

Nervous Tissue

Textbook of Histology, 4th ed.

Gartner

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Nervous Tissue

The nerve tissue is one of the four main tissues that compose our body.

It has **ectodermal** (neural crest cells) origin and its main function is communication

Composition of Nerve tissue

Neurons

Smallest $5\mu\text{m}$
Largest $150\mu\text{m}$

Neuroglia - physical and metabolic support

Anatomic Organization

- The central nervous system (CNS): brain and spinal cord
- The peripheral nervous system (PNS), composed of cranial and spinal nerves and ganglia – Afferent components (sensory) and efferent components (motor) -

Neurons

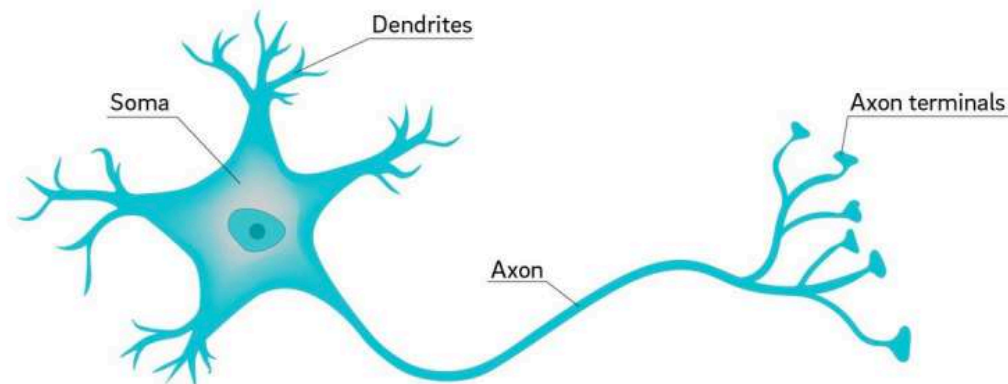
The cells responsible for the reception and transmission of nerve impulses to and from the CNS are the neurons.

Most neurons are composed of three distinct parts:

- 1- a cell body
- 2- multiple dendrites
- 3- a single axon

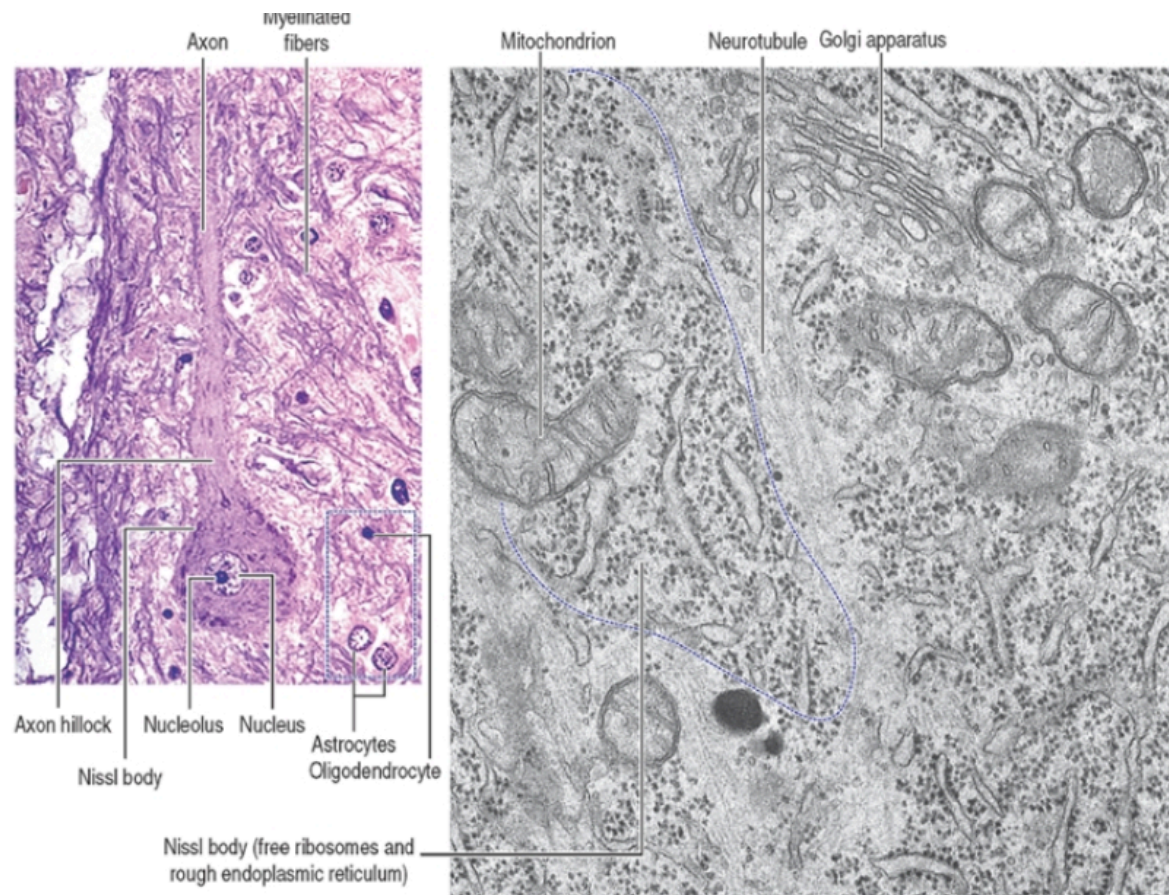
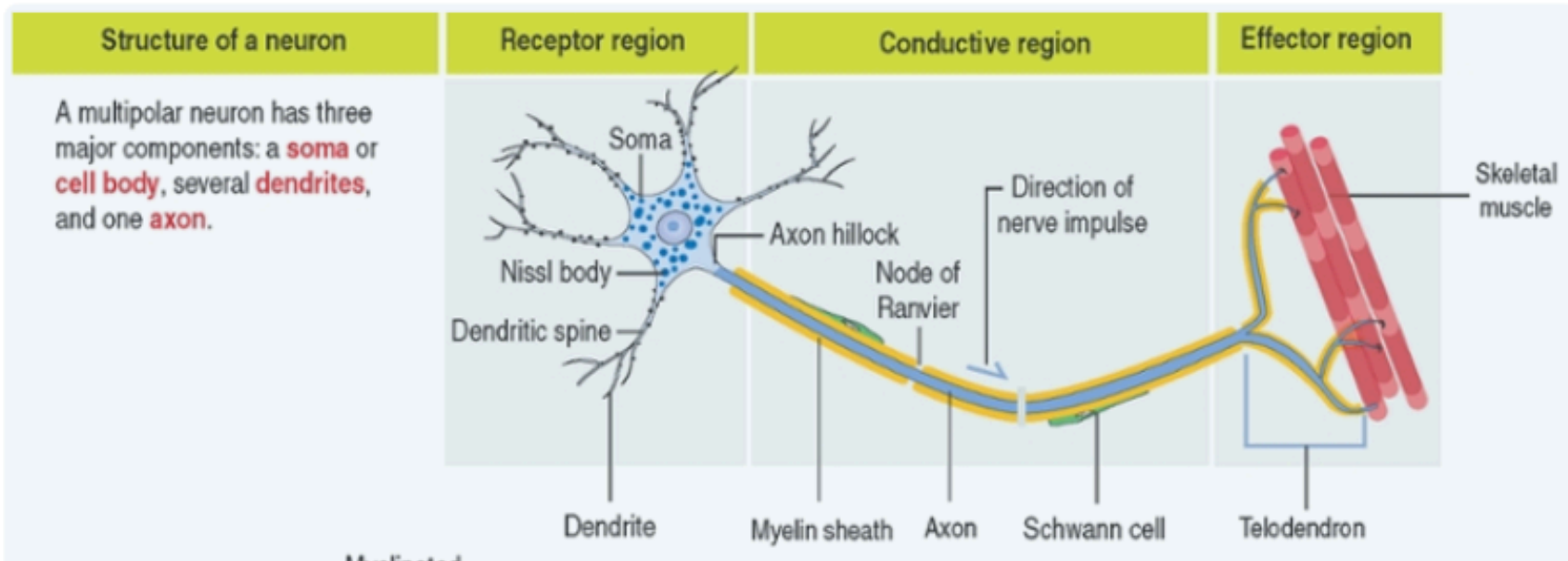
The cell body of a neuron, also known as **soma**, is the central portion of the cell where the nucleus and perinuclear cytoplasm are contained.

Neuron



The various types of neurons.

- The soma contains the nucleus and its surrounding cytoplasm (also called **perikaryon**; Greek *peri*, around; *karyon*, nucleus).
- The surface membrane of the soma and the dendritic tree are specialized for the **reception** and **integration** of information, whereas the axon is specialized for the **transmission** of information in the form of an action potential or a nerve impulse.



Neurons - dendrites

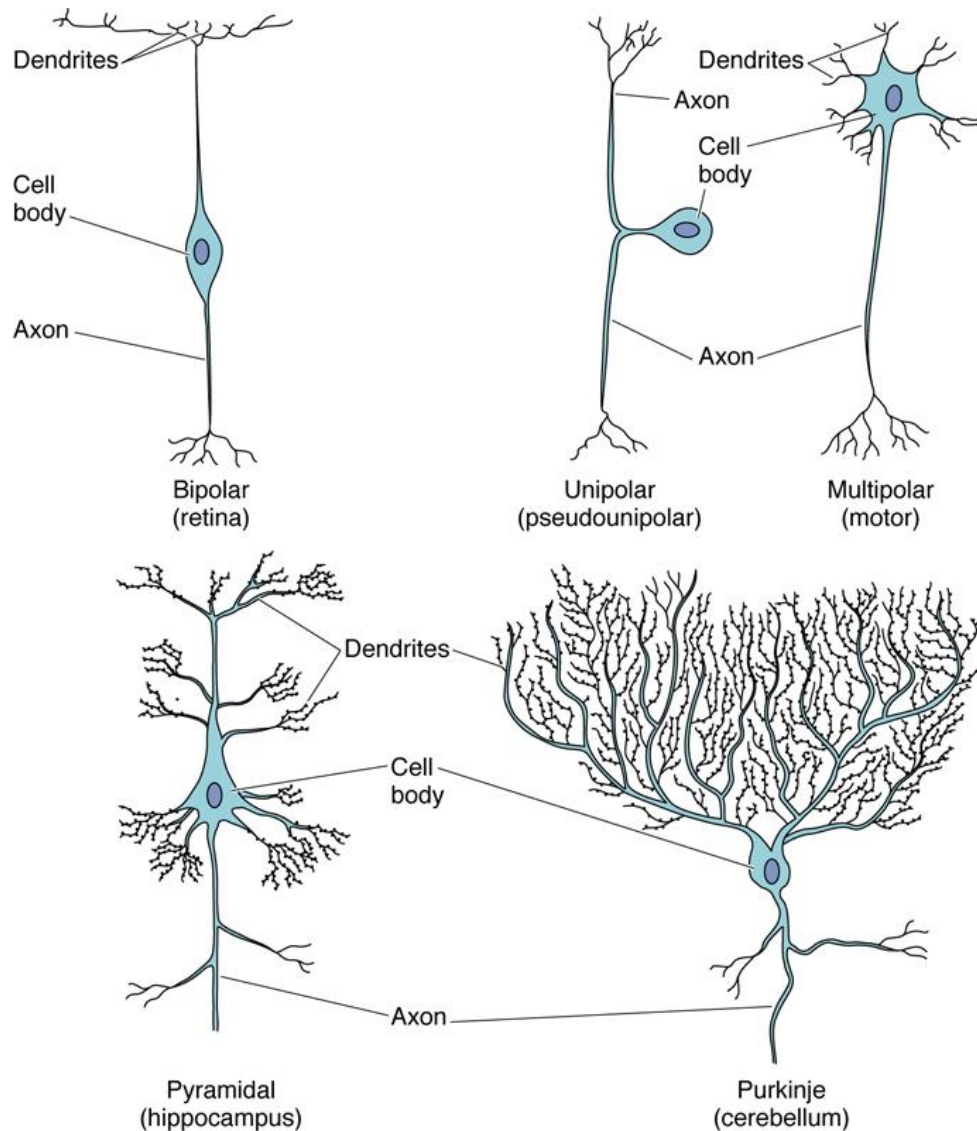
Projecting from the cell body are the dendrites, processes specialized for receiving stimuli from sensory cells, axons and other neurons.

Often the dendrites are multibranched. They are arborized so that they can receive multiple stimuli from many other neurons simultaneously.

The nerve impulses received by the dendrites are then transmitted toward the soma.

The dendrites are processes that arise as multiple tree-like branches of the soma, forming a **dendritic tree** collectively. The entire surface of the dendritic branches is covered by small protrusions called **dendritic spines**. Dendritic spines establish numerous axonal synaptic connections.

Neurons - axon



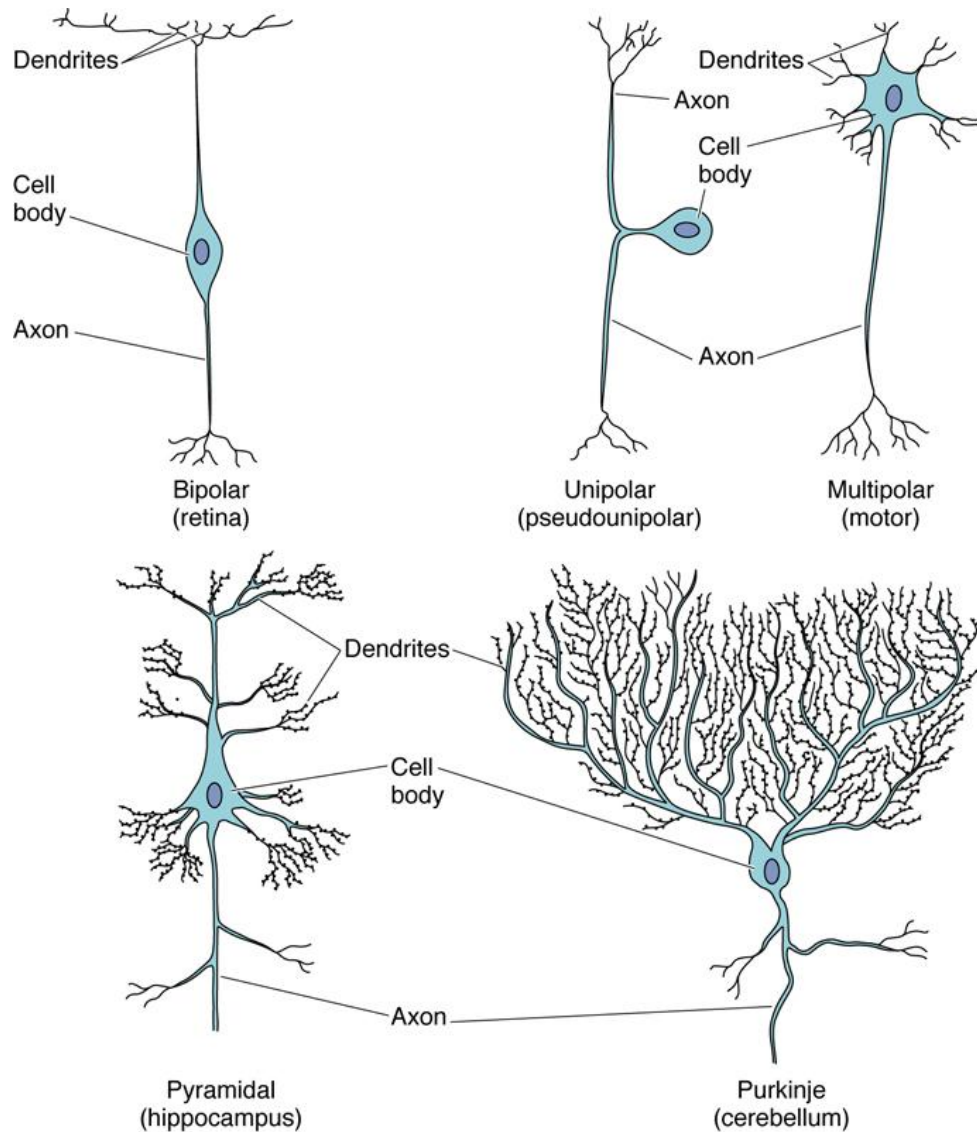
The various types of neurons.

Each neuron possesses a single axon, a process of varying diameter and up to 100 cm in length, which usually has dilatations, known as **axon terminals**, at or near its end.

The axon conducts impulses away from the soma to other neurons, muscles, or glands, but it may also receive stimuli from other neurons, which may modify its behavior.

Neurons have a **single axon** originating from the soma at the **axon hillock** and ending in a terminal arborization, the **telodendron**. Each terminal branch of the telodendron has an enlarged ending, the **synaptic terminal** or **synaptic bouton**.

Neurons - axon



Like dendrites, the axon arborizes. These axon terminals, also known as **end bulbs**, approach other cells to form a synapse, the region where impulses can be transmitted between cells.

The various types of neurons.

Neurons

Cell bodies exhibit different sizes and shapes that are characteristic for their type and location.

Generally, neurons in the CNS are polygonal, with concave surfaces between the many cell processes, whereas neurons in the dorsal root ganglion (a sensory ganglion of the PNS) have a round cell body from which only one process exits.

Neuron Classification- Types of neurons

Neurons can be classified according to the number and morphology of the processes extending from the cell body.

Multipolar neurons have a single axon and two or more dendrites.

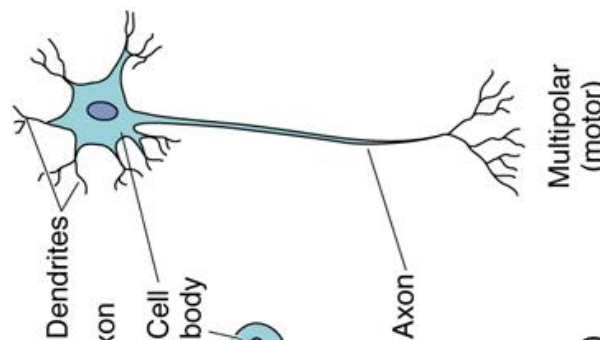
They display **many processes** attached to a polygonal-shaped soma.

Their dendrites allow the integration of information from other neurons.

Most common type of neurons

Motor neurons are examples of multipolar neurons.

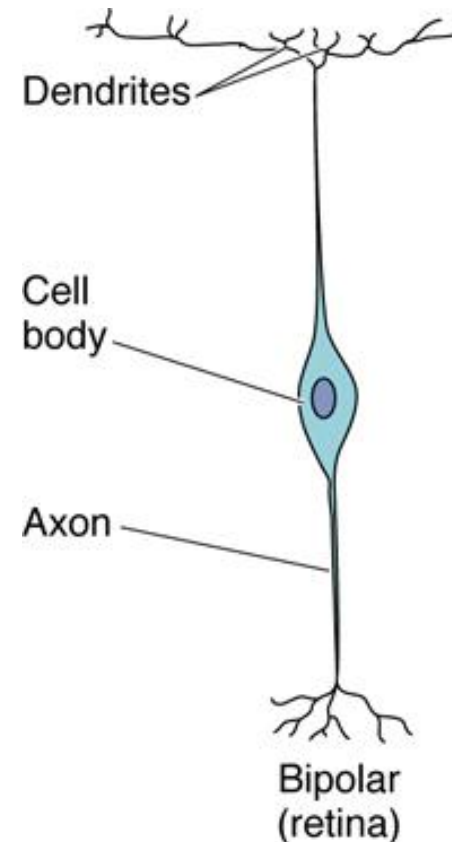
Multipolar neurons, Multipolar neurons are the most abundant neurons in the nervous system. Pyramidal cells of the cerebral cortex and Purkinje cells and neurons of the cerebellar cortex are two typical examples.



Neuron Classification

Bipolar neurons have a single axon and one dendrite. Impulses are generated in the cell body and are conducted through the axon to the target cells

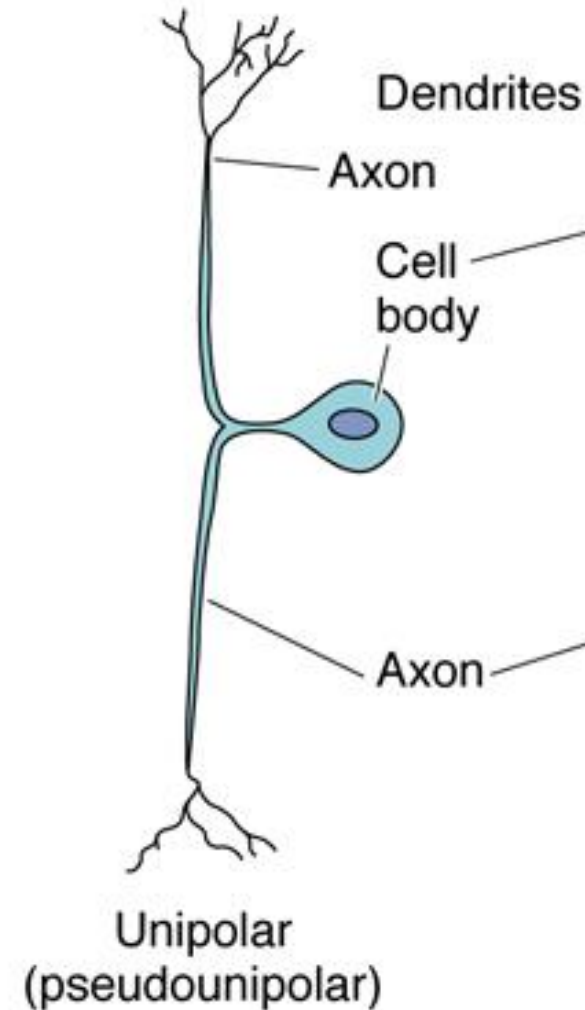
- Uncommon but are prominent in specialized tissues (e.g., olfactory epithelium, retina and inner ear)



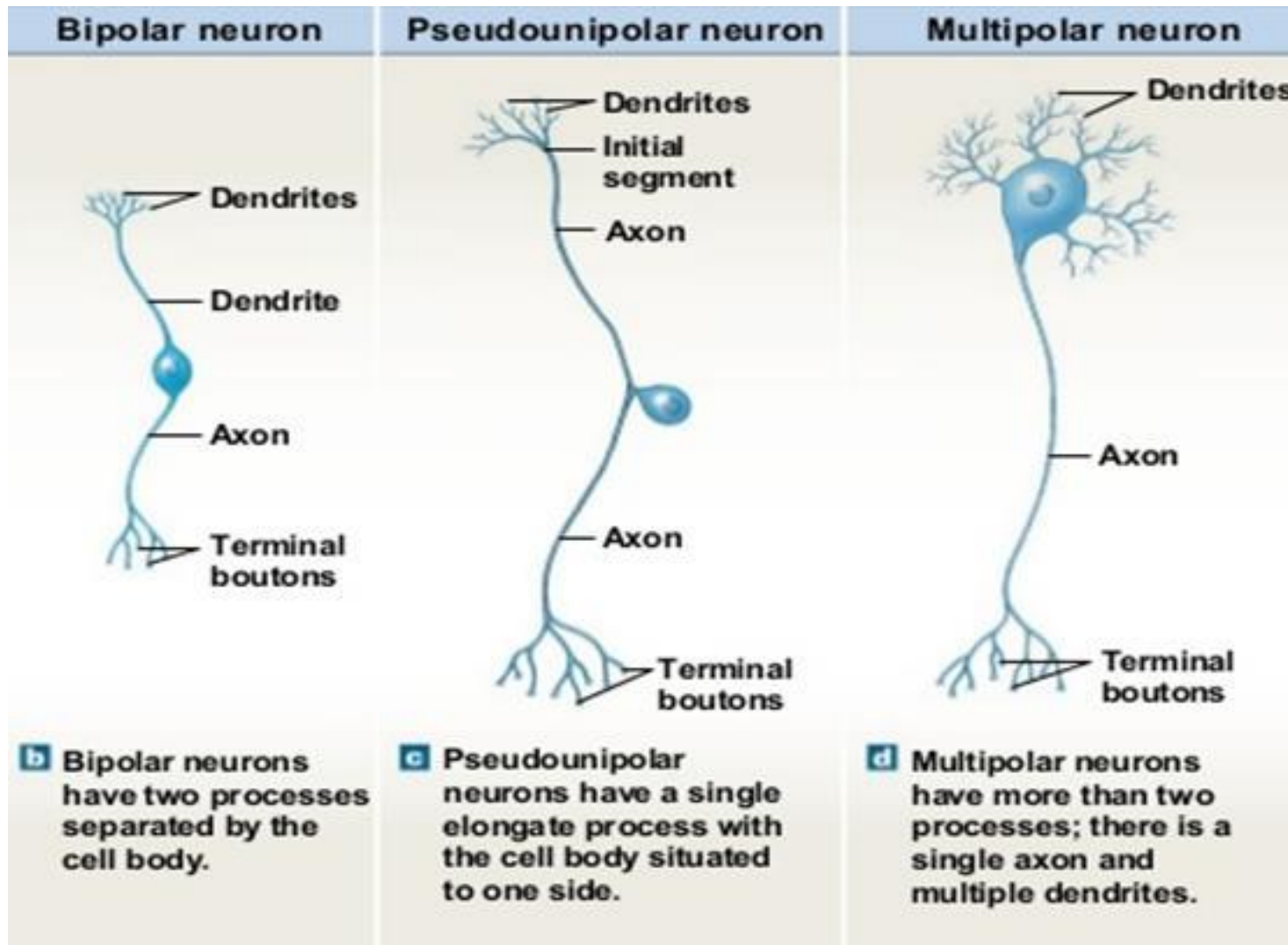
Neuron Classification

Pseudounipolar neurons have a single axon that splits into two branches - one process passes centrally, and another originates peripherally.

- Impulses are generated in the sensory endings and are then conducted through the peripheral and central axon to the CNS
- Found in sensory ganglia of the peripheral nervous system

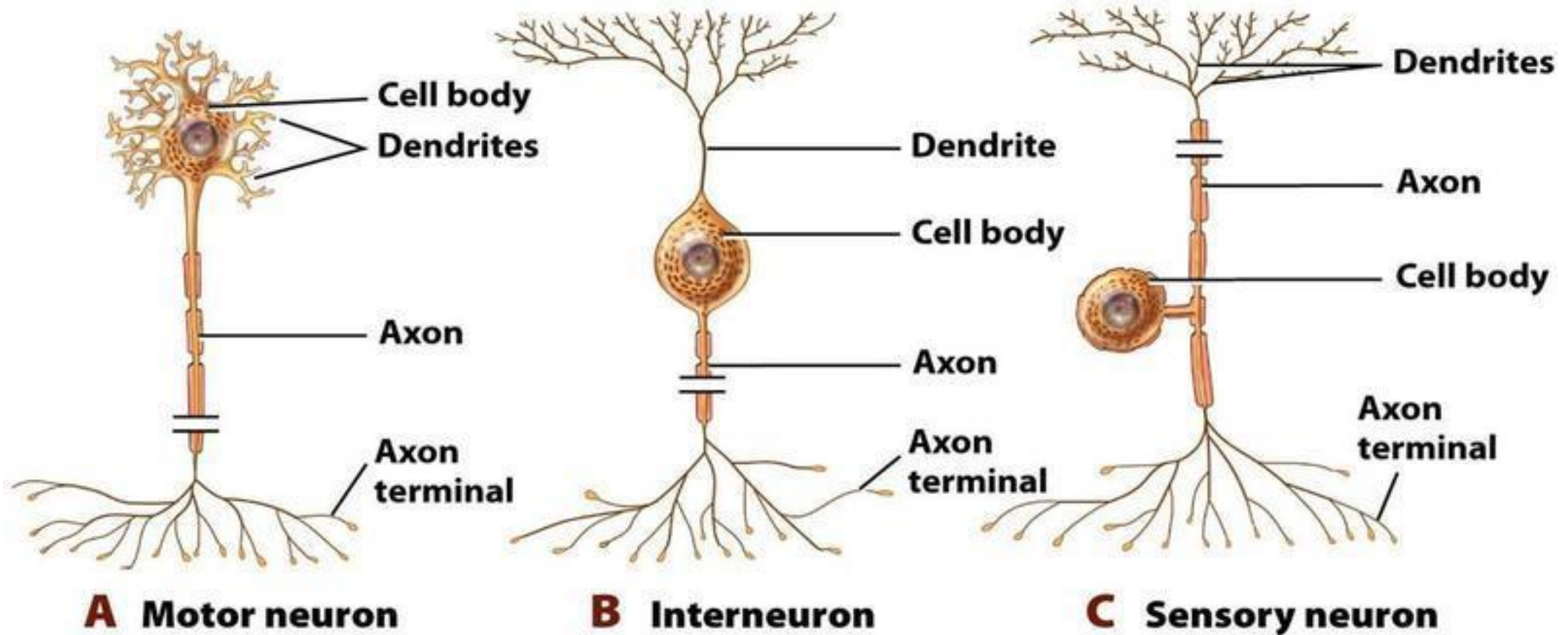


MORPHOLOGICAL CLASSIFICATION



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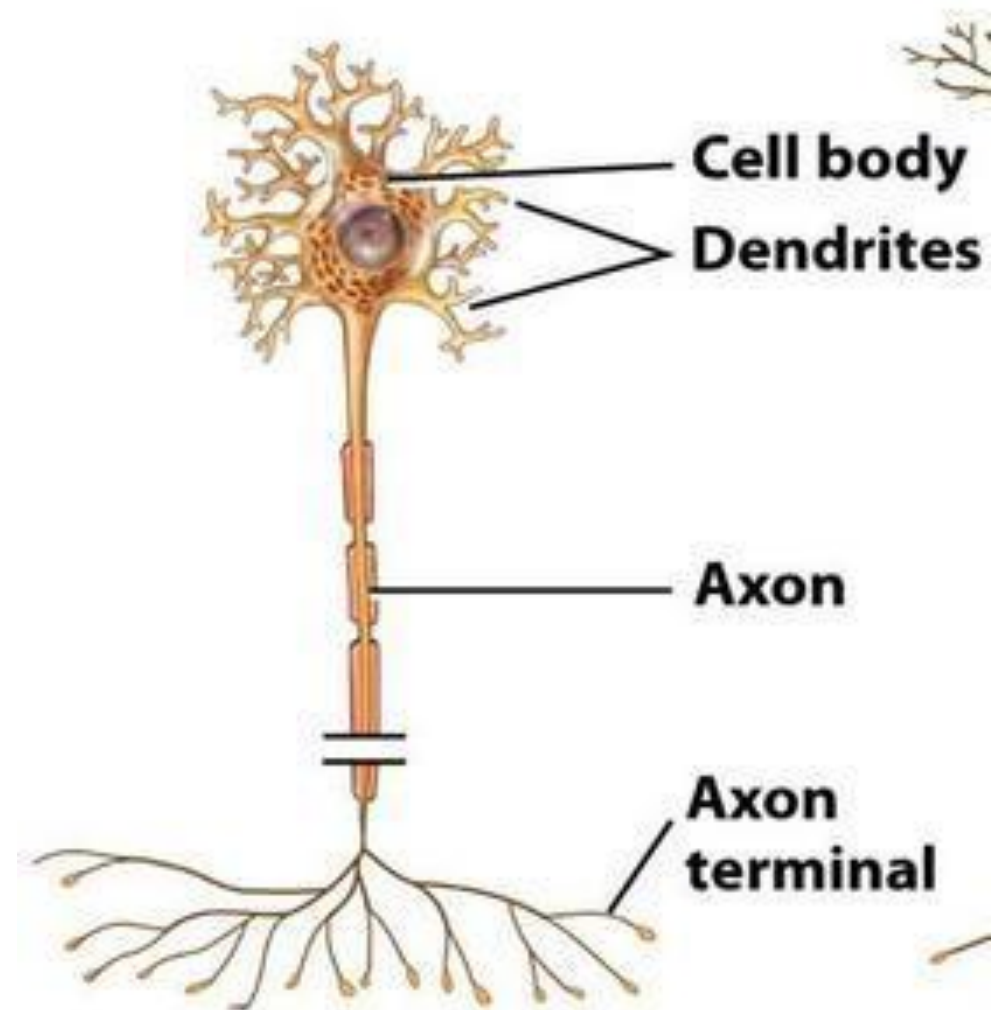
FUNCTIONAL CLASSIFICATION



MOTOR NEURONS

Convey impulses from the **CNS**
to **effector cells**

- Somatic efferent neurons-exit
- Visceral efferent neurons

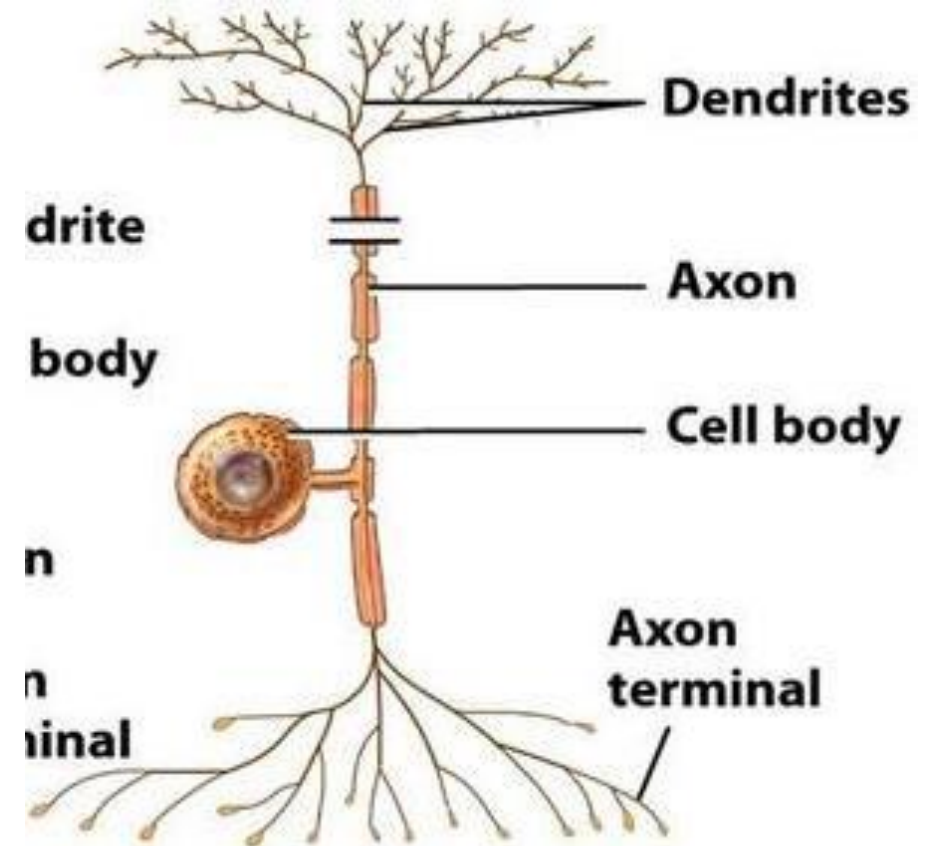


A Motor neuron

SENSORY NEURONS

Convey impulses from
receptors to CNS

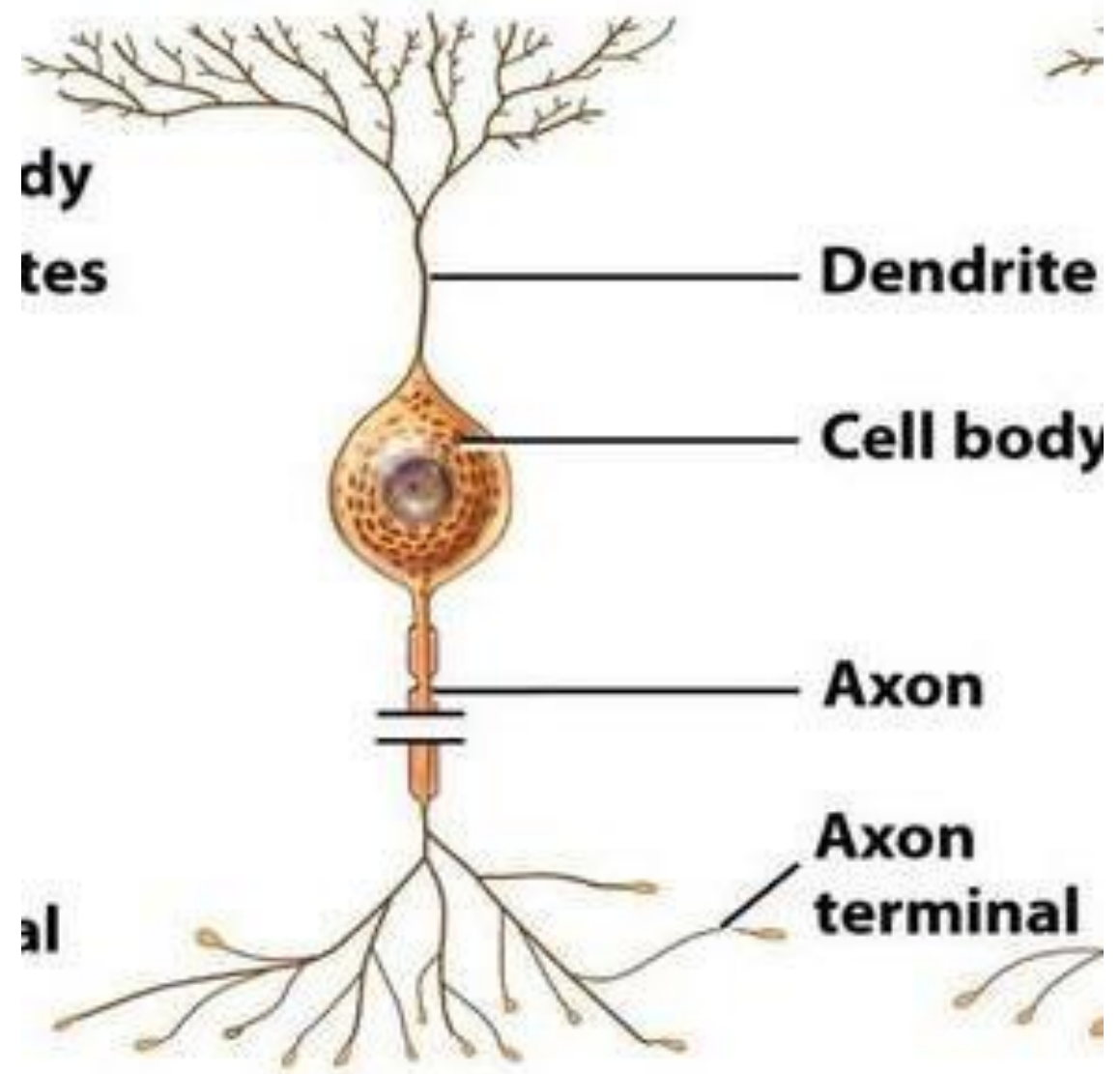
- Somatic afferent fibers-
- Visceral afferent fibers-



C Sensory neuron

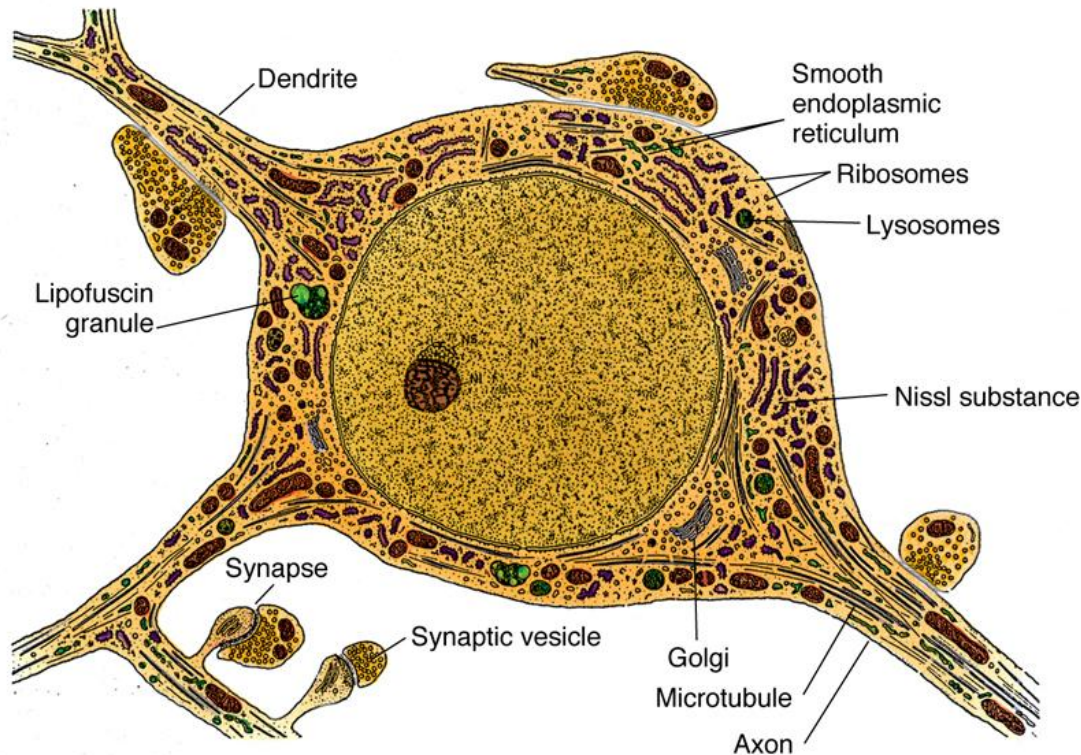
INTERNEURONS (INTERCALATED NEURONS)

Form a communicating and integrating network between the sensory and motor neurons



B Interneuron

Neuronal Cell Body

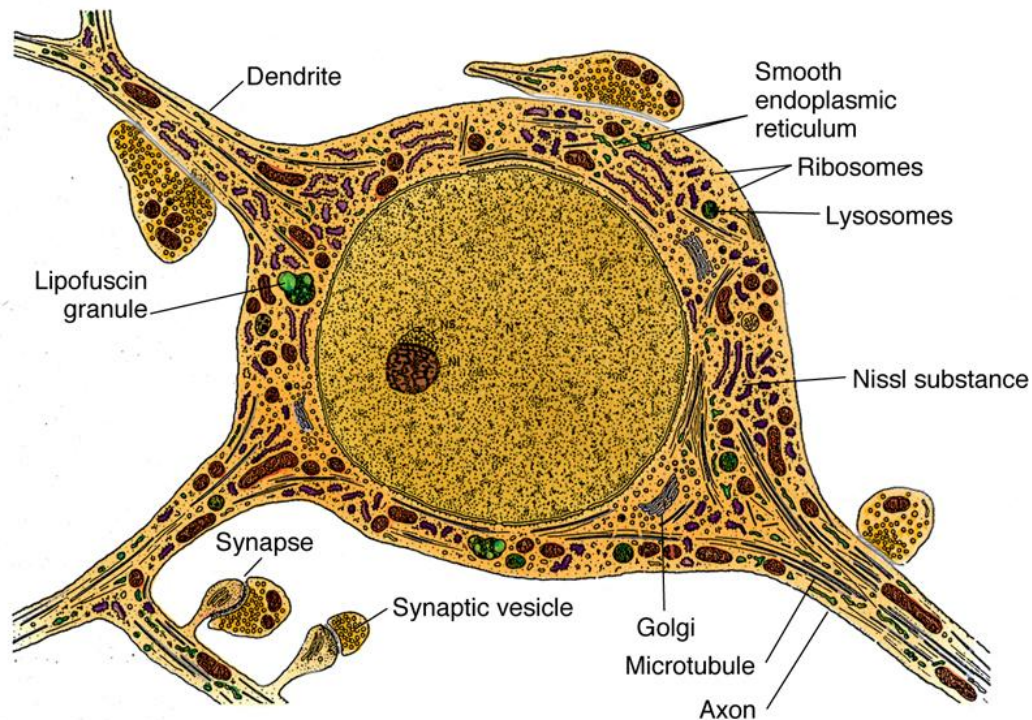


Ultrastructure of a neuronal cell body. (From Lentz TL: *Cell Fine Structure: An Atlas of Drawings of Whole-Cell Structure*. Philadelphia, WB Saunders, 1971.)

The cell body is the most conspicuous region of the neuron, but the largest volume of the neuron's cytoplasm is located in the processes originating from the cell body.

The **nucleus** is large, usually spherical, and centrally located. It contains finely dispersed chromatin, indicative of a rich synthetic activity, although smaller neurons may present some condensed, inactive heterochromatin. A well-defined nucleolus is also common.

Neuronal Cell Body



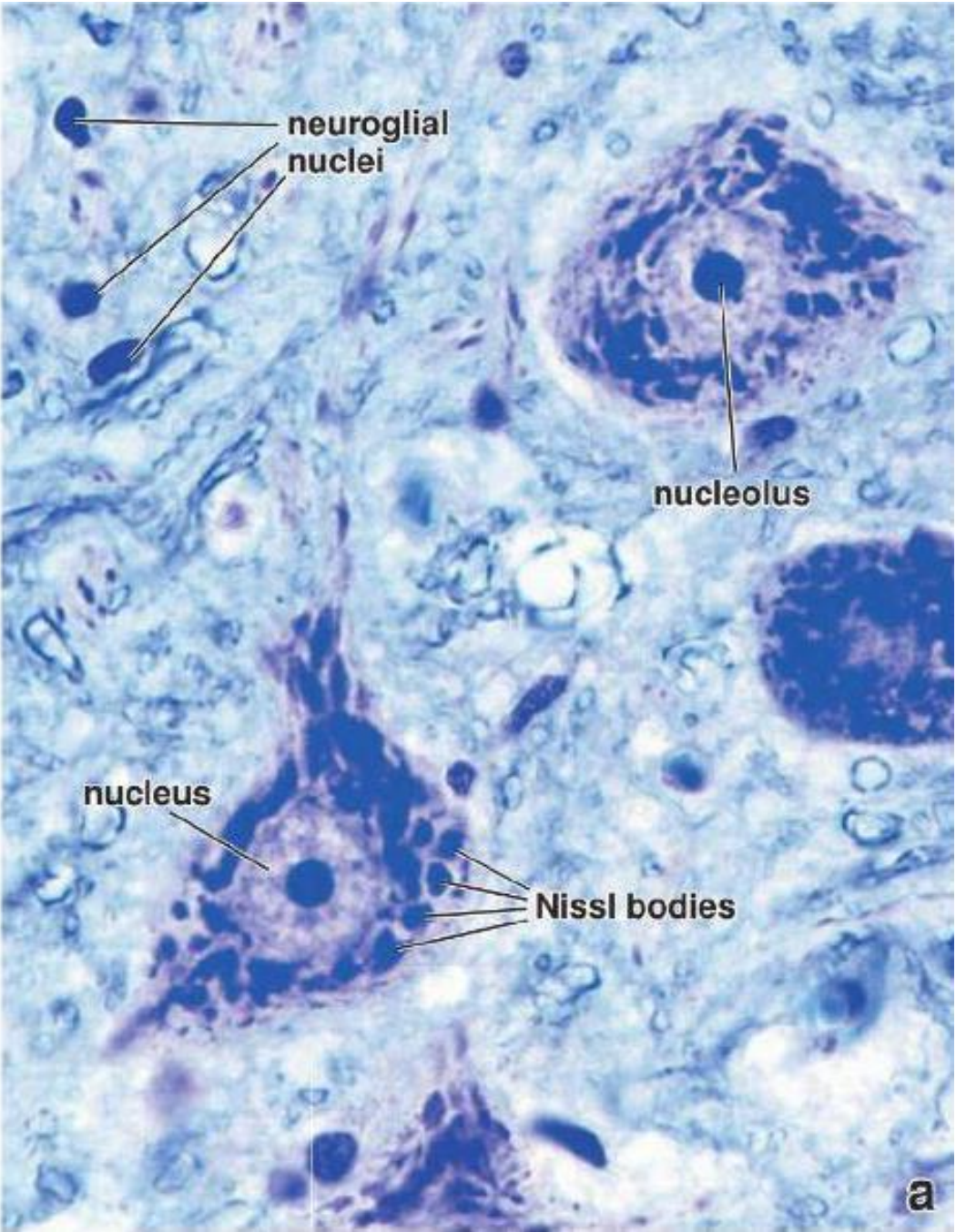
Ultrastructure of a neuronal cell body. (From Lentz TL: *Cell Fine Structure: An Atlas of Drawings of Whole-Cell Structure*. Philadelphia, WB Saunders, 1971.)

The **cytoplasm** of the cell body has abundant rough endoplasmic reticulum (RER) with many cisternae in parallel arrays, a characteristic especially prominent in large motor neurons.

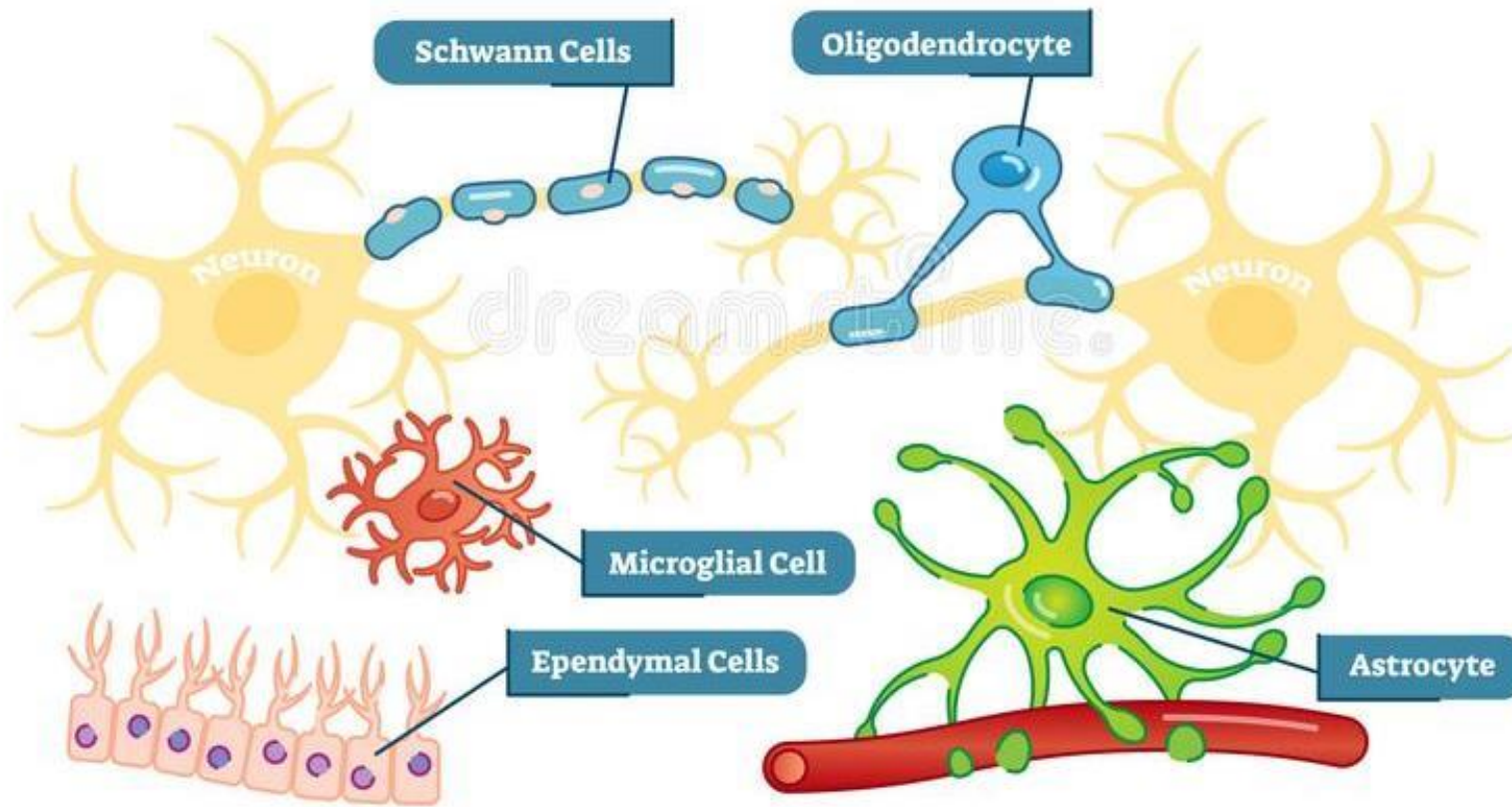
Polyribosomes are also scattered throughout the cytoplasm. When these stacked RER cisternae and polyribosomes are stained with basic dyes, they appear as **clumps of basophilic material** called **Nissl bodies**, which are visible with the light microscope.

RER is also present in the dendritic region of the neuron, but only as scattered short or branching cisternae.

RER is absent at the **axon hillock**, the region on the cell body where the axon arises; however, smooth endoplasmic reticulum (SER) is present in the axon.



Neuro-glia (“Nerve glue” = supporting cells)



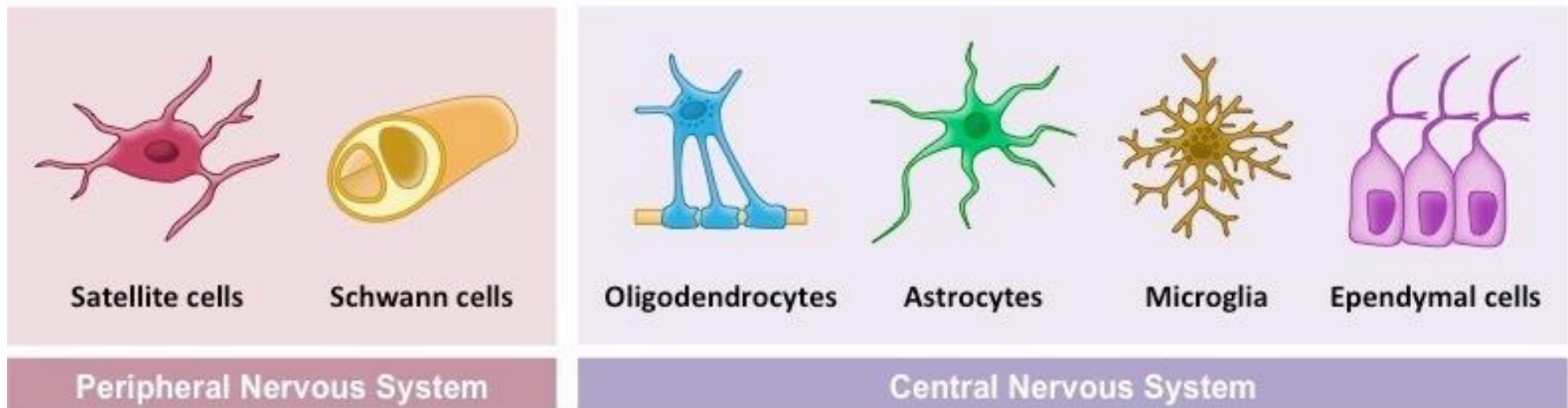
MAIN
FUNCTION:
SUPPORT

10 TIMES MORE
COMMON THAN
NEURONS

Satellite Cells - PNS

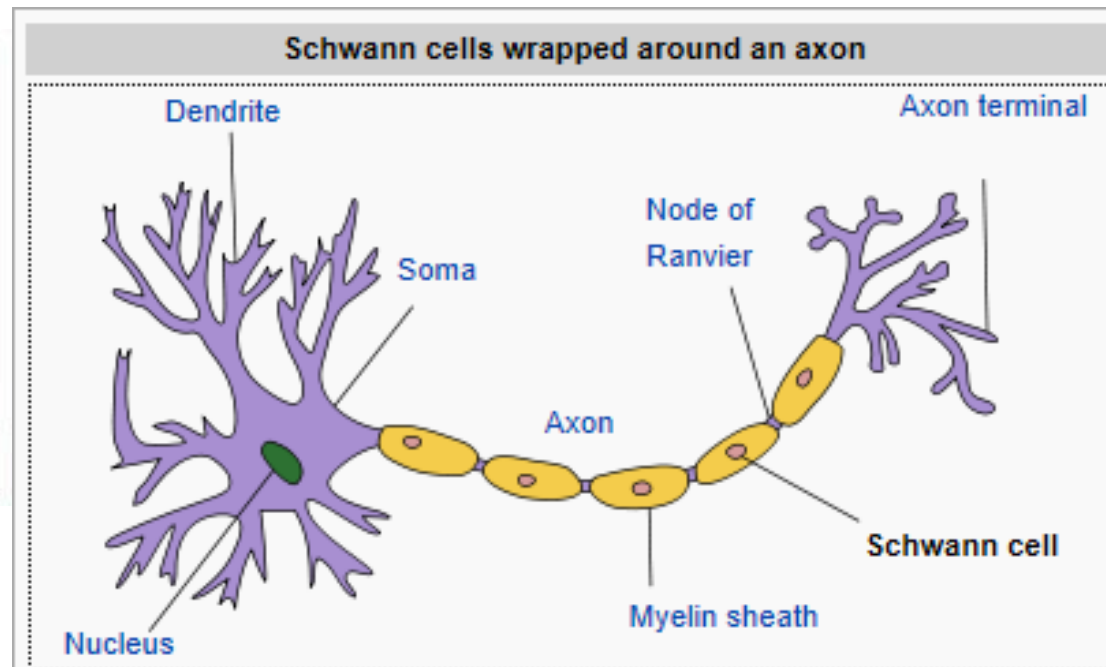
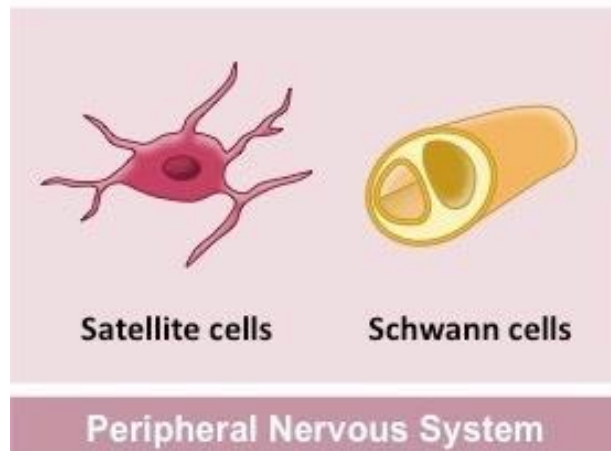
Surround neuron cell bodies in ganglia

- Layer of small, cuboidal cells
- Help to establish and maintain a controlled microenvironment



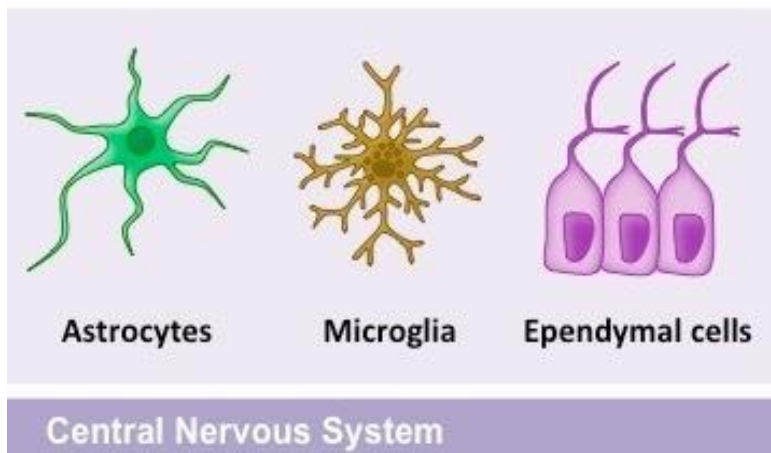
Schwann Cells-PNS

- *Surround fibers of the PNS*
- Neurolemma (or sheath of Schwann) → outer nucleated layer that surrounds the axon
- In the PNS, they produce the myelin sheath and guide the regrowth of PNS axons



Astrocytes

- support and brace neurons
- anchor neurons to their nutrients supply → BLOOD VESSELS - guide migration of young neurons
- regulate K^+ concentrations (POTASSIUM SPATIAL BUFFERING)



2 kinds of astrocytes

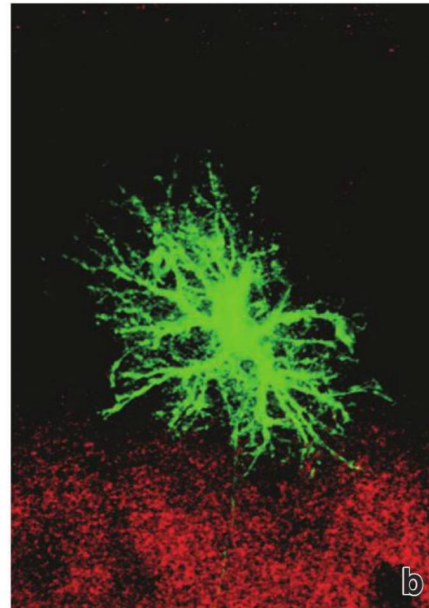
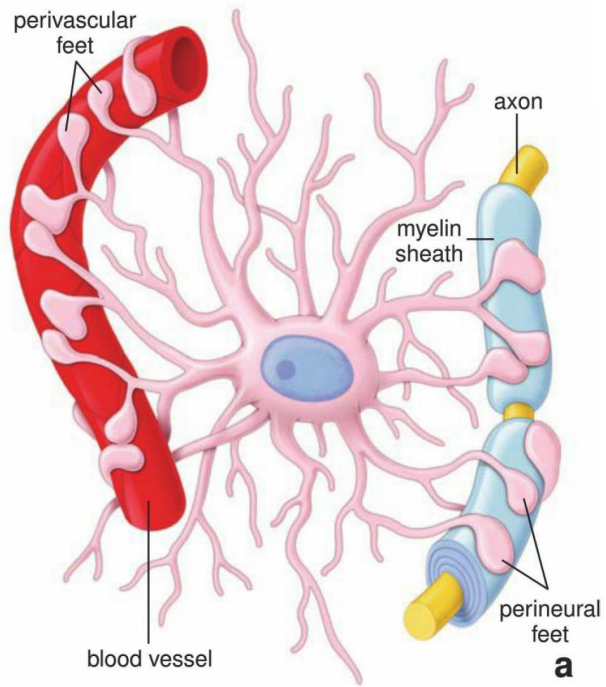
FIBROUS

(gray matter)

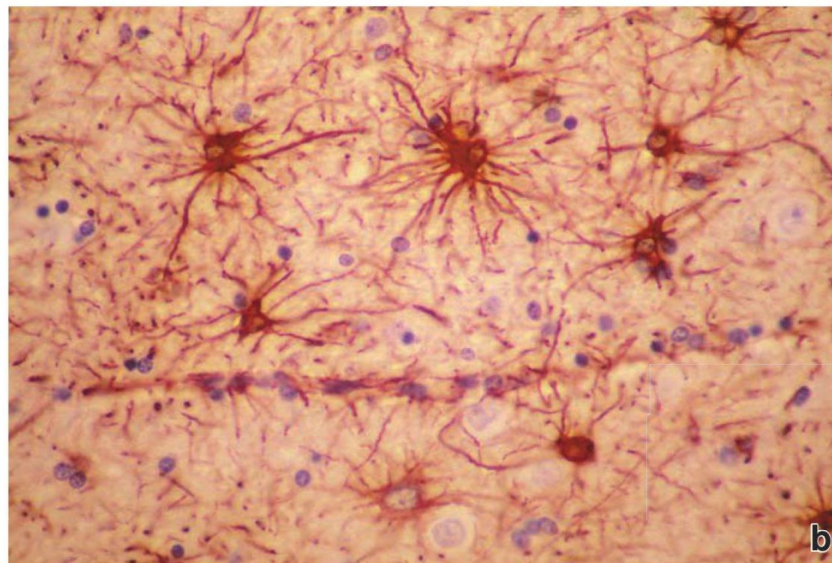
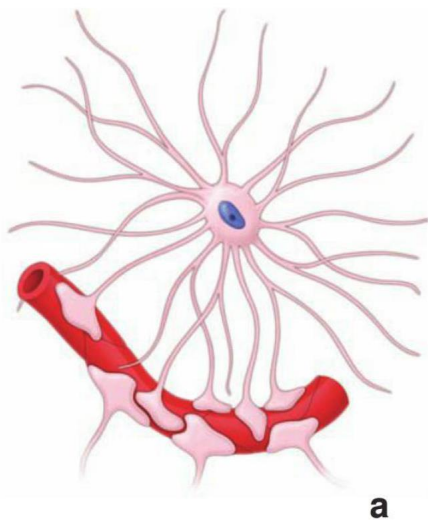
PROTOPLASMIC

(white matter)

Astrocytes



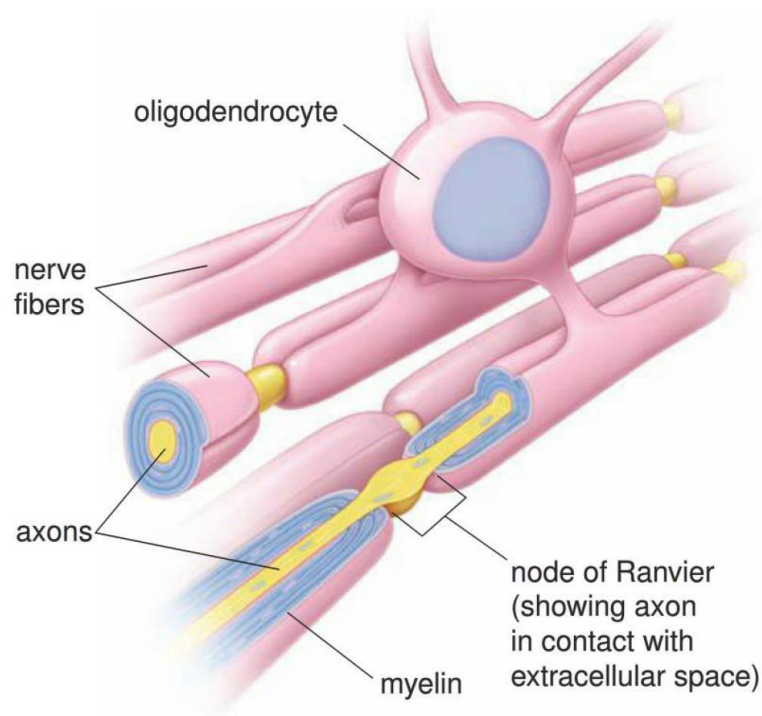
Protoplasmic astrocyte in the gray matter of the brain



Fibrous astrocytes in the white matter of the brain

Oligodendrocytes

- *Branched cells that wrap CNS nerve fibers*
- In the CNS, they produce the myelin sheath

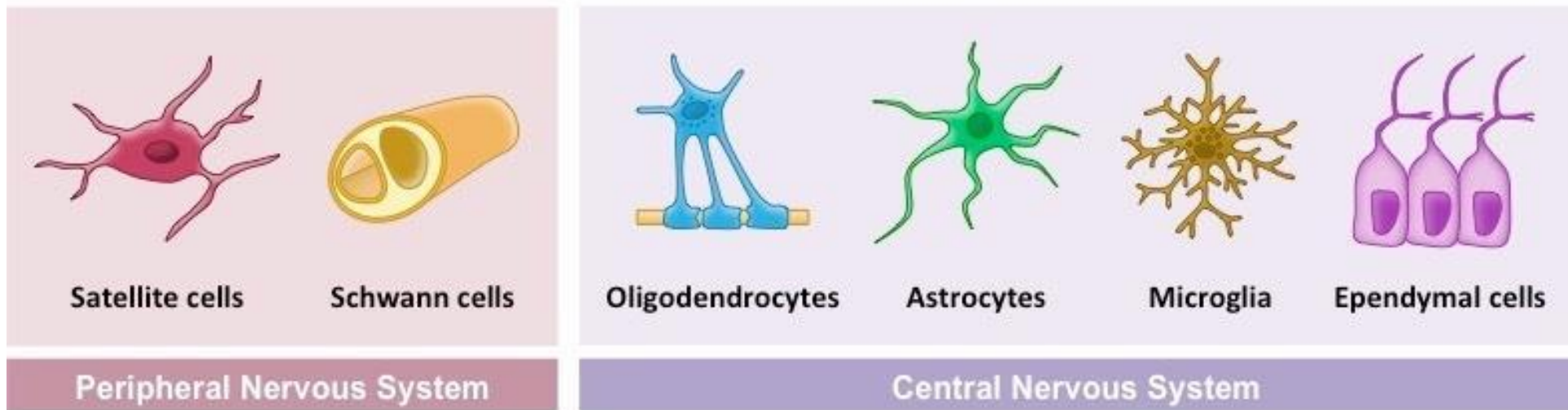


MYELIN SHEATH in CNS

- A single oligodendrocyte typically helps myelinate **multiple axons** in the CNS,
- whereas each Schwann cell helps myelinate only a single axon in the PNS

Microglia

Phagocytotic cells;
Intervene in sites of injury and disease.

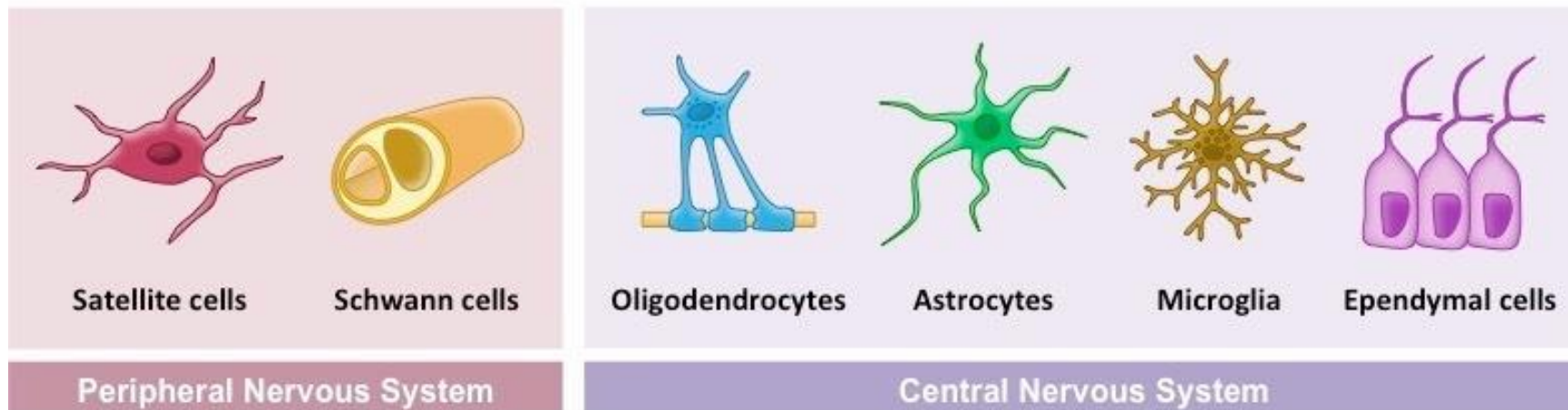


Microglia maintain their population by self-renewal.
Note that microglia are developmentally and functionally unrelated to monocytes,
the precursor of tissue macrophages.

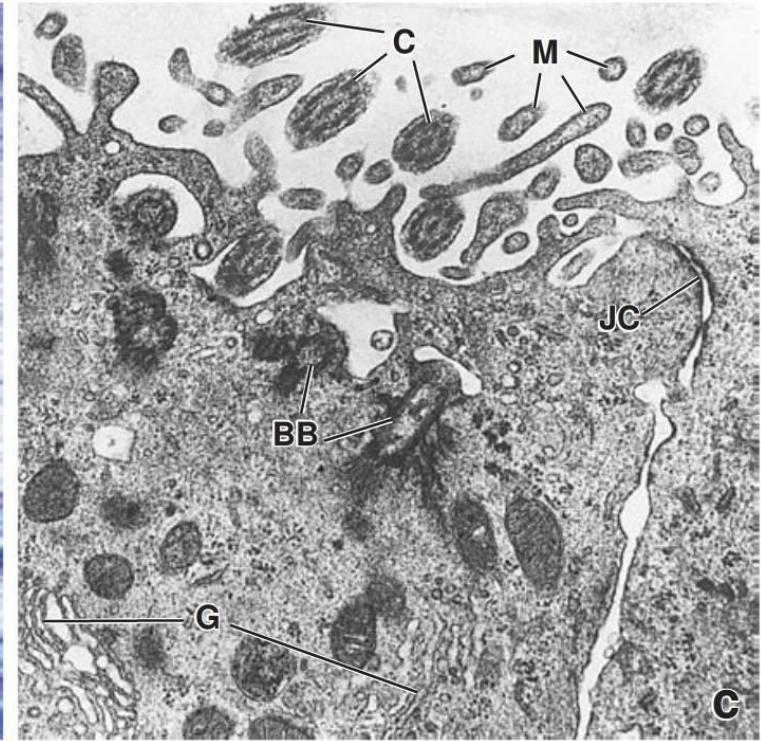
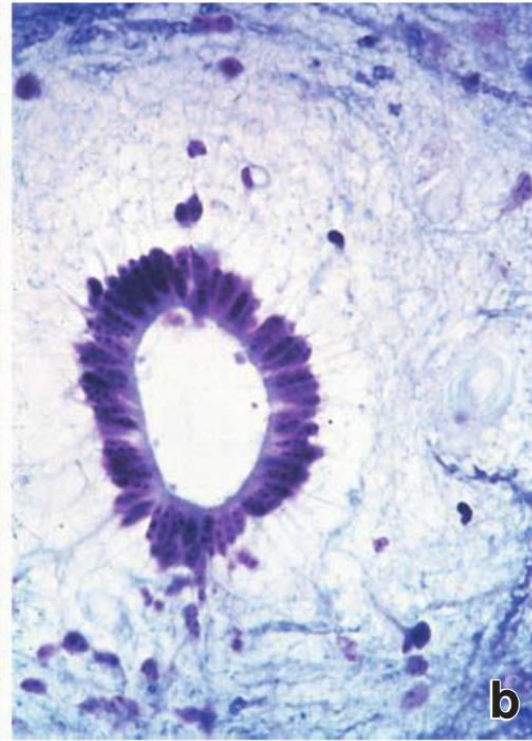
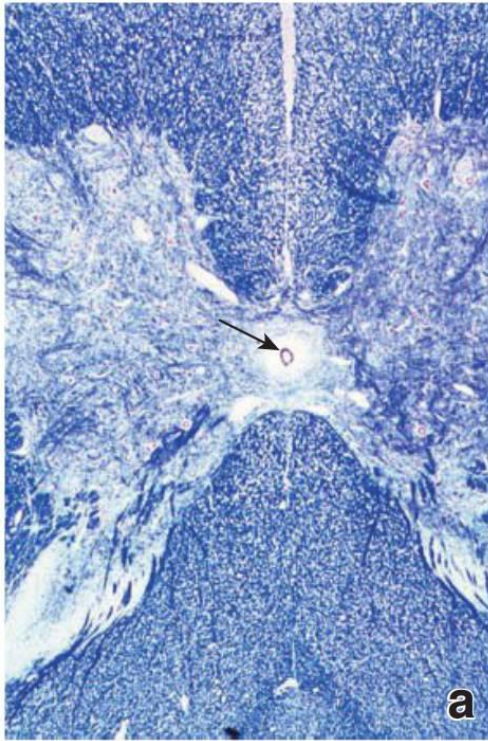
Ependymal cells

Epithelial-like lining of ventricles in the brain and the central canal of the spinal cord;

Single layer of cuboidal-to-columnar cells.

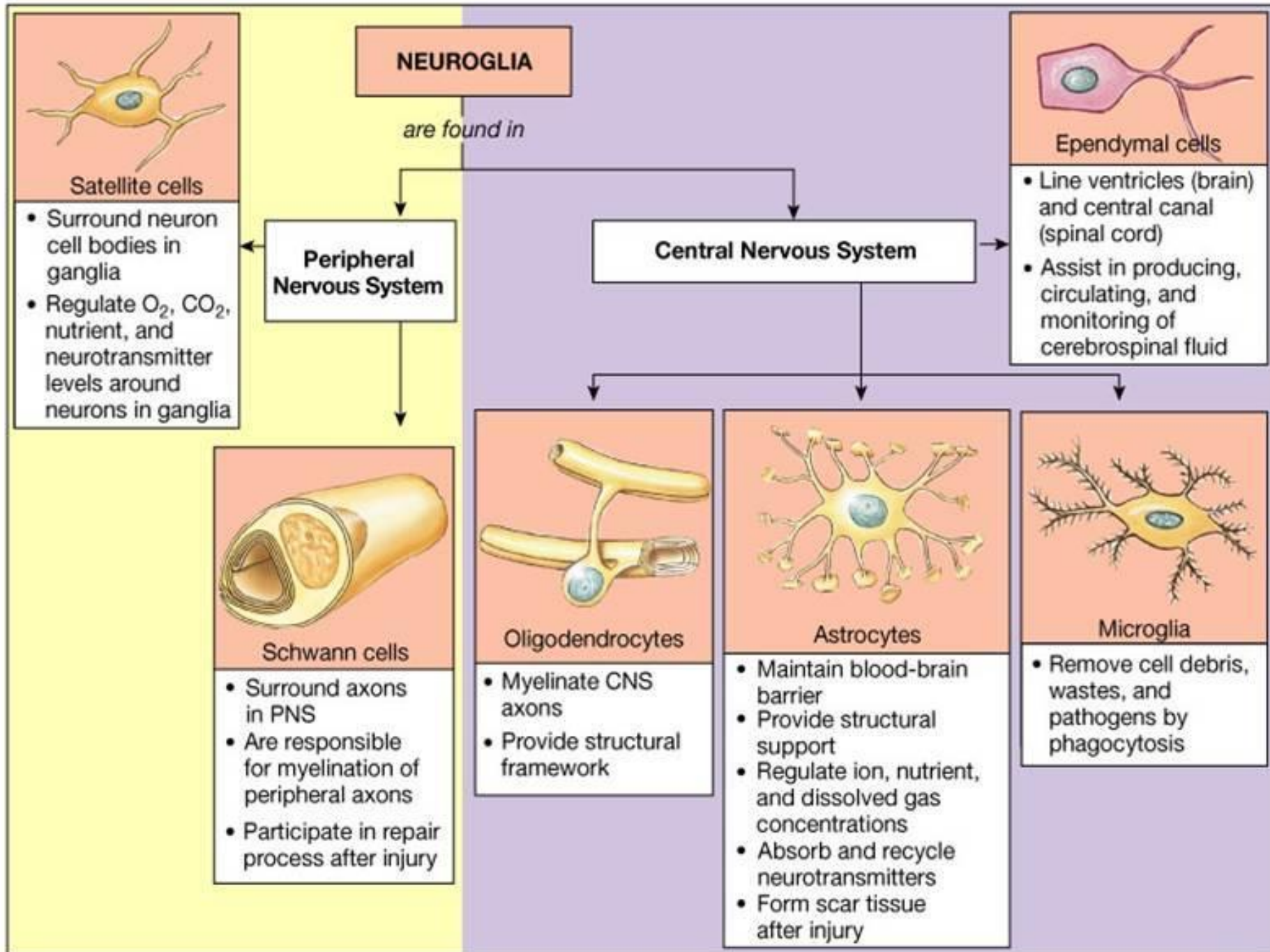


Ependymal cells



Motile cilia

Neuroglia



Shared Function

MYELINATION OF AXONS

Schwann cells (in PNS)

Oligodendrocytes (in CNS)

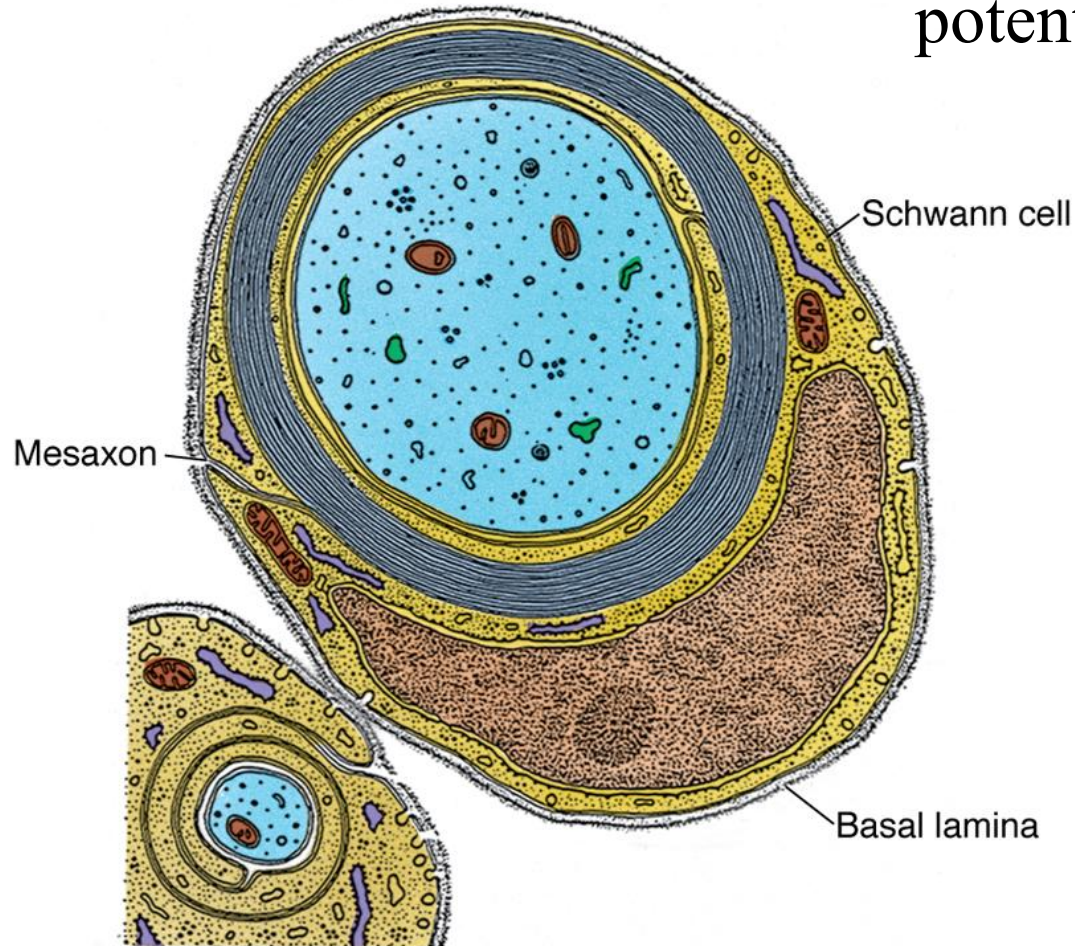
REGULATION OF ION, NUTRIENT, AND DISSOLVED GAS CONCENTRATIONS

Satellite cells (in PNS)

Astrocytes (in CNS)

Myelin Sheath

Myelin prevents the leakage of the action potential



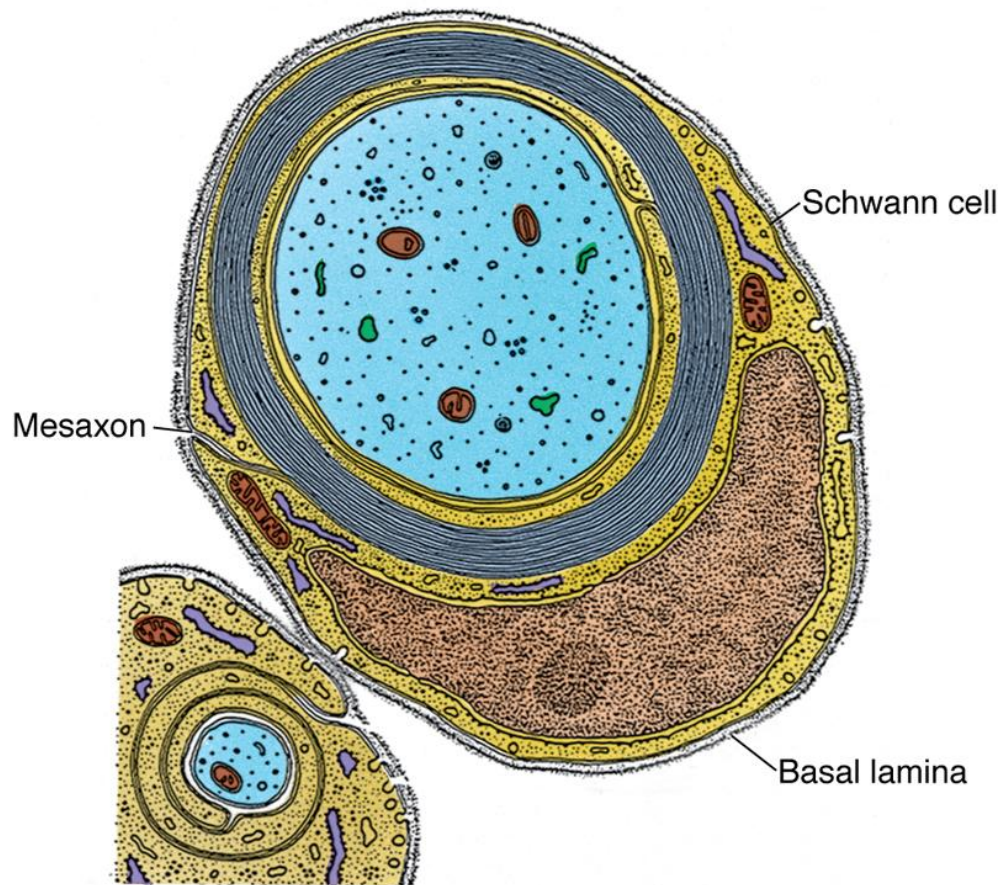
The fine structure of a myelinated nerve fiber and its Schwann cell. (From Lentz TL: *Cell Fine Structure: An Atlas of Drawings of Whole-Cell Structure*. Philadelphia, WB Saunders, 1971.)

Schwann cells are located in the PNS, where they envelop axons. They can form two types of coverings over these axons, myelinated and nonmyelinated.

Axons that have myelin wrapped around them are referred to as myelinated nerves.

Electron microscopy has revealed that myelin is the plasmalemma of the Schwann cell organized into a sheath that is wrapped several times around the axon.

Myelin Sheath



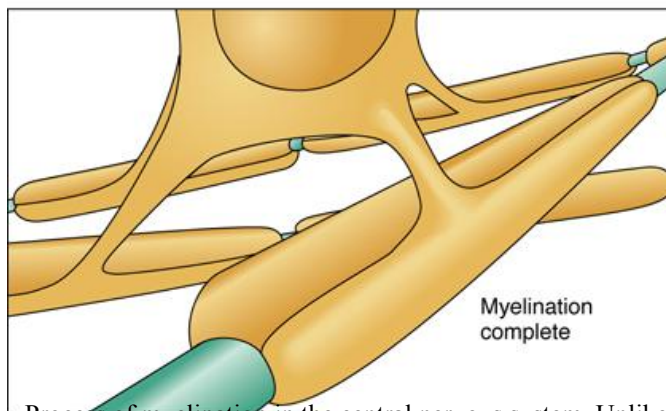
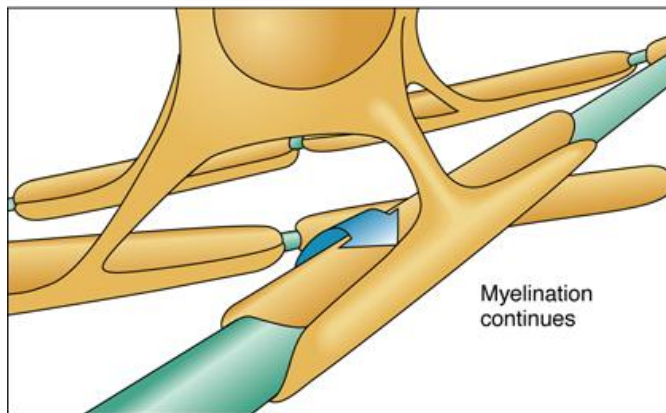
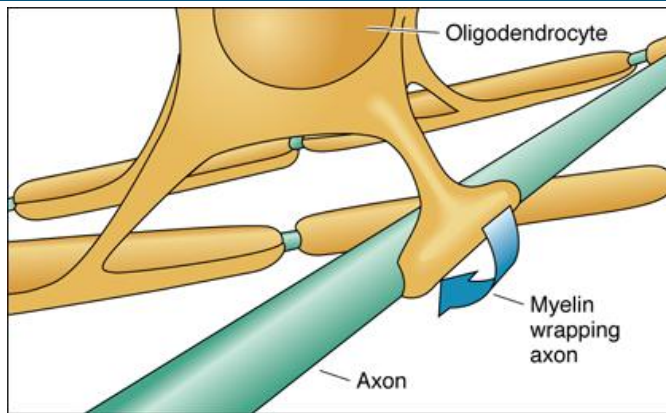
As the membrane spirals around the axon, it produces a series of alternating wide, dense lines with narrower, less dense lines occurring at **12-nm** intervals.

The wider line is known as the **major dense line**. It represents the fused cytoplasmic surfaces of the Schwann cell plasma membrane. The narrower **intraproduct line** represents the apposing outer leaflets of the Schwann cell plasma membrane.

Saltatory conduction-
Node of Ranvier

The fine structure of a myelinated nerve fiber and its Schwann cell. (From Lentz TL: *Cell Fine Structure: An Atlas of Drawings of Whole-Cell Structure*. Philadelphia, WB Saunders, 1971.)

Myelin Formation



The mechanism of **myelination**, that is, the process whereby the oligodendrocyte (or Schwann cell in the peripheral nervous system) concentrically wraps its membrane around the axon to form the myelin sheath, is unclear.

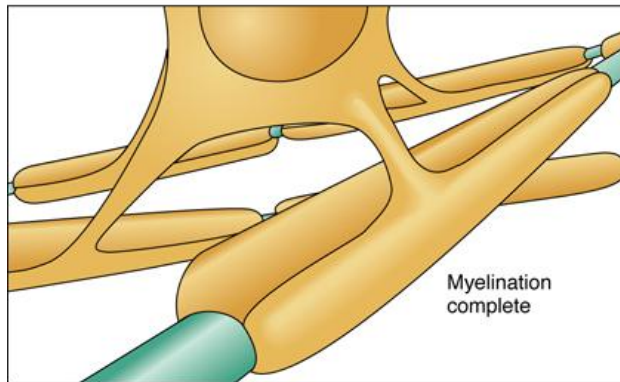
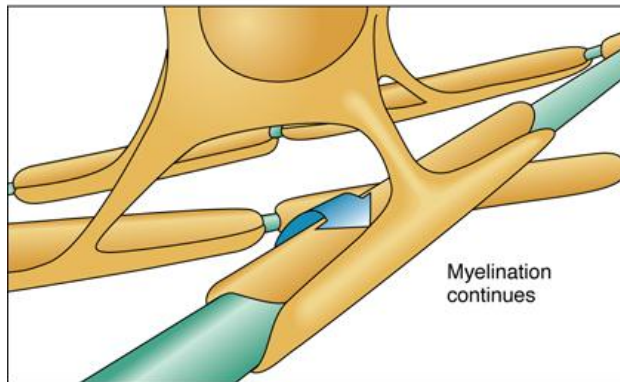
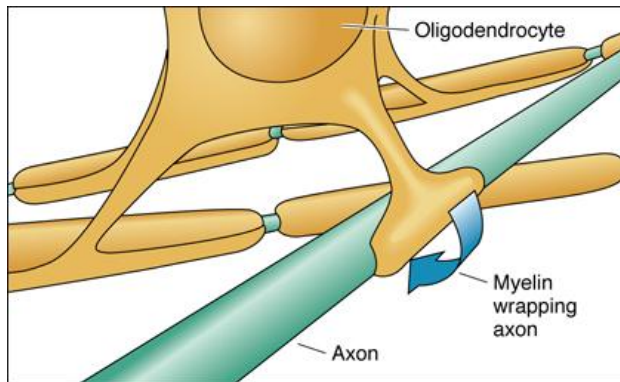
It is believed to begin when an oligodendrocyte envelops an axon and somehow wraps its membrane around the axon.

The wrapping may continue for more than 50 turns. During this process, the cytoplasm is squeezed back into the body of the oligodendrocyte, bringing the cytoplasmic surfaces of the membranes in contact with each other, thus forming the major dense line that spirals through the myelin sheath.

Process of myelination in the central nervous system. Unlike the Schwann cell of the peripheral nervous system, each oligodendroglion is capable of myelinating several axons.

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Myelin Formation



Process of myelination in the central nervous system. Unlike the Schwann cell of the peripheral nervous system, each oligodendroglion is capable of myelinating several axons.

A single Schwann cell can myelinate only one internode of a single axon (and only in the PNS), whereas oligodendrocytes can myelinate an internode of several axons (and only in the CNS).

Nerves are not myelinated simultaneously during development.

This variation seems to be correlated with function. For example, motor nerves are nearly completely myelinated at birth, whereas sensory roots are not myelinated for several months thereafter.

Some CNS nerve tracts and commissural axons are not fully myelinated until several years after birth.

Some axons in the PNS are not wrapped with the many layers of myelin typical of myelinated axons. These unmyelinated axons are surrounded by a single layer of Schwann cell plasma membrane and cytoplasm of the Schwann cell. Although a single Schwann cell can myelinate only one axon, several unmyelinated axons may be enveloped by a single Schwann cell.

Unmyelinated nerve fibers

Unmyelinated axons predominate in the gray matter. Axons are thin and they are not individually ensheathed by myelin.

In the PNS, some axons are unmyelinated. A Schwann cell can accommodate several axons in individual cytoplasmic invaginations or pockets and no myelin is produced.

In myelinated nerves, impulse conduction is confined to the nodes of Ranvier, **jumping** (saltatory) from node to node at a maximum speed of 120 m/s. The impulse conduction in unmyelinated nerves is **continuous**, with a **reduced** maximum speed of 15 m/s).

Unmyelinated nerve fibers

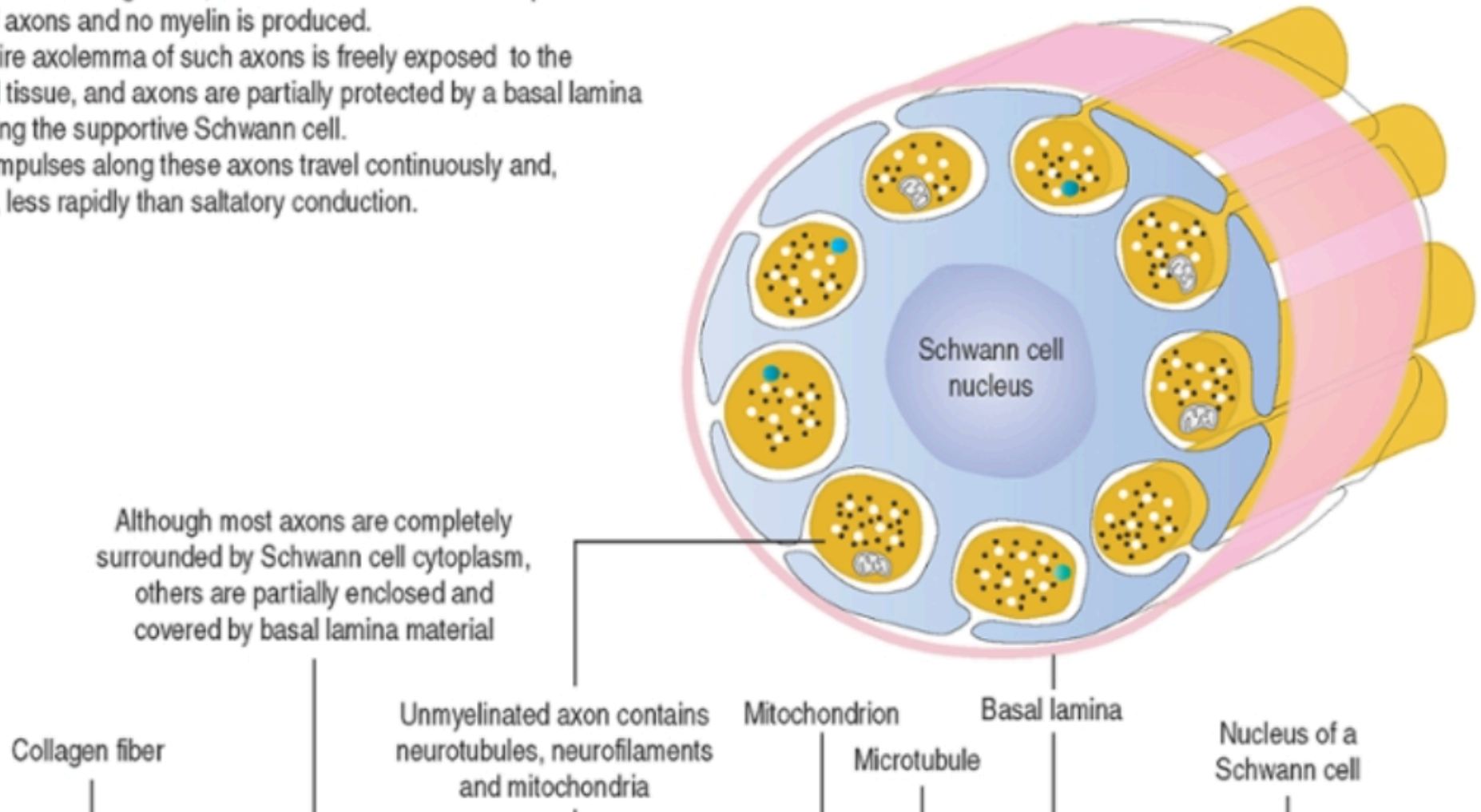
Unmyelinated nerve fibers

Some axons are unmyelinated. **Each Schwann cell is able to house a number of axons occupying individual invaginations of its cytoplasm.**

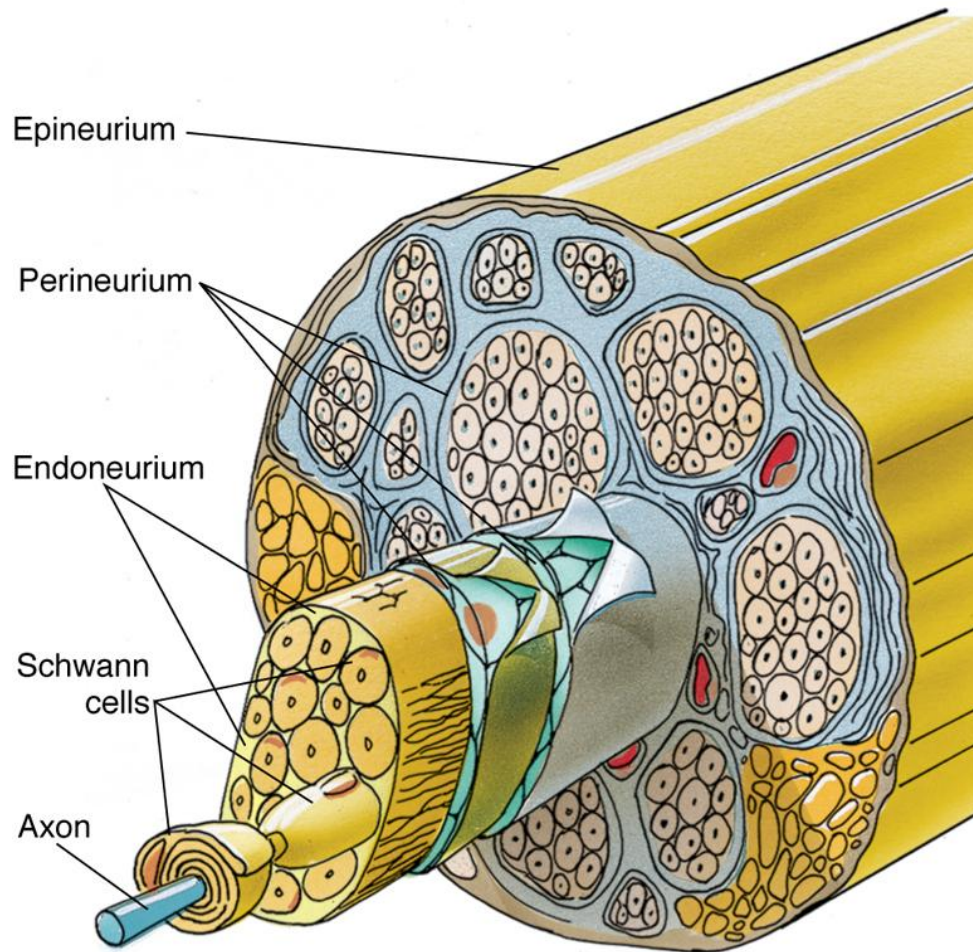
With such an arrangement, the Schwann cell cannot wrap around individual axons and no myelin is produced.

The entire axolemma of such axons is freely exposed to the interstitial tissue, and axons are partially protected by a basal lamina surrounding the supportive Schwann cell.

Nerve impulses along these axons travel continuously and, therefore, less rapidly than saltatory conduction.



Peripheral Nerves



Structure of a nerve bundle.

Peripheral nerves are bundles of nerve fibers (axons) surrounded by several investments of connective tissue sheaths.

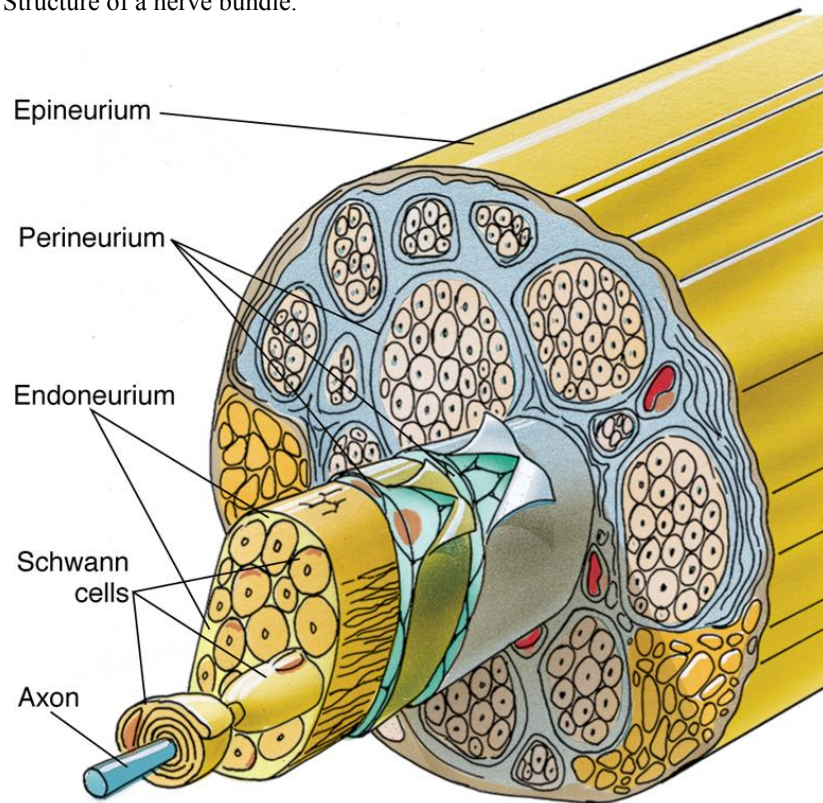
These bundles (**fascicles**) may be myelinated and appear white because of the presence of myelin.

Usually, each bundle of nerve fibers, regardless of size, has both sensory and motor components.

Connective tissue investments of peripheral nerves include the epineurium, perineurium, and endoneurium.

Peripheral Nerves

Structure of a nerve bundle.



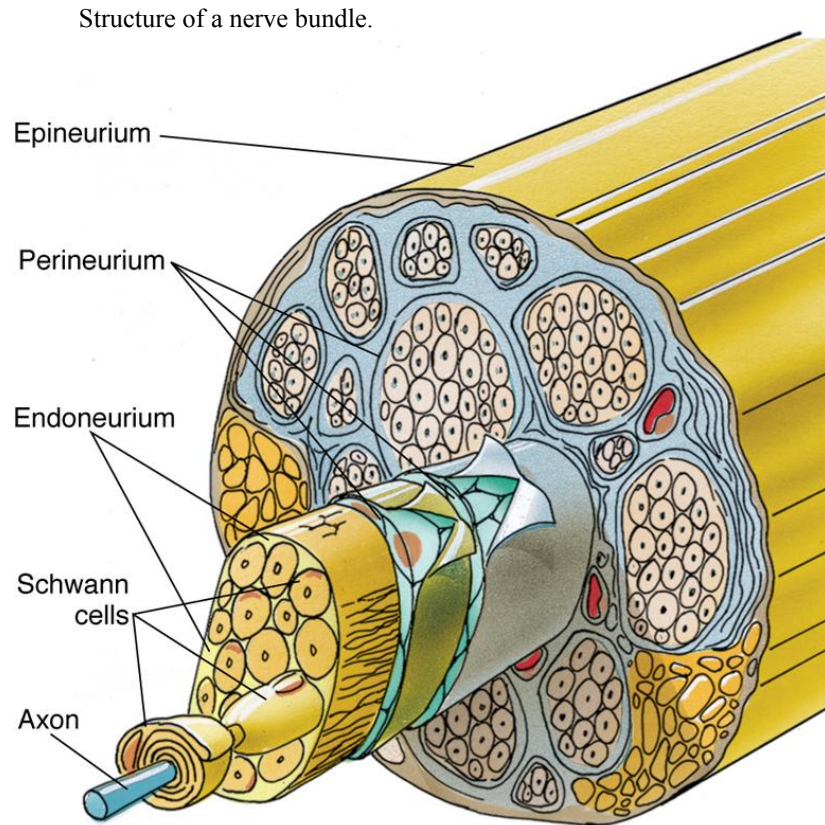
The **epineurium** is composed of dense, irregular, collagenous connective tissue.

Perineurium, the middle layer of connective tissue investments, covers each fascicle within the nerve. The perineurium is composed of dense connective tissue but is thinner than epineurium. Its inner surface is lined by several layers of epithelioid cells joined by zonulae occludentes and surrounded by a basal lamina.

Endoneurium, the innermost layer of the three connective tissue investments of a nerve, surrounds individual nerve fibers (axons).

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Peripheral Nerves



The **epineurium** is formed by type I collagen and fibroblasts and covers the entire nerve. It contains arteries, veins and lymphatic vessels.

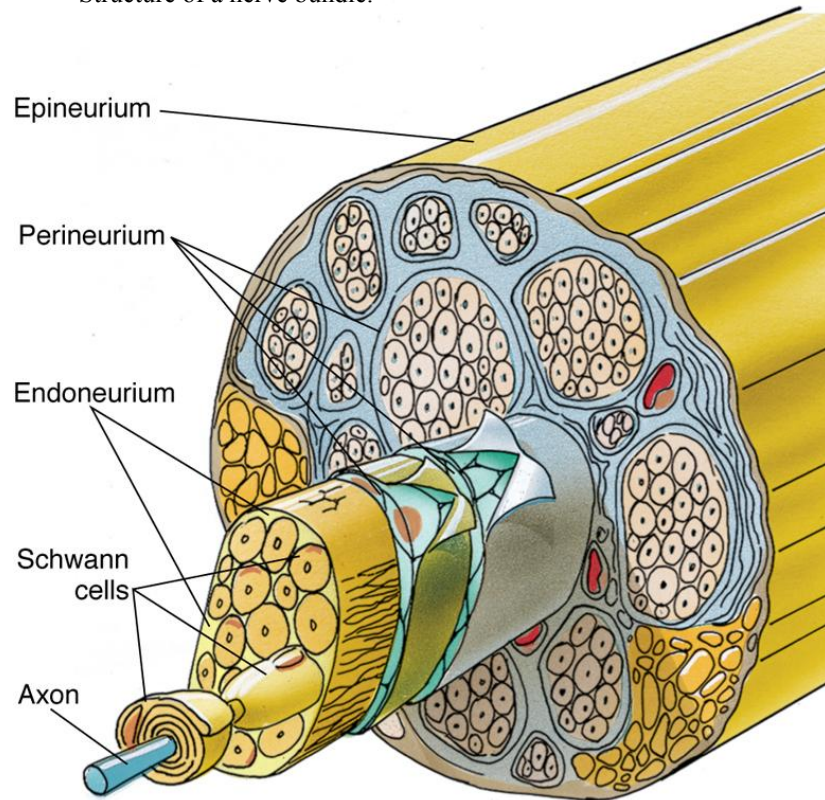
Within the nerve, the **perineurium** segregates axons into **fascicles**. The perineurium consists of several concentric layers of neuroepithelial perineurial cells:

A **basal lamina**, consisting of type IV collagen and laminin, surrounds the layers of perineurial cells.

Perineurial cells are joined to each other by tight junctions to form a protective diffusion barrier: the **blood-nerve barrier**. The barrier is responsible for maintaining the homeostasis microenvironment of the endoneurium.

Peripheral Nerves

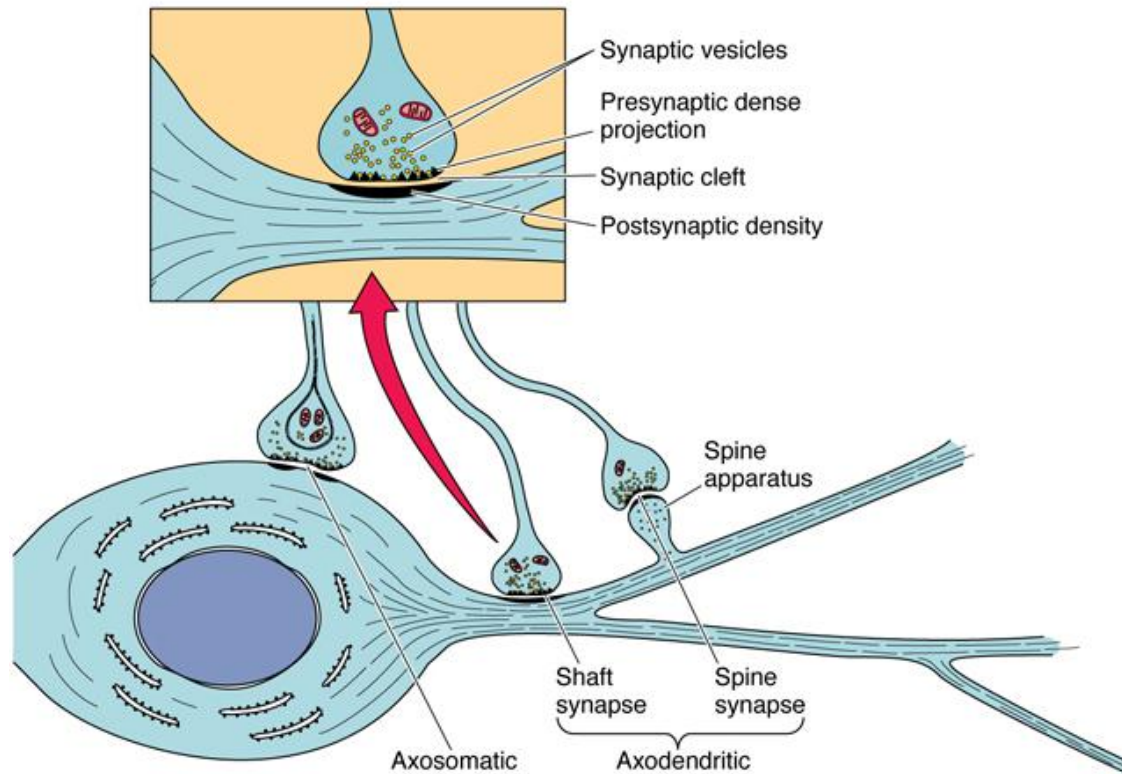
Structure of a nerve bundle.



- The **endoneurium** surrounds individual axons and their associated Schwann cells and myelin sheaths.
- It consists of type III collagen fibrils, a few fibroblasts, macrophages, mast cells and **endoneurial capillaries** between individual axons (nerve fibers).

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Synapses



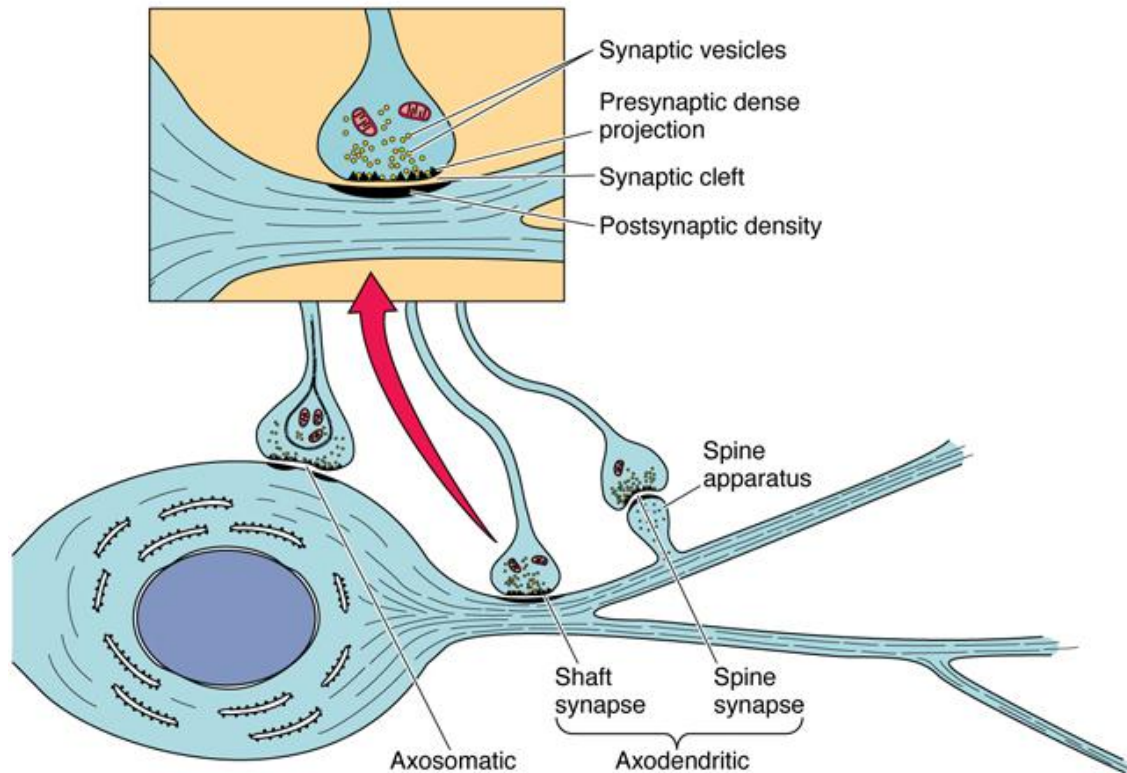
Schematic diagram of the various types of synapses.

Synapses are the sites where nerve impulses are transmitted from a presynaptic cell to a postsynaptic cell. Impulse transmission at synapses can occur electrically or chemically.

Chemical synapses are the most common mode of communication between two nerve cells.

The presynaptic membrane releases one or more neurotransmitters into the synaptic cleft, located between the presynaptic membrane of the first cell and the postsynaptic membrane of the second cell.

Synapses



Schematic diagram of the various types of synapses.

The neurotransmitter diffuses across the synaptic cleft to gated ion-channel receptors on the postsynaptic membrane. Binding of the neurotransmitter to these receptors initiates the opening of ion channels, altering the permeability of the postsynaptic membrane and reversing its membrane potential. Neurotransmitters do not accomplish the reaction events at the postsynaptic membrane; they only activate the response.

Various types of synaptic contacts between neurons have been observed.

The following are the most common:
axodendritic,
axosomatic,
axoaxonic,
and dendrodendritic.

Synapse

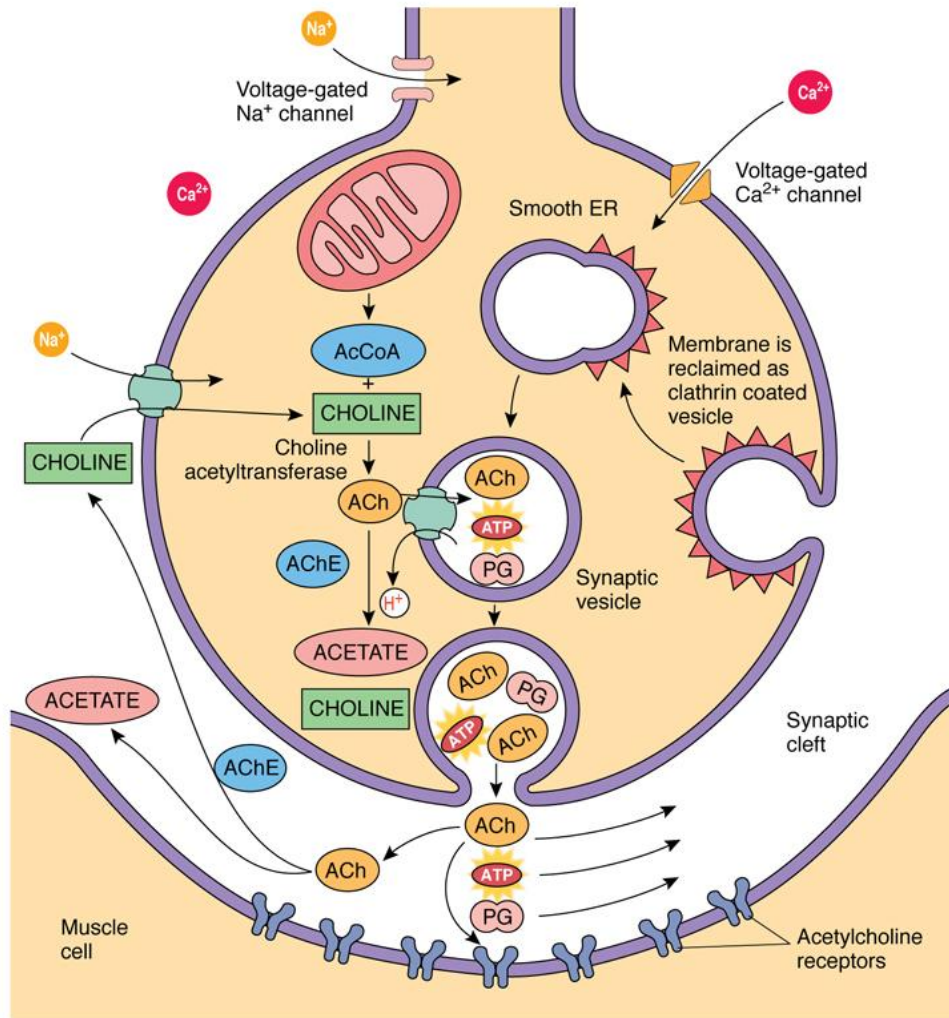


Diagram depicting events occurring at the neuromuscular junction during the release of acetylcholine. AcCoA, acetyl CoA; Ach, acetylcholine; AchE, acetylcholinesterase; ATP, adenosine triphosphate; PG, proteoglycan. (Modified from Katzung BG: *Basic and Clinical Pharmacology*, 4th ed. East Norwalk, Conn, Appleton & Lange, 1989.)

Terminals of axons vary according to the type of synaptic contact. Often the axon forms a bulbous expansion at its terminal end called bouton terminal.

The cytoplasm at the presynaptic membrane contains mitochondria, a few elements of smooth endoplasmic reticulum, and an abundance of synaptic vesicles assembled around the presynaptic membrane.

Synaptic vesicles are spherical structures (40 to 60 nm in diameter) filled with neurotransmitter substance that usually was manufactured and packaged near the axon terminal.

Peptide neurotransmitters, however, are manufactured and packaged in the cell body and are transported to the axon terminal via anterograde transport.

Enzymes located in the axoplasm protect neurotransmitters from degradation.

Synapse

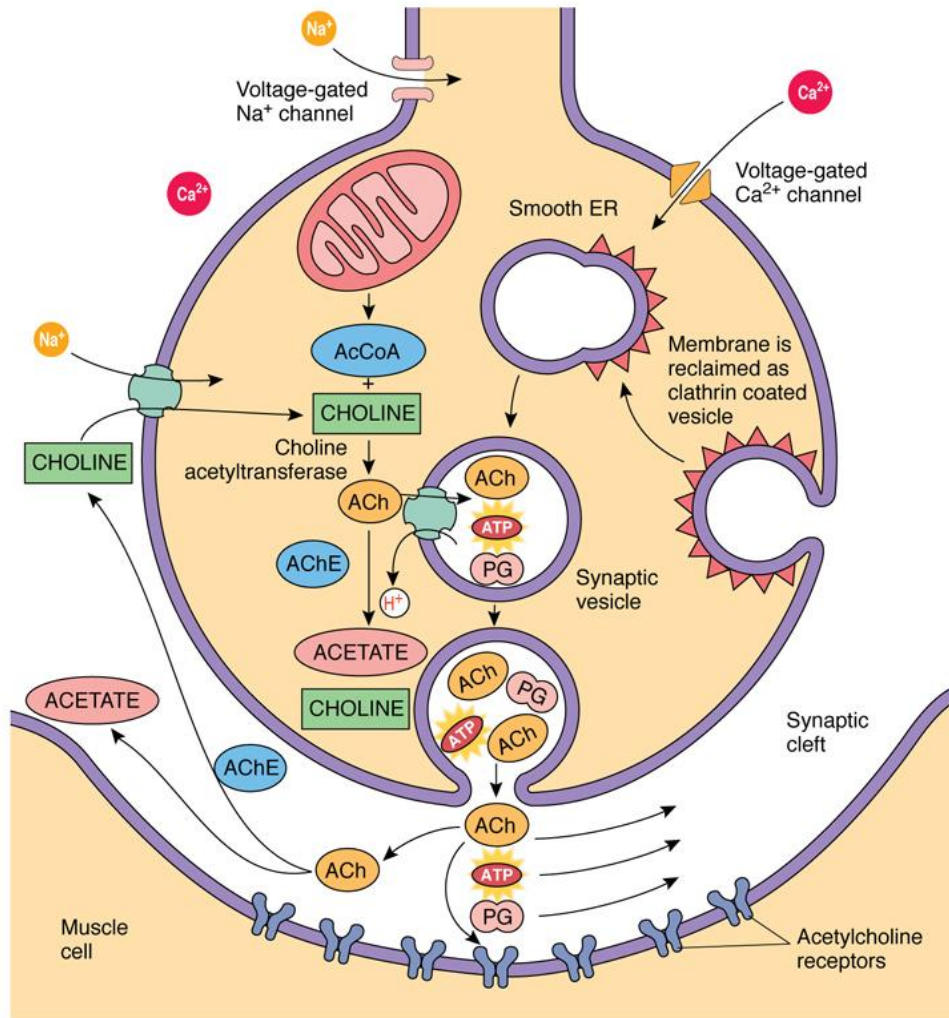


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Also located on the cytoplasmic side of the presynaptic membrane are cone-shaped densities that project from the membrane into the cytoplasm; they appear to be associated with many of the synaptic vesicles, forming the active site of the synapse. Those synaptic vesicles associated with the active site are released at stimulation.

Cell adhesion molecules (CAMs) are known to play an additional role in this location as signaling molecules at both the presynaptic and postsynaptic aspects of the synapse. Other synaptic vesicles, forming a reserve pool, adhere to actin microfilaments.

Synapse (cont.)

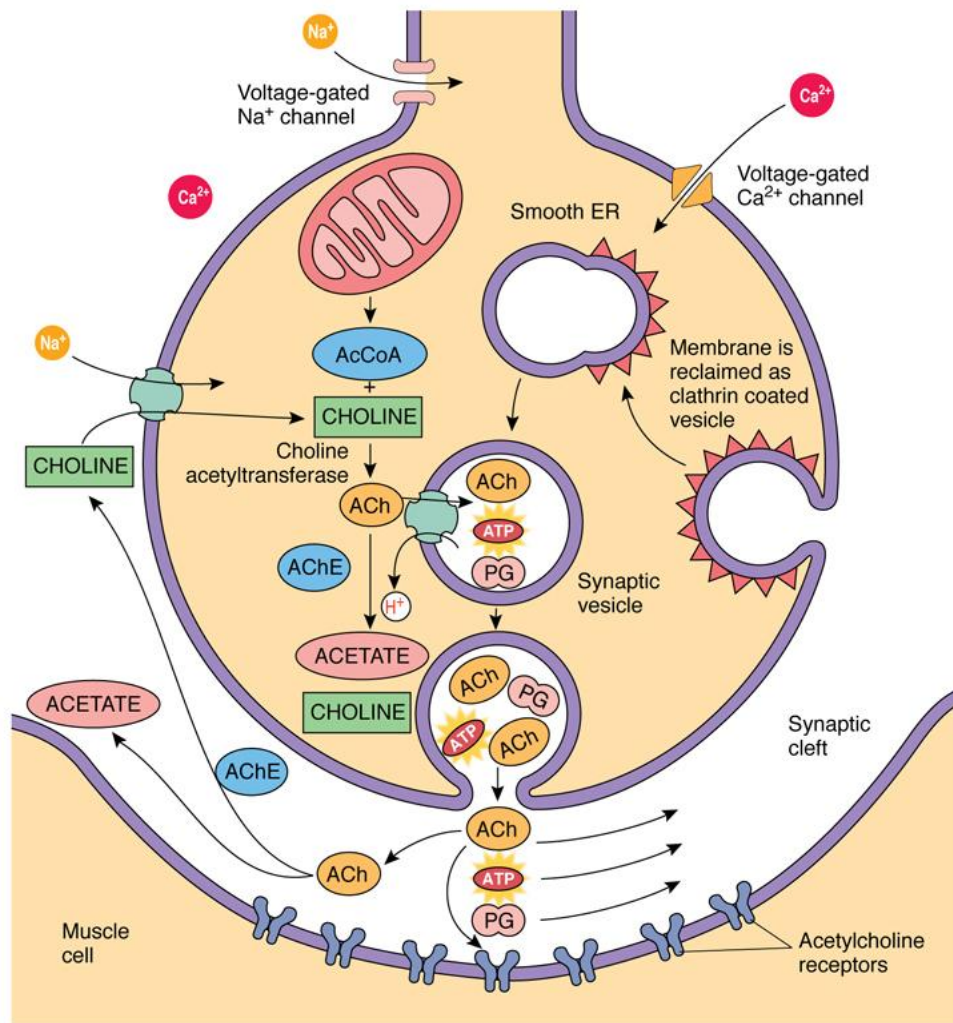


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When an action potential reaches the presynaptic membrane, it initiates opening of the voltage-gated calcium ion (Ca^{2+}) channels, permitting Ca^{2+} to enter.

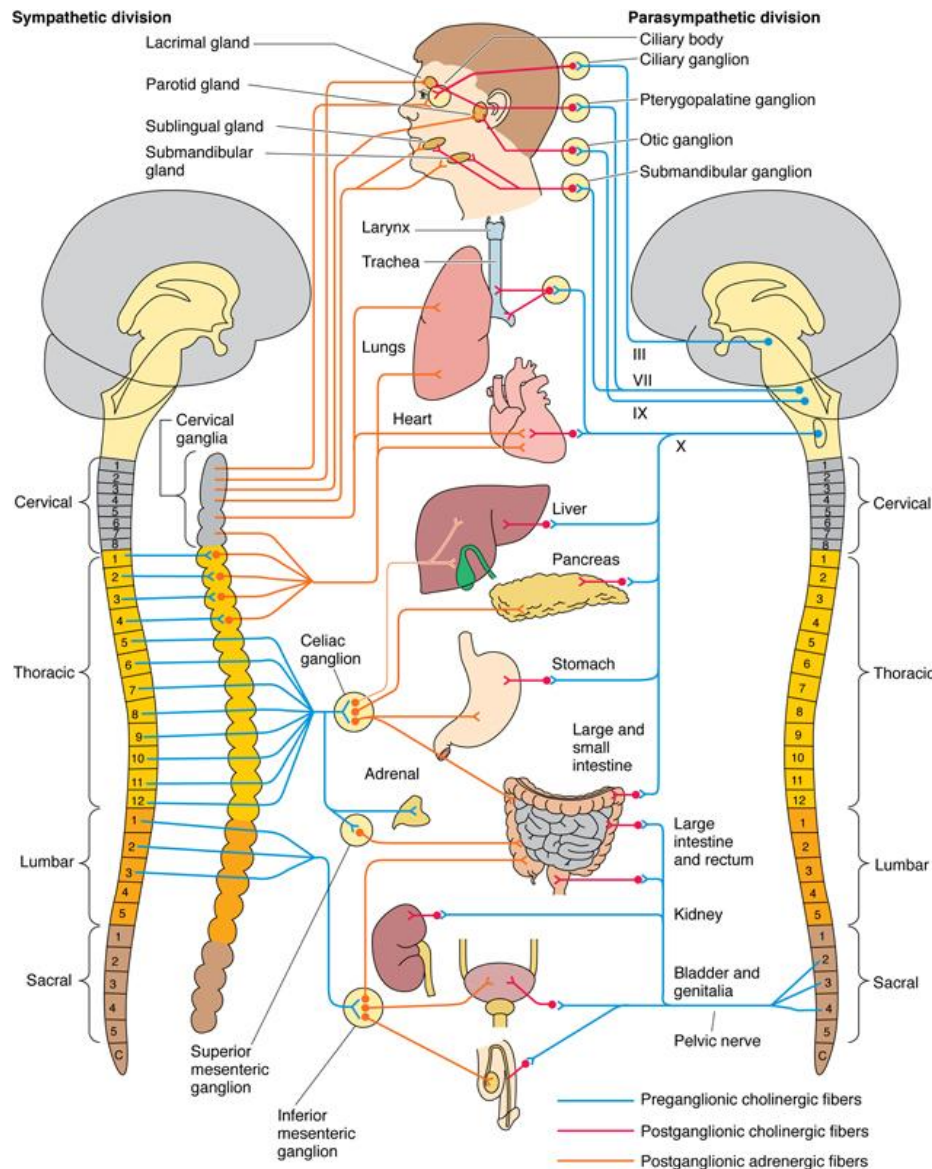
This Ca^{2+} influx causes synaptic vesicles, under the influence of SNARE (SNAP receptor) proteins to fuse with the presynaptic membrane, emptying neurotransmitter into the synaptic cleft via exocytosis.

Excess membrane is recaptured via clathrin-mediated endocytosis. The endocytic vesicle fuses with the smooth endoplasmic reticulum, where new membrane is continuously recycled.

The postsynaptic membrane, a thickened portion of the plasma membrane of the postsynaptic cell, contains neurotransmitter receptors, and the cytoplasmic area contains some dense material.

Coupling of the neurotransmitter with the receptors in the plasmalemma initiates depolarization (an excitatory response) or hyperpolarization (an inhibitory response) of the postsynaptic membrane. Glial cells have been shown to increase synaptogenesis, synaptic efficacy, and action-potential firing.

Autonomic Nervous System

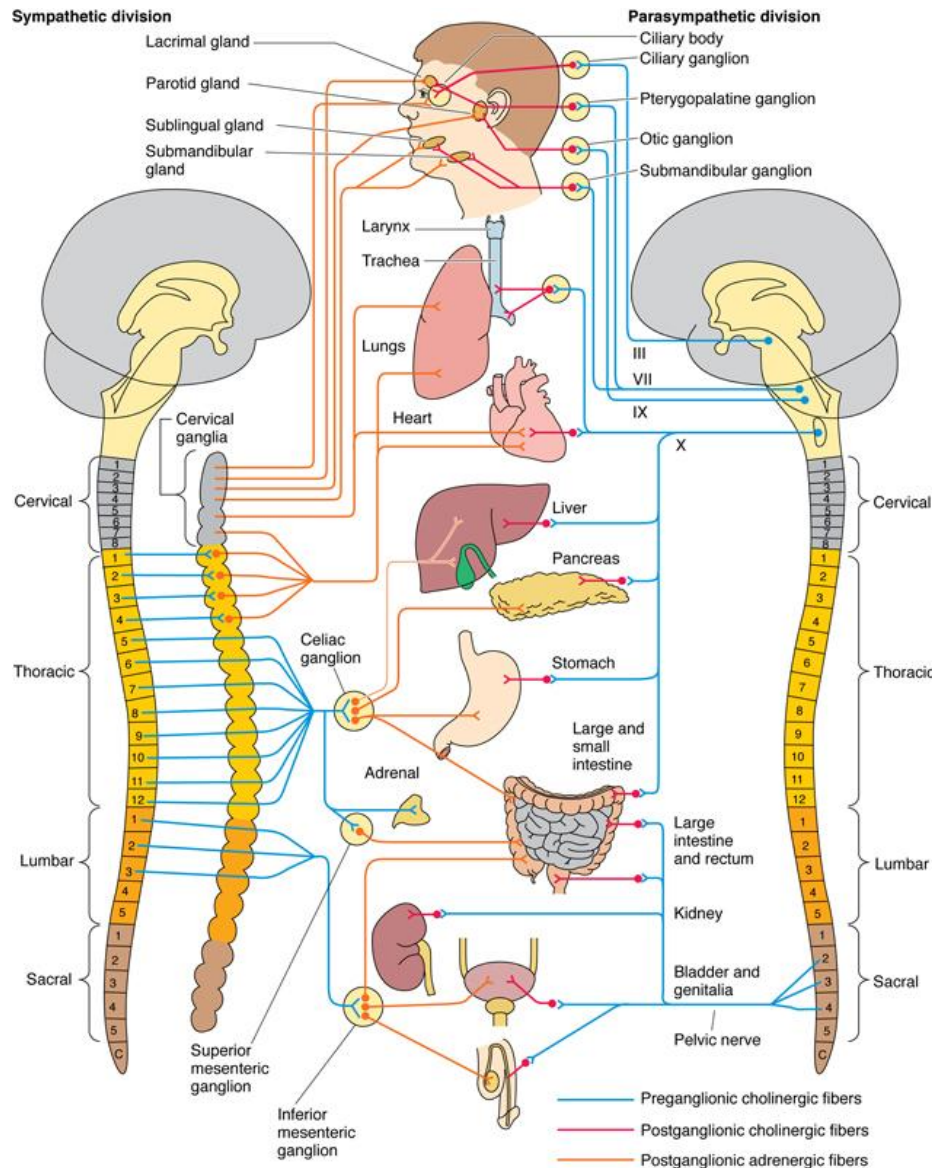


The **autonomic (involuntary, visceral) nervous system**, generally defined as a motor system, controls the viscera of the body by supplying smooth muscle, cardiac muscle, and glands.

In contrast to the somatic system, in which one neuron, originating in the CNS, acts directly on the effector organ, the autonomic nervous system possesses two neurons between the CNS and the effector organ. In addition, synapses between postganglionic fibers and effector organs differ in the two systems.

The autonomic nervous system. *Left*, Sympathetic division. *Right*, Parasympathetic division.

Autonomic Nervous System



The autonomic nervous system is subdivided into two functionally different divisions:

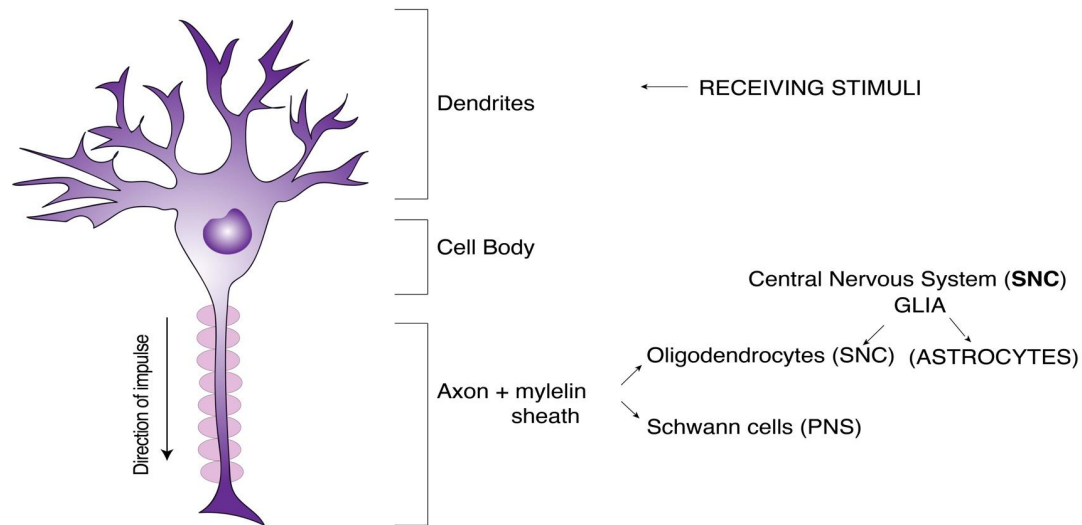
1. The sympathetic nervous system generally prepares the body for action by increasing respiration, blood pressure, heart rate, and blood flow to the skeletal muscles, dilating pupils of the eye, and generally slowing down visceral function.
2. The parasympathetic nervous system tends to be functionally antagonistic to the sympathetic system, in that it decreases respiration, blood pressure, and heart rate, reduces blood flow to skeletal muscles, constricts the pupils, and generally increases the actions and functions of the visceral system.

Thus, the parasympathetic nervous system brings about homeostasis,

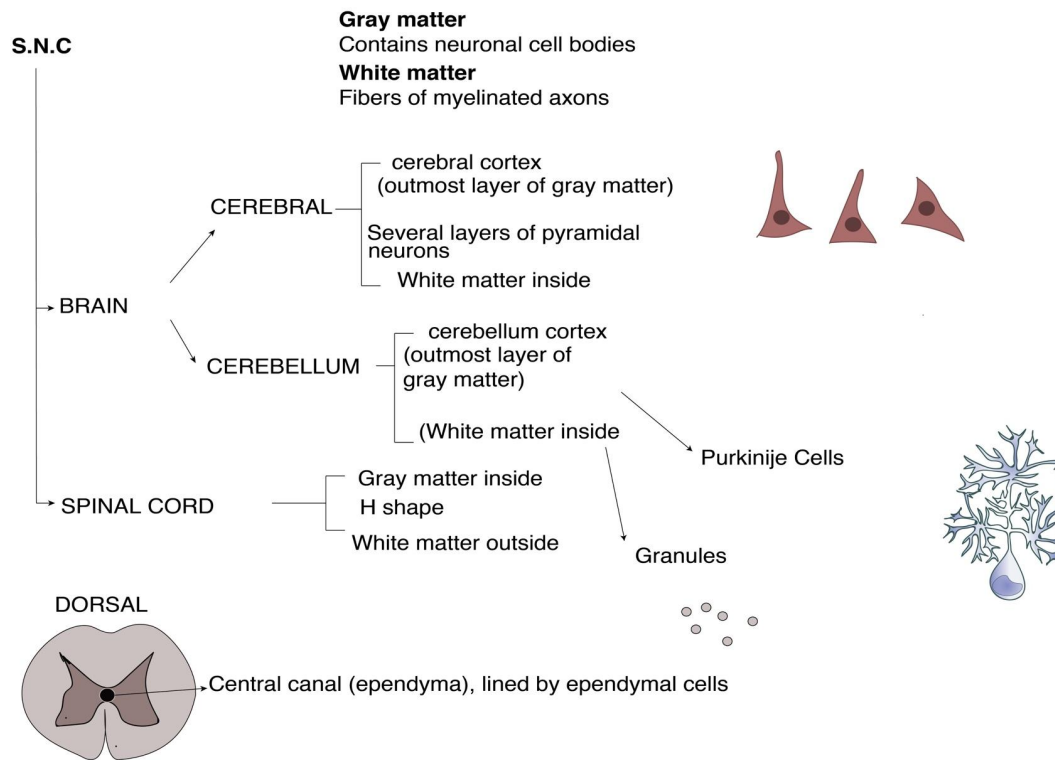
whereas the sympathetic nervous system prepares the body for “fight or flight.”

The autonomic nervous system. *Left*, Sympathetic division. *Right*, Parasympathetic division.

Neuron



SIZE OF THE CELL'S BODY:
 Ø 4 µm (granules of cerebellum)- 140 µm (motor nerve in spinal cord)



PERIPHERAL NERVE SYSTEM

PNS

GANGLIA

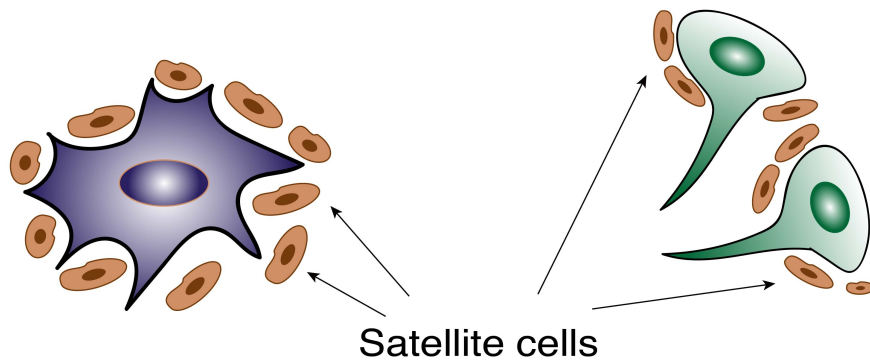
Neuronal cell bodies + glial cells

Multipolar neurons

PSEUDOUNIPOLAR

NERVES

Bundles of nerve fibers surrounded by a series of connective tissue



Endoneurium

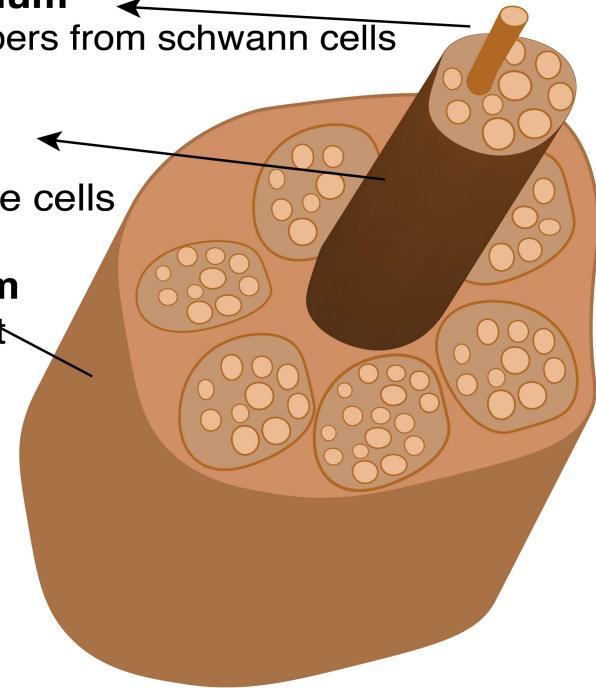
Reticular fibers from schwann cells

Perineurium

flattened epithelium-like cells

Epineurium

fibrous coat of dense connective tissue



Example of Histology Lab Exam

Histology Laboratory CFU 1 – Module of Morphology and Development (I.C.)

Name Surname. XXXXXX. XXXXX

Diagnosis

Presence of both longitudinal and cross sections. In both cases we can distinguish a structure and several rounded, centred nuclei. By that, we first inferred that our specimen must be a cardiac muscle (suspicious later confirmed by the presence of intercalated discs). We observe the presence of proper fibrosis connective tissue. We can classify it as dense and irregular (the number of visible nuclei from the cellular component is indeed negligible).

We can observe the presence of some blood vessels. Some in particular have appreciably thick walls and elastic fibers lining the lumen (most likely small arteries surrounded by the same elastic connective tissue that we described before). Some capillaries are visibly lined by a single layer of endothelial cells.