The Nervous System

The human nervous system, by far the most complex system in the body, is formed by a network of many billion **nerve cells (neurons)**, all assisted by many more supporting cells called **glial cells**. Each neuron has hundreds of interconnections with other neurons, forming a very complex system for processing information and generating responses.

The organization of the nervous system

Anatomically, the nervous system is divided into:-

1- The central nervous system (CNS): This includes the **brain** and **spinal cord**.

2- The peripheral nervous system (PNS): composed of the **cranial**, **spinal**, and **peripheral** nerves conducting impulses to and from the CNS (sensory and motor nerves, respectively) and **ganglia** that are small aggregates of nerve cells outside the CNS.

3- Autonomic nervous system (ANS) or visceral nervous system (VNS): this is part of PNS consists of motor neurons that run to all the internal organs and activate them without our conscious control.

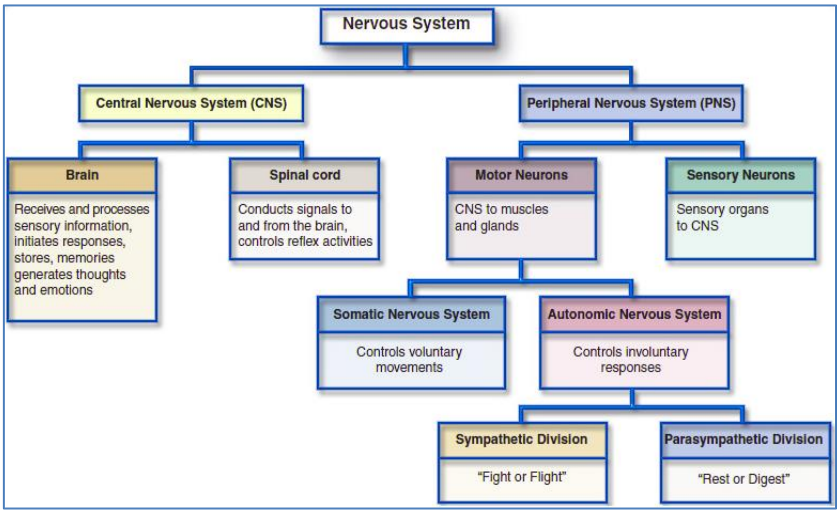

Figure 1 The organization of the nervous system

Development of nerve tissue

The nervous system develops from the outermost of the three early embryonic layers, the ectoderm, beginning in the third week of development (Figure 2). With signals from the underlying axial structure, the notochord, ectoderm on the mid-dorsal side of the embryo thickens to form the epithelial neural plate. The sides of this plate fold upward and grow toward each other medially, and within a few days fuse to form the **neural tube**. Cells of this tube give rise to the entire CNS, including neurons and most glial cells. As the folds fuse and the neural tube separates from the now overlying surface ectoderm that will form epidermis, a large population of developmentally important cells, the **neural crest**, separates from the neuroepithelium and becomes mesenchymal. Neural crest cells migrate extensively and differentiate as all the cells of the PNS, as well as a number of other non-neuronal cell types.

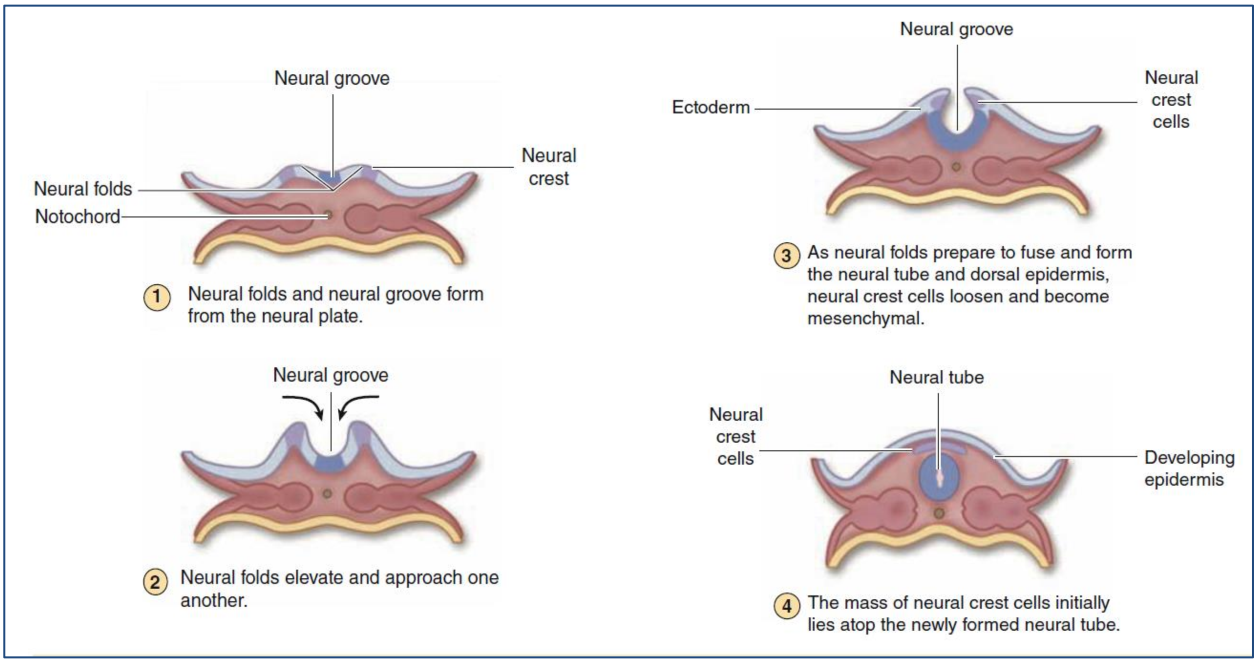

Figure 2 Stages in the process of neurulation

Neurohistology

Structurally, nerve tissue consists of two cell types:-

Nerve cells or neurons, which usually show numerous long processes and **glial cells**, which have short processes, support, and protect neurons and participate in neural activity, neural nutrition and the defence processes of the central nervous system.

Neurons

The functional unit in both the CNS and PNS is the neuron. Most neurons have three main parts (Figure 3):

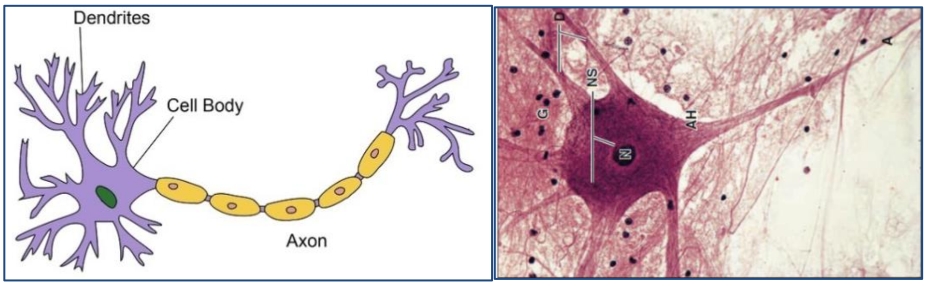

Figure 3 The neuron. Micrograph of a large motor neuron showing the large cell body and nucleus (**N**), a long axon (**A**) emerging from an axon hillock (**AH**), and several dendrites (**D**). Nissl substance (NS) can be seen throughout the cell body and cytoskeletal elements can be detected in the processes. Nuclei of scattered glial cells (**G**) are seen among the surrounding tissue. (X100; H&E).

Cell body (perikaryon or soma)

The cell body is the part of the neuron that contains the nucleus and surrounded by cytoplasm, exclusive of the cell processes. It is a trophic centre and receptive capabilities, the perikaryon receive a great number of nerve endings that convey excitatory or inhibitory stimuli generated in other nerve cells. The cell body contains mitochondria, lysosomes, a Golgi complex, highly developed rough endoplasmic reticulum and **Nissl bodies** (composed of rough endoplasmic reticulum and ribosomes and their function to manufacture and release proteins), features of a neuron cell body is shown in Figure 4. Neurofilaments and neurotubules are abundant in perikaryon and cell processes.

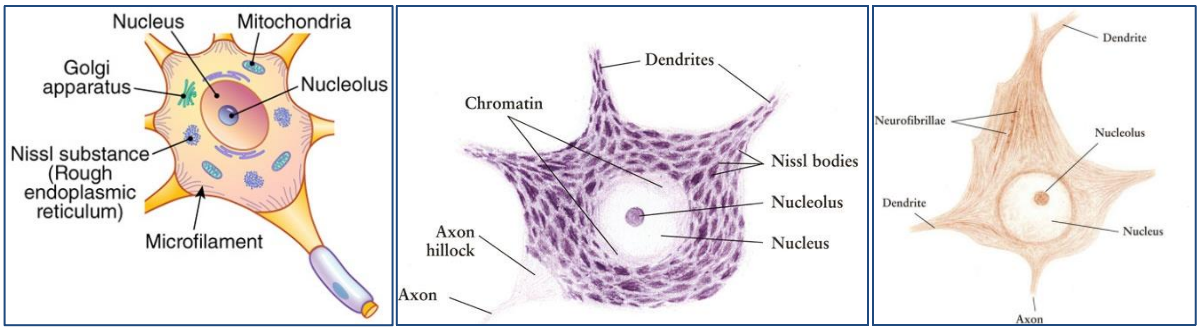

Figure 4 Features of a neuron cell body

Dendrites

Dendrites are usually short and divide like the branches of a tree. Most nerve cells have numerous dendrites, which considerable increase the receptive area of the cell. The composition of dendritic cytoplasm is similar to that of the soma; however, dendrites are devoid of Golgi complexes.

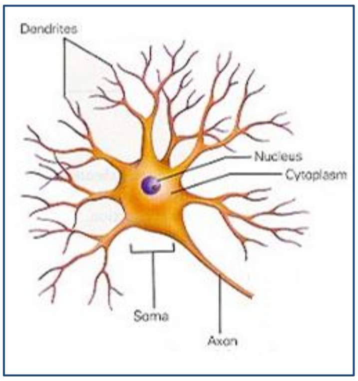

Figure 5 dendrites of neurons

Axon

Axon is a single process, specialized in generating or conducting nerve impulses to other cells. All axons originate from a short pyramid-shaped region called axon hillock that usually arises from the soma. The plasma membrane of the axon is called the axolemma, its contents are called axoplasm. Axon varies in length and diameter according to the type of neuron for example, axons of motor cells of the spinal cord that innervate the foot muscles may have a length of up to 100 cm. The whole length of an axon is generally wrapped around by a fatty or myelin sheath which acts as an insulator to prevent the spread of nerve impulses from one axon to another.

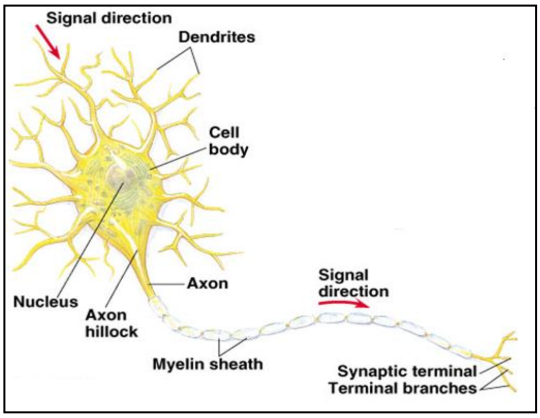

Figure 6 The axon

Different types of neurons

Neurons are variable in size (5-150 µm) - shape (spherical, angular) and they have different functions depending in which part of the body they are located.

Neurons are grouped according to **their structure** as shown below (Figure 7):-

1- Unipolar (pseudounipolar) with one process that is close to the soma and divides into two branches. The process then forms a T shape with one branch extending to a peripheral ending and the other toward the central nervous system.

2- Bipolar with one dendrite and one axon, these are found in the ear and retina of the eye.

3- Multipolar with many dendrites from cell body and one axon, these are commonly located in the brain and spinal cord.

Another way of describing neurons is to refer to **their function**:-

1- Motor neurons (efferent neurons) carry impulses away from the brain and spinal cord to the muscles and glands.

2- Sensory neurons (afferent neurons) carry impulses into the brain and spinal cord from sense organs or receptors such as eyes or ears.

3- Interneurons serve to connect sensory neurons to the motor neurons. They are found within the brain and spinal cord.

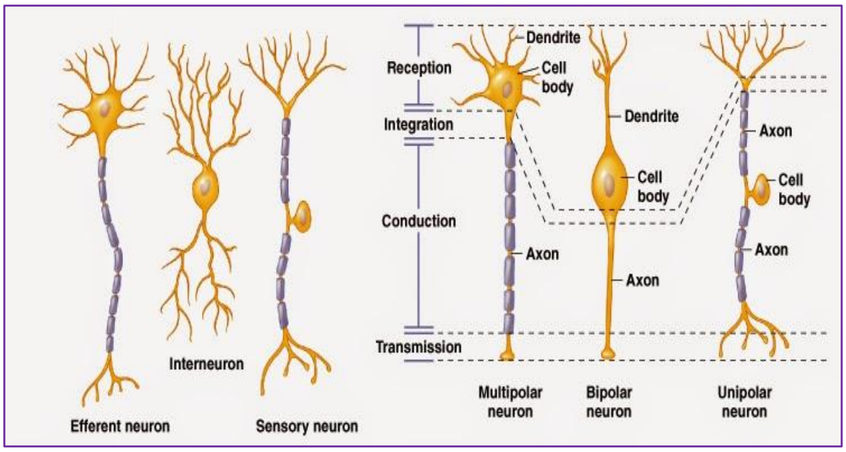

Figure 7 Types of neuron

Synaptic communication

Synapses are the sites where contact occurs between neurons or between neurons and other effector cells (muscle and gland cells). Most synapses transmit the impulse by releasing **neurotransmitters** at the axon terminal: these are chemicals substances that induce the transfer of the nervous impulse to another neuron or an effector cell. The synapse is formed by an axon terminal **(presynaptic terminal)** that delivers the impulse; a part of another cell where a new impulse is generated **(postsynaptic terminal)**; and a thin intercellular space called the **synaptic cleft** (Figure 8). If an axon synapses with a cell body it is called an **axosomatic** synapse; with a dendrites, **axodendritic**; or with an axon, **axoaxonic**.

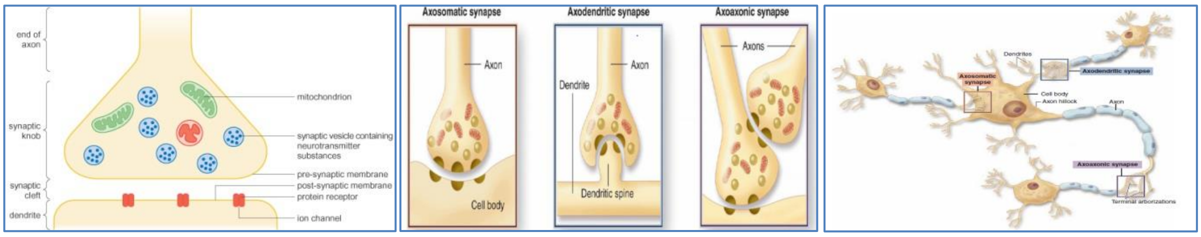

Figure 8 Major components of a synapse

The presynaptic terminal always contains synaptic vesicles and numerous mitochondria. Neurotransmitters are generally synthesized in the cell body and stored in vesicle in the presynaptic region of a synapse. During transmission of a nerve impulse, they are released into synaptic cleft by exocytosis. The vesicles contain neurotransmitters; the mitochondria furnish energy for synaptic activity. Two common neurotransmitters are **acetylcholine** and **noradrenalin (norepinephrine)**. Most synapses are **chemical synapses** and transmit nerve impulses through **neurotransmitters**. A very few synapses transmit the impulses through **gap junctions** that cross the pre- and postsynaptic membranes, ion do pass freely through these gap junctions and conduct the nerve impulses directly. These synapses are called **electric synapses**. Drug action very often takes place by acting at the synapse. The particular drug increases or decreases the action of a neurotransmitter.

Glial cells

Glial cells play an important supporting role in the nervous tissue these cells are 10 times more abundant than neurons in the mammalian brain, they surround bot cell bodies and their axonal and dendrite processes occupying the interneuronal spaces. Nervous tissue has no intercellular matrix and glial cells furnish a microenvironment suitable to neuronal activity. There are six major kinds of glial cells, as shown schematically in Figure 9, four in the CNS, two in the PNS. Their main functions, locations, and origins are summarized in Table 1.

Glial Cell Type	Origin	Location	Main Functions
Oligodendrocyte	Neural tube	CNS	Myelin production, electrical insulation
Astrocyte	Neural tube	CNS	Structural and metabolic support of neurons, especially at synapses; repair processes
Ependymal cell	Neural tube	Line ventricles and central canal of CNS	Aid production and movement of CSF
Microglia	Bone marrow (monocytes)	CNS	Defense and immune-related activities
Schwann cell	Neural crest	Peripheral nerves	Myelin production, electrical insulation
Satellite cells (of ganglia)	Neural crest	Peripheral ganglia	Structural and metabolic support for neuronal cell bodies

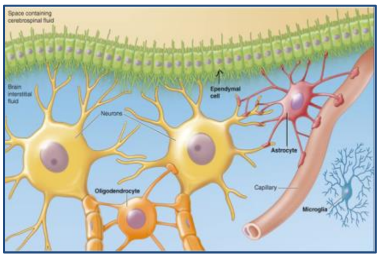

Table 1 Figure 9 Types of glial cells

Oligodendrocytes

Oligodendrocytes (Gr. oligos, small, few + dendron, tree + kytos, cell) extend many processes, each of which becomes sheet-like and wraps repeatedly around a portion of a nearby CNS axon (Figure 10). The functions of oligodendrocyte are:-

1- Myelinates and insulates axons

2- Allows faster action potential propagation along axons in the CNS

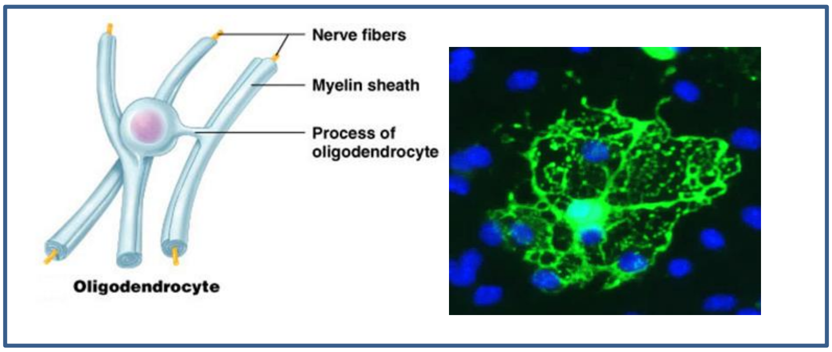

Figure 10 Oligodendrocyte

Astrocytes

Astrocytes are star shaped cells because of their multiple radiating processes. These cells have bundles of intermediate filament made of glia fibrillary acid protein that reinforce their structure. Astrocytes bind neurons to capillaries and to pia mater (a thin connective tissue that covers the CNS). Astrocytes with few long processes are called **fibrous astrocytes** and located in the **white matter**. **Protoplasmic** astrocytes with many short branched processes are found in the **gray matter**. In addition to their structural functions, astrocytes participate in controlling the ionic and chemical environment of neurons. Astrocyte develops processes with expanded end-feet that are linked to the endothelial cells by junctional complexes and form a continuous barrier between the CNS and blood vessels which is called blood brain barrier (BBB). (BBB is a functional barrier that prevents the passage of some substances such as antibiotic and chemical and bacterial toxic matter from the blood to nerve tissue). Furthermore, when the CNS is damaged, astrocytes proliferate to form cellular scar tissue.

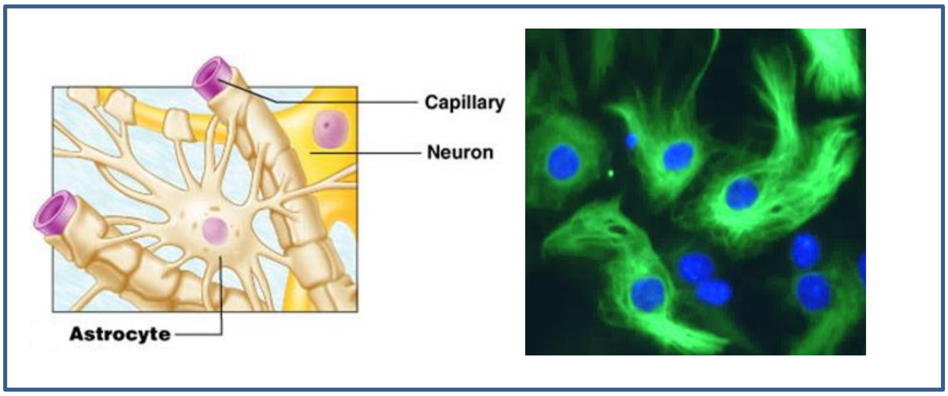

Figure 11 Astrocyte

Ependymal cells

These cells are low columnar ciliated epithelial cells that line the cavities of the CNS. The functions of the ependymal cell are:-

1- Line ventricles of the brain and central canal of the spinal cord

2- Assists in production and circulation of cerebrospinal fluid (CSF)

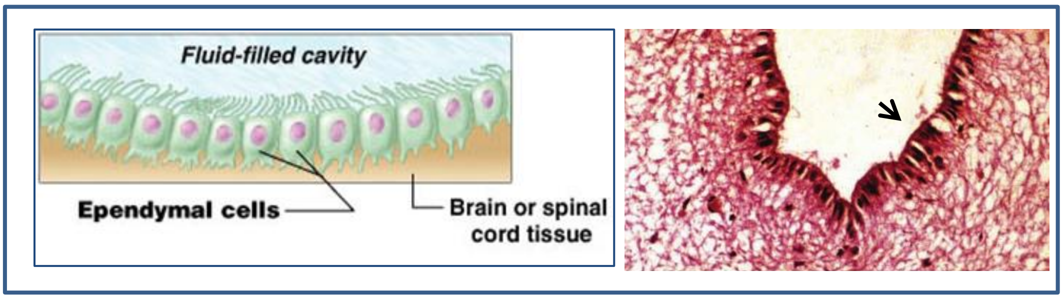

Figure 12 Ependymal cell

Microglia

Microglia are small elongated cells with short irregular processes (Figure 13). They have elongated nuclei that contrast with the spherical nuclei of other glial cells. The functions of microglia are:-

1- Microglia, phagocytic cells that represent the mononuclear phagocytic system in nervous tissue, they are involved with inflammation and repair in adult CNS.

2- Activated microglia act as antigen presenting cells, they secrete a number of immunoregulatory cytokines and dispose of unwanted cellular debris caused by CNS lesions.

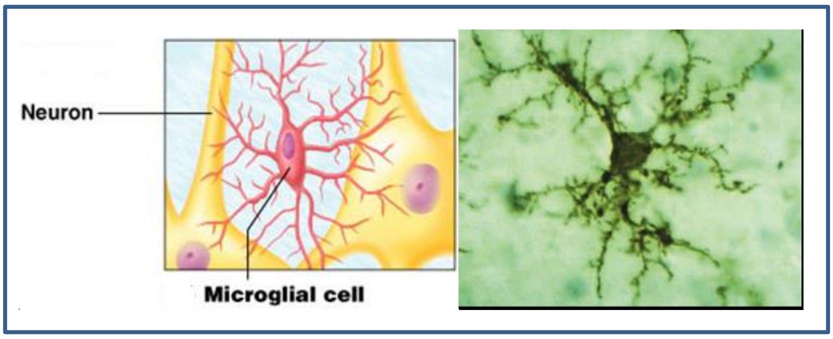

Figure 13 Microglia

Schwann cells

These cells have the same function as oligodendrocytes but are located around axons in the PNS. One Schwann cell forms myelin around a portion of only one axon, in contrast to the ability of oligodendrocytes to branch and serve more than one neuron and its processes. Figure 14 shows how the Schwann cell membrane wraps around the axon.

Satellite cells

Satellite cells also derived from the embryonic **neural crest**, small satellite cells form a thin, intimate glial layer around each large neuronal cell body in the ganglia of the PNS (Figure 13). The functions of the satellite cell are:-

1-Electrically insulates PNS cell bodies

2- Regulates nutrient and waste exchange for cell bodies in ganglia.

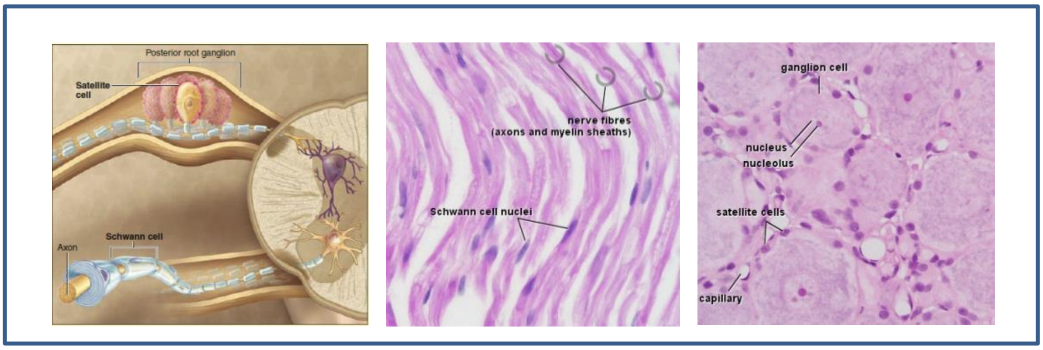

Figure 14 Schwann cell and Satellite cell