Nervous tissue

Function of nervous tissue:

1-Sensory function

2-Integration

3-Motor function

Example: when you see a glass of water you develop a sensory input (visual input), this stimulus will be converted to an electrical impulse (the photoreceptors of your retina are activated), then it goes to the brain (CNS), in the brain there is integration and interpretation of this information then taking a decision, if you decide to drink, motor impulses arise from your CNS to your peripheral muscles in order to pick up the glass and drink. Neurons respond to environmental Changes (stimuli) by altering the ionic gradient across the plasma membrane.

Anatomically the nervous system is divided into:

1. **Central nervous system:** Brain and spinal cord. CNS is responsible for the integration of information, interpretation, making memory and taking decisions.

2-**Peripheral nervous system:** peripheral nerves ex: (radial, ulnar, axillary nerves……)/ (any nervous tissue rather than the brain and spinal cord). PNS transfers the electrical messages from CNS to target organs or from organs to CNS

The peripheral nerves are classified according to their origin:

1- From the brain: cranial nerves.
2- From the spinal cord: spinal nerves.

The peripheral nervous system has two divisions:

1. Somatic: the nerve supplies a voluntary muscle (skeletal muscle) and brings sensation from the skin to the CNS.

2-Autonomic (visceral): the nerve supplies involuntary muscle (cardiac or smooth muscle) or a gland (in general to a structure that is not under our conscious control), it brings sensations from the viscera to the CNS (ex. lining of your stomach etc.). ANS regulates the internal environment of our body

The neurons can be classified (functionally) into:

1-Afferent neuron (sensory): our skin, for example, contains sensory receptors (ex. nerve endings) and when they are stimulated by a stimulus such as pressure/heat, these receptors are going to generate electrical impulses that travel from the periphery to the CNS.

2-Efferent neuron (motor): carries motor electrical impulses from the CNS to a gland or muscle whether it is skeletal or cardiac or smooth.

Note: The shape of neurons is different between the afferent and the efferent.

The structure of the neuron:

- The Neuron is composed of a cell body (Soma/ perikaryon) and this body has many processes.

- The short and branching processes are called Dendrites
- The long single process is called axon
- Axon at the terminal part gives many branches and the terminations of these branches have button like structures (swollen areas/knobs), these buttons contain vesicles of neurotransmitters (terminal buttons or knobs)
- The cell body contains large nucleus with prominent nucleolus which indicates the activity of the cell (in histological sections this appearance is very specific to neurons) ‘ Like an eye looking at you (owl eye) or fried egg’

- Dendrites: as you go away from the cell body, these processes become smaller and thinner in diameter (like a tree), they are multiple processes. “profuse branching”
- Axon: it does not branch profusely along its course (may have very few collateral branches along its course), it branches at its terminals

- The axon is surrounded by a cell with nucleus; a sheath called myelin (myelin is mainly composed of lipids), the myelin does not form a continuous layer around the axon, there are spaces (nodes) between the myelin segments. These nodes are called nodes of Ranvier.
- The area of contact between the terminal knob of the axon and the next neuron is called (synapse).
- These neurons are able to convert the stimulus into electrical signal and this electrical signal passes from dendrites to cell body to axon ((Unidirectional propagation of electrical impulses))

<u>The Histology of the neuron:</u>

- The cytoplasm of the cell body has dots which appear basophilic under the L.M. Basophilia within the cytoplasm means rough endoplasmic reticulum and ribosomes, these dots were called (Nissl bodies) at the beginning as they did not know the ultra structure of these dots, so the cytoplasm of the neuron is full with rough endoplasmic reticulum and ribosomes which again indicates the high synthetic activity of the cell. (Don't forget that these cells synthesize neurotransmitters)
- Also cell body has mitochondria, smooth ER, golgi apparatus (it's important for packaging proteins from the rough ER).
- In general, there is no organelles in the axon and dendrites (except the proximal part of dendrites); they are mainly composed of microtubules, microfilaments and intermediate filaments (neurofilaments), which give the shape of the neuron.
- The microtubules are also important for the movement of the organelles/vesicles within the cell.
- The proximal part of the dendrites contains some nissl bodies but the distal part of the dendrites has no organelles (Similar to the axon)
- We can also find in the cell body lipofuscin pigment, this pigment appears in long-lived cells and it's yellow-brownish in color. The pigment represents the residual bodies of the lysosomes (Residual bodies= undigested material)
- lipofuscin pigment can be seen in neurons and muscle cells (long lived cells)

- The neurons are highly differentiated cells, they do not undergo mitosis (long-lived cells), so we expect to find things that are related to age changes > lipofuscin pigment

<u>Terminologies of neurons:</u>

- Axoplasm = cytoplasm of an axon
- Axolemma = plasma membrane of an axon
- Axon hillock = the beginning of the axon from the cell body, it is triangular in shape and unmyelinated. This area is the start point of the action potential.
- Synaptic buttons/knobs= at the terminal site of the axon there are terminal branches, at the end of these branches, the buttons are located; they represent a bulbous area containing vesicles for neurotransmitters.
- The axon has almost a constant diameter except at the terminal part where it starts to branch, unlike the dendrites where they become thinner as you go away from the cell body
- Axons are longer than dendrites their length can reach 1 meter, for example the nerves of the lower limb, their cell bodies are in the lumbar area of spinal cord and extend their axons to the big toe
- Axon bifurcates at multiple points along its length (axon collaterals).
- The axon is mostly myelinated and it can be unmyelinated whereas the dendrites are never myelinated.
- The axoplasm of the axon contains mitochondria, microtubules, neurofilaments, transport vesicles but very few polyribosomes or cisternae of RER and no golgi apparatus.
- Where could we find mitochondria inside the axon?

The terminal part of the axon, in order for the synaptic vesicles to perform exocytosis into the synaptic cleft, this process needs energy and calcium so we expect to find mitochondria inside the axonal terminals.

- Therefore, if there is a cut in the axon, distal segment of the axon degenerates because the axon depends on the cell body for its maintenance. The cell body is the trophic center of the neuron, if the

axon is separated from the cell body it will die because it cannot synthesize its own proteins. Therefore, the cell body is important for the vitality of the axon.

- **Myelin:** lipoprotein surrounding the axon for insulation and protection and increasing the velocity of the propagation of the action potential along the axon (The same concept as the rubber around the wire.)

AXONAL TRANSPORT

At the terminal part of the neuron, there are a lot of vesicles containing neurotransmitters, but how these vesicles reach the axonal terminals? by a process called axonal transport, using microtubules and motor proteins.

Axonal transport has two types:

- Anterograde transport: movement of the vesicles from the cell body to the axon terminals, and its motor protein is kinesin
- Retrograde transport: is the movement of the vesicles from the axon terminals toward the cell body (for recycling), and its motor protein is dynein

The nervous tissue is composed of two types of cells:

1-Neurons: excitable cells. Neurons are simply us, they perceive, think, sense, and remember. They control muscle activity and regulate the glandular secretion.

2-Neuroglia : important for supporting, nourishing and protecting neurons which is vital for establishing an appropriate microenvironment for the neurons to work, plus forming a glue-like structure between the neurons.

- Neurons do not divide (have no centrioles) and they are long-lived cells, while neuroglia can divide, they are supporting cells not neurons so they undergo mitosis.
- Neuroglia are smaller in size but larger in number compared to neurons.

- Neurons have high metabolic activity. The cell body has many processes (these processes are difficult to be seen using ordinary stains (H&E))
- Neurons are excitable cells; they receive stimuli and convert them into electrical impulses. But this function cannot be done by the neuroglia!!

Note: nervous tissue of CNS "central nervous system" does not contain connective tissue other than that in the three meninges and in the walls of large blood vessels. Because of the absence of connective tissue, fresh CNS tissue (brain/spinal cord) has a very soft jelly-like consistency

Brain is a soft tissue composed of neurons and neuroglia... (As if the neurolgia compensate for the absence of the connective tissue in the CNS).

CNS has no connective tissue. While peripheral nervous system does have. Connective tissue forms sheaths surrounding the nerve fibers in PNS, however, the brain and the spinal cord are covered by layers of connective tissue known as meninges

Note: the meat that we eat is the muscles of the animal; the question is why it must be boiled (cooked)? In order to soften the connective tissue sheaths

CLASSIFICATION ON THE NEURONS ACCORDING TO THEIR SHAPE:

The shape of sensory neurons is different from the motor neurons

- Multipolar : has one axon & multiple dendrites, this type is the most common e.g.: motor neurons
- Bipolar: has two processes one is the dendrite, and one is the axon. e.g.: photoreceptors of retina, olfactory epithelium, and hearing receptors inside the inner ear.
- Pseudounipolar: has a cell body with one process (one stem) that divides into two processes, one brings messages from the periphery called peripheral process, and the other carries impulses to the CNS called the central process. e.g.: sensory neurons

Why it is called “ pseudounipolar” ?
Originally, this neuron was bipolar, but the dendrite and the axon fused to form short stem and the two processes hence the name.

Sensory neurons (pain, heat, touch or pressure) are pseudo-unipolar.
Certain sensory receptors like those found in the retina are bipolar.
While the motor neurons are multipolar

4- Anaxonic: has no axon. It has cell body and many dendrites without an axon. As there is no axon to initiate and propagate the action potential, this type does not generate action potential, but it has a regulatory function for the nearby neurons. This type is found entirely in CNS (brain and spinal cord), and never in the peripheral nervous system.

Summary:

- ✓ The nervous tissue is composed of large cells which are neurons, and small supporting neuroglial cells.
- ✓ Nervous tissue can be divided to 2 types according to its **location**:

  1. **CNS**: located and protected by the cranial cavity (brain), the vertebral canal (spinal cord).
  2. **PNS:** any nervous tissue outside the cranial cavity or the vertebral canal.
- ✓ PNS is further divided according to its function into sensory and motor:

  1- **Sensory**: carries sensations from the periphery to the CNS and it is also called (Afferent).

  2- **Motor**: carries motor impulses from CNS to muscles and glands, it is also called (Efferent).

- ✓ Classification for PNS according to the organ supplied:

a. **Somatic nervous system**:

1- Sensation: From skin to CNS.

2- Motor: From CNS to skeletal muscles (Voluntary action).

b. **Visceral nervous system (autonomic):**

1- Sensation: From viscera (stomach, heart, intestine...etc.) to CNS.

2- Motor: from CNS to involuntary structures (smooth muscles and cardiac muscle) and glands

Motor part of the ANS is further divided into:

a. Sympathetic.

b. Parasympathetic.

Note: Myelin is formed by neuroglial cells that surround the neurons.

For action potential to be generated there must be a Sodium (Na) influx. Entry of Na will cause depolarization of the cell membrane; it becomes more positive inside and more negative outside. Propagation of action potential is uni-directional always away from the cell body.

In **unmyelinated neurons** Na must enter the whole length of axon to propagate the action potential, causing the action potential propagation to be slow. While in **myelinated neurons** the propagation is faster. Myelin doesn't cover the whole length of axon but there is exposed areas between myelin segments (exposed to the extracellular fluid) called (nodes of Ranvier) and the myelin segment between 2 nodes of Ranveir is called internode. When action potential starts in Axon hillock it activates the Na gated ion channels on the nodes of Ranvier only so action potential jumps from one node to the next node.

Types of conduction:

1. Saltatory in myelinated neurons (Salta means jump).
2. Continuous in unmyelinated neurons.

Local anesthetics

How does an anesthetic work?

By stopping the action potential, stopping action potential leads to loss of sensations because no signal is sent to the CNS from the periphery. Local anesthetics are low molecular weight molecules that block the Na voltage gated channels so no sodium is going to enter the cell, no depolarization, no action potential.

There are different types of neurons according to **morphology**:

1. Multipolar
2. Pseudo-unipolar
3. Bipolar
4. Anaxonic

Types of synapses:

Synapse: meeting point between 2 structures.
Neuro-neuronal synapse: synapse between 2 neurons.
Neuro-muscular synapse: synapse between a neuron and a muscle (motor end plate)

a. **Axosomatic synapse:** between the axon terminal and the cell body (remember neuron's cell body is called soma as well).

b. **Axodendritic synapse:** between the axon terminals of pre synaptic neuron and the dendrites of the post synaptic neuron.

c. **Axoaxonic synapse:** usually axon terminals synapse with either post synaptic neuron's dendrites or cell body but sometimes we might have a third neuron with its axon synapsing with the pre synaptic axon for modulation of activity.

The Neuron has 3 parts: cell body, axon and dendrites.

The collection of cell bodies has different names according to its **location**:

- Collection of cell bodies inside the CNS is called **grey matter**/ **nucleus** (single: nucleus, plural: nuclei).

- Collection of cell bodies in the PNS is called **ganglion** (single: ganglion, plural: ganglia).

The collection of axons has different names according to its **location**:

- Collection of axons inside the CNS is called **white matter/ tract**

- Collection of axons in the PNS is called **nerve**

Structure of a peripheral nerve: the peripheral nerve is a collection of axons surrounded by sheaths of connective tissue. The outermost dense connective tissue sheath is called **Epineurium**. The epineurium sends septa that divide the nerve into groups or bundles called **fasciculi** (sing. **Fasciculus) or fascicles.** Each fasciculus is composed of a bundle of axons, and is surrounded by a perineurium. Each axon (and its myelin) is surrounded by endoneurium.

PNS is divided into:

- Spinal nerves if they originate from the spinal cord.
- Cranial nerves if they originate from the brain stem.

(sensory neuron: blue, motor neuron: red).

Spinal nerve originates as 2 roots:

1. **Anterior** (ventral) root: contains motor neuron.
2. **Posterior** (dorsal) root: contains sensory neurons (remember sensory neurons are pseudo-unipolar in shape with some exceptions).

These two roots unite together to form the spinal nerve and the spinal nerve is a mixed nerve it contains both sensory and motor neurons.

The cell bodies of sensory neurons are outside the CNS (spinal cord in this case) so we call their collection ganglion, dorsal root ganglion or sensory ganglion. While cell bodies of the motor neurons are found in the CNS so we call their collection nucleus.

After the formation of spinal nerve, the spinal nerve divides into:

- Anterior (ventral) ramus
- Posterior (dorsal) ramus

Anterior ramus supplies the anterolateral aspect of our body including upper and lower limbs, except a thin band on the back which is supplied by posterior ramus. (Refer to the figure: the purple area is supplied by posterior ramus everything else is supplied by anterior ramus of spinal nerve).

Visceral nervous system (autonomic):

1- Sensation: From the viscera (stomach, heart, intestine...etc.) to CNS.
2- Motor: From CNS to involuntary muscles (smooth muscles and cardiac muscles) and glands

Motor part of the ANS is further divided into:

a. Sympathetic.
b. Parasympathetic.

These 2 systems are important to control the internal environment of our body without our conscious control or not under our voluntary control.

Both sympathetic and para sympathetic supply the same organs but with opposite effects.

Parasympathetic:

It dominates when the body is in rest (also called rest and digest system).

- Pupils constrict.
- Decreased heart rate.
- Bronchoconstriction.
- Increased secretion from salivary glands, pancreas and stomach to stimulate digestion.

Sympathetic:

- Dominates in stressful conditions (also called fight or flight system).
- Pupils dilate: to allow for the far vision and to increase the light getting into the eye.
- Increased heart rate: to supply more blood to skeletal muscles.
- Vasodilation to skeletal blood vessels: to increase the blood flow and Oxygen.
- Bronchodilation: to increase the oxygen intake.
- Vasoconstriction of the blood vessels supplying the GI tract.

How to differentiate between somatic and autonomic anatomically?

The cell body of a motor somatic neuron is found in the CNS (nucleus) and it stimulates a skeletal muscle directly, Single neuron pathway.

In the autonomic nervous system, we have two neurons (presynaptic and postsynaptic neurons). The cell body of the preganglionic neuron is found in the CNS (nucleus) and the cell body of the postganglionic neuron is outside the CNS (ganglion), 2 neurons pathway.

Types of ganglia: sensory and autonomic
In spinal/ sensory/dorsal root ganglia there's no synapse

In autonomic ganglia there's synapse (between pre and post ganglionic)

- Sympathetic ganglia are found on the sides of the vertebral column. So preganglionic neurons are “short” while post ganglionic neurons are “long”

- Parasympathetic ganglia are found within the wall of the effector eg: the submandibular gland, the ganglion is next to it so the preganglionic is long while postganglionic is short.

<u>Type of neurotransmitter:</u>
In somatic nervous system the type of neurotransmitter is Ach.

In both parasympathetic and sympathetic the neurotransmitter of the preganglionic neuron is Ach (acetylcholine).

The neurotransmitter of the postganglionic neuron

In sympathetic: Norepinephrine

In parasympathetic: Ach

Note: the neurotransmitter in postganglionic must be different because both systems target the same organs BUT with opposite effects.

Nerve (axon) injury

When the axon is cut, the distal part will degenerate because it's no longer connected to the cell body. (Remember neurons are highly differentiated they can't go under mitosis, but neuroglial cells are able to divide).

The proximal end of an axon is still attached to the cell body and the proximal segment will grow back until it reaches the target muscle for example. This process takes between 3-6 months in order for the function to be restored.

Why is it difficult for the axon to re-establish connection with its effector muscle? Because the growing axon loses its way to the target organ.

Types of neuroglial cells

In CNS we have:

Astrocytes (star shaped)

Oligodendrocytes (oligo means few), this cell has relatively few processes

Microglia (small cell)

Ependymal cells (lining cells)

Astrocytes: are important in forming the blood brain barrier (BBB). BBB is a semipermeable border that separates the circulating blood from the CNS tissue. Our nervous tissue is very delicate and fragile, not everything in the blood should diffuse to the nervous tissue. BBB Consists of:
1- Tight junctions that seal together the endothelial cells of brain blood capillaries
2- Thick basement membrane
3- Astrocytes feet like processes
The tight gap allows only small molecules, fat-soluble molecules, and some gases to pass freely through the capillary wall and into brain tissue.

Oligodendrocytes: these cells have processes that extend and form myelin segments in CNS. Each oligodendrocyte can myelinate up to 60 myelin segments from different axons
Microglia: are the macrophage-like cells in CNS, derived from monocytes
Ependymal cells: are the lining cells of the ventricles of the brain and the central canal of the spinal cord.
Inside our brain we have spaces/ ventricles filled with fluid called cerebrospinal fluid (CSF). Inside our spinal cord is a canal called central canal filled with CSF. The ependymal cells have a ciliated simple columnar shape (much like epithelial cells) that helps in the circulation and production of CSF

Neuroglial cells in PNS
Schwann cell: is the myelin forming cell in PNS. Each Schwann cell myelinates single myelin segment (or internodal segment)

Satellite cells: are the supporting cells in the ganglia

Myelination of PNS axons
A Schwann cell engulfs one portion along the length of an axon. The Schwann cell membrane fuses around the axon and elongates as it becomes wrapped around the axon while the cell body moves around the axon many times. The Schwann cell membrane wrappings constitute the myelin sheath, with the Schwann cell nucleus are pushed to the periphery. The myelin layers are very rich in lipid, and provide insulation and facilitate formation of action potentials along the axolemma.