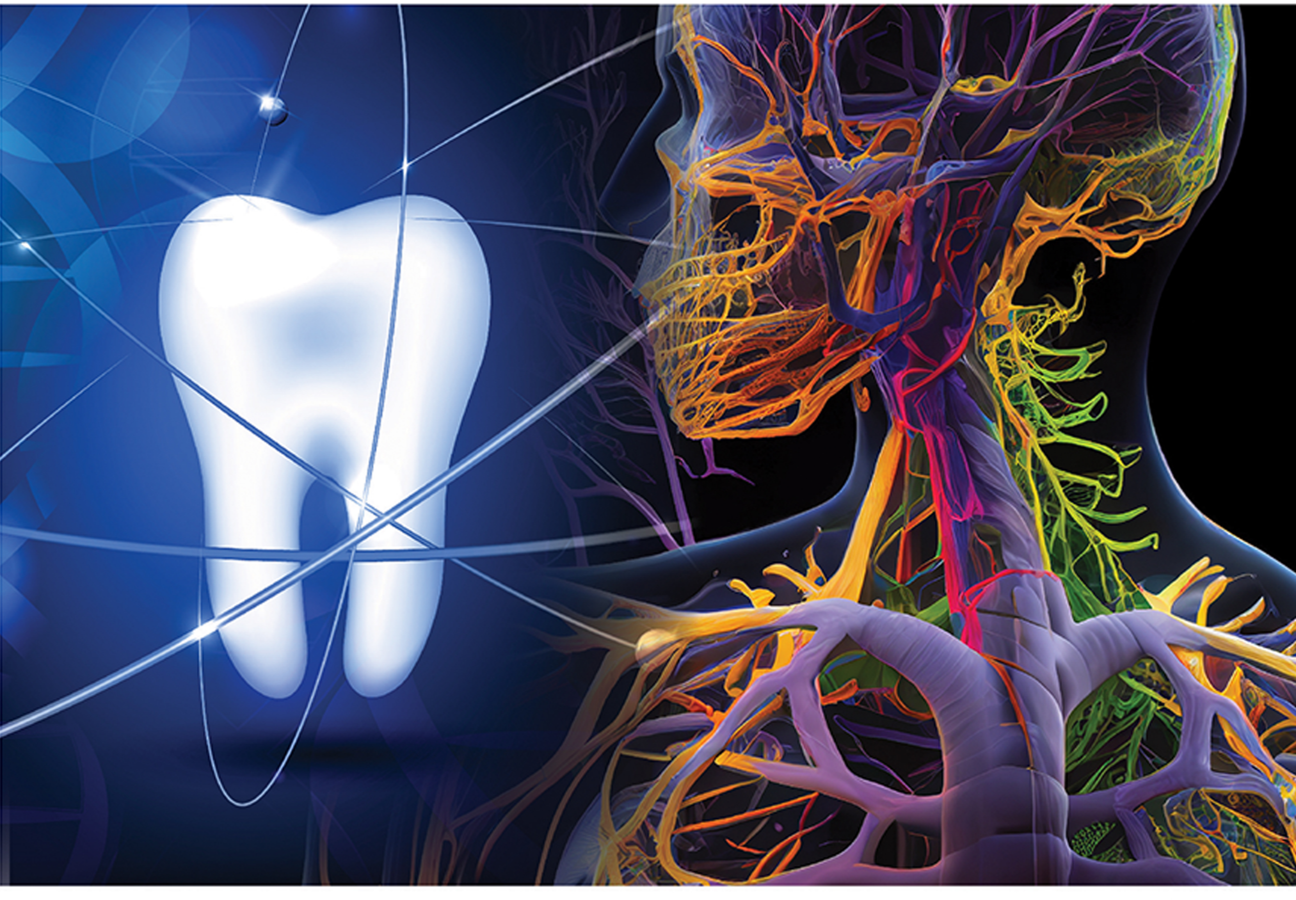
Textbook of PHYSIOLOGY for DENTAL Students



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CHAPTER

Nerve Physiology

LEARNING OBJECTIVES

- Describe the structure of a neuron with the help of a diagram.
- Know the classification of neurons.
- Describe the ionic basis of resting membrane potential.
- Define action potential. Explain the ionic basis of action potential in a nerve fiber.
- Mechanism of conduction of nerve impulse in myelinated and unmyelinated nerve fibers.

NEURON

Neuron is the **structural and functional unit** of nervous system. The specialized function of neuron is integration and transmission of nerve impulses.

Human central nervous system consists of about 10^{11} neurons and 10–50 times more number of **glial cells** or supporting cells. A neuron contains a cell body and processes. The processes are axon and dendrites. Some neurons are <1 mm in length while some are the longest cells in the body, measuring about 1 meter in length.

CLASSIFICATION OF NEURONS

Structural Classification

This is based on the number of processes extending from the cell body. Neurons are classified into unipolar, bipolar, multipolar and anaxonic neuron **(Fig. 2.1)**.

All neurons contain only one axon, but dendrites may be one or many.

Unipolar Neuron

Unipolar neurons are seen only in the embryonic life of human beings.

Dorsal root ganglion cell of spinal cord is referred to as **pseudounipolar** since only one

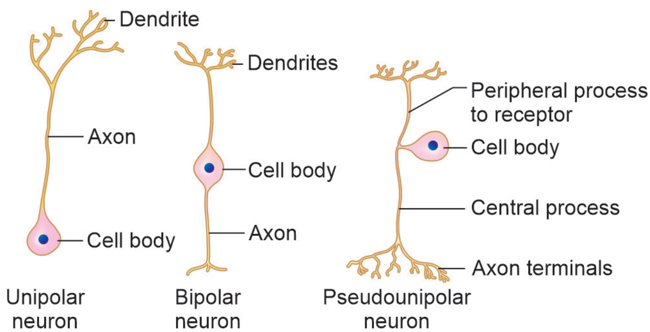


Fig. 2.1: Types of neurons based on structure.

process arises from the cell body which divides to form two processes one going to the periphery (receptor) bringing sensory information from the receptor, and the other entering the spinal cord.

Bipolar Neurons

Here dendrite arises from one pole and axon arises from the opposite pole, e.g., olfactory cells, auditory cells, bipolar neurons of retina etc.

Multipolar Neurons

In multipolar neurons, axon and dendrites arise from different points of the cell body. Example is anterior horn cell of spinal cord.

Anaxonic Neuron

Sometimes axon may be absent in the neuron, e.g., amacrine cells of retina.

Functional Classification

Sensory or Afferent Neuron

They transmit sensory impulses from receptors to central nervous system.

Motor or Efferent Neurons

They convey motor nerve impulses from central nervous system to the effectors.

Association Neurons or Interneurons

This group includes all other neurons that are not specifically sensory or motor. 90% of neurons are association neurons.

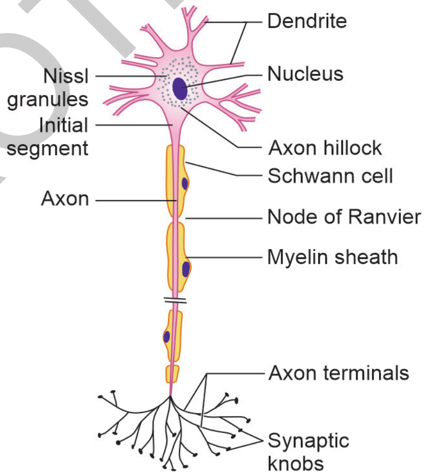


Fig. 2.2: Structure of a motor neuron (multipolar neuron).

MORPHOLOGY OF A TYPICAL NEURON

Anterior horn cell is considered as a typical neuron **(Fig. 2.2)**

Nerve Cell Body or Soma

It contains the following structures: nucleus, Nissl granules and all cell organelles except centrosome. *Since there is no centrosome in the neuron, regeneration of the cell body is not possible and formation of new neurons stops in the intrauterine life.*

Nucleus

Nucleus occupies the central part of soma and usually contains one nucleolus.

Nissl Granules or Nissl Bodies

They are present all over the cell body except axon hillock. They are organelles containing **ribosomes**. The number and size of Nissl granules depend on the functional state of the cell. When the cell is highly active or injured or fatigued, disintegration of Nissl granules occurs called **chromatolysis**. The function of Nissl granules is to synthesize the proteins necessary for the neuron.

Mitochondria

Mitochondria are present in the cell body as well as in the axon in plenty. They supply energy for the cell.

The cell body is present only in the following areas of the nervous system:
- Gray matter of brain and spinal cord
- Nuclei of brain
- Ganglia of peripheral nervous system.

Processes of the Neuron

The nerve cell processes are **dendrites and axon**. Dendrites bring information towards the cell body and hence sensory in function. Axon takes away information from the cell body and hence motor in function. Nerve fiber is a general term for any neuronal process, i.e., dendrite or axon. A **nerve** is a bundle of many nerve fibers in the peripheral nervous system. A **tract** is a bundle of nerve fibers in the central nervous system, e.g., pyramidal tract.

Axon

The portion of the cell body from which axon arises is slightly thickened and is called **axon hillock**. The first portion of the axon is called **initial segment**. The axon divides into terminal branches, each ending in a number of **synaptic knobs** or terminal buttons. These knobs contain vesicles in which the **synaptic transmitters** secreted by nerves are stored.

Distal to the initial segment in most neurons, axon is covered by **myelin sheath**, a protein lipid complex made up of many layers of cell membrane of **Schwann cells**. These fibers are called myelinated fibers. Schwann cells are glial cells found along peripheral nerves. The myelin sheath is absent at the **nodes of Ranvier**. These are gaps in between Schwann cells that are about 1 mm apart. All mammalian neurons are not myelinated. *Nerve fibers <1 mm in diameter are unmyelinated.* In the central nervous system myelination is done by **oligodendrocytes**.

Functions of Myelin

- Form insulation for axon
- Helps in the conduction of impulses at a faster rate
- Helps in regeneration of nerve fiber after injury

Properties of Nerve Fibers

- **Excitability** denotes the ease with which an action potential can be produced in the nerve.
- **Conductivity** is the self-propagating process in a nerve by which an action potential is actively conducted along the nerve at a constant amplitude and velocity along the axon to the nerve terminal.

MEMBRANE POTENTIALS

Most animal cells maintain an electrical potential difference (voltage) across their cell membrane.

There are three types of membrane potentials:
1. Resting membrane potential (RMP)
2. Graded potential
3. Action potential (AP)

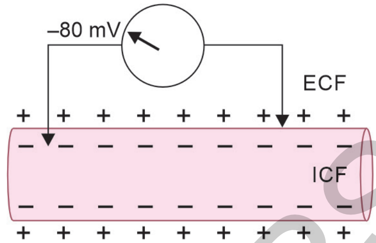


Fig. 2.3: Membrane potential in a polarized cell.
(ECF: extracellular fluid, ICF: intracellular fluid)

Resting Membrane Potential

Resting membrane potential is defined as the potential difference existing *just across* the cell membrane in the resting state of the cell with the interior of the cell negative and the outside positive. It is always denoted by a **minus sign** signifying that the inside is negative relative to the outside. A cell that exhibits a membrane potential is said to be **polarized (Fig. 2.3)**.

The magnitude of RMP varies from tissue to tissue ranging from –9 to –100 mV. RMP of nerve fiber is –70 mV.

Recording of Resting Membrane Potential

Monophasic method alone can measure RMP. It is recorded with one electrode inside and another outside the cell membrane connected to a **cathode ray oscilloscope (recording device)**.

Ionic Basis of Resting Membrane Potential or Genesis of RMP or production of RMP

Two factors are responsible for the production of RMP:
1. Diffusion of ions across the cell membrane
2. Electrogenic pump

Diffusion of Ions

This depends on two factors:
1. Differential concentration of ions across the cell membrane
2. Differential permeability of ions

The composition of the major ions in the intracellular and the extracellular fluid are entirely different **(Table 2.1)**.

TABLE 2.1: Distribution of ions across the cell membrane at rest.

Ion	ICF (mmol/L of H_2O)	ECF (mmol/L of H_2O)
Na^+	15	150
K^+	150	5.5
Cl^-	9	125
Ca^{2+}	0.0001	1.2
Protein anion	65	—

Initially there is no potential difference across the cell membrane. K^+ has a **leak channel** and has high permeability and mobility through the membrane. The permeability of plasma membrane to K^+ is 50–100 times more than to sodium. So, K^+ moves from inside to outside according to the concentration gradient. This process is called **efflux** of potassium. This efflux of K^+ upsets the electrical equilibrium both inside and outside the membrane. There are two ways in which this can be prevented:
1. An anion should come along with K^+ to the outside
2. A cation should come from outside to inside of the membrane.

Na^+ cannot come to the inside because the channel is closed in the resting state of the cell. Ca^{2+} channel is also closed from outside in the resting state. So Na^+ comes and lines the outside of the membrane.

Inside the cell, the anions are Cl^- and protein anion (A^-). Chloride ions have to move against a concentration gradient. Protein anions cannot go out because they are very large. So the protein anions come and stay close to the inside of the cell membrane, with the cation just outside the membrane, thus creating a charge difference across the membrane called resting membrane potential.

Role of Electrogenic Pump or Na^+–K^+ ATPase

Na^+ pump is said to be **electrogenic** because it contributes to the negativity of RMP by pumping out three Na^+ in exchange for only two K^+, thus contributing to the charge difference.

Measurement of Resting Membrane Potential

Monophasic method alone can measure RMP.

There are three components for measuring RMP:
1. Electrode
2. Amplifier
3. Recording device

Two electrodes are necessary. The electrode introduced into the interior of the cell is called **ultra microelectrode.** It has a tip diameter of 0.25 µm. The other electrode is placed outside the cell membrane. The two electrodes are connected to a **biological amplifier** or differential amplifier which amplifies biological signals alone and unwanted signals will be rejected.

Recording Device

The recording device used is **cathode ray oscilloscope (CRO)**. This device can convert electrical signals into visible record **(Fig. 2.4)**.

CRO consists of a special type of tube with a narrow end and a broad end, and inside of the tube is vacuum. At the narrow end is a cathode. In front of the cathode are two anodes. Cathode and anode are connected to a power supply. When high voltage is applied, cathode is heated and emits electrons. The principle is **thermionic emission**. Electrons emitted are collimated, focused and brought to a narrow beam by anode. This beam is accelerated towards the fluorescent screen at the broad end of the tube by **accelerating anode** placed behind the screen. When electrons strike the screen it is seen as a visible spot of light on the screen. The intensity of the spot of light can be varied by means of a **control grid** placed in front of the cathode.

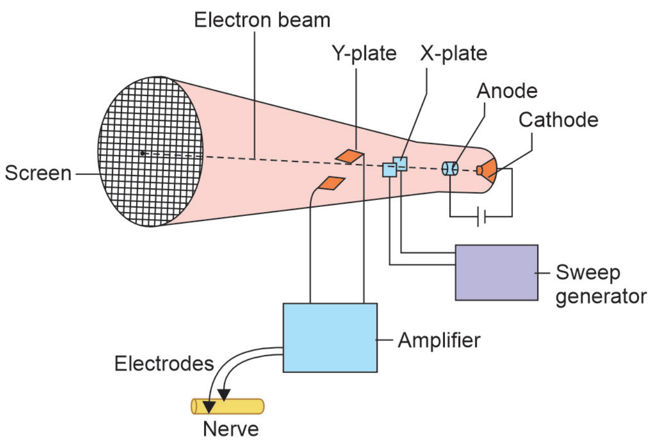


Fig. 2.4: Cathode ray oscilloscope.

As the beam moves forwards there is a set of **X plates** one on either side of the beam. These plates are connected to a sweep generator which produces a **saw-toothed voltage**. The plates are made alternatively positive so that the beam sweeps in the horizontal direction across the screen.

In front of X plates, there are two **Y plates** placed above and below the electron beam and this is connected to the amplifier. The amplifier is connected to the electrodes on the nerve fiber. If the upper plate is positive, the beam moves in the upward direction and vice versa. Any changes in the potential occurring in the nerve are recorded as vertical deflections of the beam as it moves across the tube.

The screen is graduated in the X-axis and Y-axis. X-axis represents time and Y-axis amplitude of the signal. When the two electrodes are outside the cell membrane there is no deflection and the beam moves only in the horizontal direction. When one electrode is introduced into the cell, there is a downward deflection and so far as the electrode is inside the cell the deflection remains the same **(Fig. 2.5)**. This is the RMP.

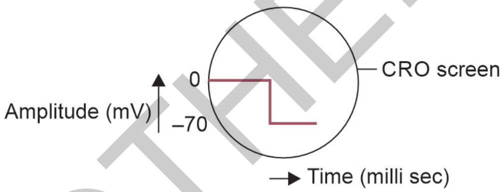


Fig. 2.5: Resting membrane potential recorded from a nerve fiber on a CRO screen. RMP –70 mV.

Graded Potentials

Stimulus is a sudden change in the environment which produces a response in the cell. There are different types of stimuli like mechanical, electrical, chemical, thermal etc.

Depending on the strength of the stimulus, two types of responses are produced **(Table 2.2)**:
1. Local, non-propagated potentials called graded potentials
2. Propagated potentials called action potential.

Graded potential is a small deviation from resting membrane potential that is caused by a stimulus. **A graded potential** may make the membrane either more polarized, i.e., more negative than the resting potential, or less polarized, i.e., less negative than the resting level. Polarization more negative than the resting level is called **hyper polarization** and polarization less negative than the resting level is referred to as **depolarization**.

Action Potential

Action potential is a sequence of rapidly occurring changes in the membrane potential, i.e., depolarization and repolarization, in an excitable cell, when a stimulus of sufficient strength is applied. The nerve transmits information in the form of nerve impulse called **action potential**.

TABLE 2.2: Differences between action potential and graded responses.

Action potential	*Graded potential*
1. Large response	1. Small response
2. Propagated along the entire length of the excitable cell	2. Localized or non-propagated
3. The size and shape of the action potential remains the same as it travels along the fiber	3. It has variable amplitude
4. Obey all-or-none law	4. Does not obey all-or-none law
5. Exhibit refractory period	5. Do not exhibit refractory period so they can be summated

Recording of Action Potential

- **Monophasic recording**—one electrode is placed inside and another outside the cell membrane.
- **Biphasic recording**—both electrodes are placed outside the cell membrane.

Monophasic Action Potential from a Single Nerve Fiber

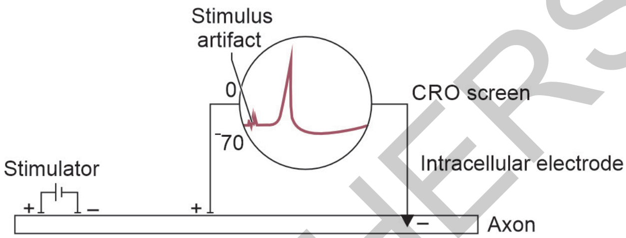


Fig. 2.6: Monophasic recording from an axon. Note that the baseline starts at –70 mV.

When a stimulus is applied, a brief irregular deflection of the baseline is recorded on the CRO, known as **stimulus artifact (Fig. 2.6)**. This is due to current leakage from the stimulating electrodes to the recording electrodes. It marks the point of application of the stimulus on the cathode ray screen. This is followed by an isopotential interval called **latent period**. Latent period ends with the start of action potential. Latent period denotes the time taken by the impulse to travel from the point of stimulation to the recording electrodes.

Ionic Basis of Action Potential

When a stimulus of sufficient strength is applied to a nerve, the nerve becomes active and there is slight opening of sodium channel. This is called **sodium channel activation**. Na^+ will pass from outside to inside according to electrical and concentration gradient. The potential changes from –70 to a less negative value. As more and more Na^+ enters the cell, the gates open more and more widely and the potential goes more and more to the positive side. At a critical voltage of –55 mV there is sudden wide opening of Na^+ channel. This critical voltage is called **firing level or threshold potential**. Gradual change of potential from resting stage to firing level is called **partial depolarization (Fig. 2.7)**.

At the firing level there is explosive entry of Na^+ into the cell. The potential goes to the positive side for a brief period. This phase is called **depolarization phase** (the resting cell is said to be in a polarized state). Going of the potential to the positive side is called **reversal of polarity**. The inside becomes positive and outside negative at the point of stimulation.

Next change is closure of inactivation gate of Na^+ from inside, which is a slow process. When the gate from outside opens, the gate from inside starts to close. But it takes a longer time to close so that, for a brief period the channel is fully opened. So, increase in Na^+ permeability is short lived **(Fig. 2.8A)**.

Along with Na^+ channels, Ca^{2+} channels also open during cellular excitation allowing calcium ions to enter the cell from outside according to concentration gradient. Opening of calcium channels is a very slow process and the role of calcium channel is more important in cardiac and smooth muscle cells.

Repolarization

Repolarization is initiated by the closure of Na^+ channel from inside. (Sodium channel has two gates, one on the outside called activation gate and another on the inside of the channel

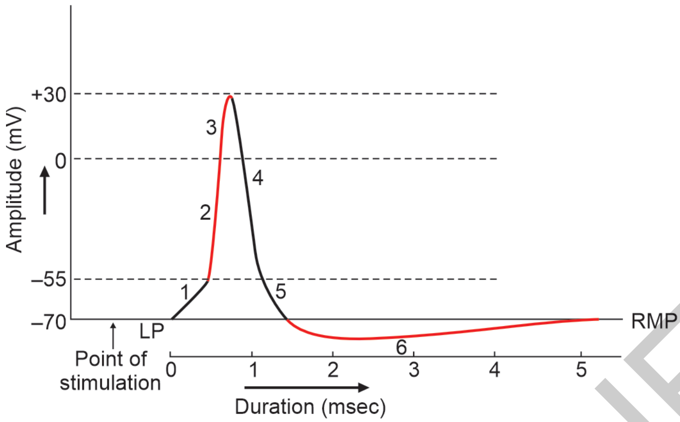
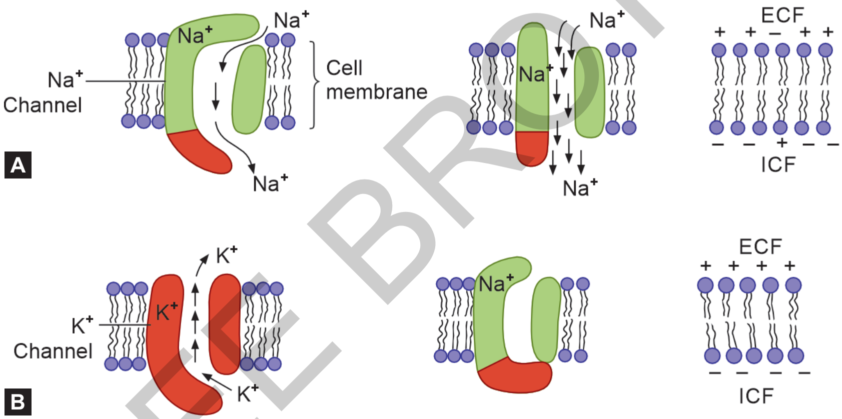


Fig. 2.7: Monophasic recording of nerve action potential LP: Latent period. Numbers denote: 1. Slow depolarization; 2. Rapid depolarization; 3. Reversal of polarity; 4. Rapid repolarization; 5. After-depolarization; 6. After-hyperpolarization.



Figs. 2.8A and B: Ionic basis of action potential: (A) Depolarization; (B) Repolarization.

called inactivation gate. In the resting state activation gate remains closed and inactivation gate remains open.) Next change is opening of K^+ channel from inside. According to concentration gradient K^+ goes from inside to outside and causes rapid repolarization. Towards the end of repolarization phase the process is slowed down and this phase is called **after-depolarization**. This is due to accumulation of K^+ just outside the cell membrane, thereby slowing down the efflux of K^+ **(Fig. 2.8B)**.

The repolarization phase overshoots to the negative side to some extent and this is called **after-hyperpolarization**. This is because it takes a longer time for the K^+ gates to close.

At the end of action potential the Na^+—K^+ pump will function to reestablish the concentration gradient because there is some excess Na^+ inside the cell and excess K^+ outside the cell membrane. Action potential in nerve fiber is also called **spike potential** because it resembles a spike.

Recording of Action Potential in a Mixed Nerve

The pattern of action potential obtained from a mixed nerve is called **compound action potential or multipeaked action potential.** This pattern is obtained when recording electrodes are kept at a greater distance from the stimulating electrodes **(Fig. 2.9)**.

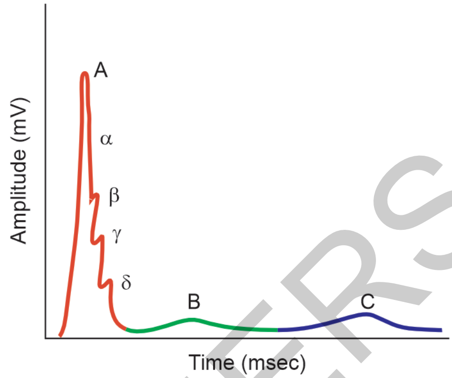


Fig. 2.9: Compound or multipeaked action potential recorded from a mixed nerve.

Clinical Importance of Action Potential

ECG, EMG, ERG, EEG etc., are basically action potentials.

EXCITABILITY

Excitability is the ease with which excitation or action potentials can be produced. In order to produce an action potential the membrane potential should reach the firing level from resting level. Nearer the resting membrane potential to firing level greater will be the excitability.

Characteristics of the Electrical Stimulus Used for Excitation

Commonly used stimulus in experimental studies is electrical. According to strength, stimuli are divided into:
- Threshold stimulus
- Subthreshold stimulus
- Suprathreshold stimulus
- Maximal stimulus
- Supramaximal stimulus

Threshold stimulus—here the strength of stimulus is just sufficient to bring the RMP to firing level and produce an action potential.

Subthreshold stimulus—the strength is less than threshold stimulus. Even though it does not produce an action potential it brings the membrane potential nearer to the firing level. This state of the cell is called local excitatory state or local response (*refer* local response).

Suprathreshold stimulus—here the strength of stimulus is more than threshold value. It will not produce a further increase in the amplitude of action potential. This phenomenon is called **all-or-none phenomenon.**

All-or-none law—all-or-none law states that a stimulus capable of producing an action potential will produce the maximum possible amplitude of action potential. All- or-none law is applicable to a **single fiber or cell only**. When a mixed nerve is stimulated it will not obey all-or- none law. Similarly, a single skeletal muscle fiber and not a whole muscle will obey all-or-none law.

Maximal stimulus—it is that strength of the stimulus which will excite all the axons in a mixed nerve.

Supramaximal stimulus—here the strength is more than maximal stimulus and it has no additional effect.

Refractory Period

It is the period during which excitability of excitable tissue is decreased. During the rising and much of the falling phases of the spike potential the neuron is refractory to stimulation **(Fig. 2.10)**. Refractory period is divided into:
- Absolute refractory period
- Relative refractory period

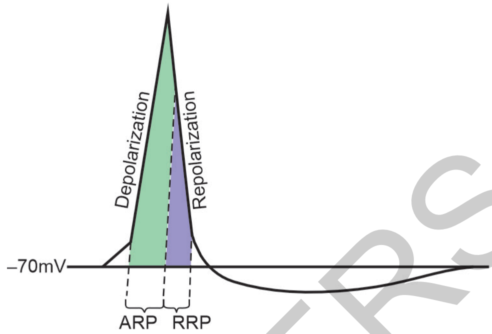


Fig. 2.10: Nerve action potential showing refractory period. ARP, Absolute refractory period; RRP, Relative refractory period.

Absolute Refractory Period

Absolute refractory period (ARP) is the period during which the strongest stimulus cannot produce an action potential. It extends from firing level to 1/3 of repolarization. Refractory period makes a continuous excitatory state of a nerve impossible and limits the frequency of the impulses.

Relative Refractory Period

It is the period during which a stronger than normal stimulus can produce a response. It extends from 1/3 of repolarization to the start of after-depolarization.

CONDUCTION OF NERVE IMPULSE OR PROPAGATION OF ACTION POTENTIAL

Conduction of Nerve Impulse through an Unmyelinated Axon

The principal function of neuron is to transmit nerve impulse in the form of action potential. Conduction of impulse is an active and self-propagating phenomenon. Once an action potential is produced it spreads automatically.

The region where excitation is produced in the axon is called **active region**. Outside the membrane current flows from the neighboring inactive region into the active region, whereas inside the membrane current flows from active to inactive region. Active region is also called **current sink (Fig. 2.11)**.

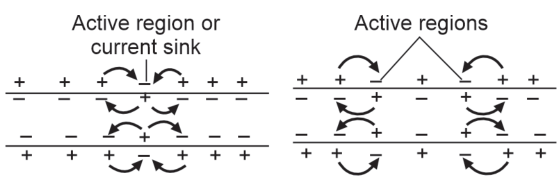


Fig. 2.11: Conduction of nerve impulse through an unmyelinated axon showing local circuit current flow.

This type of circular current flow is called **local circuit current flow**. The current flow from inside to outside at the two neighboring areas will open up the sodium channels at these points and action potentials are produced. Neighboring regions become active regions and the process is repeated by setting a series of local circuit current flow and action potential spread throughout the membrane.

At the same time repolarization also starts at the point of stimulation and spreads in both directions. If the axon is stimulated at the center impulses travel in both directions. Conduction towards the effector organ is called **orthodromic conduction** and conduction towards the cell body is called **antidromic conduction**. Once initiated, a moving impulse does not depolarize the area behind it to the firing level because this area is in the refractory period.

Conduction in a Myelinated Nerve Fiber

Myelin is an effective insulator and current flow through it is negligible. When the nerve is stimulated in the center, action potential is generated only at the node of Ranvier. Here instead of active region it is called **active node**. From neighboring inactive nodes current will flow into the active nodes outside the membrane and from active node to inactive node inside the membrane thus setting up a local circuit current flow **(Fig. 2.12)**.

At the two inactive nodes current flow from inside to outside will open up sodium channels, and action potentials are produced at the two neighboring nodes. The process is repeated and impulse is conducted by jumping from one node to another, and this type of conduction in a myelinated fiber is called **saltatory conduction** (saltare means to leap). Saltatory conduction occurs in both the peripheral and central nervous system. Conduction through myelinated fiber is 50–100 times faster than in an unmyelinated fiber.

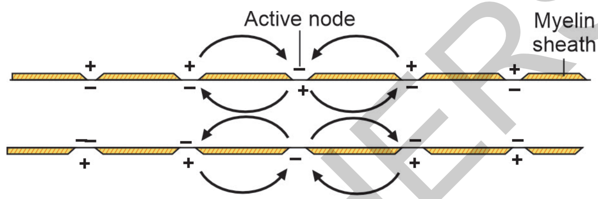


Fig. 2.12: Conduction of nerve impulse in a myelinated axon showing saltatory conduction.

CLASSIFICATION OF NERVE FIBERS

I. a. MYELINATED (medullated)
   b. NONMYELINATED (unmyelinated or nonmedullated)
II. a. SENSORY (afferent)
   b. MOTOR (efferent)
III. Classification of nerve fibers depending on conduction velocity and fiber diameter by Erlanger and Gasser **(Table 2.3)**
IV. Numerical classification for sensory fibers **(Table 2.4)**

TABLE 2.3: Erlanger and Gasser classification of nerve fibers.

Fiber type	Function	Diameter (μm)	Conduction velocity (m/sec)
Aα	Proprioception, somatic motor	12–20	70–120
Aβ	Touch, pressure	5–12	30–70
Aγ	Motor to muscle spindle	3–6	15–30
Aδ	Pricking pain, cold crude touch	2–5	12–30
B	Preganglionic autonomic fibers	<3	3–15
C-dorsal root	Burning pain, temperature, reflex responses	0.4–1.2	0.5–2
C-sympathetic	Postganglionic sympathetic fibers	0.3–1.3	0.7–2.3

TABLE 2.4: Numerical classification of nerve fibers.

Number	Origin	Fiber type
Ia	Muscle spindle (annulospiral ending)	A α
Ib	Golgi tendon organ	A α
II	Muscle spindle (flower spray ending), touch, pressure	A β
III	Pricking pain, cold receptors	Aδ
IV	Burning pain, temperature	Dorsal root C

FACTORS INFLUENCING THE VELOCITY OF CONDUCTION IN A NERVE FIBER

- **Myelination—**myelinated fibers conduct impulses 50–100 times faster than unmyelinated fibers. C fibers are unmyelinated and form the majority of fibers in the peripheral nerves.
- **Fiber diameter—**greater the diameter of the fiber greater will be the velocity of conduction.
- **pH**—increase in pH within physiological limits increases the velocity of conduction.
- **Temperature—**increase in temperature within physiological limits increases the velocity of conduction. Cold decreases the conduction velocity.
- **Anesthetics**—anesthetics decrease the velocity of conduction.

PERIPHERAL NERVE INJURY

Types of Nerve Injury

A nerve can get damaged by various means:

- Transection of nerve
- Crush injury
- Leprosy, diabetes mellitus, etc.

RESPONSE OF NEURONS TO INJURY

Injury to the Nerve Cell Body

Severe damage of the nerve cell body leads to degeneration of the entire neuron. The tissue macrophages remove the debris and the local fibroblasts replace the neuron with scar tissue.

Effect of Cutting a Peripheral Nerve

When a nerve is cut, it will have two parts:

1. A proximal part attached to the cell body.
2. A distal part not attached to the cell body.

Changes mainly occur in the cell body and in the distal part. Degeneration in the distal part is called **anterograde degeneration or Wallerian degeneration** and that in the proximal part is called **retrograde degeneration**.

INJURY TO THE AXON

Axon is a part of the neuron and it is the cell body that maintains the structural and functional integrity of the axon. All the necessary proteins responsible for maintaining the integrity of the axon is synthesized in the cell body and is transported along the axon by means of axoplasmic flow.

When an axon is bisected completely, certain physical and chemical changes occur in the nerve. Changes occur in two stages:

Stage of Degeneration

When an axon is injured, degenerative changes occur in the cell body, distal segment and in the proximal segment.

Changes in the Cell Body

- 24 to 48 hours after injury there will be degeneration of Nissl granules referred to as chromatolysis.
- Golgi apparatus fragments.
- The cell body swells up and becomes rounded due to increased fluid content.
- The neurofibrils disappear and the nucleus gets displaced towards the cell margin.

Changes in the Distal Segment or Wallerian Degeneration

Degenerative changes occurring in the distal segment of the injured neuron are referred to as Wallerian degeneration described by Sir Augustus Waller. The changes spread distally from the site of lesion to its termination. The changes include:

- The axon becomes swollen and fragments. The entire axon gets destroyed within a week.
- Within 10 days after injury, the myelin sheath disintegrates and oily droplets appear in the Schwann cell cytoplasm. These droplets will be extruded out and will be phagocytosed by tissue macrophages.
- At the site of injury, the nucleus of Schwann cells divides rapidly and form parallel cords of cells within the persisting basement membrane.
- Within 3 months, macrophages invade the injured area and phagocytose the degenerating myelin sheath and axon fragments.
- If regeneration does not occur, the axon and the Schwann cells will be replaced by fibrous tissue produced by local fibroblasts.

Changes in the Proximal Segment

Changes in the proximal segment is similar to the changes in the distal segment and is called retrograde degeneration. The changes occur only up to the first node of Ranvier.

Stage of Regeneration

- Regeneration of the nerve fiber occurs only if the neurilemma and endoneurium are intact.
- Regeneration is not possible if the gap between the cut ends is more than 3 mm.
- Regeneration is also not possible if nucleus is extruded from the cell.
- Regeneration is not possible if there is infection at the site of wound.
- There is a better chance of regeneration in crush injury than in cut injury as the neurilemmal sheath and endoneurium are intact.

Regenerative Changes in the Cell Body

- Nissl granules and Golgi apparatus reappear.
- Nucleus returns to the central position.
- Cell regains its normal size.

Changes in the Distal Segment

- The Schwann cells on either side of the injured site multiply by mitosis and grow towards each other and form a regeneration tube across the cut end.
- Hundreds of neurofibrils start growing from the tip of the axis cylinder of the proximal stem called regenerative sprouting or axonal sprouting.
- The neurofibrils grow at a rate of 3 to 4 mm per day towards the distal stem.
- Eventually one single neurofibril grows towards the distally located receptors, muscle or gland.
- This neurofibril will increase in diameter and myelin sheath starts appearing in about 15 days. Myelination is completed by one year.
- Once the regenerated axon reaches its target, a new functional connection is formed.
- If no connection is established between the proximal and distal cut ends, the sprouting neurofibrils coalesce to form a very painful tumor like mass called **neuroma**. This is commonly seen in amputation stumps.

MULTIPLE CHOICE QUESTIONS

1. What is true regarding action potential?
a. Decremental potential
b. Does not obey all or none phenomenon
c. K ions go from inside to outside of cell
d. Theshold stimulus is required

2. False about saltatory conduction:
a. Occurs in unmyelinated nerve fibers
b. Depends on nodes of Ranvier
c. It is a fast process
d. Less energy is consumed

3. The organelle that synthesize proteins in the neuron:
a. Golgi complex
b. Nissl granules
c. Mitochondria
d. Smooth endoplasmic reticulum

4. In a neuron, the impulse is generated at the:
a. Node of Ranvier
b. Cell body
c. Initial segment
d. Axon hillock

5. In excitable cells, repolarization is closely associated with:
a. Na influx
b. K efflux
c. K influx
d. Na and K influx

ANSWERS

1. d 2. a 3. b 4. c 5. b

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- More flowcharts included for easy remembrance.
- Clinical photos included in relevant topics.
- Important terminologies given in bold letters.

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