Nerve and Muscle Physiology-1

BY

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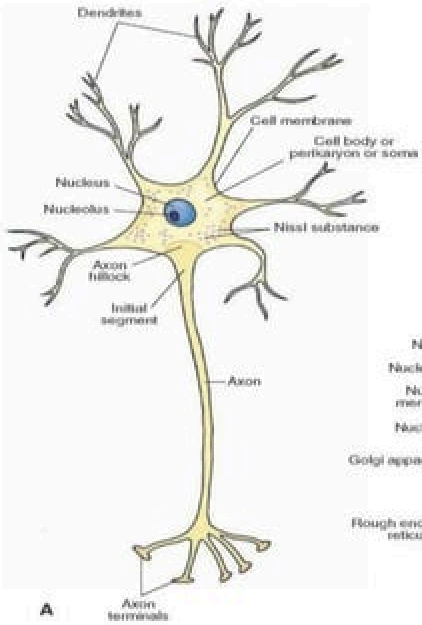
Structure of neuron

- **Definition:** Neurons are specialized cells that transmit chemical and electrical signals to facilitate communication between the brain and the body.
- **INTRODUCTION**
- 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.
- <u>However, it is different from other cells by two ways:</u>
- 1. Neuron has branches or processes called axon and dendrites
- 2. Neuron does not have centrosome. So, it cannot undergo division
- Centrosome= mitotic conductor, responsible for division into daughter cells

- **Neuronal Structure**
- The brain contains many billions of neurons that work together to produce sensation, thought, learning, movement, emotion, and many other processes.
- The coordination of these activities requires rapid and extensive communication among individual neurons and tissues (e.g. muscles).
- **In order to achieve this**, neurons use electrical signals to transmit information within a single cell and chemical signals between cells.
- These unique functions have forced the neuron to adopt a cell structure unlike that of other cells.
- **At birth**, the human brain consists of an estimated 100 billion neurons. Unlike other cells, neurons don't reproduce or regenerate. They aren't replaced once they die.


Dendrites
Cell membrane
Cell body or
perikaryon or soma
Nucleus
Nucleolus
Nissi substance
Axon
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Initial
segment
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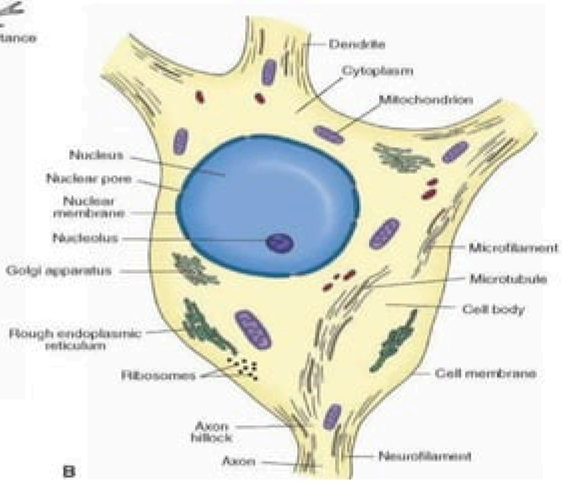
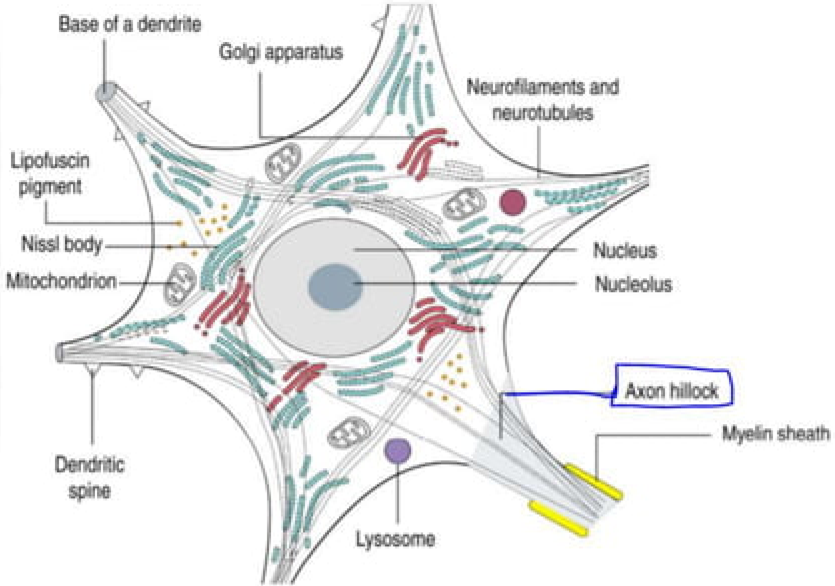
terminals
A


Dendrite
Cytoplasm
Mitochondrion
Nucleus
Nuclear pore
Nuclear
membrane
Nucleolus
Golgi apparatus
Microfilament
Microtubule
Cell body
Rough endoplasmic
reticulum
Ribosomes
Cell membrane
Axon
hillock
Axon
Neurofilament
B

Structure of neuron

- Neurons vary in size, shape, and structure depending on their role and location. However, nearly all neurons have three essential parts:
- a cell body, an axon, dendrites.
- **Cell body (soma)**
- The cell body is the neuron's core.
- The cell body carries genetic information, maintains the neuron's structure, and provides energy to drive activities.
- Like other cell bodies, a neuron's soma contains a nucleus and specialized organelles that contains smooth and rough endoplasmic reticulum (machinery for protein synthesis), Golgi apparatus (post office), mitochondria (power house), and other cellular components. It's enclosed by a membrane which both protects it and allows it to interact with its immediate surroundings.



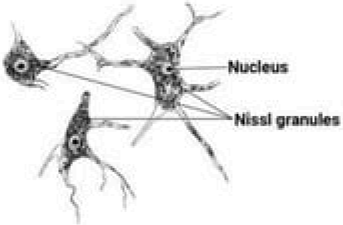
Base of a dendrite
Golgi apparatus
Neurofilaments and neurotubules
Lipofuscin pigment
Nissl body
Mitochondrion
Nucleus
Nucleolus
Axon hillock
Myelin sheath
Dendritic spine
Lysosome

CELL BODY

- Nerve cell body is also known as soma or perikaryon. It is irregular in shape.
- 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.
- **Nucleus**
- Each neuron has one nucleus, which is centrally placed in the nerve cell body.
- Nucleus has **one or two prominent nucleoli** (composed of RNA & proteins)
- Nucleus does not contain centrosome. So, the nerve cell cannot multiply like other cells.

CELL BODY

- **Nissl Bodies:**
- Nissl bodies or Nissl granules are small basophilic granules found in cytoplasm of neurons and are named after the discoverer.
- These bodies are present in soma and dendrite but not in axon and axon hillock.
- Nissl bodies are called tigroid substances (rough E-R & ribosomes), since these bodies are responsible for tigroid or spotted appearance of soma after suitable staining.



- Dendrites are distinguished from axons by the presence of Nissl granules under microscope.

CELL BODY

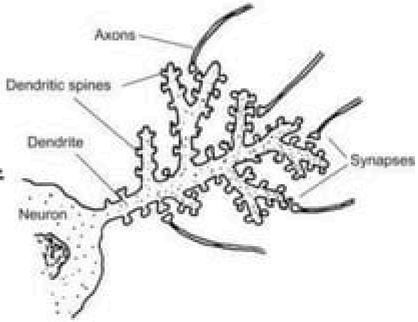
- Nissl bodies are membranous organelles containing ribosomes. So, these bodies are concerned with synthesis of proteins in the neurons.
- Proteins formed in soma are transported to the axon by axonal flow.
- During fatigue or injury of the neuron, these bodies fragment and disappear by a process called **chromatolysis**. Granules reappear after recovery from fatigue or after regeneration of nerve fibers.
- **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. (transport of protein & other substances within the cytoplasa)
- **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**

AXON

- Axon is the longer process of nerve cell. Each neuron has **only one axon.**
- Axon arises from axon hillock of the nerve cell body and it is devoid of Nissl granules.
- Axon extends for a long distance away from the nerve cell body.
- **Length** of longest axon is **about 1 meter.**
- **Function:** Axon transmits impulses away from the nerve cell body.
- **Internal Structure of Axon** has a long central core of cytoplasm called **axoplasm.**
- Axoplasm is covered by the tubular sheath like membrane called **axolemma.**
- Axolemma is the continuation of the cell membrane of nerve cell body.
- **Axoplasm contains** mitochondria, neurofibrils and axoplasmic vesicles.
- Because of the **absence of Nissl bodies in the axon**, **proteins necessary for the nerve fibers 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.

DENDRITE

- Dendrite is the **branched process** of neuron and it is **branched repeatedly.**
- Dendrite may be present or absent. If present, it may be one or many in number.
- **Dendrite has Nissl granules and neurofibrils.**
- **Their job** is to receive messages from other neurons and allow those messages to travel to the cell body
- **Length:** Usually, the dendrite is shorter than axon.
- Dendrites can have small protrusions called dendritic spines, which further increase surface area for possible connections with other neurons.



The basic functions of a neuron

If you think about the roles of the three classes of neurons, you can make the generalization that all neurons have three basic functions. These are to:

1. Receive signals (or information).
2. Integrate incoming signals (to determine whether or not the information should be passed along).
3. Communicate signals to target cells (other neurons or muscles or glands).

These neuronal functions are reflected in the anatomy of the neuron.

Types of neurons

- **In terms of function,** scientists classify neurons into three broad types: sensory, motor, and interneurons.
- **Sensory neurons**
- Sensory neurons help you:
- taste
- smell
- hear
- see
- feel things around you
- Sensory neurons are triggered by physical and chemical inputs from your environment. Sound, touch, heat, and light are physical inputs. Smell and taste are chemical inputs.
- For example, stepping on hot sand activates sensory neurons in the soles of your feet. Those neurons send a message to your brain, which makes you aware of the heat.

- **Motor neurons**
- Motor neurons play a role in movement, including voluntary and involuntary movements.
- These neurons allow the brain and spinal cord to communicate with muscles, organs, and glands all over the body.
- There are two types of motor neurons: lower and upper.
- **Lower motor neurons** carry signals from the spinal cord to the smooth muscles and the skeletal muscles.
- **Upper motor neurons** carry signals between your brain and spinal cord.
- When you eat, for instance, lower motor neurons in your spinal cord send signals to the smooth muscles in your esophagus, stomach, and intestines. These muscles contract, which allows food to move through your digestive tract.

- **Interneurons**
- Interneurons are neural intermediaries found in your brain and spinal cord. They're the most common type of neuron. They **pass signals from sensory neurons and other interneurons** to **motor neurons and other interneurons**. Often, they form complex circuits that help you to react to external stimuli.
- For instance, when you touch something hot, sensory neurons in your fingertips send a signal to interneurons in your spinal cord. Some interneurons pass the signal on to motor neurons in your hand, which allows you to move your hand away. Other interneurons send a signal to the pain center in your brain, and you experience pain.

- Whether it is blinking when an object comes close to the eyes or snatching your hand back when touching something hot - reflexes are designed to adjust to these stimuli to protect the body from harm. While **sensory neurons** are responsible for detecting a stimulus and **motor neurons** are responsible for stimulating a muscular or glandular response, **interneurons** serve as the connection point between these two pathways.

Action potential

- Neurons send messages **electrochemically**. This means that chemicals cause an electrical signal.
- Chemicals in the body are "**electrically-charged**" when they have an electrical charge, they are called **ions.**
- **The important ions in the nervous system** are sodium and potassium (both have 1 positive charge, +), calcium (has 2 positive charges, ++) and chloride (has a negative charge, -).
- **There are also some negatively charged protein molecules**.
- It is also important to remember that nerve cells are surrounded by a membrane that allows some ions to pass through and blocks the passage of other ions.
- This type of membrane is called **semi-permeable**.

Action potential

- **Resting membrane potential**
- When a neuron is not sending a signal, it is "at rest." When a neuron is at rest, the inside of the neuron is negative relative to the outside. Although the concentrations of the different ions attempt to balance out on both sides of the membrane, they cannot because the cell membrane allows only some ions to pass through channels (ion channels). At rest, potassium ions (K^+) can cross through the membrane easily. Also at rest, chloride ions (Cl^-)and sodium ions (Na^+) have a more difficult time crossing.
- The negatively charged protein molecules (A^-) inside the neuron cannot cross the membrane
- In addition to these selective ion channels, there is a **pump** that uses energy to move three sodium ions out of the neuron for every two potassium ions it puts in. Finally, when all these forces balance out, and the difference in the voltage between the inside and outside of the neuron is measured, you have the **resting potential**. The resting membrane potential of a neuron is about -70 mV (mV=millivolt) - this means that the inside of the neuron is 70 mV less than the outside.
- At rest, there are relatively more sodium ions outside the neuron and more potassium ions inside that neuron

Action potential

- **An action potential occurs** when a neuron sends information down an axon, away from the cell body.
- Neuroscientists use other words, such as a "**spike**" or an "**impulse**" for the action potential.
- The action potential is an explosion of electrical activity that is created by a **depolarizing current**.
- This means that some event **(a stimulus)** causes the resting potential to move toward 0 mV. **When the depolarization reaches about -55 mV a neuron will fire an action potential.** This is the **threshold.**
- If the neuron does not reach this critical threshold level, then no action potential will fire. Also, when the threshold level is reached, an action potential of a fixed sized will always fire...for any given neuron, the size of the action potential is always the same.
- There are no big or small action potentials in one nerve cell - all action potentials are the same size. Therefore, the neuron either does not reach the threshold or a full action potential is fired - this is the **"ALL OR NONE"** principle.

- Action potentials are caused when different ions cross the neuron membrane.
- A stimulus first causes sodium channels to open. Because there are many more sodium ions on the outside, and the inside of the neuron is negative relative to the outside, sodium ions rush into the neuron.
- Remember, sodium has a positive charge, so the neuron becomes more positive and becomes depolarized.
- It takes longer for potassium channels to open. When they do open, potassium rushes out of the cell, **reversing the depolarization.**
- Also at about this time, sodium channels start to close. This causes the action potential to go back toward -70 mV (**a repolarization**).
- The action potential actually goes past -70 mV (**a hyperpolarization**) because the potassium channels stay open a bit

Action potential

NERVE FIBER

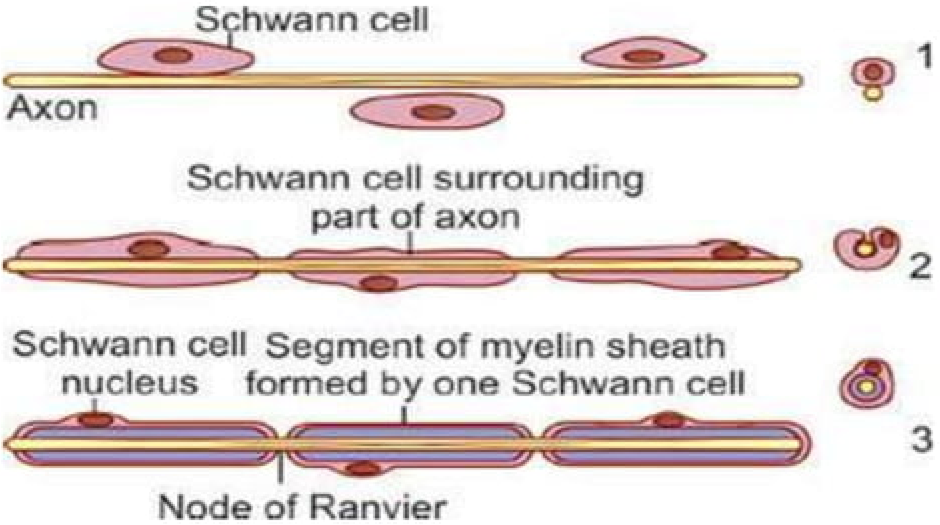
- An axon (from Greek , axis), or **nerve fiber** is a long, slender projection of a **nerve** cell, or neuron, in vertebrates, that typically conducts electrical impulses known as action potentials away from the nerve cell body.
- **Properties of nerve fibers**
- **1- Excitability:**
- Nerve fibers are highly excitable tissues
- Respond to various stimulus
- Capable of generating electrical impulses

- **2- Conductivity:**
- Action potential is generated in the nerve fibers, which travels along its entire length to axon terminal
- **3- Refractive period:**
- During action potential excitability of nerve becomes reduced
- i-e a new impulse can not be generated during action potential
- **4- Unfatiguability:**
- Nerve fibers can not be fatigued even when they are stimulated continuously.

- **5- All or none response:**
- Either all of action potential is seen or none at all
- If a stimulus of threshold strength is applied, action potential will be generated.
- Further increase in strength of stimulus or duration has no effect on amplitude of action potential but can effect frequency.
- **6- Accommodation:**
- Application of continuous stimuli may decrease the excitability of nerve fibers.
- **7- Summation:**
- Application of sub threshold stimulus (a stimulus which is too small to produce action potential) does not evoke an action potential. However if sub threshold stimuli are applied in rapid succession they are added and they produce an action potential.

- **MYELIN SHEATH**
- Myelin sheath is a thick lipoprotein sheath. It is formed by Schwann cells. Schwann cells wrap up and rotate around the axis cylinder in many concentric layers. The concentric layers fuse to produce myelin sheath.
- 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 fiber between two nodes is called **internode**.
- Myelin sheath is responsible for white color of nerve fibers.
- **Functions of Myelin Sheath**
- **1. Faster conduction**: Myelin sheath is responsible for faster conduction of impulse through the nerve fibers. In myelinated nerve fibers, the impulses jump from one node to another node. 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 fiber and prevents the stimulation of neighboring nerve fibers.

- Insulate- to separate
- Schwann cell- glia of peripheral system


Schwann cell
Axon
1
Schwann cell surrounding
part of axon
2
Schwann cell
nucleus
Segment of myelin sheath
formed by one Schwann cell
3
Node of Ranvier

Synapse

- The synapse is the junction where neurons trade information. It is not a physical component of a cell but rather a name for the gap between two cells:
- the presynaptic cell (giving the signal) and the postsynaptic cell (receiving the signal).
- There are two types of possible reactions at the synapse chemical or electrical.
- **During a chemical reaction**, a chemical called a neurotransmitter is released from one cell into another.
- **In an electrical reaction**, the electrical charge of one cell is influenced by the charge an adjacent cell.
- **Neurotransmitters**
- Neurotransmitters are chemicals that transmit signals from a neuron across a synapse to a target cell.

Synapse

- All synapses have a few common characteristics:
- **Presynaptic cell:** a specialized area within the axon of the giving cell that transmits information to the dendrite of the receiving cell.
- **Synaptic cleft:** the small space at the synapse that receives neurotransmitters.
- **G-protein coupled receptors:** receptors that sense molecules outside the cell and thereby activate signals within it.
- **Ligand-gated ion channels:** receptors that are opened or closed in response to the binding of a chemical messenger.
- **Postsynaptic cell:** a specialized area within the dendrite of the receiving cell that is designed to process neurotransmitters.

Synapse

- **Chemical synapse:**
- In a chemical synapse, action potentials affect other neurons via a gap between neurons called a synapse. Synapses consist of a presynaptic ending, a synaptic cleft, and a postsynaptic ending.
- When an action potential is generated, it's carried along the axon to a presynaptic ending. This triggers the release of chemical messengers called neurotransmitters. These molecules cross the synaptic cleft and bind to receptors in the postsynaptic ending of a dendrite.
- Neurotransmitters can excite the postsynaptic neuron, causing it to generate an action potential of its own. Alternatively, they can inhibit the postsynaptic neuron, in which case it doesn't generate an action potential.
- **Electrical synapse**
- Electrical synapses can only excite. They occur when two neurons are connected via a gap junction. This gap is much smaller than a synapse, and includes ion channels which facilitate the direct transmission of a positive electrical signal. As a result, electrical synapses are much faster than chemical synapses. However, the signal diminishes from one neuron to the next, making them less effective at transmitting.

Conduction of nerve impulse

Generation - Conduction of Neural Impulses

- Dependent on concentration gradients of Na^+ & K^+
  - Na^+ 14x greater outside
  - K^+ 28x greater inside
- Membrane permeability
  - lipid bilayer bars passage of K^+ & Na^+ ions
  - protein channels and pumps regulate passage of K^+ & Na^+
- at rest more K^+ move out than Na^+ move in
- K^+ ions diffuse out leave behind excess negative charge
- Sodium-potassium pump
  - Na^+ out - K^+ in (more Na+ out than K^+ in
  - contributes to loss of (+)