THE PERIPHERAL NERVOUS SYSTEM

Nervous System

- **Two parts**
  - Central Nervous System (CNS);
    - Brain and spinal cord
  - Peripheral Nervous System (PNS);
    - Connects body to brain & spinal cord
    - 12 pairs of nerves from your brain (cranial nerves)
    - 31 pairs from your spinal cord (spinal nerves)
    - Bundles of sensory and motor neurons held together by connective tissue

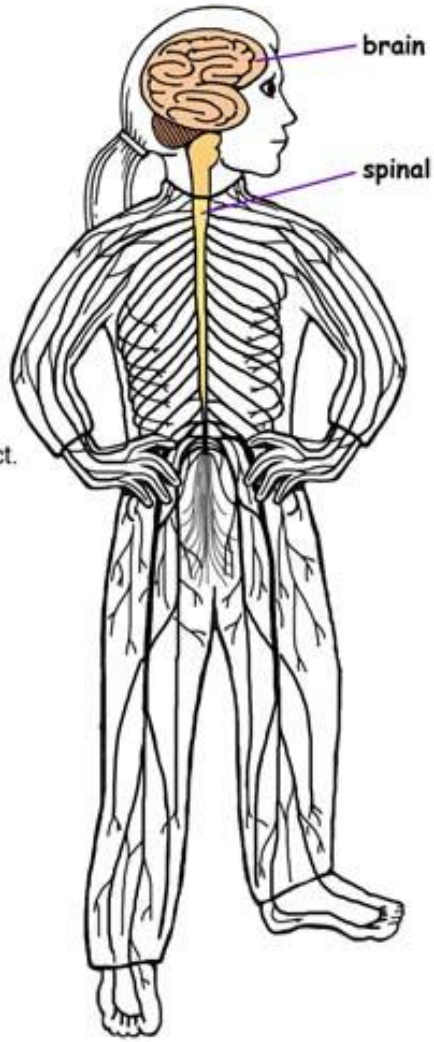
The Nervous System

The nervous system acts as a continuous, complete unit, but is broken down into two parts for better understanding –

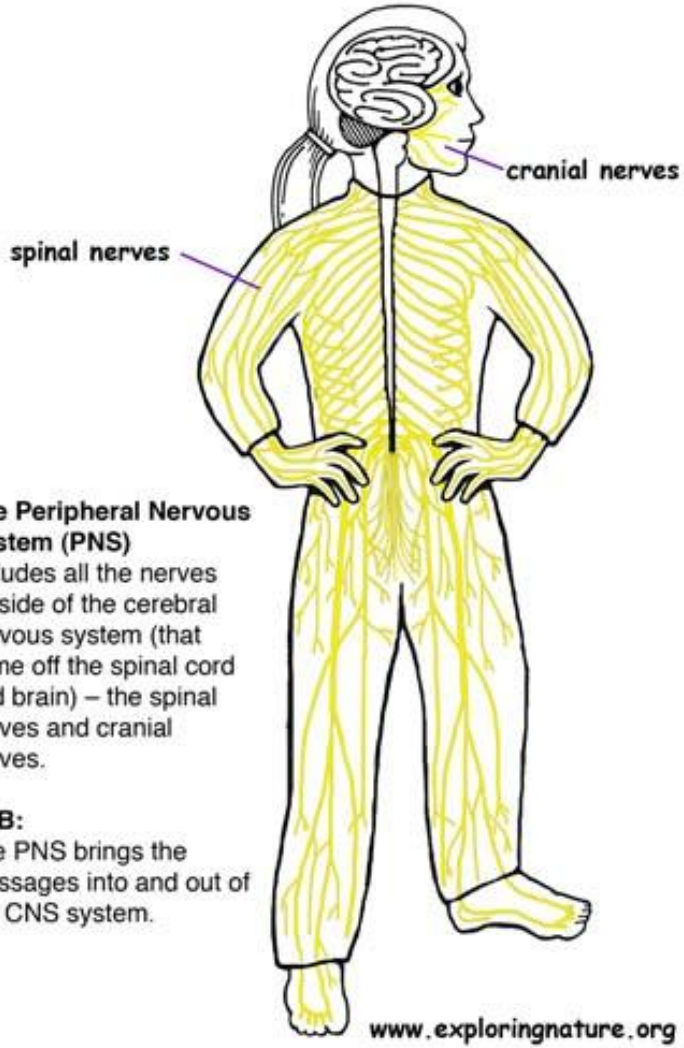
The Central Nervous System

The Central Nervous System (CNS) includes the brain and spinal cord (which runs down the back inside the bony vertebral column).

JOB:
The CNS receives the information, decides what to do with it and gives the orders for the muscles or glands to act.



The Peripheral Nervous System



The Peripheral Nervous System (PNS) includes all the nerves outside of the cerebral nervous system (that come off the spinal cord and brain) – the spinal nerves and cranial nerves.

JOB:
The PNS brings the messages into and out of the CNS system.

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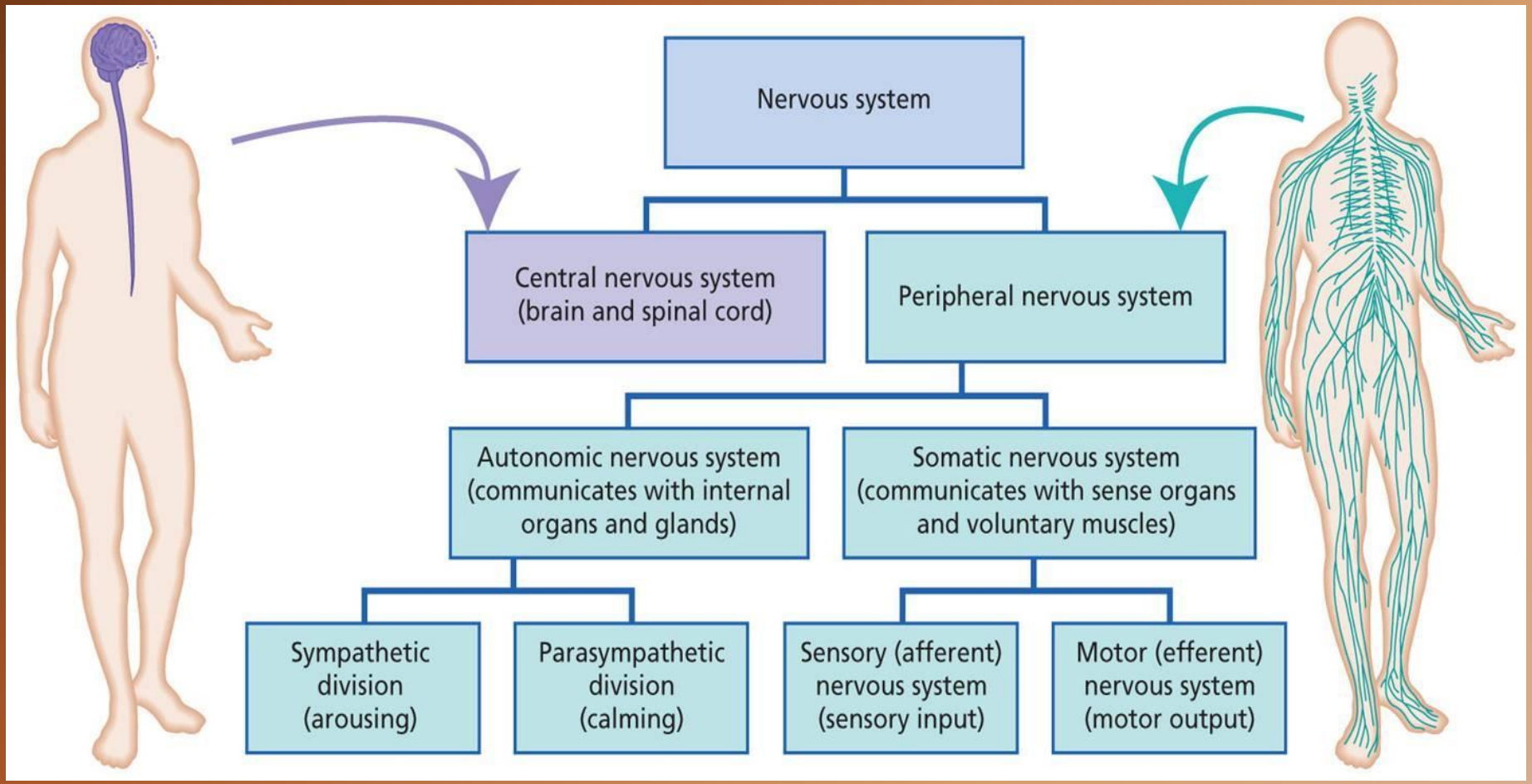
- The peripheral nervous system includes the nervous structures outside the brain and spinal cord
- Peripheral nerves allow the CNS to receive information and take action
- *Functional components of the PNS;*
  - Sensory inputs and motor outputs categorized as somatic or visceral
  - Sensory inputs also classified as general or special


Nervous system
Central nervous system (brain and spinal cord)
Peripheral nervous system
Autonomic nervous system (communicates with internal organs and glands)
Somatic nervous system (communicates with sense organs and voluntary muscles)
Sympathetic division (arousing)
Parasympathetic division (calming)
Sensory (afferent) nervous system (sensory input)
Motor (efferent) nervous system (motor output)

- Basic Structural Components of the PNS;
  - **Sensory receptors** – pick up stimuli from inside or outside the body
  - **Motor endings** – axon terminals of motor neurons innervate effectors (muscle fibers and glands)
  - **Nerves and ganglia**
    - **Nerves** – bundles of peripheral axons
    - **Ganglia** – clusters of peripheral neuronal cell bodies

Neurons

- The basic unit of the nervous system is the individual nerve cell, or neuron.
- Neurons are the basic building block of the nervous system.
- Neurons occur in a wide variety of sizes and shapes.
- Nevertheless, all neurons share features that allow cell-to-cell communication.

- Most neurons contain four parts:

  (1) a cell body,

  (2) dendrites,

  (3) an axon, and

  (4) axon terminals.

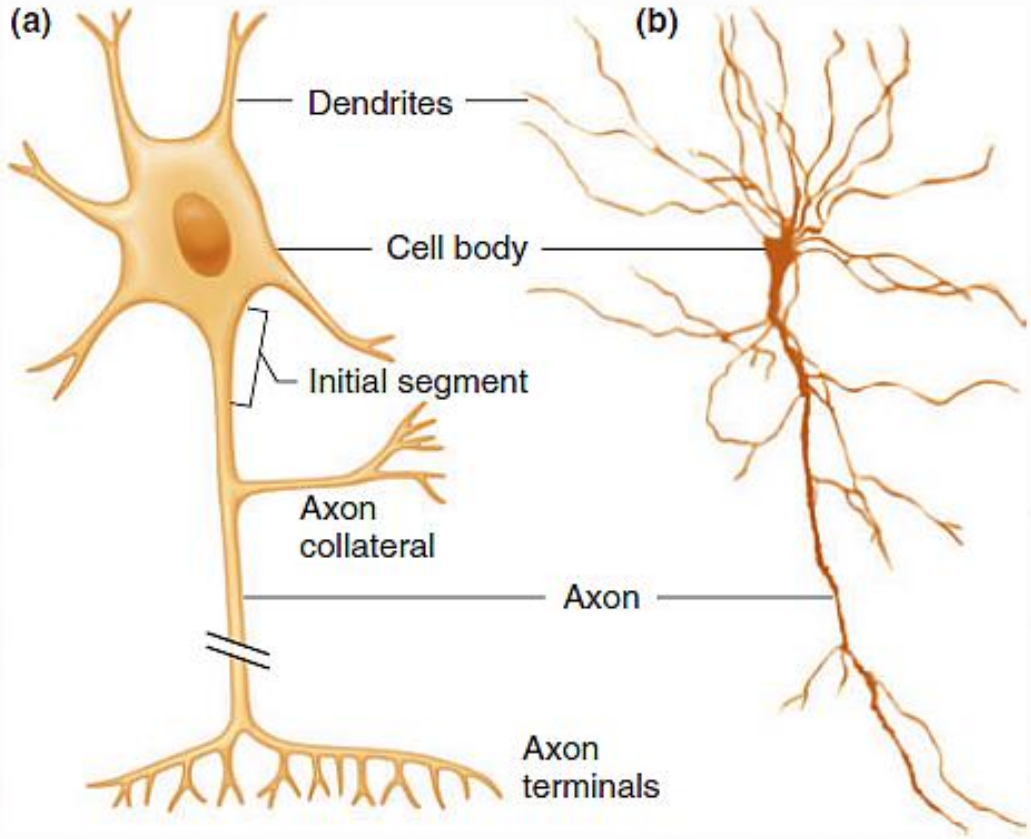
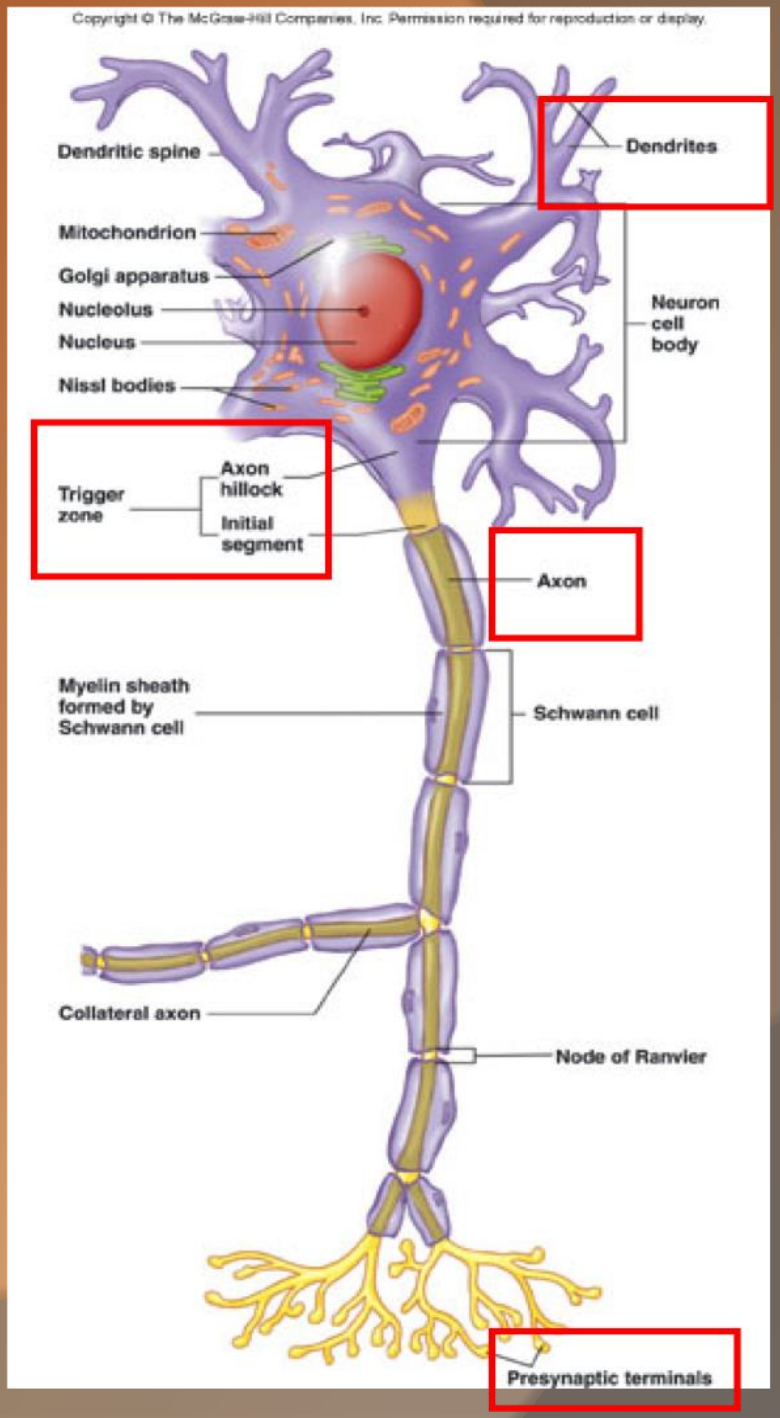


FIGURE 6–1

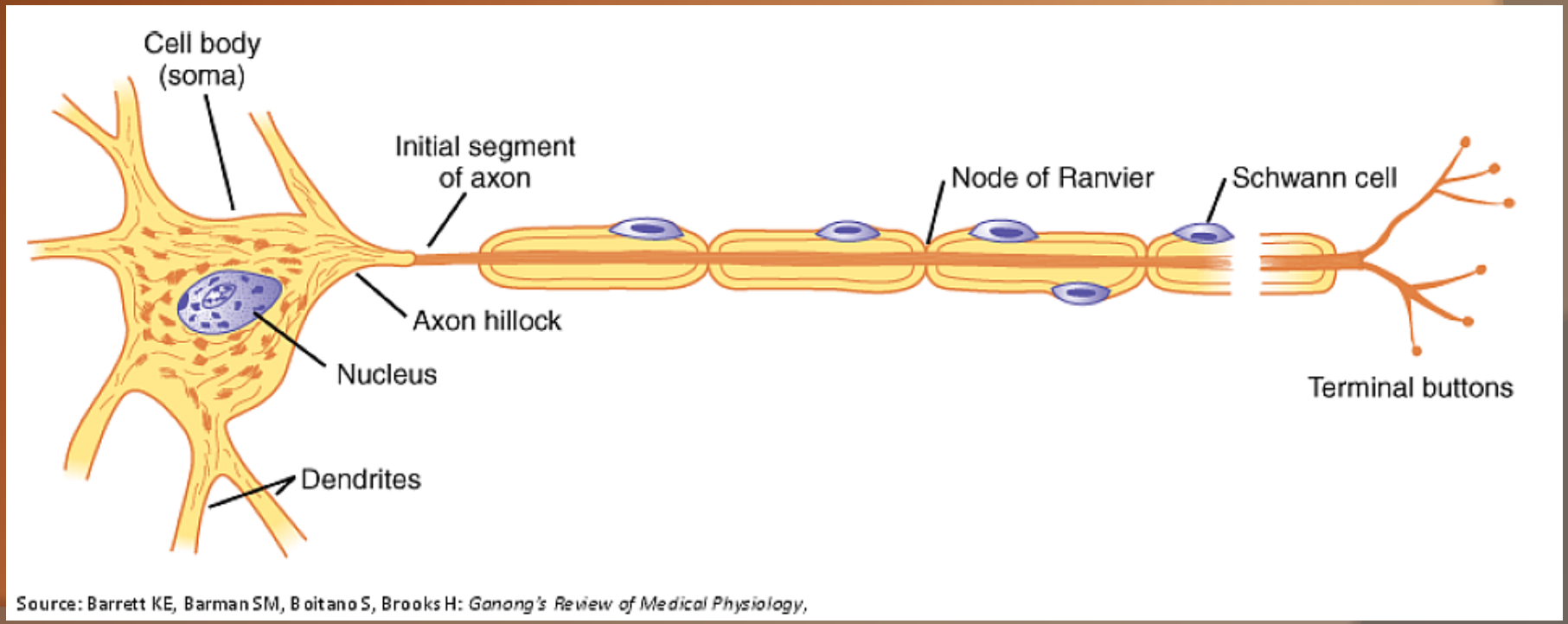
(a) Diagrammatic representation of a neuron. The break in the axon indicates that axons may extend for long distances and may be 5000 to 10,000 times longer than the cell body is wide. This neuron is a common type, but there are a wide variety of neuronal morphologies, one of which has no axon. (b) A neuron as observed through a microscope. The axon terminals cannot be seen at this magnification.

- As in other types of cells, **a neuron's cell body (or soma)** contains the nucleus and ribosomes and thus has the genetic information and machinery necessary for protein synthesis.
- **The dendrites** are a series of highly branched outgrowths of the cell body. They and the cell body receive most of the inputs from other neurons, the dendrites being more important in this role than the cell body.
- The branching dendrites (some neurons may have as many as 400,000!) increase the cell's surface area. Thus, dendrites increase a cell's capacity to receive signals from many other neurons.

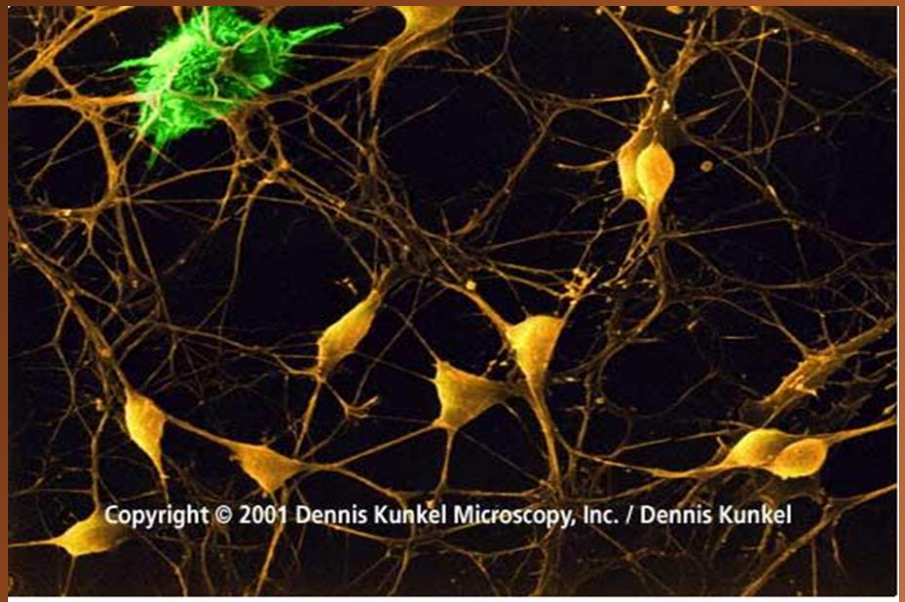
- The axon, sometimes also called a nerve fiber, is a single long process that extends from the cell body and carries output to its target cells.
- Axons range in length from a few micrometers to over a meter.
- The portion of the axon closest to the cell body plus the part of the cell body where the axon is joined is known as the initial segment, (or **axon hillock**).
- The initial segment is the "trigger zone" where, in most neurons, the electrical signals are generated.



- The axon divides into presynaptic terminals, each ending in a number of synaptic knobs which are also called terminal buttons or boutons. They contain granules or vesicles in which the synaptic transmitters secreted by the nerves are stored.



Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology*,



Caption: Cortical neurons growing in culture. Note the large, round, textured, astrocytic glial cell (central nervous system).
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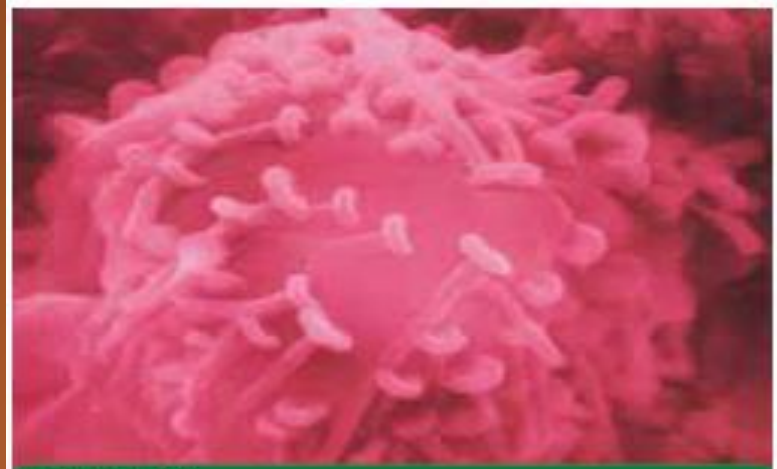
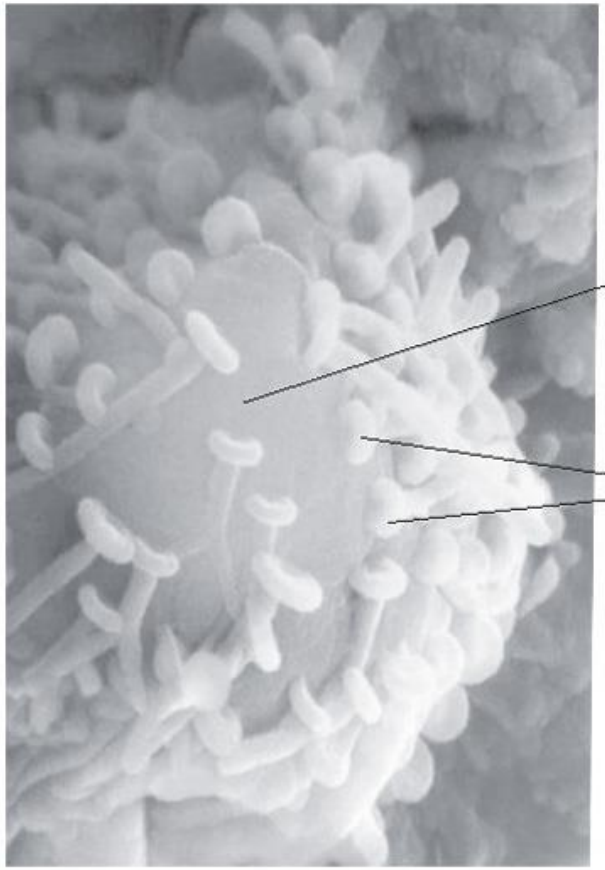


Figure 2.17

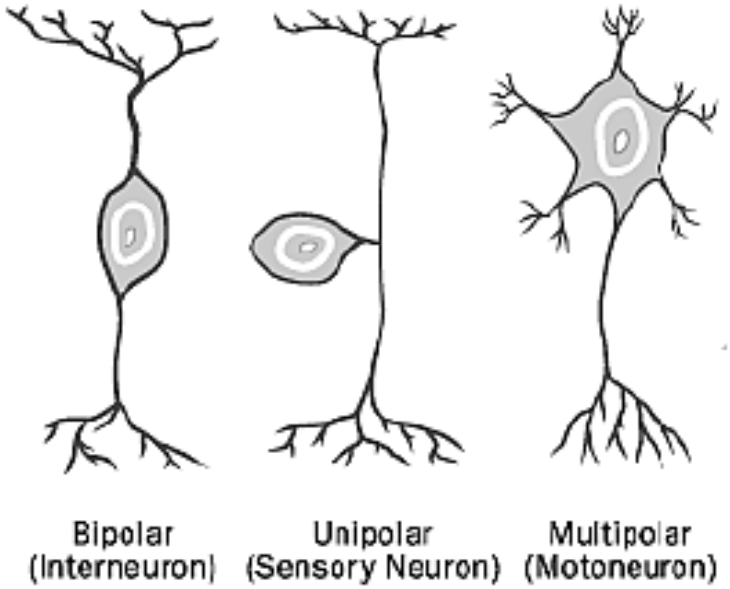
A Cell Body Virtually Covered With Axon Terminals.

Source: © Science VU/Lewis-Everhart-Zeevi / Visuals Unlimited



Classification of Neurons

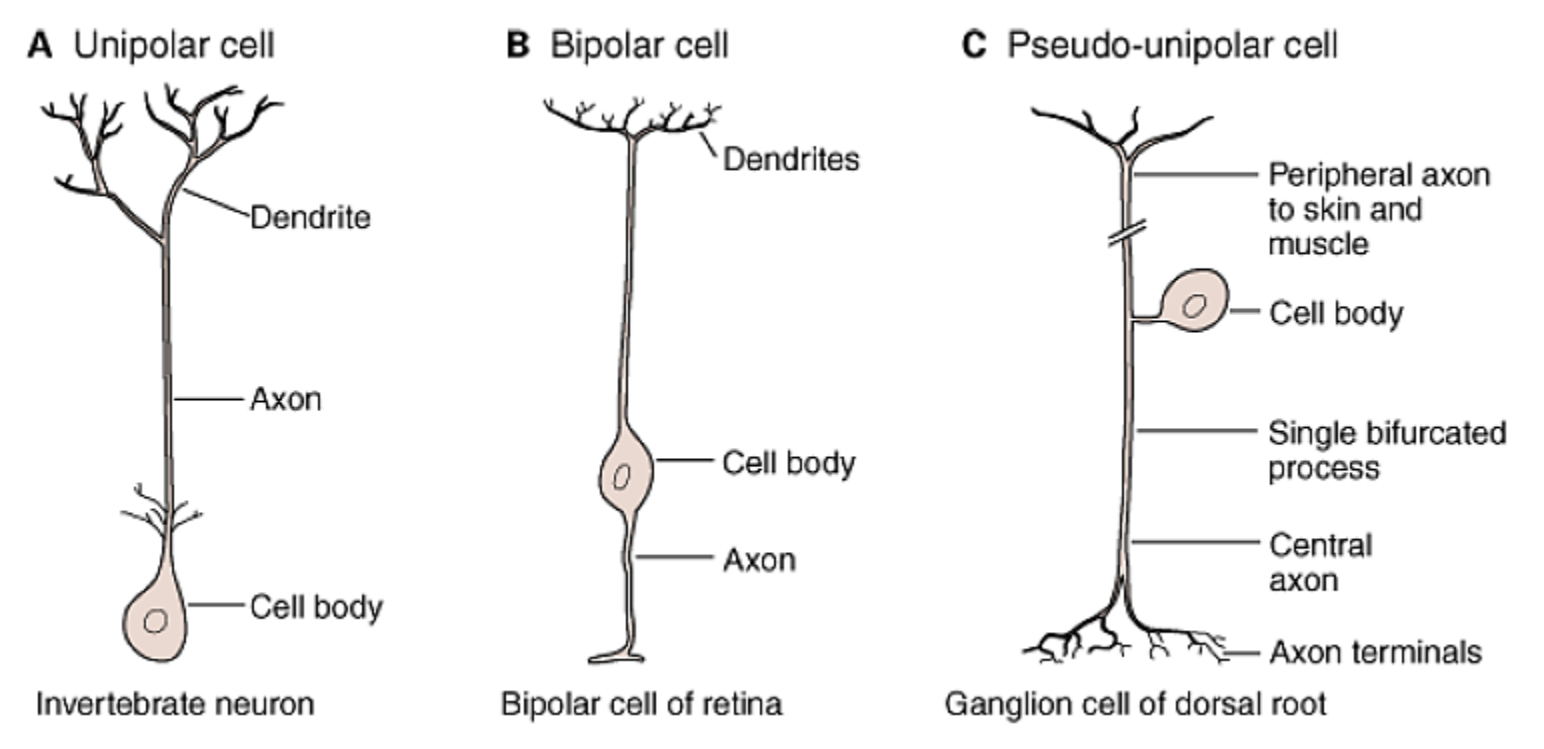
- 3 structural groups:
  - MULTIPOLAR
  - BIPOLAR
  - UNIPOLAR



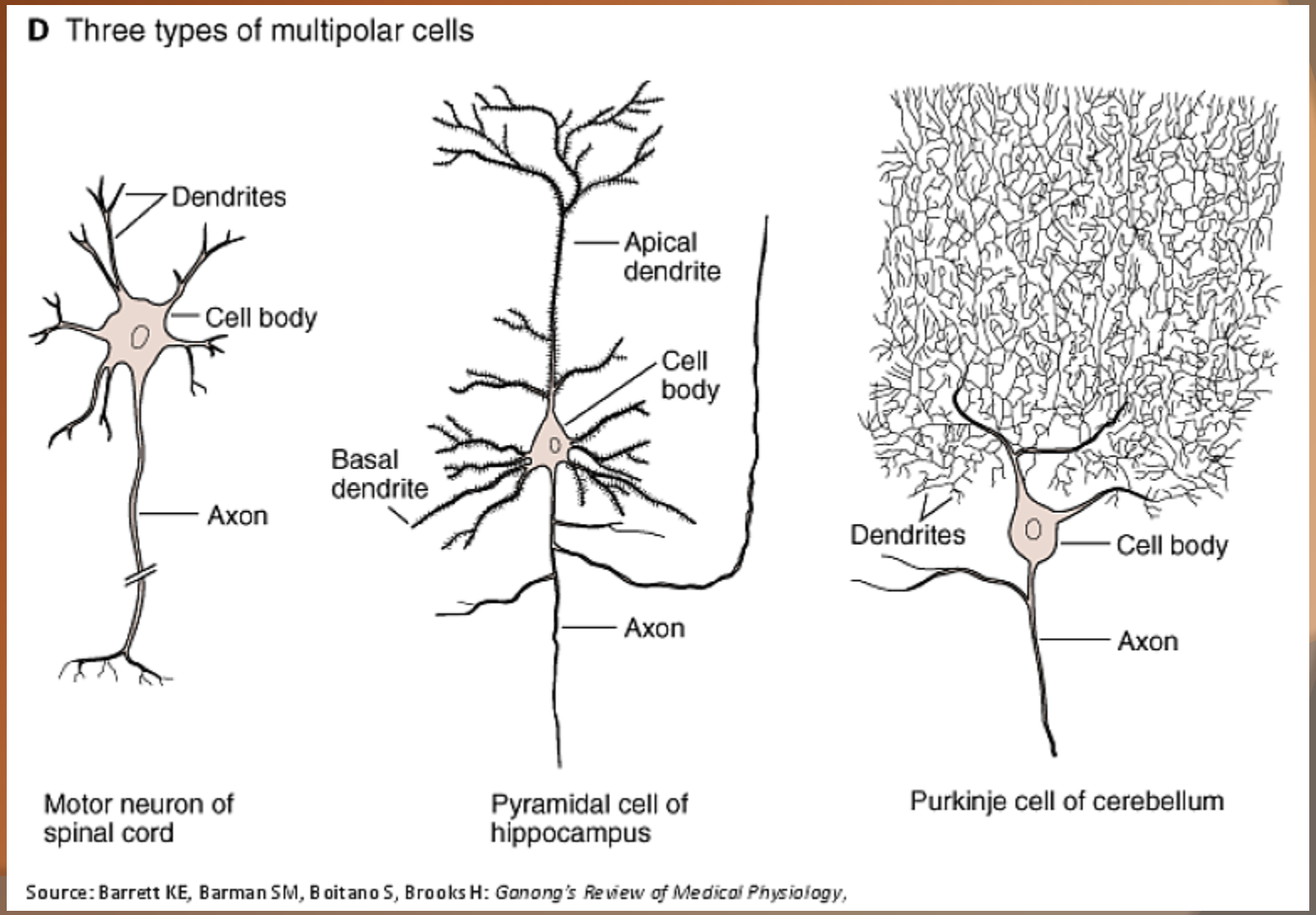
- Each sends a signal in *one direction* beginning at TRIGGER ZONE

- Unipolar neurons have one process, with different segments serving as receptive surfaces and releasing terminals.
- Bipolar neurons have two specialized processes: a dendrite that carries information to the cell and an axon that transmits information from the cell.

  - Some sensory neurons are in a subclass of bipolar cells called pseudo-unipolar cells. As the cell develops, a single process splits into two, both of which function as axons—one going to skin or muscle and another to the spinal cord.



- ✓ Multipolar neurons have one axon and many dendrites.
  - Examples include motor neurons, hippocampal pyramidal cells with dendrites in the apex and base, and cerebellar Purkinje cells with an extensive dendritic tree in a single plane.



Glial cells

- Neurons account for only about 10 percent of the cells in the central nervous system. The remainder are glial cells, also called neuroglia.
- However, because the neurons branch more extensively than glia do, neurons occupy about 50 percent of the volume of the brain and spinal cord.
- Glial cells surround the soma, axon, and dendrites of neurons and physically and metabolically support neurons.

Glial roles include;

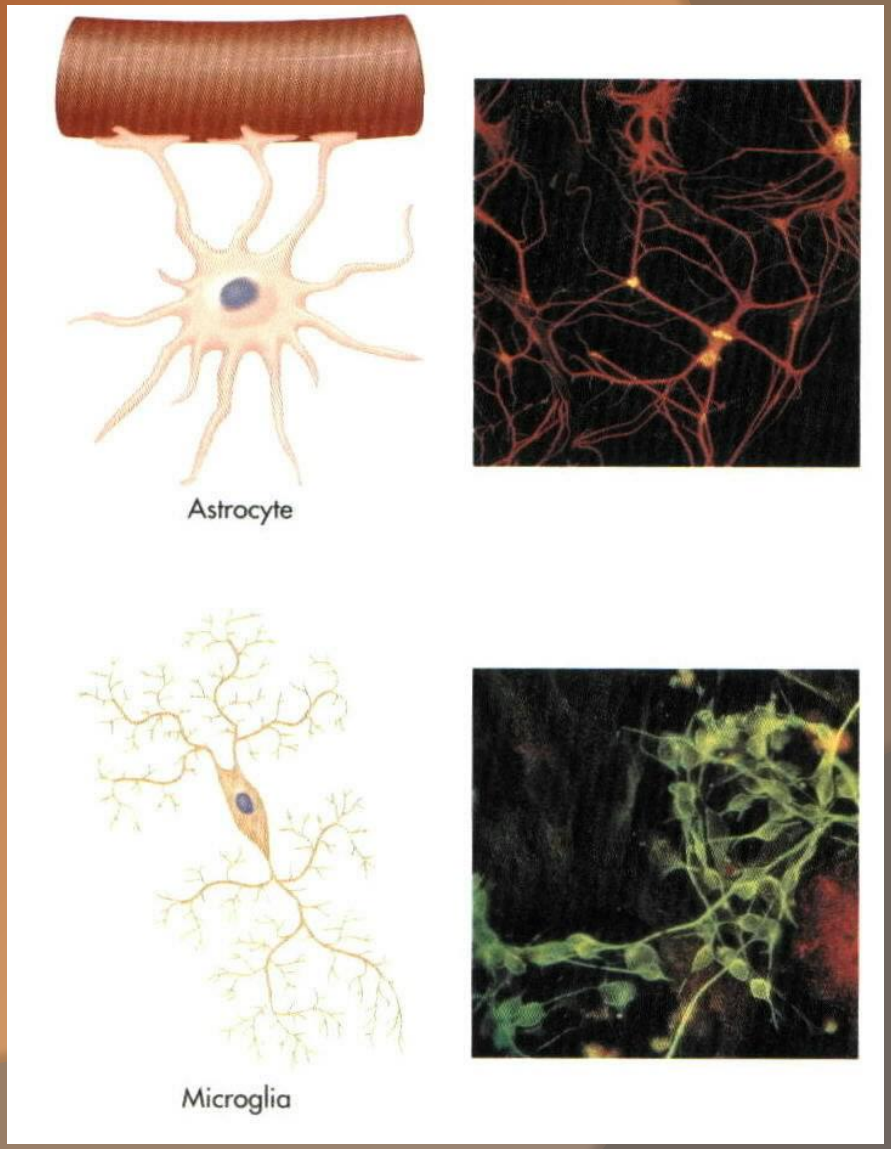
- maintaining the ionic milieu of nerve cells
- modulating the rate of nerve signal propagation
- modulating synaptic action by controlling the uptake of neurotransmitters at or near the synaptic cleft
- providing a scaffold for some aspects of neural development

Types of glial cells

1. **Microglia**
2. **Astrocytes**
3. **Oligodendrocytes**
4. **Schwann cells**

Types of glial cells

1. **Microglia**
   a. act as phagocytes
   b. part of brain's immune system



Types of glial cells

2. Astrocytes

a. mechanical support

b. metabolic support

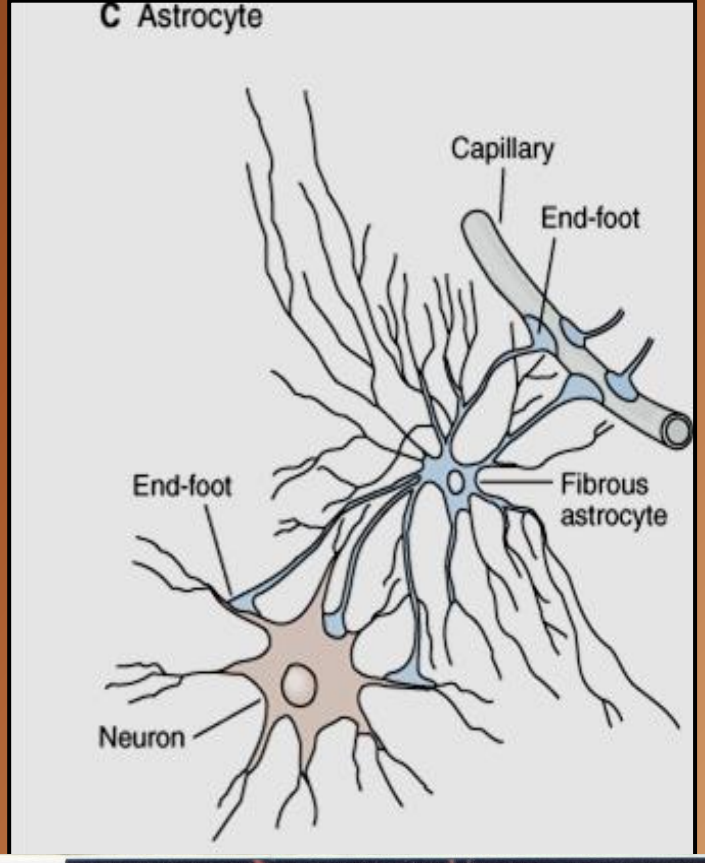
transport nutrients and wastes

c. encapsulate synapses

d. regulate chemical and ionic environment

e. form scar tissue

f. act as phagocytes



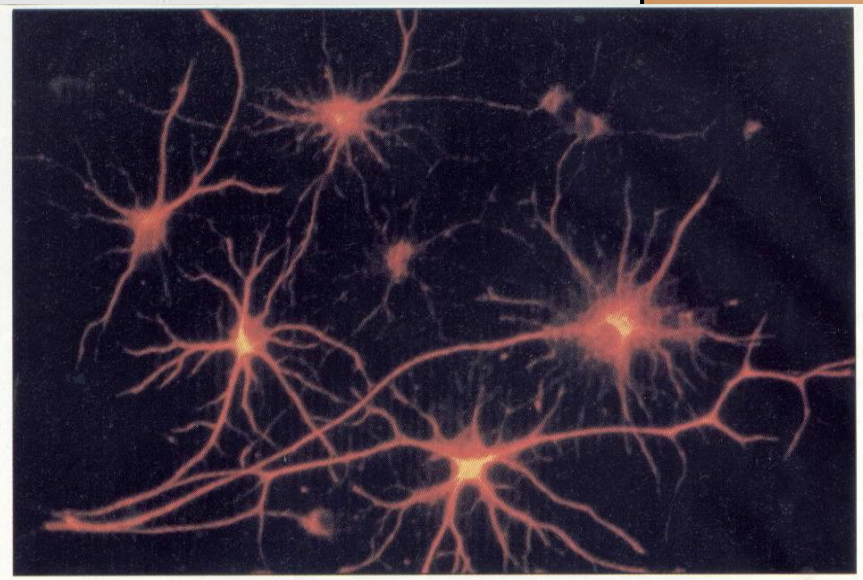
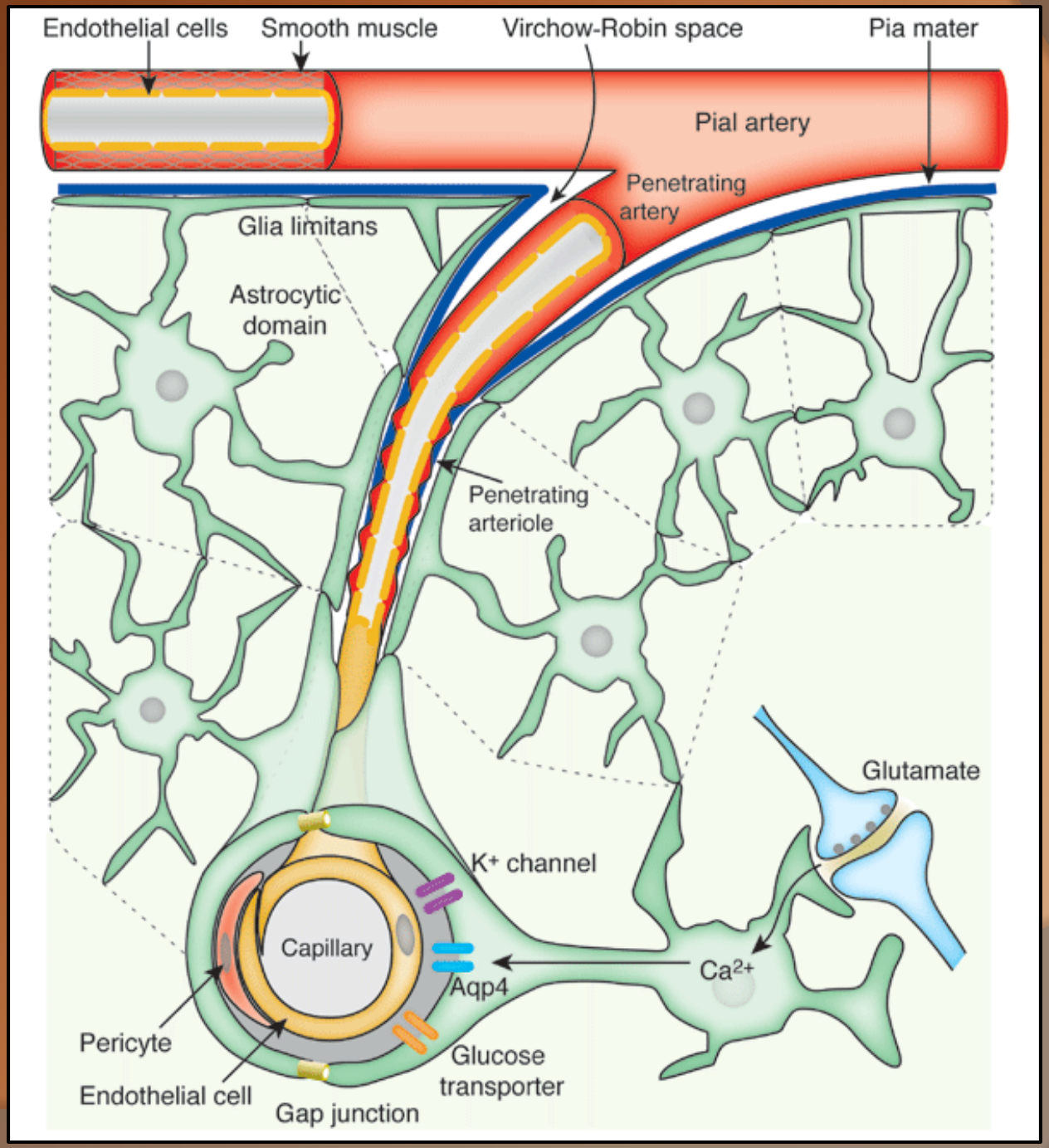


FIGURE 3.11 • **Astrocytes** These star-shaped cells are a prominent type of glia in the brain, performing a number of supporting functions for the neurons.


Endothelial cells
Smooth muscle
Virchow-Robin space
Pia mater
Pial artery
Penetrating artery
Glia limitans
Astrocytic domain
Penetrating arteriole
Glutamate
K+ channel
Capillary
Ca2+
Aqp4
Pericyte
Endothelial cell
Gap junction
Glucose transporter

Types of glial cells

3. Oligodendrocytes

myelinate axons of central nervous system

4. Schwann cells

myelinate axons of peripheral nervous system

- The axons of most but not all neurons are covered by **myelin**, which consists of 20 to 200 layers of highly modified plasma membrane wrapped around the axon by a nearby supporting cell.
- In the brain and spinal cord these myelin-forming cells are the oligodendrocytes.
- Each oligodendrocyte may branch to form myelin on as many as 40 axons.

- In the peripheral nervous system single myelin-forming cells, called Schwann cells, form one individual myelin sheath.
- The spaces between adjacent sections of myelin where the axon’s plasma membrane is exposed to extracellular fluid are the nodes of Ranvier.
- The myelin sheath speeds up conduction of the electrical signals along the axon and conserves energy.

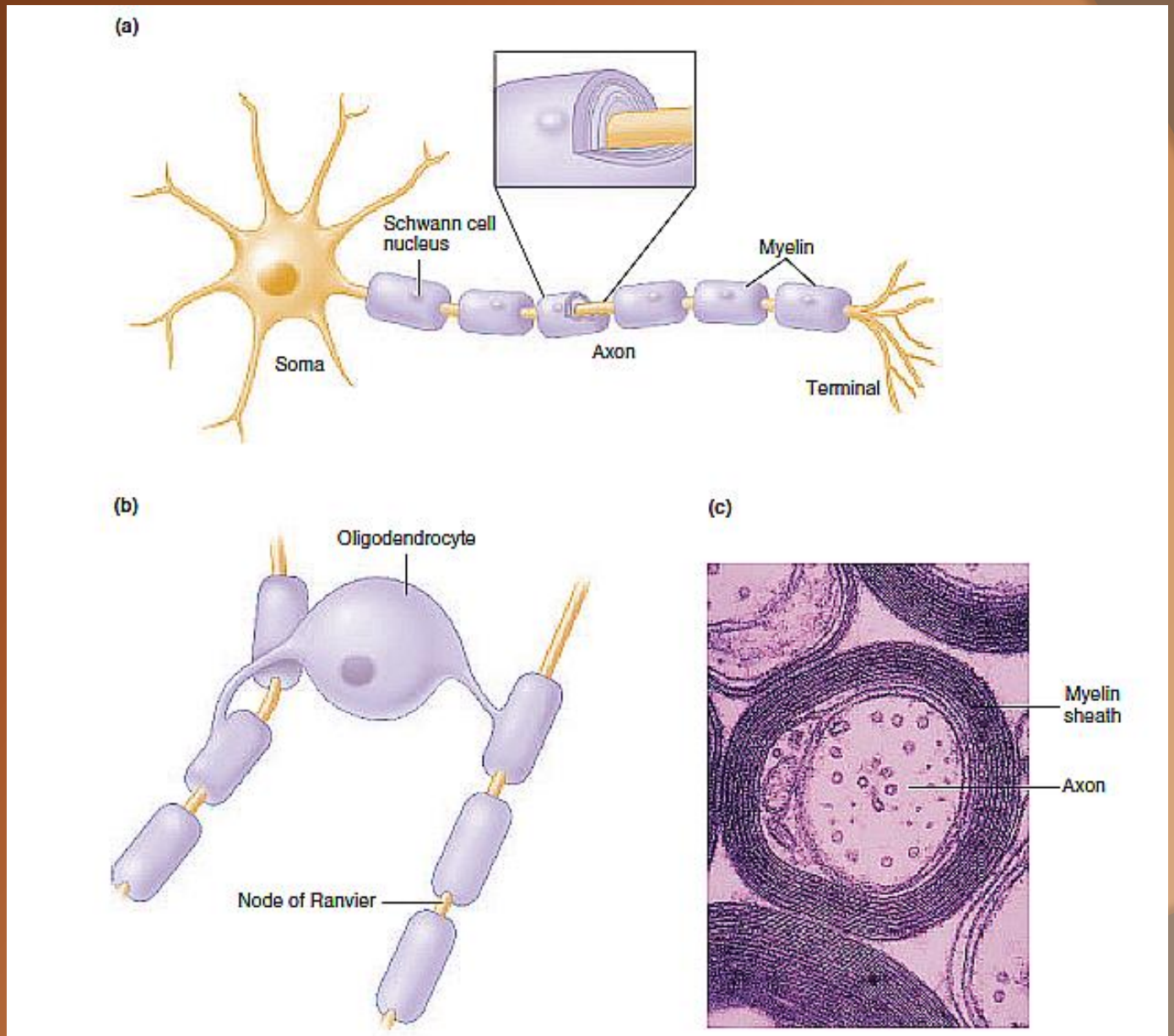
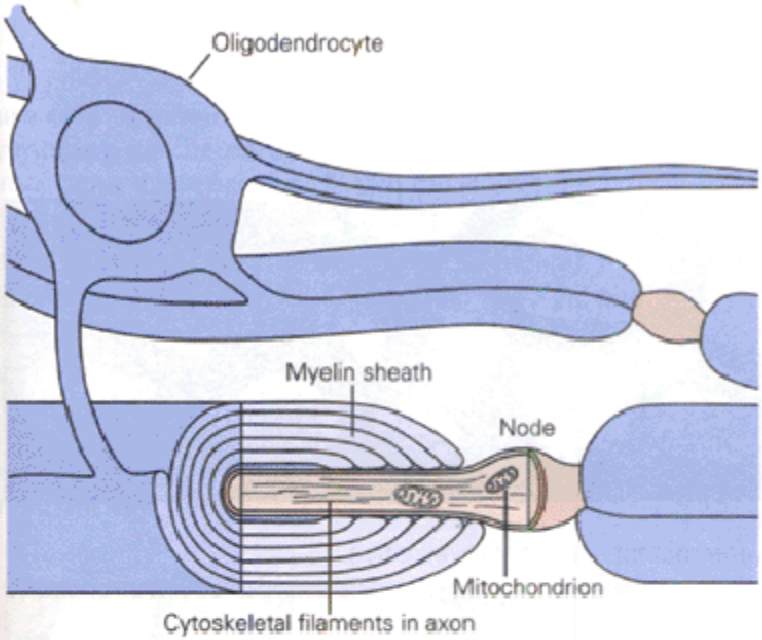


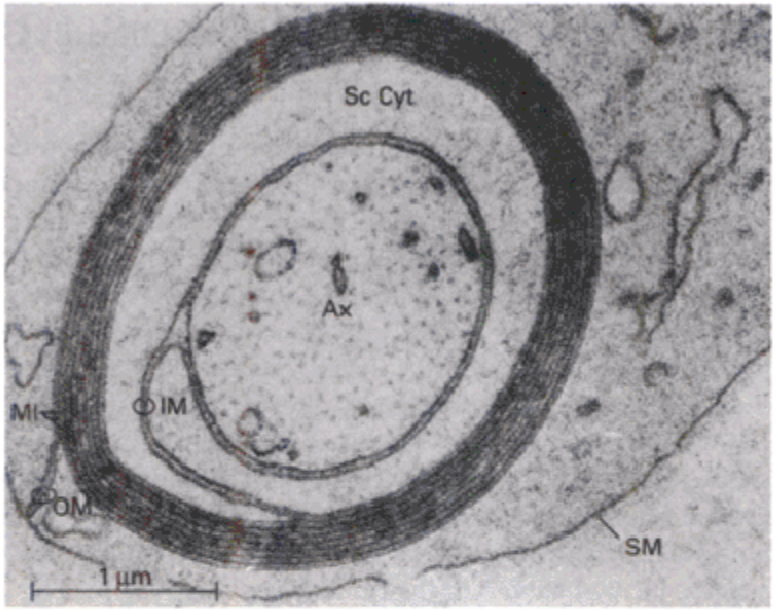
FIGURE 6–2

Myelin formed by Schwann cells (a) and oligodendrocytes (b) on axons. Electron micrograph of transverse sections of myelinated axons in brain (c).

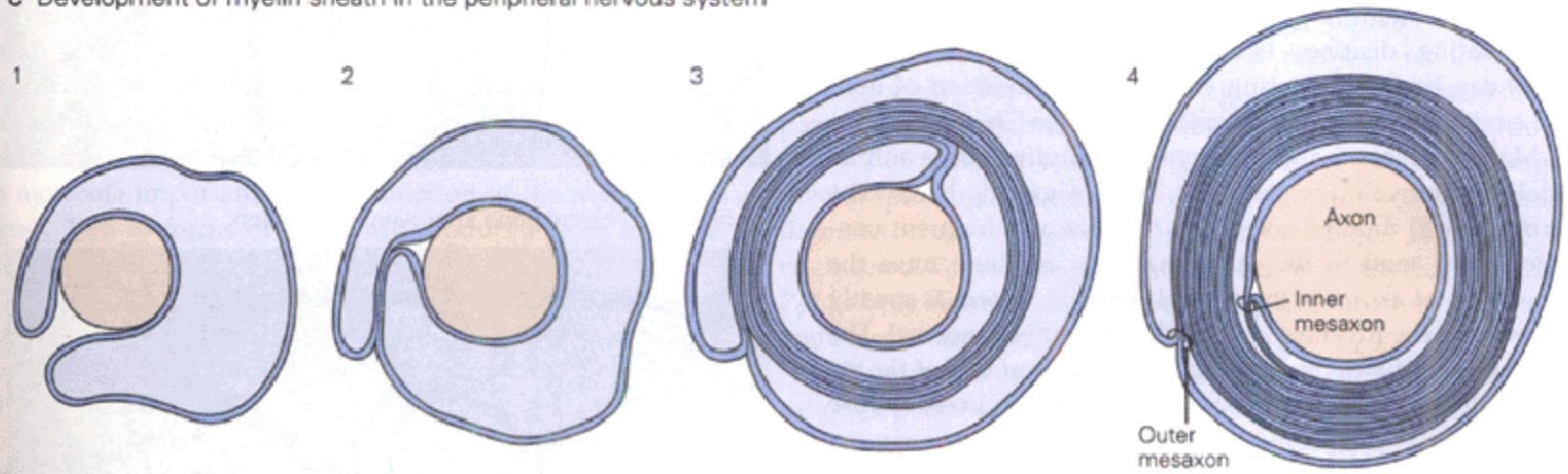
A Myelination in the central nervous system



B Myelination in the peripheral nervous system

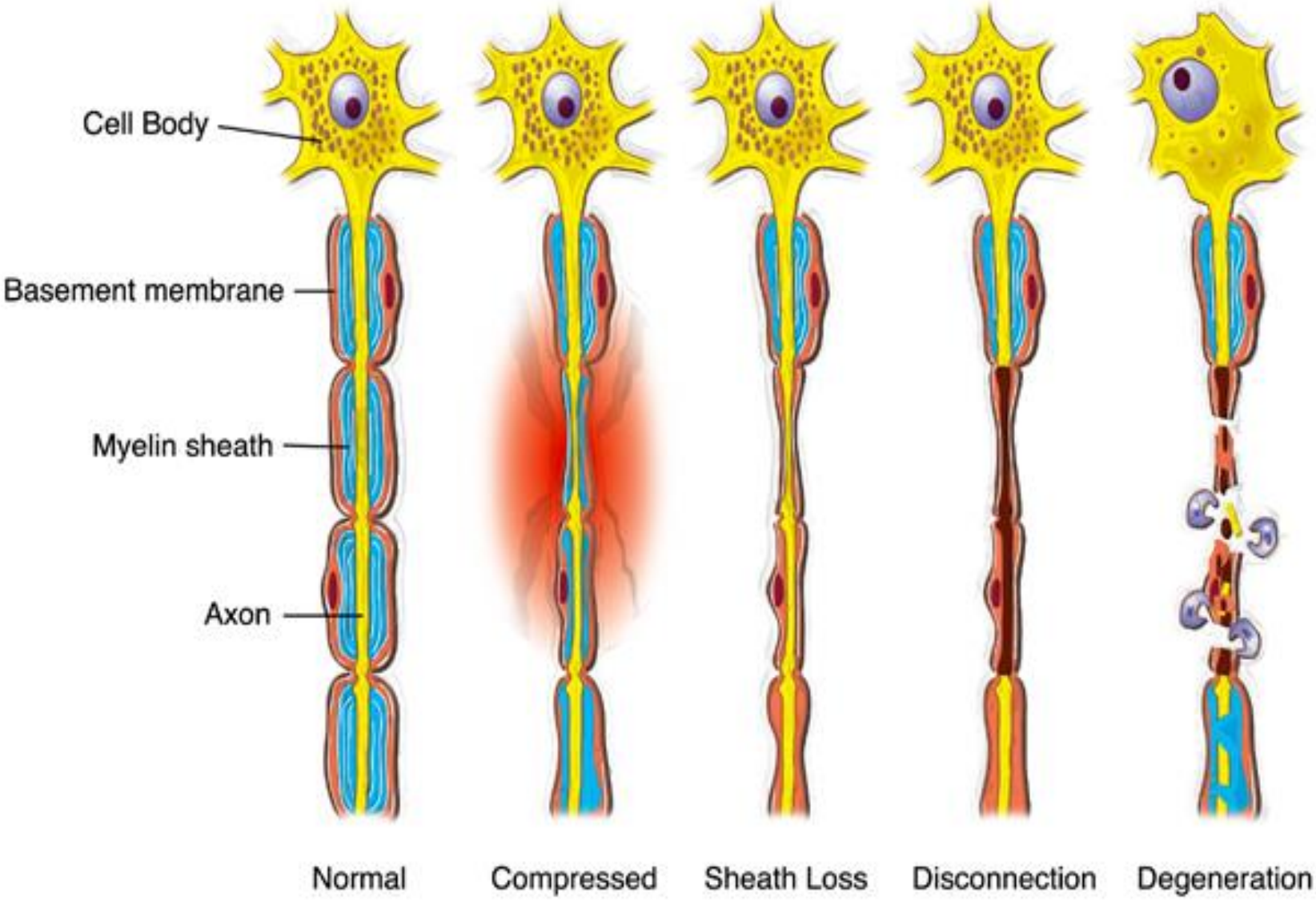


C Development of myelin sheath in the peripheral nervous system

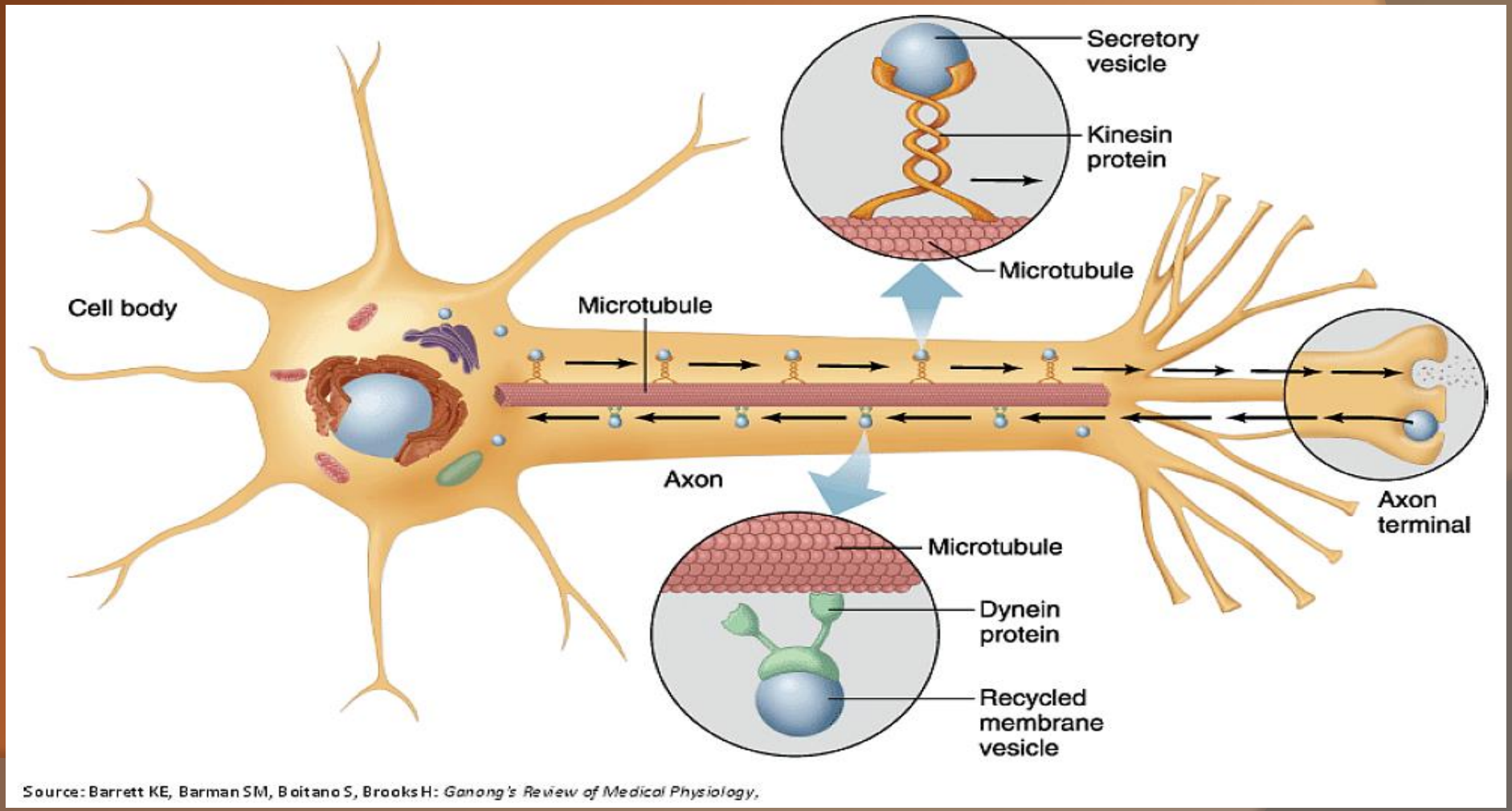


Axonal Transport

- Neurons are secretory cells, but they differ from other secretory cells in that the secretory zone is generally at the end of the axon, far removed from the cell body.
- The apparatus for protein synthesis is located for the most part in the cell body, with transport of proteins and polypeptides to the axonal ending by axoplasmic flow. Thus, the cell body maintains the functional and anatomic integrity of the axon; if the axon is cut, the part distal to the cut degenerates (**wallerian degeneration**).
- **Orthograde transport** occurs along microtubules that run along the length of the axon and requires two molecular motors, dynein and kinesin.
- Orthograde transport moves from the cell body toward the axon terminals.It has both fast and slow components;
  - fast axonal transport occurs at about 400 mm/day, and
  - slow axonal transport occurs at 0.5 to 10 mm/day.


Cell Body
Basement membrane
Myelin sheath
Axon
Normal
Compressed
Sheath Loss
Disconnection
Degeneration

- *The substances and organelles being moved are linked by proteins to microtubules in the cell body and axon. The microtubules serve as the "rails" along which the transport occurs. The linking proteins (dynein and kinesin) act as the "motors" of axon transport and, as ATPase enzymes, they also transfer energy from ATP to the "motors."*



Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology*.

- **Retrograde transport,** which is in the opposite direction (from the nerve ending to the cell body), occurs along microtubules at about 200 mm/day. Synaptic vesicles recycle in the membrane, but some used vesicles are carried back to the cell body and deposited in lysosomes.
- By this route, growth factors and other chemical signals picked up at the terminals can affect the neuron's morphology, biochemistry, and connectivity.
- This is also the route by which certain harmful substances, such as tetanus toxin, herpes, and other viruses can be taken up by the peripheral axon terminals and enter the central nervous system.

Functional Classes of Neurons

- **Neurons can be divided into three functional classes:** afferent neurons, efferent neurons, and interneurons.
- **Afferent neurons** convey information from the tissues and organs of the body into the central nervous system.
- **Efferent neurons** convey information from the central nervous system out to effector cells (particularly muscle or gland cells or other neurons).
- **Interneurons** connect neurons within the central nervous system.

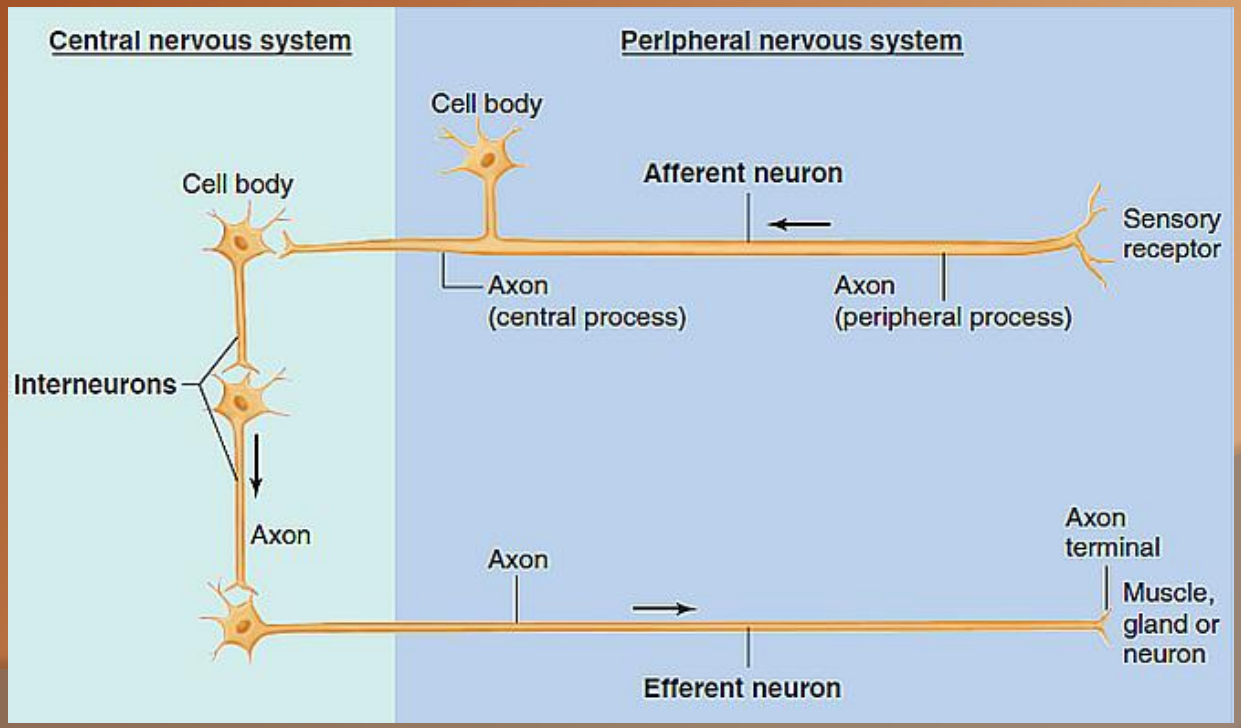


TABLE 6–1 Characteristics of Three Classes of Neurons

I. Afferent neurons

A. Transmit information into the central nervous system from receptors at their peripheral endings

B. Cell body and the long peripheral process of the axon are in the peripheral nervous system; only the short central process of the axon enters the central nervous system

C. Have no dendrites (do not receive inputs from other neurons)

II. Efferent neurons

A. Transmit information out of the central nervous system to effector cells, particularly muscles, glands, or other neurons

B. Cell body, dendrites, and a small segment of the axon are in the central nervous system; most of the axon is in the peripheral nervous system

III. Interneurons

A. Function as integrators and signal changers

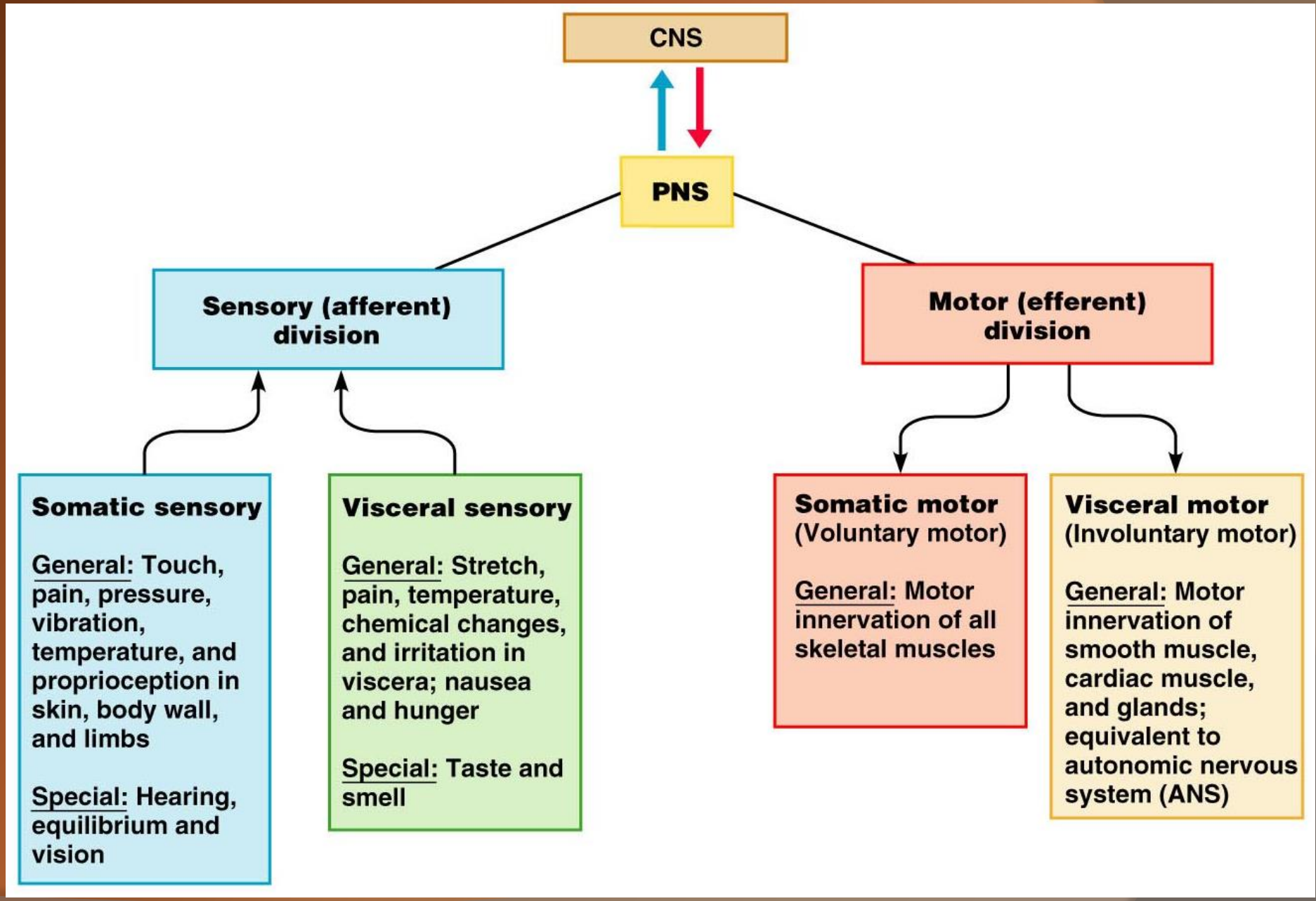
B. Integrate groups of afferent and efferent neurons into reflex circuits

C. Lie entirely within the central nervous system

D. Account for 99 percent of all neurons

Sensory Input and Motor Output

- Sensory (afferent) signals picked up by sensory receptors, carried by nerve fibers of PNS to the CNS
- Motor (efferent) signals are carried away from the CNS, innervate muscles and glands
- Divided according to region they serve
  - Somatic body region
  - Visceral body region
- Results in four main subdivisions
  - Somatic sensory
  - Visceral sensory
  - Somatic motor
  - Visceral motor


CNS
PNS
Sensory (afferent) division
Motor (efferent) division
Somatic sensory
General: Touch, pain, pressure, vibration, temperature, and proprioception in skin, body wall, and limbs
Special: Hearing, equilibrium and vision
Visceral sensory
General: Stretch, pain, temperature, chemical changes, and irritation in viscera; nausea and hunger
Special: Taste and smell
Somatic motor (Voluntary motor)
General: Motor innervation of all skeletal muscles
Visceral motor (Involuntary motor)
General: Motor innervation of smooth muscle, cardiac muscle, and glands; equivalent to autonomic nervous system (ANS)

- Afferent (sensory) division – transmits impulses from receptors to the CNS.
  - Somatic afferent fibers – carry impulses from skin, skeletal muscles, and joints
  - Visceral afferent fibers – transmit impulses from visceral organs
- Motor (efferent) division – transmits impulses from the CNS to effector organs. Has two subdivisions:
  - Somatic nervous system – provides conscious control of skeletal muscles
  - Autonomic nervous system – regulates smooth muscle, cardiac muscle, and glands

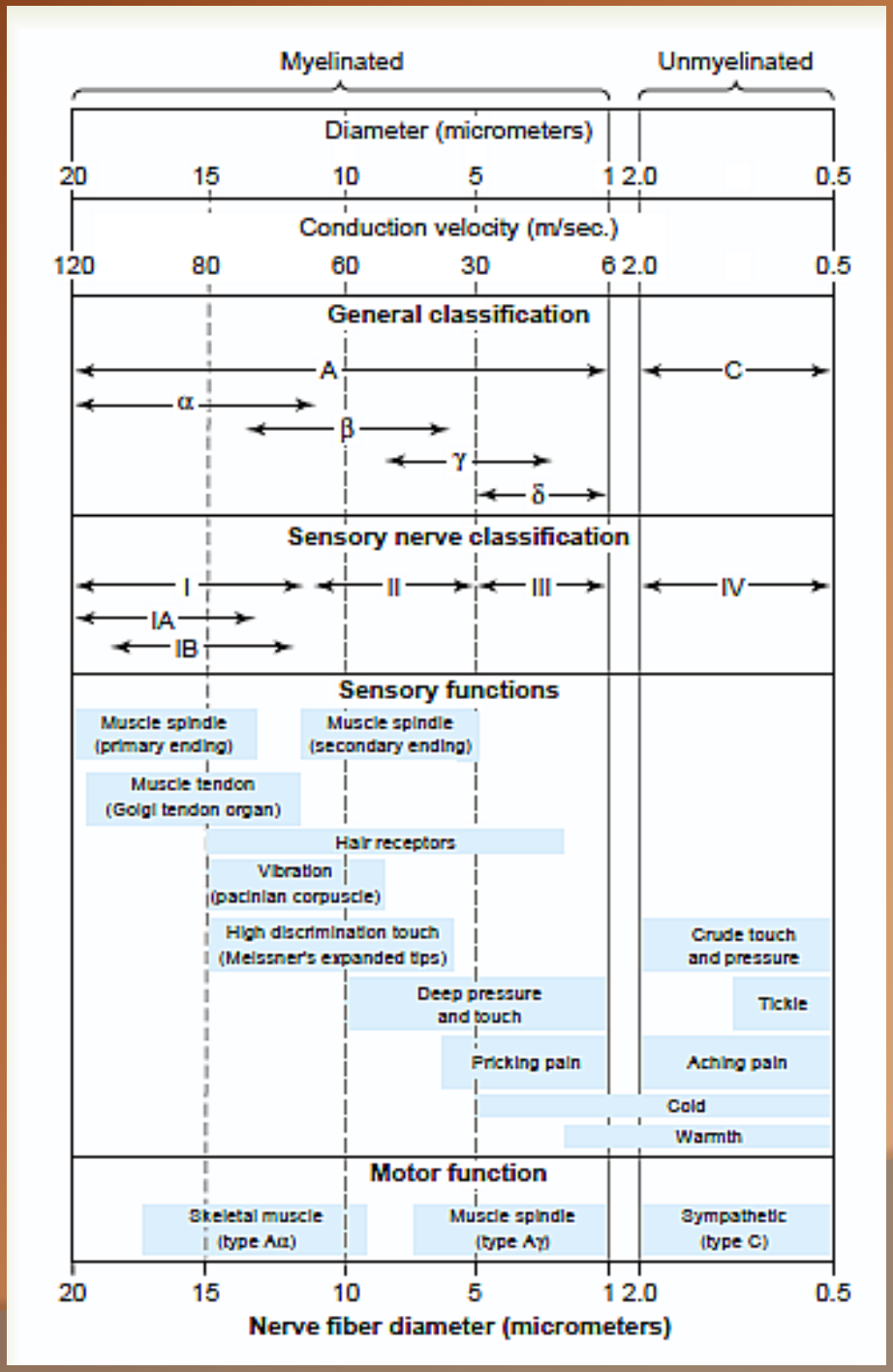
Types of Nerve Fibers

- Nerve fibers are classified according to their conduction velocity, which depends on the size of the fibers and the presence or absence of myelination.
- Conduction is increased by the fiber diameter (Briefly, the larger the fiber, the higher the conduction velocity).
- Conduction velocity also is increased by the presence of a myelin sheath around the nerve fiber. Thus, large myelinated nerve fibers have the fastest conduction velocities, and small unmyelinated nerve fibers have the slowest conduction velocities.

- Two classification systems, which are based on differences in conduction velocity, are used:
  - The first system applies to *both* sensory (afferent) and motor (efferent) nerve fibers and uses a lettered nomenclature of A, B, and C.
  - The second system applies *only* to sensory nerve fibers and uses a Roman numeral nomenclature of I, II, III, and IV.

Table 3-1. Classification of Nerve Fibers

Classification	Type of Nerve Fiber	Example	Relative Diameter	Relative Conduction Velocity	Myelination
Sensory and Motor	A alpha (Aα)	α Motoneurons	Largest	Fastest	Yes
	A beta (Aβ)	Touch, pressure	Medium	Medium	Yes
	A gamma (Aγ)	γ Motoneurons to muscle spindles (intrafusal fibers)	Medium	Medium	Yes
	A delta (Aδ)	Touch, pressure, temperature, pain	Small	Medium	Yes
	B	Preganglionic autonomic nerves	Small	Medium	Yes
	C	Slow pain; postganglionic autonomic nerves; olfaction	Smallest	Slowest	No
Sensory Only	Ia	Muscle spindle afferents	Largest	Fastest	Yes
	Ib	Golgi tendon organ afferents	Largest	Fastest	Yes
	II	Secondary afferents of muscle spindles; touch, pressure	Medium	Medium	Yes
	III	Touch, pressure, fast pain, temperature	Small	Medium	Yes
	IV	Pain, temperature; olfaction	Smallest	Slowest	No


Myelinated
Unmyelinated
Diameter (micrometers)
20 15 10 5 1 2.0 0.5
Conduction velocity (m/sec.)
120 80 60 30 6 2.0 0.5
General classification
A
C
α
β
γ
δ
Sensory nerve classification
I
II
III
IV
IA
IB
Sensory functions
Muscle spindle (primary ending)
Muscle spindle (secondary ending)
Muscle tendon (Golgi tendon organ)
Hair receptors
Vibration (pacinian corpuscle)
High discrimination touch (Meissner's expanded tips)
Crude touch and pressure
Deep pressure and touch
Tickle
Pricking pain
Aching pain
Cold
Warmth
Motor function
Skeletal muscle (type Aα)
Muscle spindle (type Aγ)
Sympathetic (type C)
20 15 10 5 1 2.0 0.5
Nerve fiber diameter (micrometers)

Sensory

- General somatic senses – include touch, pain, vibration, pressure, temperature
- Proprioceptive senses – detect stretch in tendons and muscle provide information on body position, orientation and movement of body in space
- Special Senses – hearing, balance, vision, olfaction (smell), gustation (taste)

- There are five major divisions of these sensory receptors based on stimuli that they respond to:
  1. Mechanoreceptors
  2. Thermoreceptors
  3. Photoreceptors
  4. Chemoreceptors
  5. Nociceptors

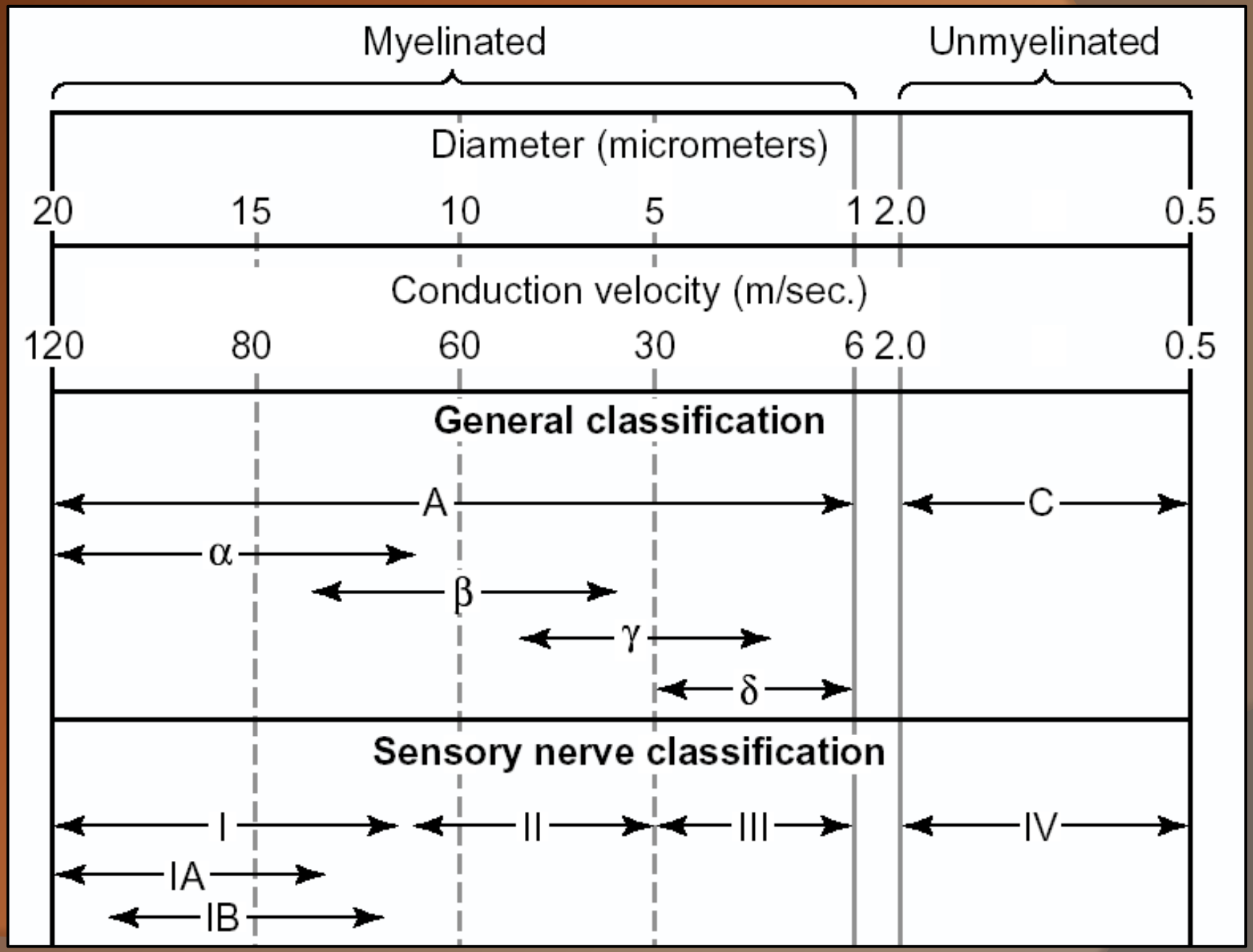
Table 3-2. Types and Examples of Sensory Receptors

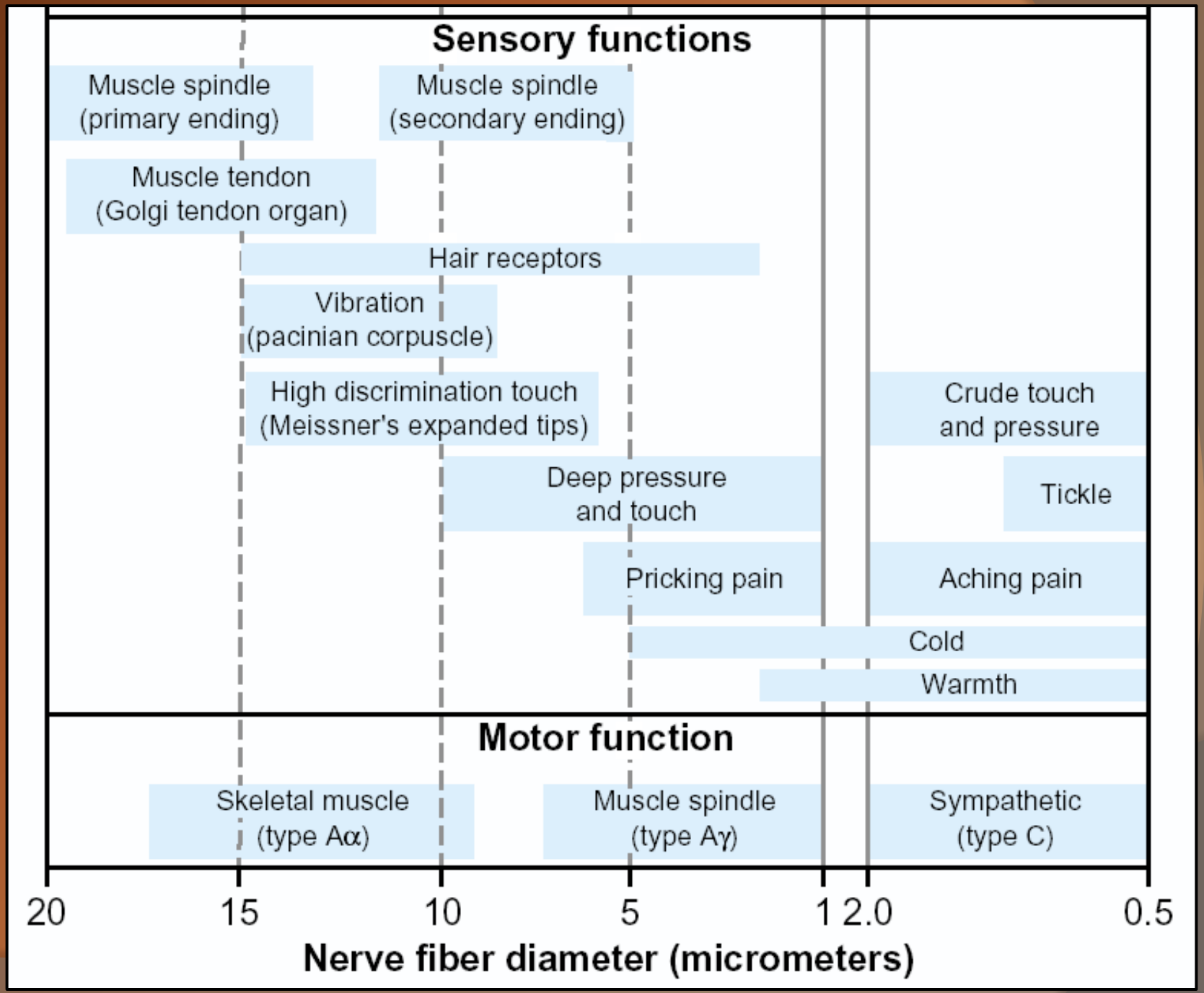
Type of Receptor	Modality	Receptor	Location
Mechanoreceptors	Touch	Pacinian corpuscle	Skin
	Audition	Hair cell	Organ of Corti
	Vestibular	Hair cell	Cupula, semicircular canal
Photoreceptors	Vision	Rods and cones	Retina
Chemoreceptors	Olfaction	Olfactory receptor	Olfactory mucosa
	Taste	Taste buds	Tongue
	Arterial PO_2		Carotid and aortic bodies
	pH of CSF		Ventrolateral medulla
Thermoreceptors	Temperature	Cold receptors	Skin
		Warm receptors	Skin
Nociceptors	Extremes of pain and temperature	Thermal nociceptors	Skin
		Polymodal nociceptors	Skin

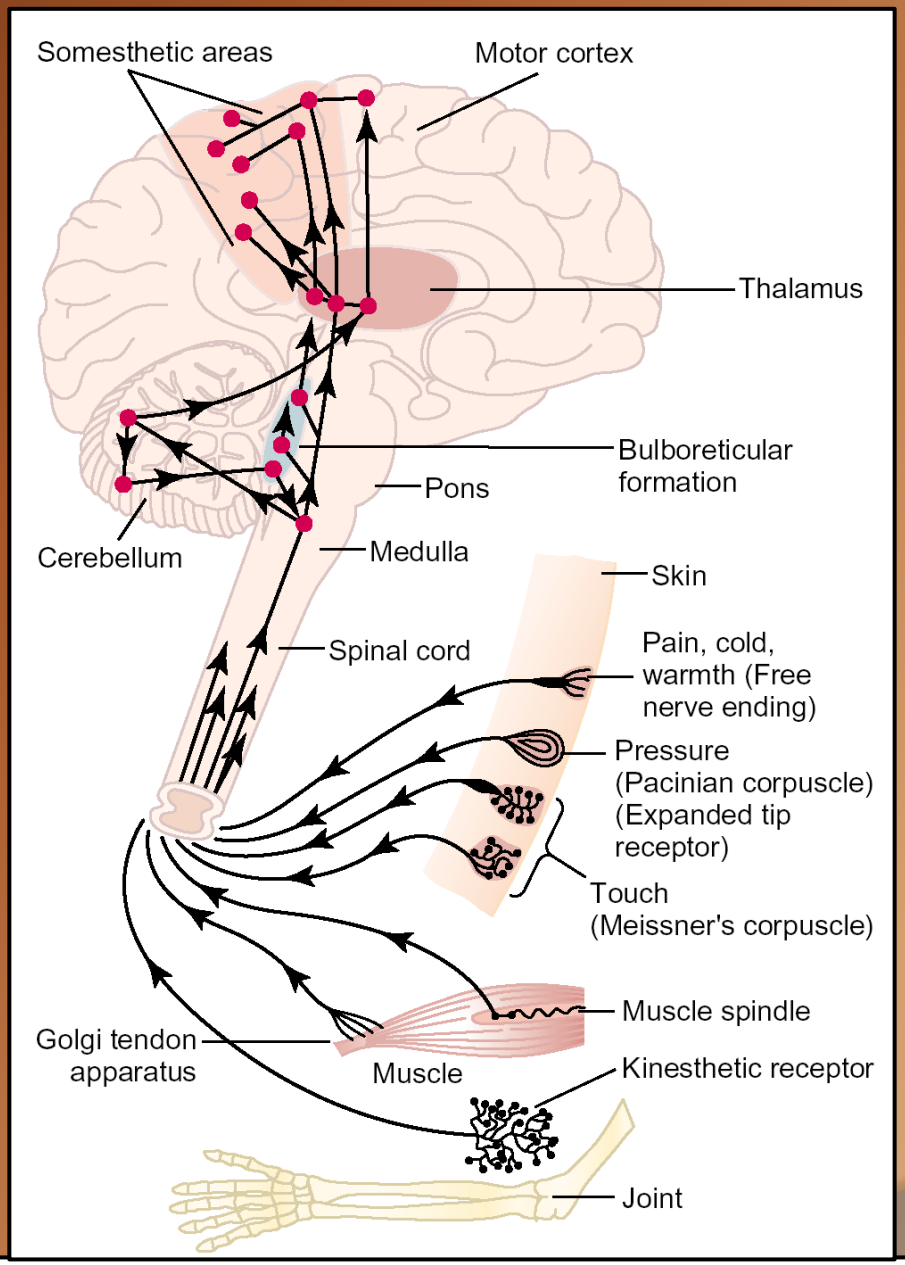
CSF, Cerebrospinal fluid; PO_2, partial pressure of oxygen.

- **Mechanoreceptors** are activated by pressure or changes in pressure.
- Mechanoreceptors include, but are not limited to the;
  - Pacinian corpuscles in subcutaneous tissue
  - Meissner's corpuscles in nonhairy skin (touch)
  - Baroreceptors in the carotid sinus (blood pressure)
  - Hair cells on the organ of Corti (audition) and in the Semicircular canals (vestibular system)

- **Photoreceptors** are activated by light and are involved in vision.
- **Chemoreceptors** are activated by chemicals and are involved in olfaction, taste, and detection of oxygen and carbon dioxide in the control of breathing.
- **Thermoreceptors** are activated by temperature or changes in temperature.
- **Nociceptors** are activated by extremes of pressure, temperature or noxious chemicals.


Myelinated
Unmyelinated
Diameter (micrometers)
20
15
10
5
1
2.0
0.5
Conduction velocity (m/sec.)
120
80
60
30
6
2.0
0.5
General classification
A
C
α
β
γ
δ
Sensory nerve classification
I
II
III
IV
IA
IB


Sensory functions
Muscle spindle (primary ending)
Muscle spindle (secondary ending)
Muscle tendon (Golgi tendon organ)
Hair receptors
Vibration (pacinian corpuscle)
High discrimination touch (Meissner's expanded tips)
Crude touch and pressure
Deep pressure and touch
Tickle
Pricking pain
Aching pain
Cold
Warmth
Motor function
Skeletal muscle (type Aα)
Muscle spindle (type Aγ)
Sympathetic (type C)
20
15
10
5
1
2.0
0.5
Nerve fiber diameter (micrometers)



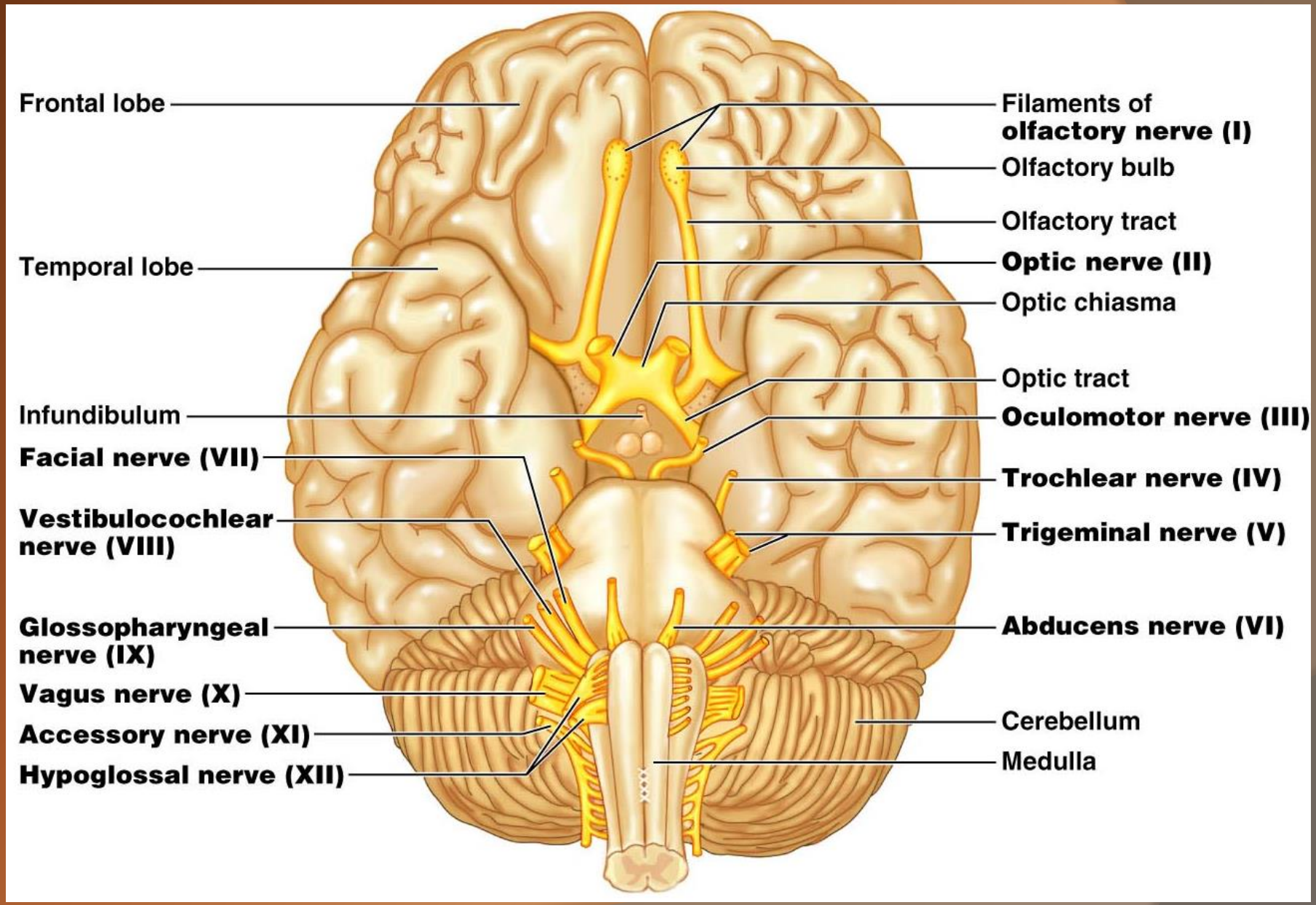
Sensory fibers which carry impulses from skin, skeletal muscles, and joints

Motor

- General somatic motor
  - Signals contraction of skeletal muscles
  - Under our voluntary control
- Visceral motor
  - Makes up autonomic nervous system (ANS)
  - Regulates the contraction of smooth and cardiac muscle, controls function of visceral organs

Cranial Nerves

- The human body contains **12 pairs** of cranial nerves
- Cranial nerves I and II attach to the forebrain
  - All others attach to the brain stem
- Primarily serve head and neck structures
  - The vagus nerve (X) extends into the abdomen


Frontal lobe
Temporal lobe
Infundibulum
Facial nerve (VII)
Vestibulocochlear nerve (VIII)
Glossopharyngeal nerve (IX)
Vagus nerve (X)
Accessory nerve (XI)
Hypoglossal nerve (XII)
Filaments of olfactory nerve (I)
Olfactory bulb
Olfactory tract
Optic nerve (II)
Optic chiasma
Optic tract
Oculomotor nerve (III)
Trochlear nerve (IV)
Trigeminal nerve (V)
Abducens nerve (VI)
Cerebellum
Medulla

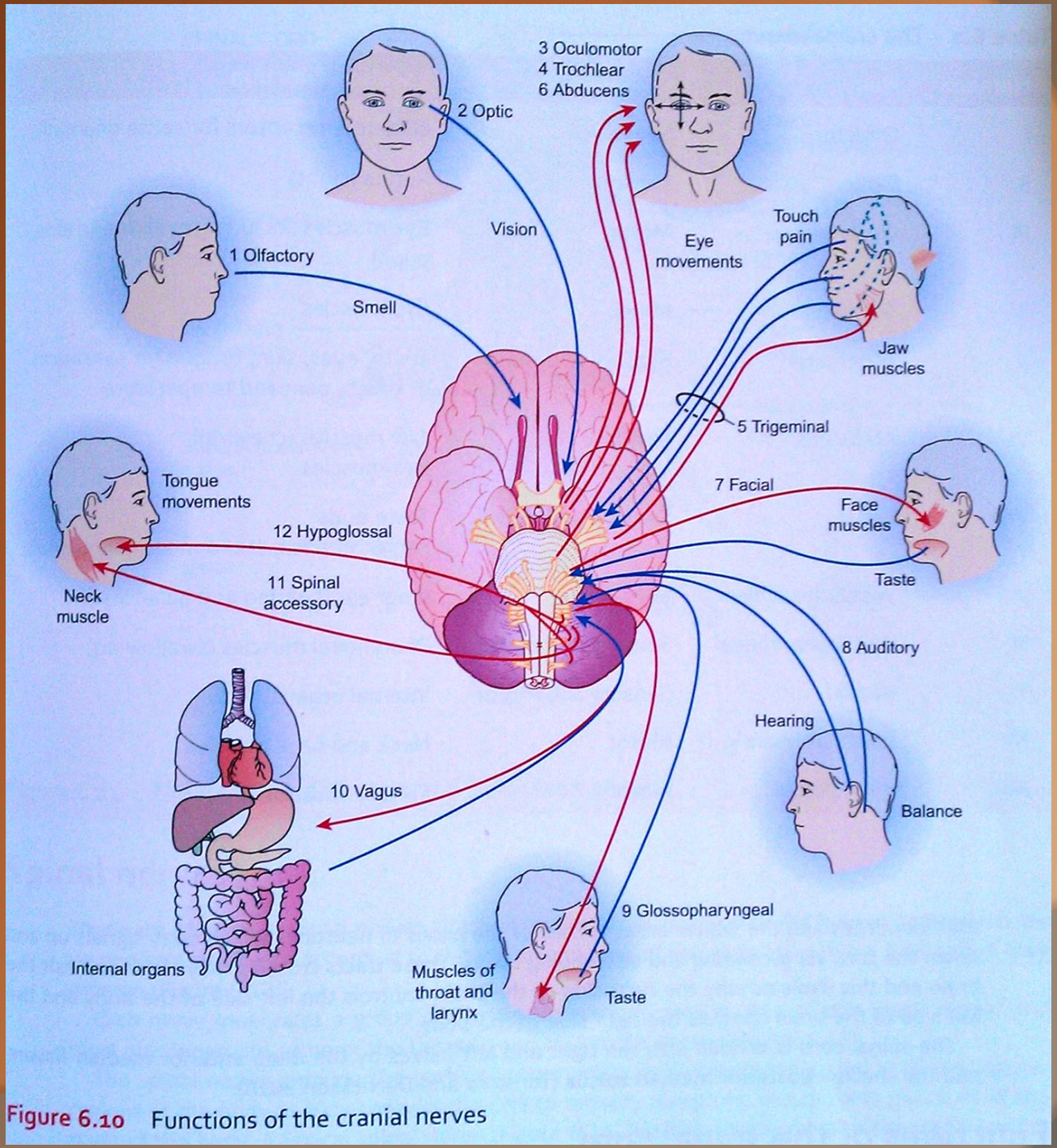


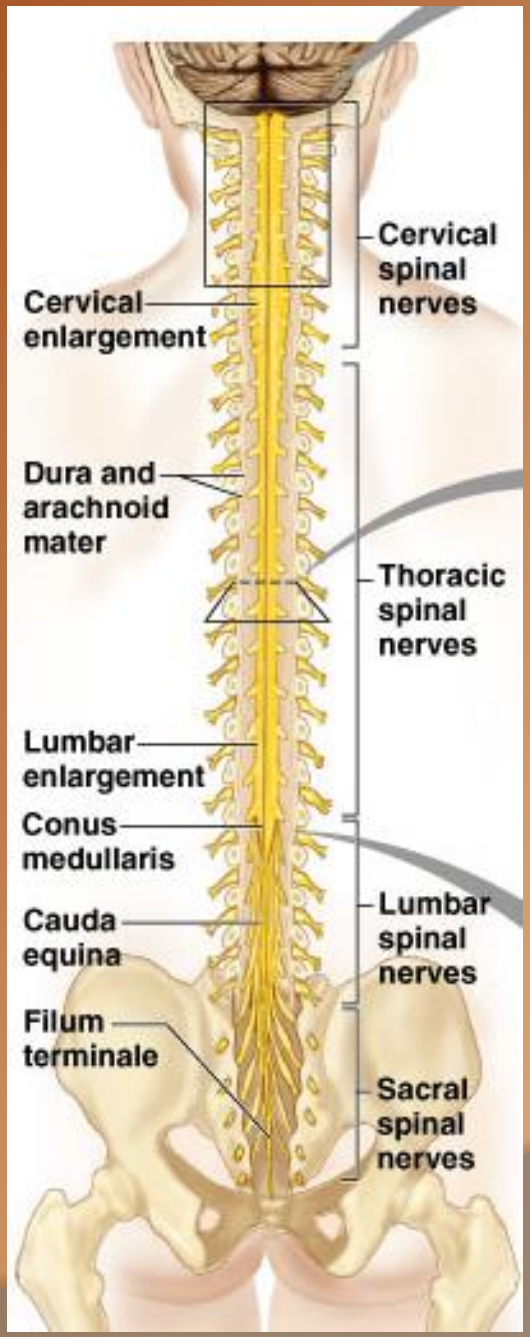
Figure 6.10 Functions of the cranial nerves

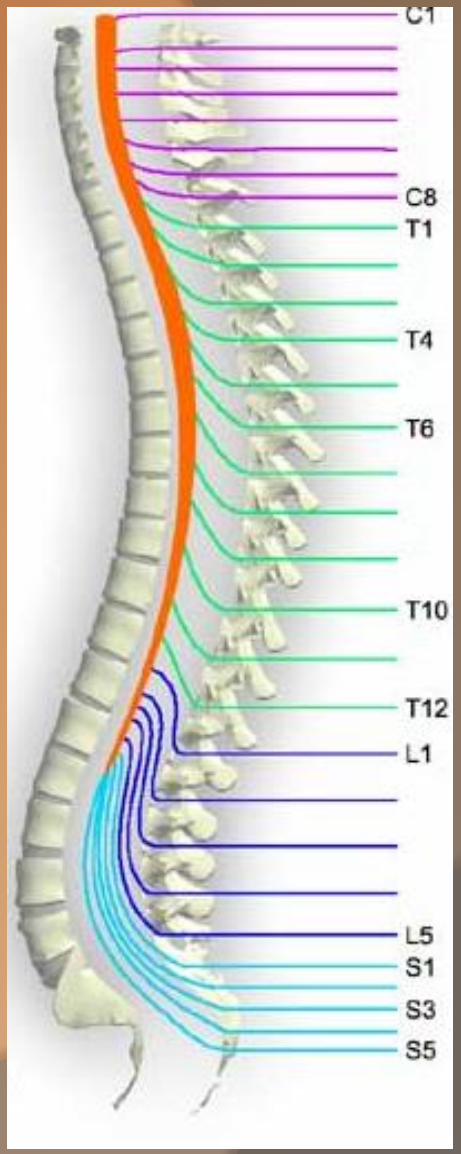
Table 6.1 The cranial nerves

Number	Name	Components	Location/Function
I	Olfactory	Sensory	Olfactory receptors for sense of smell
II	Optic	Sensory	Retina (sight)
III	Oculomotor	Motor	Eye muscles (including eyelids and lens, pupil)
IV	Trochlear	Motor	Eye muscles
V	Trigeminal	Sensory and motor	Teeth, eyes, skin, tongue for sensation of touch, pain and temperature
VI	Abducens	Motor	Jaw muscles (chewing) Eye muscles
VII	Facial	Sensory and motor	Taste buds Facial muscles, tear and salivary glands
VIII	Vestibulocochlear	Sensory	Inner ear (hearing and balance)
IX	Glossopharyngeal	Sensory and motor	Pharyngeal muscles (swallowing)
X	Vagus	Sensory and motor	Internal organs
XI	Spinal accessory	Motor	Neck and back muscles
XII	Hypoglossal	Motor	Tongue muscles

Spinal cord

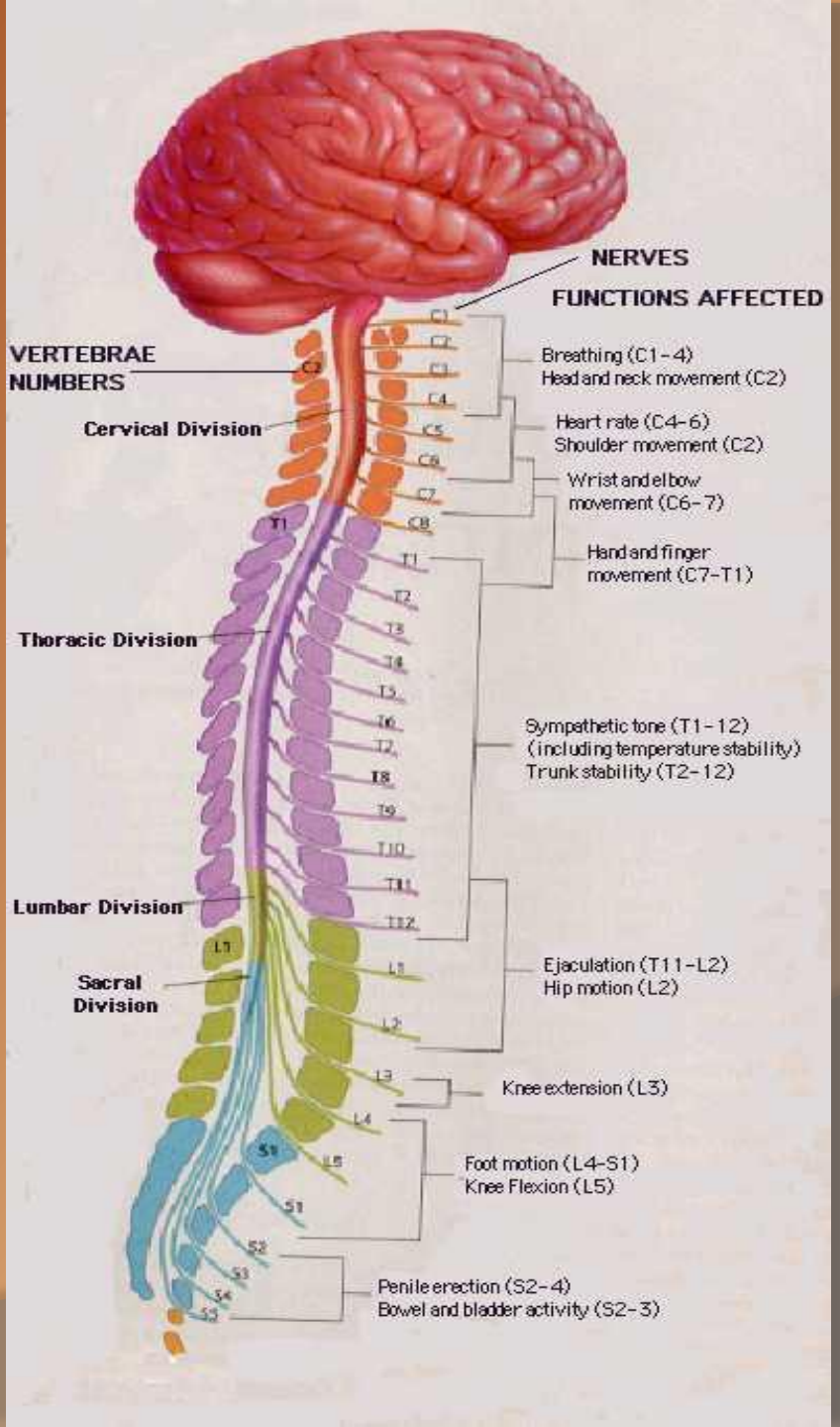
- The spinal cord is the most caudal portion of the CNS, extending from the base of the skull to the first lumbar vertebra.
- The spinal cord is segmented, with **31 pairs** of spinal nerves that contain both **sensory** (afferent) nerves and **motor** (efferent) nerves.



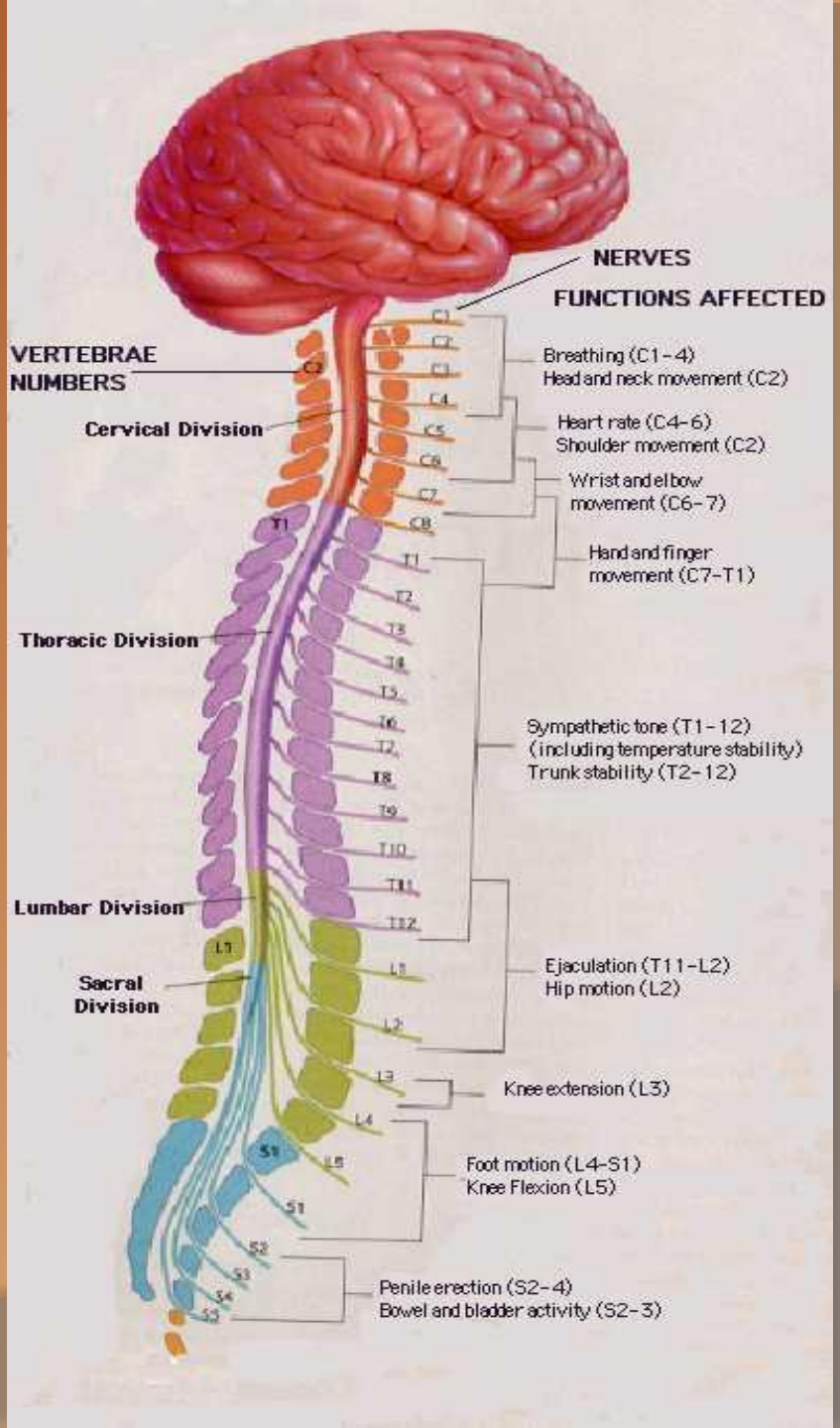


Functions:

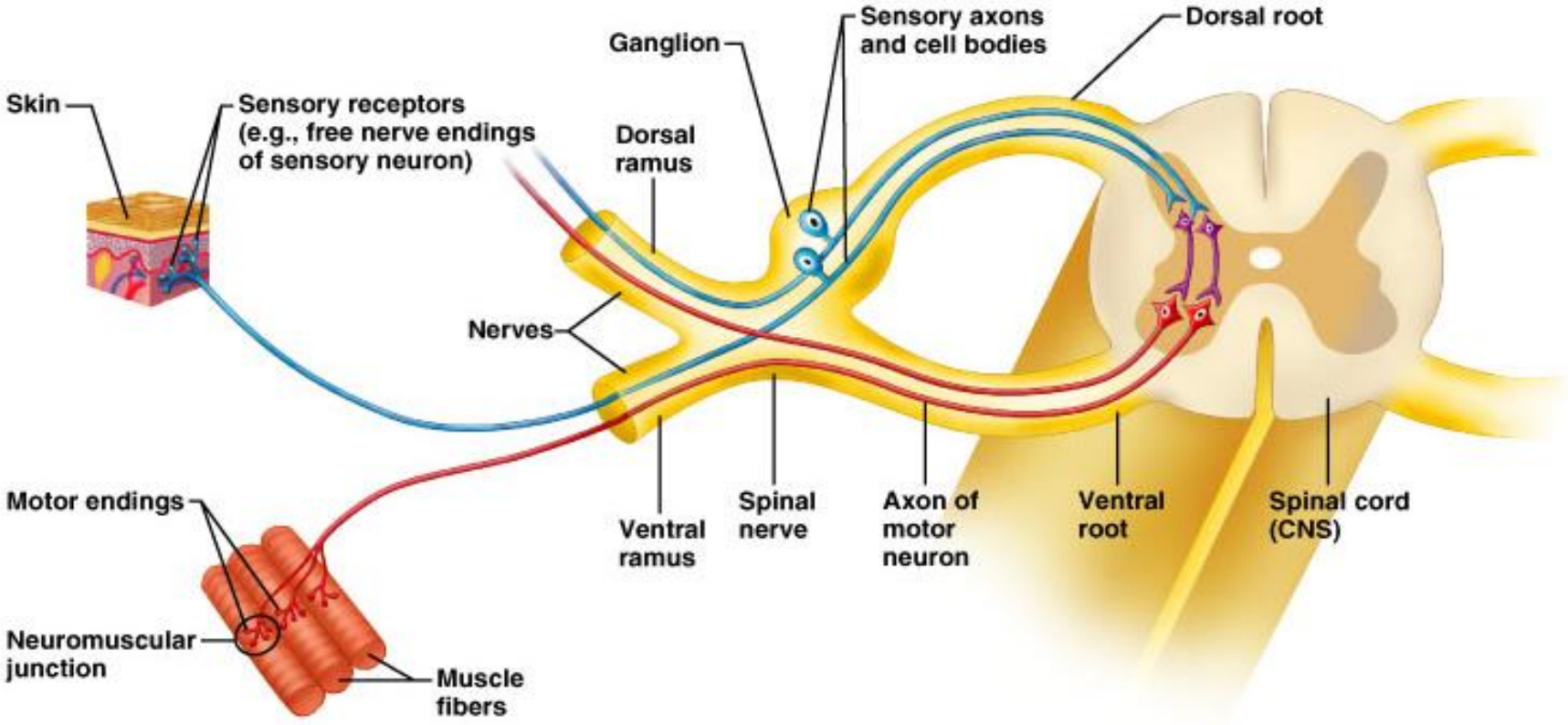
1. Sensory and motor innervation of entire body inferior to the head through the spinal nerves
2. Two-way conduction pathway between the body and the brain
3. Major center for reflexes



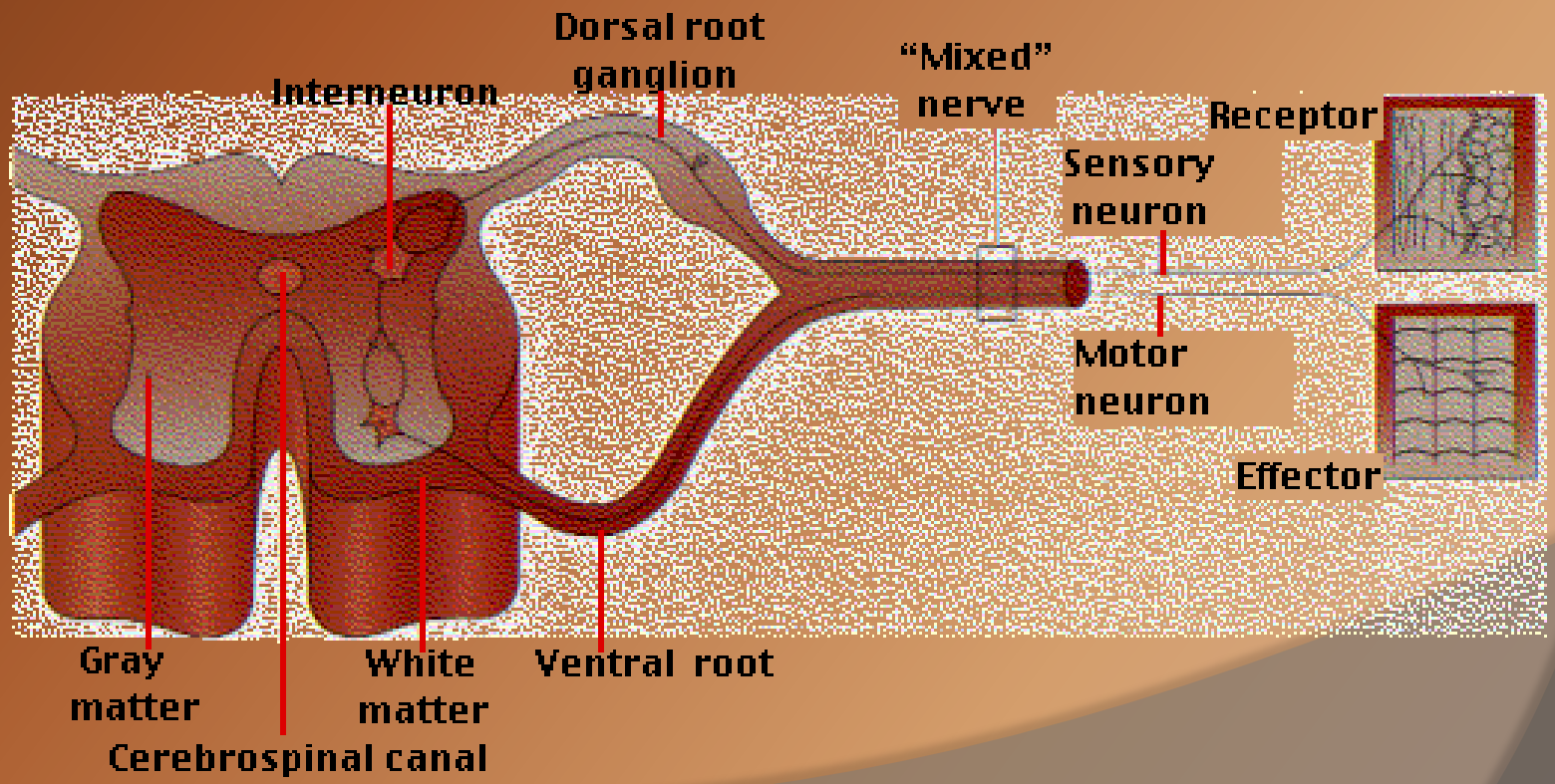
- In general, the eight cervical nerves (C1-8) control the muscles and glands and receive sensory input from the neck, shoulder, arm, and hand.
- The 12 thoracic nerves (T1-12) are associated with the chest and abdominal walls.
- The five lumbar nerves (L1-5) are associated with the hip and leg, and the five sacral nerves (S1-5) are associated with the genitals and lower digestive tract.



Basic Anatomical Scheme of the PNS in the Region of a Spinal Nerve



- Sensory nerves carry information to the spinal cord from the skin, joints, muscles, and visceral organs in the periphery via dorsal root and cranial nerve ganglia



- Motor nerves carry information from the spinal cord to the periphery and include both somatic motor nerves (which innervate skeletal muscle) and motor nerves of the autonomic nervous system (which innervate cardiac muscle, smooth muscle, glands, and secretory cells)