PHYSIOLOGY OF NERVOUS TISSUE

By

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2^{nd} Year/Lecture 1

OVERVIEW OF NERVOUS SYSTEM

- endocrine and nervous system maintain internal coordination
  - endocrine system - communicates by means of chemical messengers (hormones) secreted into to the blood
  - nervous system - employs electrical and chemical means to send messages from cell to cell

- nervous system carries out its task in three basic steps:
  - sense organs receive information about changes in the body and the external environment, and transmits coded messages to the spinal cord and the brain
  - brain and spinal cord processes this information, relates it to past experiences, and determine what response is appropriate to the circumstances
  - brain and spinal cord issue commands to muscles and gland cells to carry out such a response

TWO MAJOR ANATOMICAL SUBDIVISIONS OF NERVOUS SYSTEM

- central nervous system (CNS)
  - brain and spinal cord enclosed in bony coverings
    - enclosed by cranium and vertebral column
- peripheral nervous system (PNS)
  - all the nervous system except the brain and spinal cord
  - composed of nerves and ganglia
    - nerve – a bundle of nerve fibers (axons) wrapped in fibrous connective tissue
    - ganglion – a knot-like swelling in a nerve where neuron cell bodies are concentrated

SUBDIVISIONS OF NERVOUS SYSTEM

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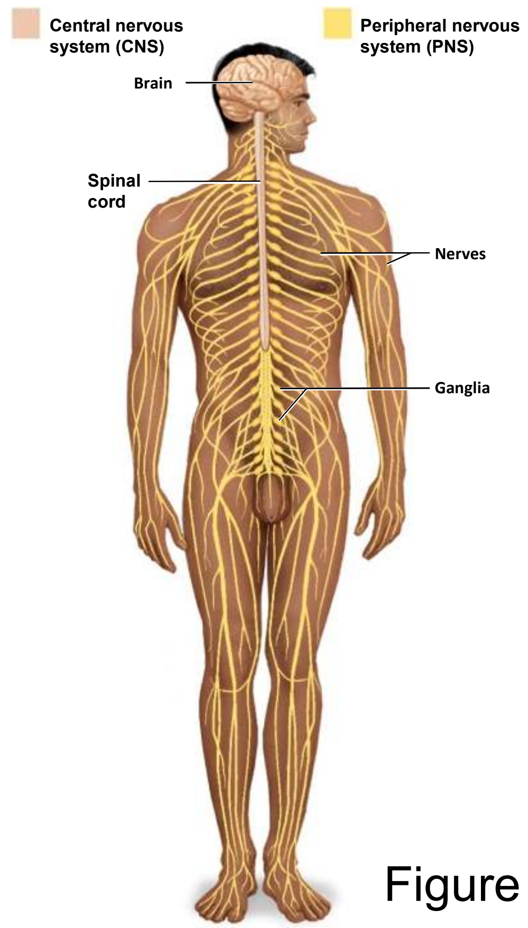

Figure 12.1

Sensory Divisions of PNS

- sensory (afferent) division – carries sensory signals from various receptors to the CNS
  - informs the CNS of stimuli within or around the body
  - somatic sensory division – carries signals from receptors in the skin, muscles, bones, and joints
  - visceral sensory division – carries signals from the viscera of the thoracic and abdominal cavities
    - heart, lungs, stomach, and urinary bladder

Motor Divisions of PNS

- motor (efferent) division – carries signals from the CNS to gland and muscle cells that carry out the body's response
    - effectors – cells and organs that respond to commands from the CNS
  - somatic motor division – carries signals to skeletal muscles
    - output produces muscular contraction as well as somatic reflexes – involuntary muscle contractions
  - visceral motor division (autonomic nervous system) - carries signals to glands, cardiac muscle, and smooth muscle
    - involuntary, and responses of this system and its receptors are visceral reflexes
    - sympathetic division
      - tends to arouse body for action
      - accelerating heart beat and respiration, while inhibiting digestive and urinary systems
    - parasympathetic division
      - tends to have calming effect
      - slows heart rate and breathing
      - stimulates digestive and urinary systems

Subdivisions of Nervous System

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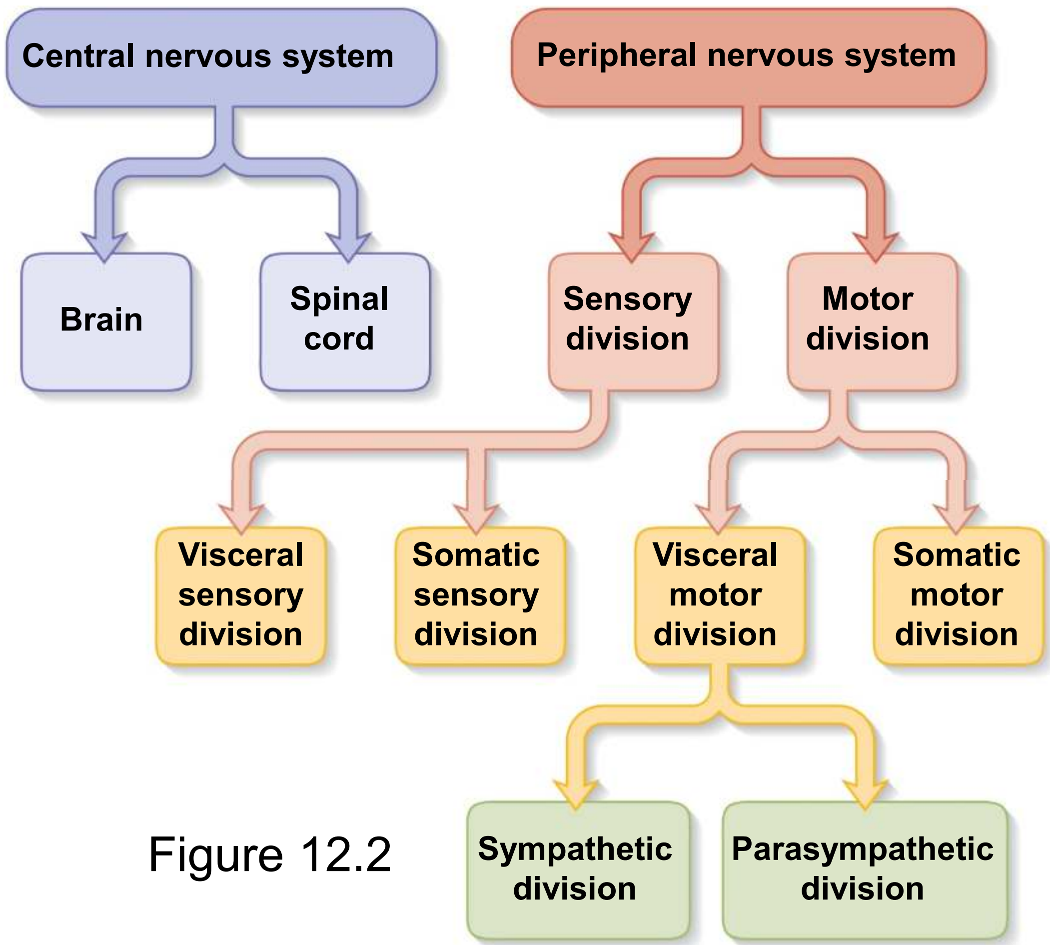

Figure 12.2

UNIVERSAL PROPERTIES OF NEURONS

- excitability (irritability)
  - respond to environmental changes called stimuli
- conductivity
  - neurons respond to stimuli by producing electrical signals that are quickly conducted to other cells at distant locations
- secretion
  - when electrical signal reaches end of nerve fiber, a chemical neurotransmitter is secreted that crosses the gap and stimulates the next cell

FUNCTIONAL TYPES OF NEURONS

- sensory (afferent) neurons
  - specialized to detect stimuli
  - transmit information about them to the CNS
    - begin in almost every organ in the body and end in CNS
    - afferent – conducting signals toward CNS
- interneurons (association) neurons
  - lie entirely within the CNS
  - receive signals from many neurons and carry out the integrative function
    - process, store, and retrieve information and 'make decisions' that determine how the body will respond to stimuli
  - 90% of all neurons are interneurons
  - lie between, and interconnect the incoming sensory pathways, and the outgoing motor pathways of the CNS
- motor (efferent) neuron
  - send signals out to muscles and gland cells (the effectors)
    - motor because most of them lead to muscles
    - efferent neurons conduct signals away from the CNS

FUNCTIONAL CLASSES OF NEURONS

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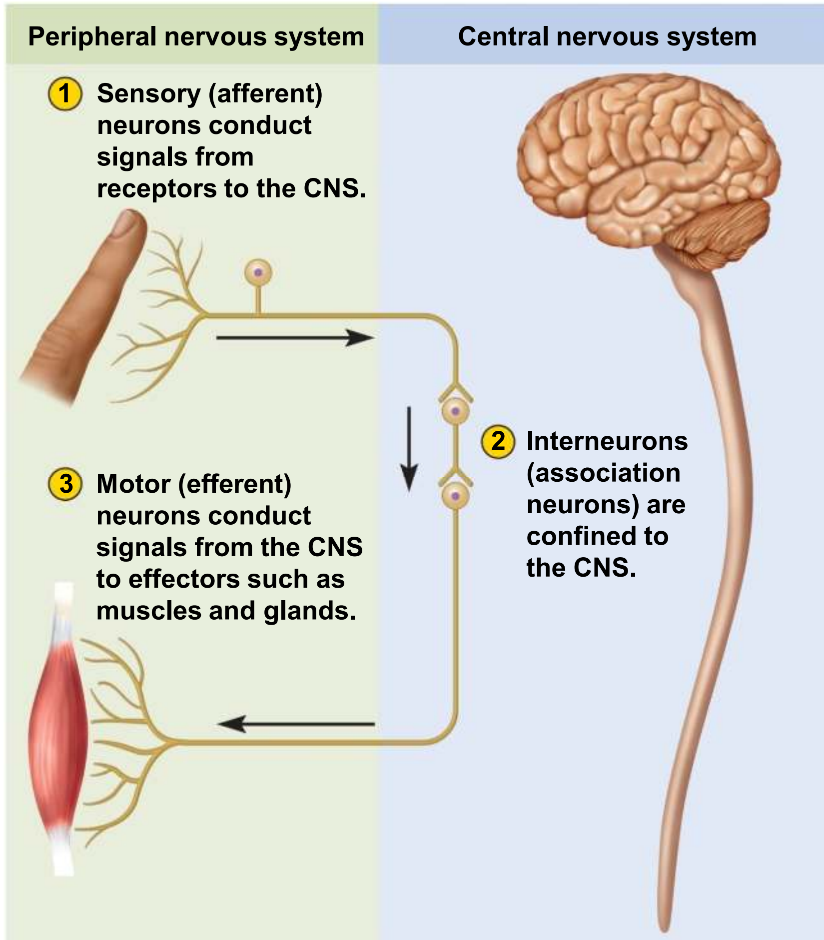

Figure 12.3

STRUCTURE OF A NEURON

- soma – the control center of the neuron
  - also called neurosoma, cell body, or perikaryon
  - has a single, centrally located nucleus with large nucleolus
  - cytoplasm contains mitochondria, lysosomes, a Golgi complex, numerous inclusions, and extensive rough endoplasmic reticulum and cytoskeleton
  - cytoskeleton consists of dense mesh of microtubules and neurofibrils (bundles of actin filaments)
    - compartmentalizes rough ER into dark staining Nissl bodies
  - no centrioles – no further cell division
  - inclusions – glycogen granules, lipid droplets, melanin, and lipofuscin (golden brown pigment produced when lysosomes digest worn-out organelles)
    - lipofuscin accumulates with age
    - wear-and-tear granules
    - most abundant in old neurons

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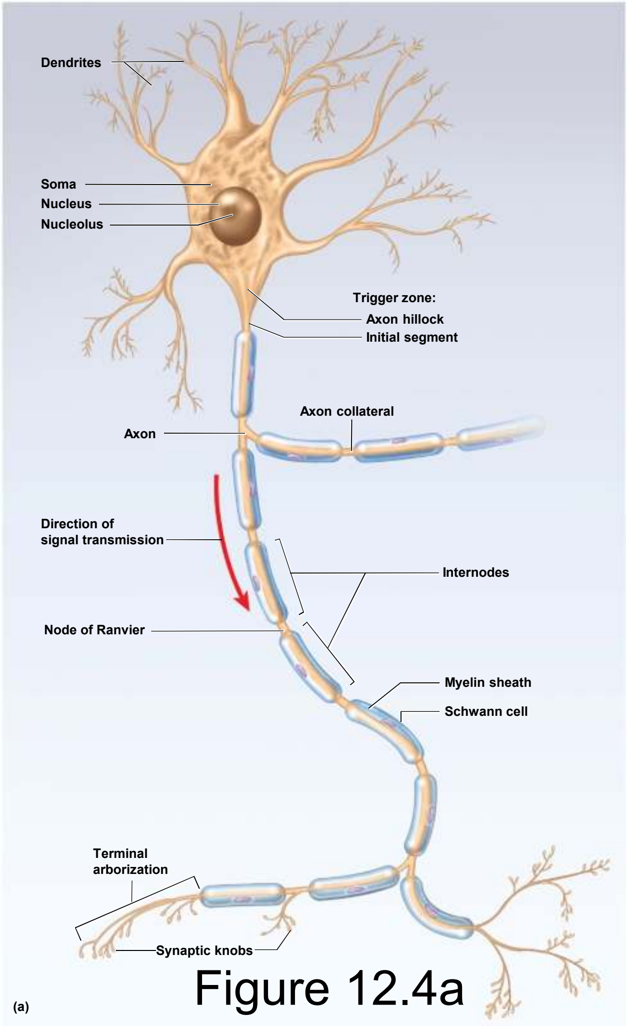

Figure 12.4a

Structure of a Neuron

- dendrites – vast number of branches coming from a few thick branches from the soma
  - resemble bare branches of a tree in winter
  - primary site for receiving signals from other neurons
  - the more dendrites the neuron has, the more information it can receive and incorporate into decision making
  - provide precise pathway for the reception and processing of neural information

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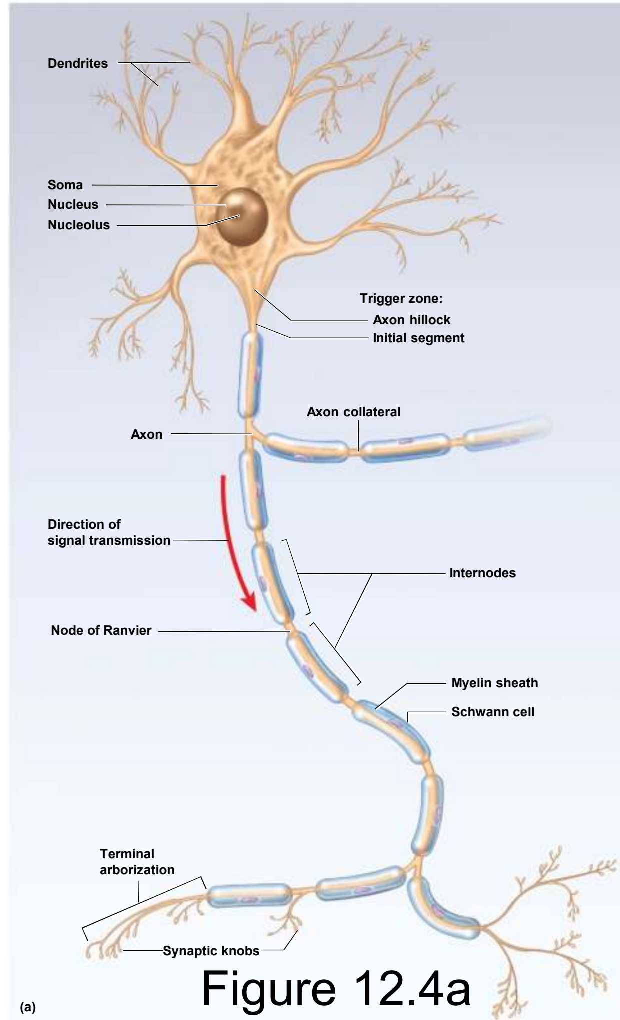

Figure 12.4a

Structure of a Neuron

- axon (nerve fiber) – originates from a mound on one side of the soma called the axon hillock
  - cylindrical, relatively unbranched for most of its length
    - axon collaterals – branches of axon
  - branch extensively on distal end
  - specialized for rapid conduction of nerve signals to points remote to the soma
  - axoplasm – cytoplasm of axon
  - axolemma – plasma membrane of axon
  - only one axon per neuron
  - Schwann cells and myelin sheath enclose axon
  - distal end, axon has terminal arborization – extensive complex of fine branches
    - synaptic knob (terminal button) – little swelling that forms a junction (synapse) with the next cell
    - contains synaptic vesicles full of neurotransmitter

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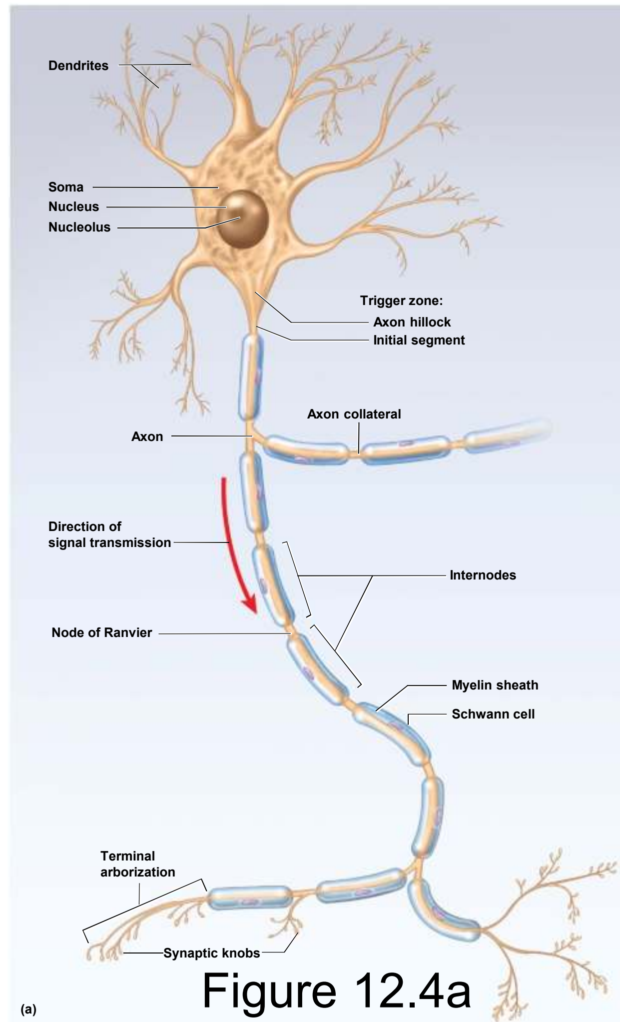

Figure 12.4a

VARIATION IN NEURON STRUCTURE

- multipolar neuron
  - one axon and multiple dendrites
  - most common
  - most neurons in the brain and spinal cord
- bipolar neuron
  - one axon and one dendrite
  - olfactory cells, retina, inner ear
- unipolar neuron
  - single process leading away from the soma
  - sensory from skin and organs to spinal cord
- anaxonic neuron
  - many dendrites but no axon
  - help in visual processes

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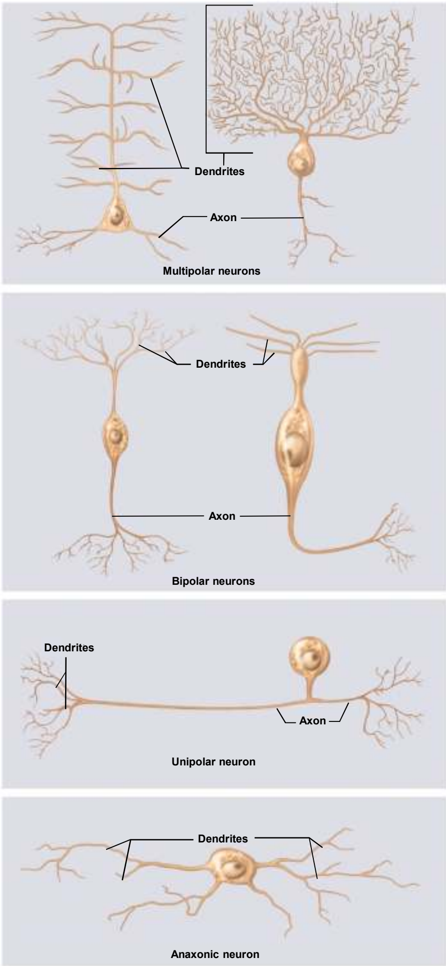

Figure 12.5

AXONAL TRANSPORT

- many proteins made in soma must be transported to axon and axon terminal
  - to repair axolemma, serve as gated ion channel proteins, as enzymes or neurotransmitters

- axonal transport – two-way passage of proteins, organelles, and other material along an axon
  - anterograde transport – movement down the axon away from soma
  - retrograde transport – movement up the axon toward the soma

- microtubules guide materials along axon
  - motor proteins (kinesin and dynein) carry materials "on their backs" while they "crawl" along microtubules
    - kinesin – motor proteins in anterograde transport
    - dynein – motor proteins in retrograde transport

TWO TYPES OF AXONAL TRANSPORT FAST AND SLOW

- fast axonal transport – occurs at a rate of 20 – 400 mm/day
  - fast anterograde transport (up to 400 mm/day)
    - organelles, enzymes, synaptic vesicles and small molecules
  - fast retrograde transport
    - for recycled materials and pathogens - rabies, herpes simplex, tetanus, polio viruses
      - delay between infection and symptoms is time needed for transport up the axon
- slow axonal transport or axoplasmic flow - 0.5 to 10 mm/day
  - always anterograde
  - moves enzymes, cytoskeletal components, and new axoplasm down the axon during repair and regeneration of damaged axons
  - damaged nerve fibers regenerate at a speed governed by slow axonal transport

NEUROGLIAL CELLS

- about a trillion (10^{12}) neurons in the nervous system
- neuroglia outnumber the neurons by as much as 50 to 1
- neuroglia or glial cells
  - support and protect the neurons
  - bind neurons together and form framework for nervous tissue
  - in fetus, guide migrating neurons to their destination
  - if mature neuron is not in synaptic contact with another neuron is covered by glial cells
    - prevents neurons from touching each other
    - gives precision to conduction pathways

SIX TYPES OF NEUROGLIAL CELLS

- four types occur only in CNS
  - oligodendrocytes
    - form myelin sheaths in CNS
    - each arm-like process wraps around a nerve fiber forming an insulating layer that speeds up signal conduction
  - ependymal cells
    - lines internal cavities of the brain
    - cuboidal epithelium with cilia on apical surface
    - secretes and circulates cerebrospinal fluid (CSF)
      - clear liquid that bathes the CNS
  - microglia
    - small, wandering macrophages formed white blood cell called monocytes
    - thought to perform a complete checkup on the brain tissue several times a day
    - wander in search of cellular debris to phagocytize

SIX TYPES OF NEUROGLIAL CELLS

- four types occur only in CNS
  - astrocytes
    - most abundant glial cell in CNS
    - cover entire brain surface and most nonsynaptic regions of the neurons in the gray matter of the CNS
    - diverse functions
      - form a supportive framework of nervous tissue
      - have extensions (perivascular feet) that contact blood capillaries that stimulate them to form a tight seal called the blood-brain barrier
      - convert blood glucose to lactate and supply this to the neurons for nourishment
      - nerve growth factors secreted by astrocytes promote neuron growth and synapse formation
      - communicate electrically with neurons and may influence synaptic signaling
      - regulate chemical composition of tissue fluid by absorbing excess neurotransmitters and ions
      - astrocytosis or sclerosis – when neuron is damaged, astrocytes form hardened scar tissue and fill space formerly occupied by the neuron

SIX TYPES OF NEUROGLIAL CELLS

- two types occur only in PNS
  - Schwann cells
    - envelope nerve fibers in PNS
    - wind repeatedly around a nerve fiber
    - produces a myelin sheath similar to the ones produced by oligodendrocytes in CNS
    - assist in the regeneration of damaged fibers
  - satellite cells
    - surround the neurosomas in ganglia of the PNS
    - provide electrical insulation around the soma
    - regulate the chemical environment of the neurons

NEUROGLIAL CELLS OF CNS

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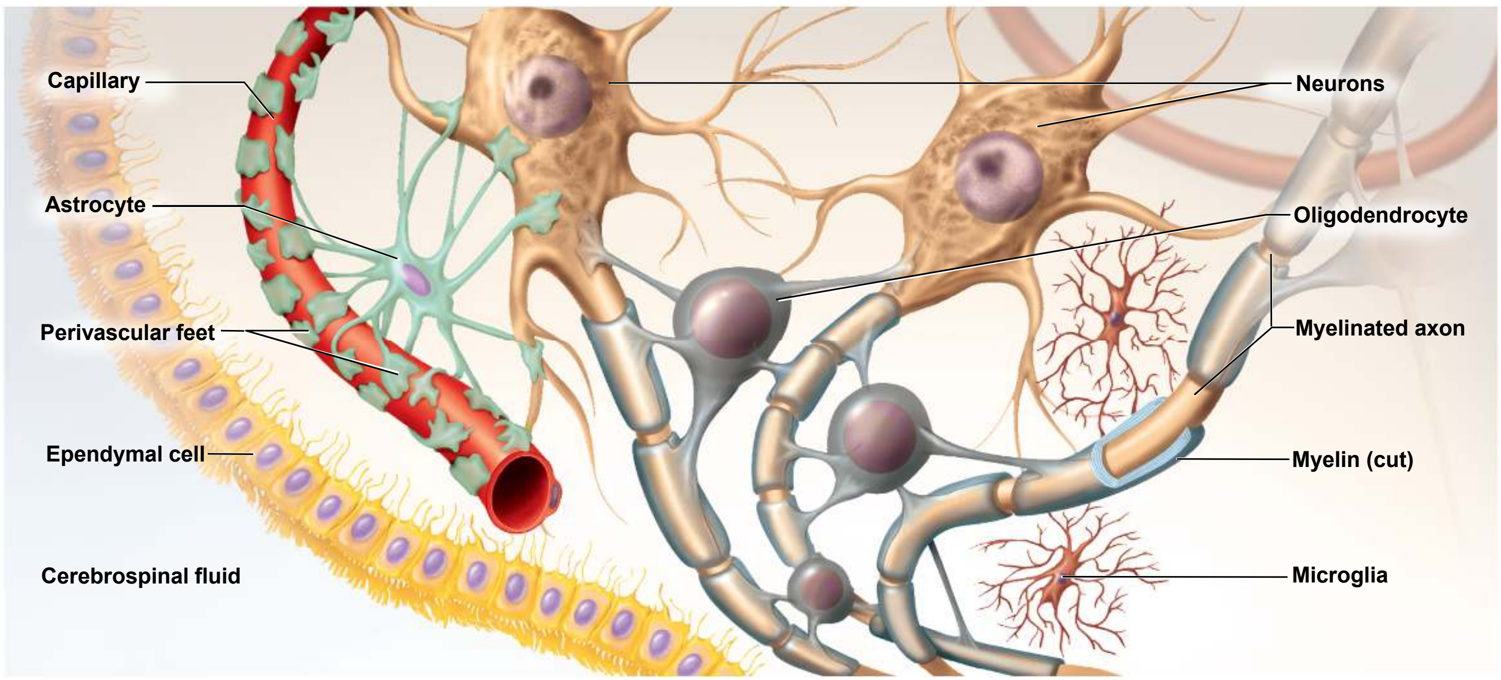

Figure 12.6

GLIAL CELLS AND BRAIN TUMORS

- tumors - masses of rapidly dividing cells
  - mature neurons have little or no capacity for mitosis and seldom form tumors
- brain tumors arise from:
  - meninges (protective membranes of CNS)
  - by metastasis from non-neuronal tumors in other organs
  - most come from glial cells that are mitotically active throughout life
- gliomas grow rapidly and are highly malignant
  - blood-brain barrier decreases effectiveness of chemotherapy
  - treatment consists of radiation or surgery

MYELIN

- myelin sheath – an insulating layer around a nerve fiber
  - formed by oligodendrocytes in CNS and Schwann cells in PNS
  - consists of the plasma membrane of glial cells
    - 20% protein and 80 % lipid
- myelination – production of the myelin sheath
  - begins the 14th week of fetal development
  - proceeds rapidly during infancy
  - completed in late adolescence
  - dietary fat is important to nervous system development

MYELIN

- in PNS, Schwann cell spirals repeatedly around a single nerve fiber
  - lays down as many as a hundred layers of its own membrane
  - no cytoplasm between the membranes
  - neurilemma – thick outermost coil of myelin sheath
    - contains nucleus and most of its cytoplasm
    - external to neurilemma is basal lamina and a thin layer of fibrous connective tissue – endoneurium
- in CNS – oligodendrocytes reaches out to myelinate several nerve fibers in its immediate vicinity
  - anchored to multiple nerve fibers
  - cannot migrate around any one of them like Schwann cells
  - must push newer layers of myelin under the older ones
    - so myelination spirals inward toward nerve fiber
  - nerve fibers in CNS have no neurilemma or endoneurium

MYELIN

- many Schwann cells or oligodendrocytes are needed to cover one nerve fiber
- myelin sheath is segmented
  - nodes of Ranvier – gap between segments
  - internodes – myelin covered segments from one gap to the next
  - initial segment – short section of nerve fiber between the axon hillock and the first glial cell
  - trigger zone – the axon hillock and the initial segment
    - play an important role in initiating a nerve signal

MYELIN SHEATH IN PNS

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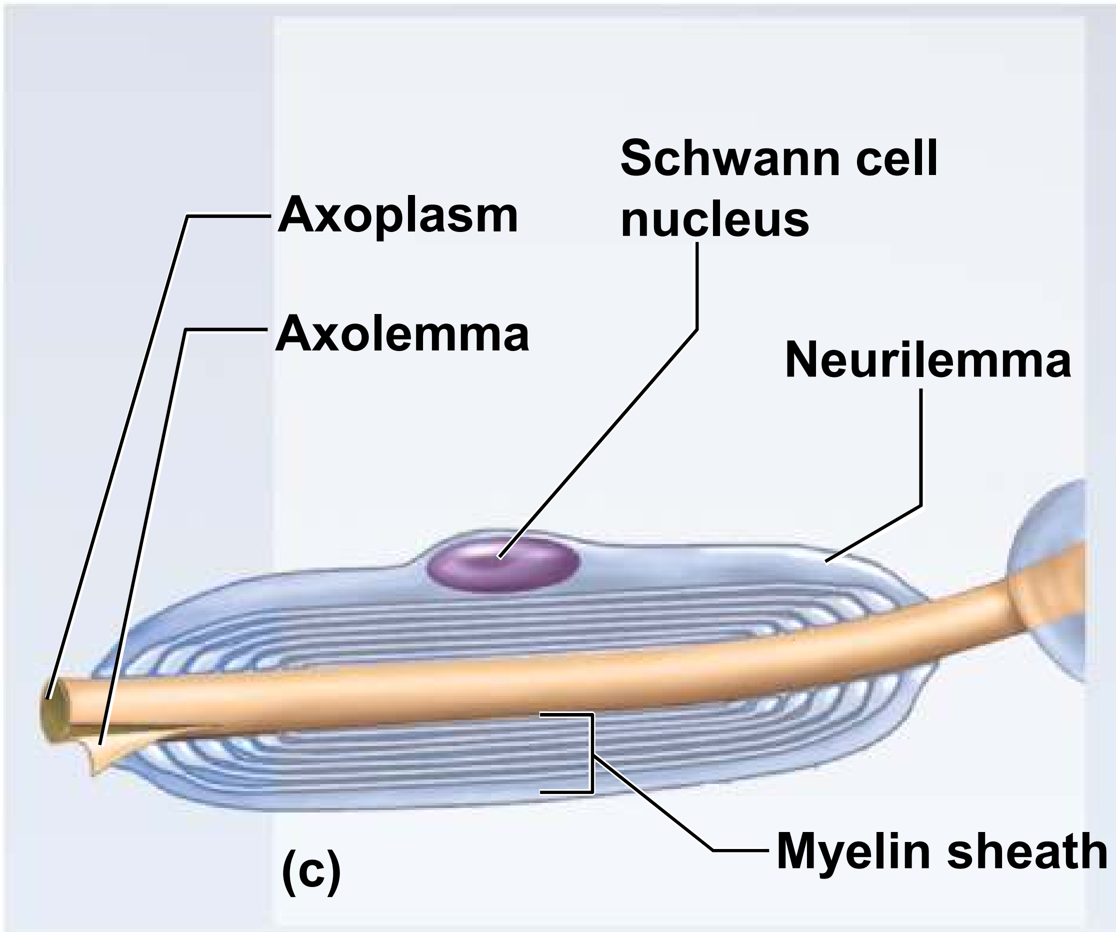

Figure 12.4c

nodes of Ranvier and internodes

MYELINATION IN CNS

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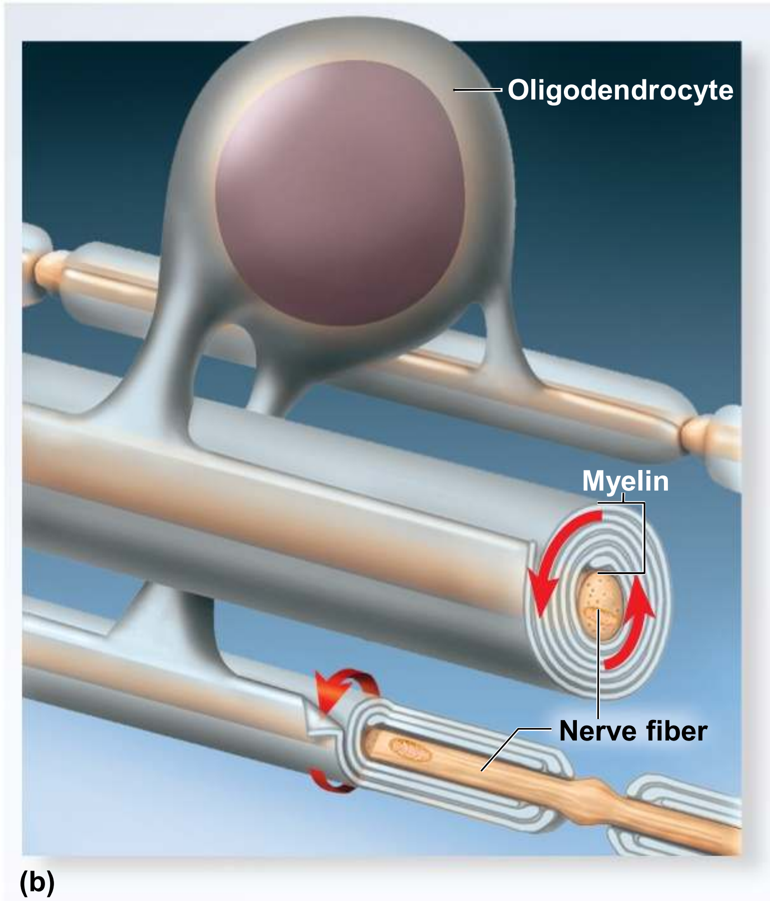

Figure 12.7b

MYELINATION IN PNS

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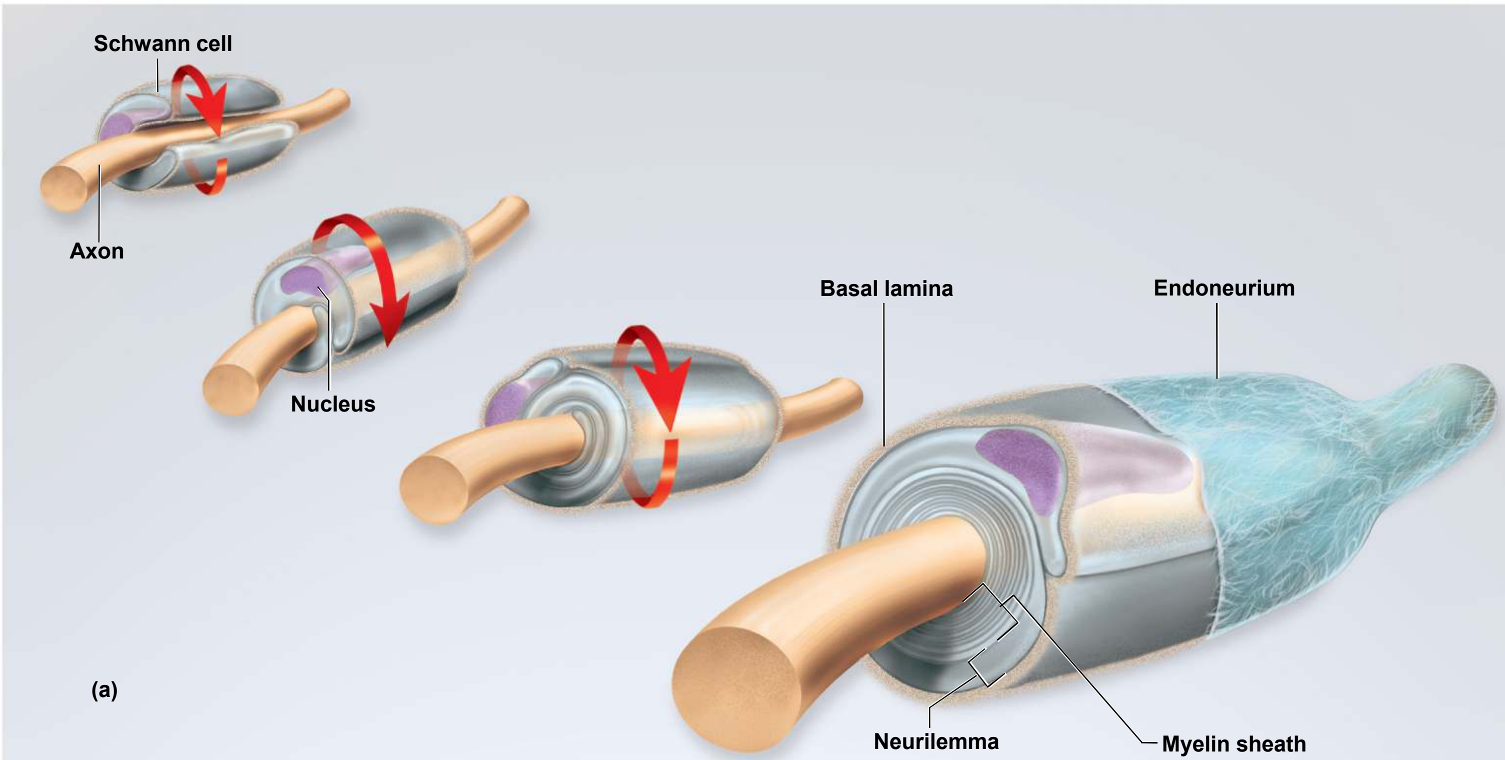

Figure 12.7a

UNMYELINATED AXONS OF PNS

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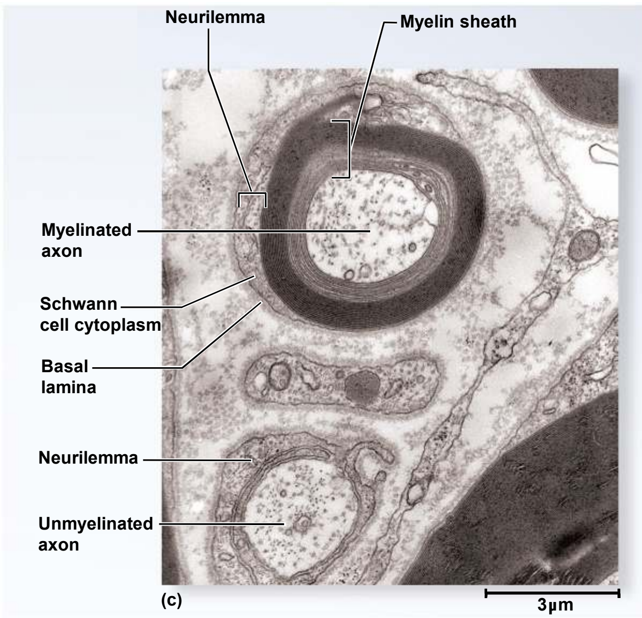

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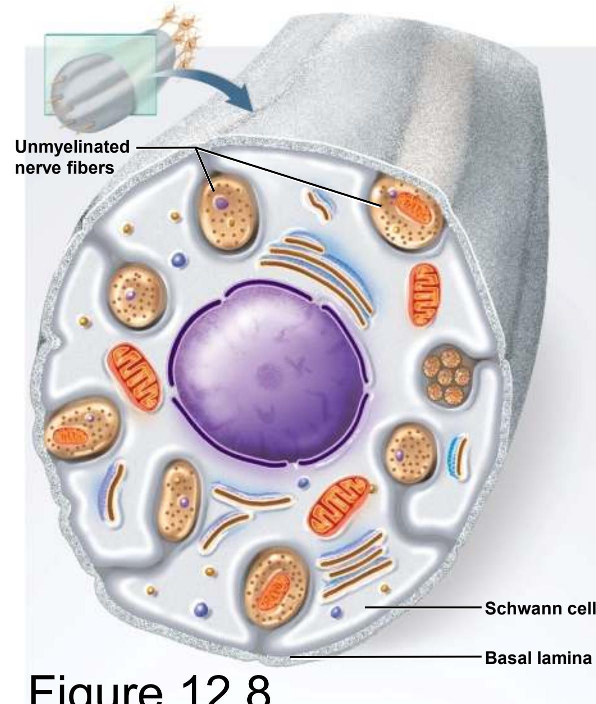

Figure 12.7c Figure 12.8

- Schwann cells hold 1 – 12 small nerve fibers in grooves on its surface
- membrane folds once around each fiber overlapping itself along the edges
- mesaxon – neurilemma wrapping of unmyelinated nerve fibers

CONDUCTION SPEED OF NERVE FIBERS

- speed at which a nerve signal travels along a nerve fiber depends on two factors
  - diameter of fiber
  - presence or absence of myelin
- signal conduction occurs along the surface of a fiber
  - larger fibers have more surface area and conduct signals more rapidly
  - myelin further speeds signal conduction
- conduction speed
  - small, unmyelinated fibers - 0.5 - 2.0 m/sec
  - small, myelinated fibers - 3 - 15.0 m/sec
  - large, myelinated fibers - up to 120 m/sec
  - slow signals supply the stomach and dilate pupil where speed is less of an issue
  - fast signals supply skeletal muscles and transport sensory signals for vision and balance

REGENERATION OF PERIPHERAL NERVES

- regeneration of a damaged peripheral nerve fiber can occur if:
  - its soma is intact
  - at least some neurilemma remains
- fiber distal to the injury cannot survive and degenerates
  - macrophages clean up tissue debris at the point of injury and beyond
- soma swells, ER breaks up, and nucleus moves off center
  - due to loss of nerve growth factor from neuron's target cell
- axon stump sprouts multiple growth processes
  - severed distal end continues to degenerate
- regeneration tube – formed by Schwann cells, basal lamina, and the neurilemma near the injury
  - regeneration tube guides the growing sprout back to the original target cells and reestablishes synaptic contact
- nucleus returns to normal shape
- regeneration of damaged nerve fibers in the CNS cannot occur at all

REGENERATION OF NERVE FIBER

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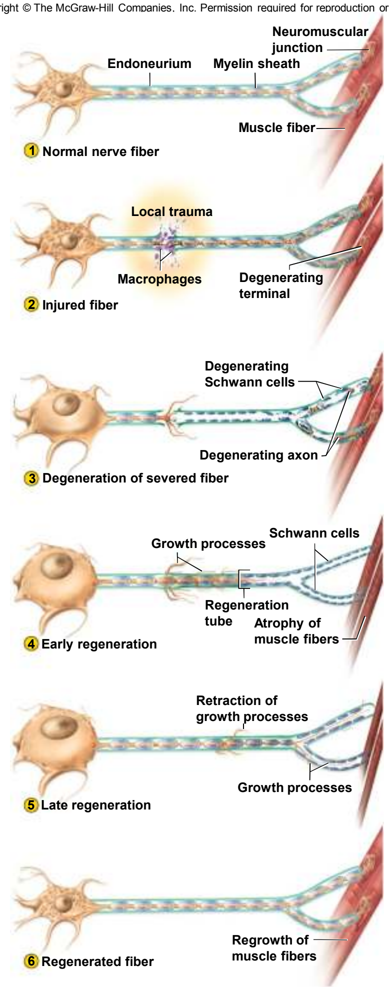

denervation atrophy of muscle due to loss of nerve contact by damaged nerve

Figure 12.9