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Nerve Impulse Transmission

Definition

It is a wave of action potential or rapid sequence of changes in the membrane potential of nerve fibres, due to changes in the electrochemical gradient of the fibres, followed by quick return of resting potential in response to any kind of chemical, electrical, thermal or mechanical stimule

Origin

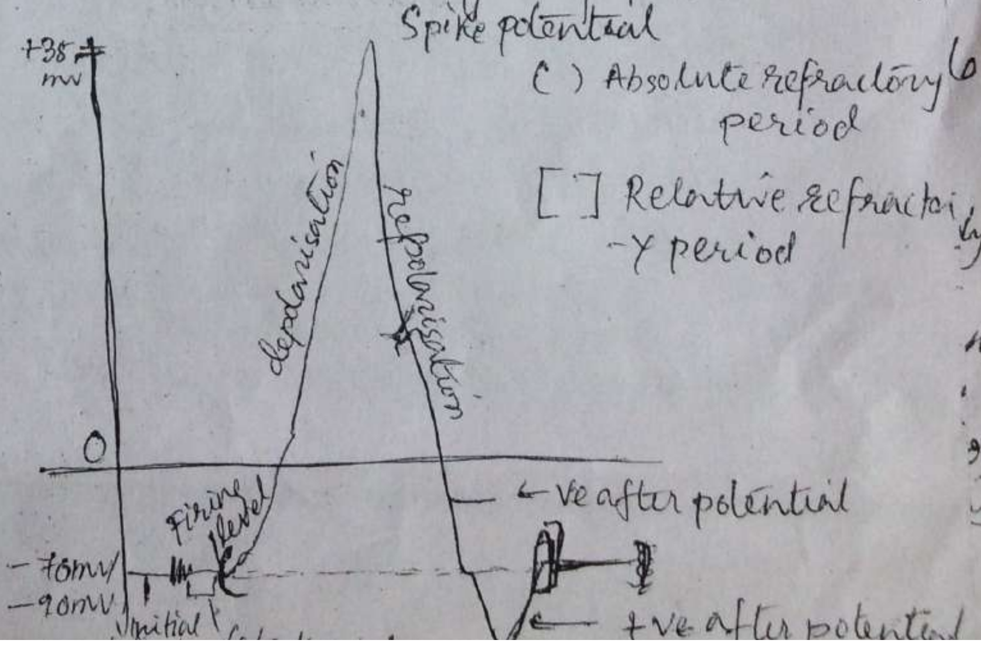
The origin of nerve impulse was first demonstrated by Hodking & Huxley in 1950s.

Propagation of Nerve Impulse

Along the nerve fibre, nerve impulses are conducted through resting membrane potential & action potential.

- **Threshold intensity**

The minimal intensity of stimulating current required for a given duration to just produce action potential is called threshold intensity. The threshold intensity varies with duration. The relation b/w duration & strength of threshold inten



-sity is called strength-duration curve.

Slowly rising currents fail to fire the nerve fibres, because they adapts with applied stimuli, a process called accomodation. Once threshold intensity is reached A.P. is produ-ced. Further ~~rise~~ increase in the intensity of stimulus does not produce any increase in A.P.

- Refractory period

It can be of two types:—

1) Absolute refractory period

Corresponding to the period from the time the firing level is reached until repolarization is about 1/3rd complete.

2) Relative refractory period

Corresponds to the time from the period of absolute refractory period to the start of after depolarisation.

During absolute refractory period, no stimulus, no matter how strong it ~~may~~ might be, will never ~~cause any excitation~~ excite the nerve, but during relative refractory period, stronger than normal stimulus can cause excitation.

- Resting membrane potential

1) When two electrodes are connected through a suitable amplifier to a CRO & placed on the surface of a single axon, no potential difference is observed. But if one electrode is inserted into the interior of the ~~membrane~~ cell a constant potential difference is observed with +ve outside & −ve inside. This is called resting membrane potential.

2) Thus, in unexcited state, the potential difference b/w intracellular fluid (ICF) & extracellular

fluid (ECF) is called resting membrane potential. In this state, the nerve fibre is not capable of ~~generating~~ transmitting any impulse.

3) The potential difference is due to unequal distribution of Na^+ & K^+ ions on either side of the membrane.

4) K^+ conc. is 28-30 times greater in ICF than in ECF; while Na^+ conc. is 10-14 times greater in ECF than in ICF. The RMP is maintained at −70mv by following operations :—

a) Active transport of Na^+ & K^+ through the membrane by Na^+–K^+ pump/ ATPase system, which obtain energy by breakdown of intracellular ATP. For 3Na^+ pumped out of the cell, 2K^+ pumped into the cell.

b) −Ve charged large protein ions inside the neuron, can't diffuse outside, or if they diffuse at all, they do so very poorly.

Na^+ develops +Ve charge outside the cell, but although K^+ are present inside the cell, they are not ~~capable~~ enough to equalize non-diffusible, −Ve ly charge protein ions trapped within ~~present~~ inside the cell.

c) Leakage of Na^+ & K^+ ions through the membrane. During the resting state, Na^+ ion voltage gated channels remains closed by Ca^{2+} ions but K^+ ion voltage gated channels are not. K^+ permeability is greater at rest than Na^+ permeability. K^+ leaks out very slowly from ICF into ECF during RMP.

• Action potential

1) When the stimulus is applied, the stimulus artifact, a brief irregular deflection of the baseline occurs. This stimulus artifact is due to current leakage from the stimulating electrode to the recording electrode.

2) The stimulus artifact is followed by isopotential interval latent ~~poto~~ period, which ends with a start of AP & corrosponds to the time it takes for the stimulation to travel along the axon, from the site of stimulation to the recording area.

3) As soon as the stimulus hits a nerve fiber, it inactivates a $Na^+ - K^+$ pump immediately.

4) The voltage gated Na^+ channels become active & dislodge the Ca^{2+} bound to surface proteins of membrane pores. Thus increasing permeability of Na^+ into ICF.

5) Maximum influx of Na^+ inside the cell, changes ~~increase~~ the ionic concentration of ICF & it becomes +ve with a −ve outside. This is termed as membrane depolarisation. After initial 15 mv of depolarisation, the rate of depolarisation increases. The point at which this change in ~~the~~ rate occurs is termed as threshold or firing level.

Thus, ~~the~~ electric potential of membrane begins to change & overshoot the isopotential line or zeropotential to approx. +35 mv.

6) The direction of electrical gradient for Na^+ is reversed during overshoot because the membrane potential is reversed, this complete change in polarity

(positivity of ICF) limits further influx of Na^+ by rebinding of Ca^{2+} to the membrane pores; thus preventing Na^+ entrance.

7) Although the equilibrium potential for Na^+ in mammalian neurons is found by Nernst equation at +60mv, but AP can't be reached upto this value because increase in Na^+ conductance is short-lived. (Na^+ channels rapidly enter a closed state called inactivated state & remain in it for few msec before it returns to the resting state.)

8) (At +35 mv, voltage gated K^+ channels open wide) The opening of this channel is slower & much prolong than Na^+ channels, so much of the increase in K^+ conductance comes after Na^+ conductance. So (the net movement of +ve charge from ICF takes place by K^+ efflux (as all Na^+ channels are already closed). This increased K^+ efflux complete the process of repolarisation, when the outside of the fibre is +ve with -ve inside.)

9) <u>Negative after potential</u>

It is also termed as after depolarisation. When the repolarisation is 70% completed, the rate of depolarisation decreases & reach the resting level very slowly. This abrupt delay of few millisec. to reach the resting membrane potential is called -ve after potential. This occurs because delay in the efflux of K^+ from ICF to ECF due to the repulsive force exerted by K^+ already present outside.

10) Positive after potential

(After reaching the previous resting level, the impulse overshoot slightly in the hyperpolarising direction to form a small but prolong afterhyperpo-larisation.) At the end of –Ve after potential the resting potential value of nerve fibre is restored but the resting ionic status is yet to be restored. because Na^+ have entered the nerve fibre while K^+ conc. is more outside. This the resting ionic status is reached by operating Na^+-K^+ pump/ ATPase system by which $3Na^+$ are pumped outside for every $2K^+$ pumped inside.

11) This sharp rise & rapid fall in the potential of a stimulated neuron is described as Spike potential.

12) Decreasing external Na^+ conc. decreases the size of AP but it has little or no effect on RMP while increasing K^+ conc. decreases RMP.

Duration of Action potential

The total process of AP is accomplished in 5–10 millisec.

Properties of Action potential

1. It obeys 'All or None Law'.
2. Depends upon strength & duration of stimulus — Sufficient stimulus intensity than can produce AP is called threshold stimulus intensity & any intensity below this is subliminal. Lack of Ca^{2+} shows simi-lar effect.
3. AP passes through the entire length of nerve fibre.

• Factors Affecting Origin Of Nerve Impulse

1. Strength of stimulus

A minimum strength of stimulus (electrical, chemical, mechanical) is required to generate AP. In case of electrical stimulus, the intensity of current adequate to produce response is called threshold intensity & the magnitude of current ~~required~~ sufficient to excite a nerve fibre is called rheobase.

2. Duration of stimulus

The shortest duration of current strength equal to twice rheobase, required to excite a fibre, is called chronaxie.

3. Direction of current

If the current is passed transversely across the nerve fibre, no response is obtained but if the current is passed along the nerve fibre, then response is obtained.

4. Frequency of stimulus

Usually one stimulus generates one response.

5. Injury

Injury to the nerve fibre, increases the excitibility near the injury site, but later the excitibility is depressed & it spreads along the entire nerve.

6. Temperature

Low temperature depresses excitibility of nerve fibre.

7. Lack of O_2 & blood supply

If the blood supply to a fibre is severed, then its excitability is concomittantly depressed. Also lack of O_2 depresses the excitability of nerve fibre.

8. Chemicals

CO_2 & narcotics such as chloroform, alcohol diminish & finally abolish excitability. Ca^{2+} & Na^+ channels are neurosedative, while Mg^{2+} & K^+ channels are neuroexcitatory.

9. PH

Alkalinity or increase in pH increases excitability, while acidity or decrease in pH decreases excitability.