. It is corrected by using different appropriate lens for each eye.

3. Astigmatism : Astigmatism is due to refractive error of the lens. Light rays are not brought to a sharp point upon retina. This defect is present in all eyes. Example: The stars appear as small dots of light to a person with normal eye. But in astigmatism, the stars appear as radiating short lines of light.

Cause : In a normal eye, lens has approximately same curvature in all meridians. Thus, the light rays are refracted equally and brought to a focus. If the curvature is different in different meridians, the refractive power is also different in different meridians. Meridian with greater curvature refracts the light rays more strongly than the other meridians. Therefore, these light

rays are brought to a focus in front of the light rays, which pass through other meridians.

Correction : Astigmatism is corrected by using cylindrical glass lens having the convexity in the meridians, corresponding to that of lens of eye.

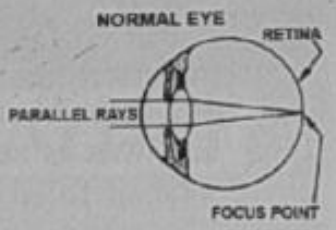

Fig. 10.11 Normal Vision

4. Presbyopia : Presbyopia is characterized by diminished ability of eyes to focus on near objects with age. It is due to the reduction in the amplitude of accommodation. Presbyopia starts developing after middle age. It progresses as the age advances. The distant vision is unaffected. The anterior curvature of lens does not increase during near vision. So, the light rays from near objects are not brought to focus on retina.

Causes : Decreased elasticity of lens during old age. Decreased convergence of eyeballs due to the weakness of ocular muscles in old age.

Correction : Presbyopia is corrected by using biconvex lens.

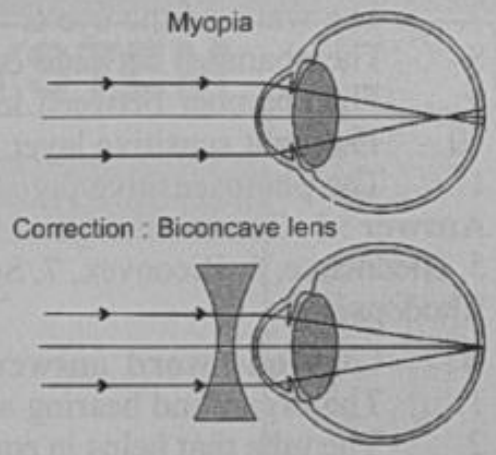

Fig. 10.11 Myopia

5. Glaucoma : Also called "Kala motia". It is common in old people. It is a kind of blindness due to increased intraocular pressure, which causes damage of optic nerve, resulting in blindness. The drainage of aqueous humor through trabeculae is blocked, resulting in increased intraocular pressure. When the intraocular pressure rises above 60 mm Hg, the optic nerve fibres at the optic disk are compressed. Initially it decreases the visual field (loss of peripheral vision), which eventually leads to total blindness. With early treatment,often the eyes may be protected against vision loss. Untreated glaucoma leads to permanent damage of the optic nerve and results in blindness.

Correction : Treatment does not cure the disease but can prevent further damage of optic nerve. Treatment is aimed at lowering the intraocular pressure by using eye drops or medicines or with laser treatment. If not controlled by these methods, surgery is required.

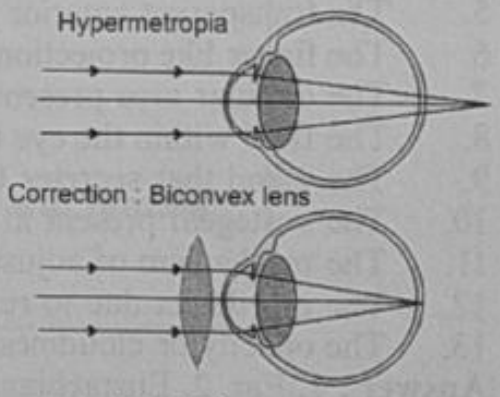

Fig. 10.11 Hypermetropia

6. Cataract : Also called "Safed motia". Cataract is the opacity or cloudiness in the natural lens of the eye. When lens becomes cloudy, lightrays cannot pass through it easily and vision is blurred. Cataract develops in old age after 55 to 60 years. Lens is situated within a capsule. Old cells die and accumulate within the capsule. The accumulation of cells is associated with accumulation of fluid and denaturation of proteins in lens fibres, causing cloudiness of lens and blurred image.

Causes : In addition to age,cataract develops due to eye injuries; previous eye surgery; diabetes; long-term use of steroids, and tranquilizers; long exposure to sunlight; alcoholism; diet containing large quantity of salt.

Treatment : Surgery is the only treatment for cataract. During surgery, cloudy lens is removed from the eye and is replaced with a permanent, clear and plastic intraocular lens (IOL) implant.

EXERCISE

A. Fill in the blanks:

1. Ear wax is secreted by ————.
2. The air filled cavity of the middle ear is called ————.
3. The stapes fits into the ———— of internal eye.
4. The other name for incus is ————.
5. Myopia is corrected by ———— lens.
6. Hypermetropia is corrected by ———— lens.
7. The white of the eye is ————.
8. The chamber between cornea and lens is ————.
9. The chamber between lens and retina is _____.
10. The light sensitive layer of the eye is ————.
11. The photosensitive pigment of rod is ————.

Answer : 1. Ceruminous gland, 2. Tympanic cavity, 3. Oval window / Fenestra Ovalis, 4. Anvil, 5. Biconcave, 6. Biconvex, 7. Sclera, 8. Anterior chamber, 9. Posterior chamber, 10. Retina, 11. Rhodopsin

B. Give one word answer.

1. The organ and hearing and balance.
2. The tube that helps in equalization of air pressure between outside and middle ear cavity.
3. Other name for Stapes.
4. Other name for Malleus
5. The transparent anterior portion of the eyeball.
6. The finger like projection from the ciliary body.
7. The circular area present opposite to the entrance of optic nerve.
8. The fluid within the eye ball responsible for the maintenance of shape.
9. The gland that secretes tear.
10. The vestegeal present in the human eye.
11. The mechanism of adjustment of eye to see near and distant oblects.
12. The eye defect due to refractive error of the lens.
13. The opacity or cloudiness in the natural lens of the eye.

Answer : 1. Ear, 2. Eustachian Tube, 3. Stirrup, 4. Hammer 5. Cornea, 6. Ciliary process, 7. Optic disc, 8. Intra-ocular fluid, 9. Lacrimal gland, 10. Plica semilunaris, 11. Accommodation, 12. Astigmatism, 13. Cateract.

C. Answer in two to three sentences each.

1. Ear ossicles, 2. Tympanic membrane, 3. Vestibule, 4. Cochlea, 5. Membranous labyrinth, 6. Endolymph, 7. Perilymph, 8. Scala vestibuli, 9. Scala tympani, 10. Scala media, 11. Aqueous humor, 12. Veterous humor

D. Anwer in 75 words.

1. Semicircular canal, 2. Organ of Corti, 3. Ciliary body, 4. Rod cells and cone cells, 5. Accommodation, 6. Astigmatism, 7. Glaucoma, 8. Cataract

E. Answer within 500 words.

1. Describe the structure of human ear. Add a note on the physiology of hearing.
2. Describe the strucutre of human eye. Add a note on the physiology of vision.

●●●