Chapter 12
Nervous Tissue

• Controls and integrates all body activities within limits that maintain life

• Three basic functions
  • sensing changes with sensory receptors
    • fullness of stomach or sun on your face
  • interpreting and remembering those changes
  • reacting to those changes with effectors
    • muscular contractions
    • glandular secretions
Major Structures of the Nervous System

- Brain, cranial nerves, spinal cord, spinal nerves, ganglia, enteric plexuses and sensory receptors
Organization of the Nervous System

- **CNS** is brain and spinal cord
- **PNS** is everything else
Nervous System Divisions

- Central nervous system (CNS)
  - consists of the brain and spinal cord
- Peripheral nervous system (PNS)
  - consists of cranial and spinal nerves that contain both sensory and motor fibers
  - connects CNS to muscles, glands & all sensory receptors
Subdivisions of the PNS

- Somatic (voluntary) nervous system (SNS)
  - neurons from cutaneous and special sensory receptors to the CNS
  - motor neurons to skeletal muscle tissue
- Autonomic (involuntary) nervous systems
  - sensory neurons from visceral organs to CNS
  - motor neurons to smooth & cardiac muscle and glands
    - sympathetic division (speeds up heart rate)
    - parasympathetic division (slow down heart rate)
- Enteric nervous system (ENS)
  - involuntary sensory & motor neurons control GI tract
- neurons function independently of ANS & CNS
Neurons

- Functional unit of nervous system
- Have capacity to produce action potentials
  - electrical excitability
- Cell body
  - single nucleus with prominent nucleolus
  - Nissl bodies (chromatophilic substance)
    - rough ER & free ribosomes for protein synthesis
  - neurofilaments give cell shape and support
  - microtubules move material inside cell
  - lipofuscin pigment clumps (harmless aging)
- Cell processes = dendrites & axons
Parts of a Neuron

- Cell body
- Nucleus with Nucleolus
- Neuroglial cells
- Axons or Dendrites
Dendrites

- Conducts impulses towards the cell body
- Typically short, highly branched & unmyelinated
- Surfaces specialized for contact with other neurons
- Contains neurofibrils & Nissl bodies
Axons

- Conduct impulses away from cell body
- Long, thin cylindrical process of cell
- Arises at axon hillock
- Impulses arise from initial segment (trigger zone)
- Swollen tips called synaptic end bulbs contain vesicles filled with neurotransmitters
Axonal Transport

- Cell body is location for most protein synthesis
  - neurotransmitters & repair proteins
- Axonal transport system moves substances
  - slow axonal flow
    - movement at 1-5 mm per day
    - movement in one direction only -- away from cell body
  - fast axonal flow
    - moves organelles & materials along surface of microtubules
    - at 200-400 mm per day
    - transports in either direction
    - for use or for recycling in cell body
Axonal Transport & Disease

- Fast axonal transport route by which toxins or pathogens reach neuron cell bodies
- tetanus (Clostridium tetani bacteria)
- disrupts motor neurons causing painful muscle spasms
- Bacteria enter the body through a laceration or puncture injury
- more serious if wound is in head or neck because of shorter transit time
Functional Classification of Neurons

- **Sensory (afferent) neurons**
  - transport sensory information from skin, muscles, joints, sense organs & viscera to CNS

- **Motor (efferent) neurons**
  - send motor nerve impulses to muscles & glands

- **Interneurons (association) neurons**
  - connect sensory to motor neurons
  - 90% of neurons in the body
Structural Classification of

- Based on number of processes found on cell body
  - multipolar = several dendrites & one axon
    - most common cell type
  - bipolar neurons = one main dendrite & one axon
    - found in retina, inner ear & olfactory
  - unipolar neurons = one process only (develops from a bipolar)
Association or

- Named for histologist that first described them or their appearance

(a) Perkinje cell  (b) Pyramidal cell
Neuroglial Cells

- Half of the volume of the CNS
- Smaller cells than neurons
- 50X more numerous
- Cells can divide
  - rapid mitosis in tumor formation (gliomas)
- 4 cell types in CNS
  - astrocytes, oligodendrocytes, microglia & ependymal
- 2 cell types in PNS
  - schwann and satellite cells
Astrocytes

- Star-shaped cells
- Form blood-brain barrier by covering blood capillaries
- Metabolize neurotransmitters
- Regulate K+ balance
- Provide structural support
Oligodendrocytes

- Most common glial cell type
- Each forms myelin sheath around more than one axons in CNS
- Analogous to Schwann cells of PNS
Microglia

- Small cells found near blood vessels
- Phagocytic role -- clear away dead cells
- Derived from cells that also gave rise to macrophages & monocytes
Ependymal cells

- Form epithelial membrane lining cerebral cavities & central canal
- Produce cerebrospinal fluid (CSF)
Satellite Cells

- Flat cells surrounding neuronal cell bodies in peripheral ganglia
- Support neurons in the PNS ganglia
Schwann Cell

- Cells encircling PNS axons
- Each cell produces part of the myelin sheath surrounding an axon in the PNS
Axon Coverings in PNS

- All axons surrounded by a lipid & protein covering (myelin sheath) produced by Schwann cells
- Neurilemma is cytoplasm & nucleus of Schwann cell
  - gaps called nodes of Ranvier
- Myelinated fibers appear white
  - jelly-roll like wrappings made of lipoprotein = myelin
  - acts as electrical insulator
  - speeds conduction of nerve impulses
- Unmyelinated fibers
1. Neurolemmocyte starts to wrap around a portion of an axon.

3. The overlapping inner layers of the plasma membrane form the myelin sheath.

4. The neurolemmocyte cytoplasm and nucleus are pushed to the periphery of the cell as the myelin sheath is formed.
Myelinated vs. Unmyelinated Axons

- In a myelinated axon, the nerve impulse “jumps” from neurofibril node to neurofibril node and is known as saltatory conduction.
- In an unmyelinated axon, the nerve impulse must travel the entire length of the axon, a process called continuous conduction.
- A myelinated axon produces a faster nerve impulse.
Gray and White Matter

- **White matter** = myelinated processes (white in color)
- **Gray matter** = nerve cell bodies, dendrites, axon terminals, bundles of unmyelinated axons and neuroglia (gray color)
  - In the spinal cord = gray matter forms an H-shaped inner core surrounded by white matter
  - In the brain = a thin outer shell of gray matter covers the...
Electrical Signals in Neurons

- Neurons are electrically excitable due to the voltage difference across their membrane
- Communicate with 2 types of electric signals
  - action potentials that can travel long distances
  - graded potentials that are local membrane changes only
- In living cells, a flow of ions occurs through ion channels in the cell membrane
Two Types of Ion Channels

- Leakage (nongated) channels are always open
- Gated channels open and close in response to a stimulus results in neuron excitability
Gated Ion Channels

(a) Voltage-gated ion channel

Voltage $= -70 \text{ mV}$

Voltage-gated $K^+$ channel closed

Extracellular fluid

Cytosol

Change in membrane potential

(b) Ligand-gated ion channel

Acetylcholine

Voltage $= -60 \text{ mV}$

Voltage-gated $K^+$ channel open

Cation channel open

Chemical stimulus
Local Anesthetics

- Prevent opening of voltage-gated Na+ channels
- Nerve impulses cannot pass the anesthetized region
- Novocaine and lidocaine
Encoding of Stimulus Intensity

- How do we differentiate a light touch from a firmer touch?
  - frequency of impulses
    - firm pressure generates impulses at a higher frequency
  - number of sensory neurons activated
    - firm pressure stimulates more neurons than does a light touch
Signal Transmission at Synapses

- 2 Types of synapses
  - electrical
    - ionic current spreads to next cell through gap junctions
    - faster, two-way transmission & capable of synchronizing groups of neurons
  - chemical
    - one-way information transfer from a presynaptic neuron to a postsynaptic neuron
Chemical Synapses

- Action potential reaches end bulb and voltage-gated Ca\(^{2+}\) channels open
- Ca\(^{2+}\) flows inward triggering release of neurotransmitter
- Neurotransmitter crosses synaptic cleft & binding to ligand-gated receptors
  - the more neurotransmitter released the greater the change in potential of the postsynaptic cell
- Synaptic delay is 0.5 msec
Removal of Neurotransmitter

- Diffusion
  - move down concentration gradient
- Enzymatic degradation
  - acetylcholinesterase
- Uptake by neurons or glia cells
  - neurotransmitter transporters
  - Prozac = serotonin reuptake inhibitor
Strychnine Poisoning

- In spinal cord, Renshaw cells normally release an inhibitory neurotransmitter (glycine) onto motor neurons preventing excessive muscle contraction
- Strychnine binds to and blocks glycine receptors in the spinal cord
- Massive tetanic contractions of all skeletal muscles are produced
  - when the diaphragm contracts & remains contracted, breathing can not occur
Neurotransmitter Effects

- Neurotransmitter effects can be modified
  - synthesis can be stimulated or inhibited
  - release can be blocked or enhanced
  - removal can be stimulated or blocked
  - receptor site can be blocked or activated

- Agonist
  - anything that enhances a transmitter's effects

- Antagonist
  - anything that blocks the action of a neurotransmitter
Small-Molecule

- Acetylcholine (ACh)
  - released by many PNS neurons & some CNS
  - excitatory on NMJ but inhibitory at others
  - inactivated by acetylcholinesterase
- Amino Acids
  - glutamate released by nearly all excitatory neurons in the brain ---- inactivated by glutamate specific transporters
  - GABA is inhibitory neurotransmitter for 1/3 of all brain synapses (Valium is a GABA agonist -- enhancing its inhibitory effect)
Small-Molecule Neurotransmitters (2)

- Biogenic Amines
  - modified amino acids (tyrosine)
    - norepinephrine -- regulates mood, dreaming, awakening from deep sleep
    - dopamine -- regulating skeletal muscle tone
    - serotonin -- control of mood, temperature regulation, & induction of sleep
  - removed from synapse & recycled or destroyed by enzymes (monoamine oxidase or catechol-0-methyltransferase)
Neuropeptides

- 3-40 amino acids linked by peptide bonds
- Substance P -- enhances our perception of pain
- Pain relief
  - enkephalins -- pain-relieving effect by blocking the release of substance P
  - acupuncture may produce loss of pain sensation because of release of opioids-like substances such as endorphins or dynorphins
Regeneration & Repair

- Plasticity maintained throughout life
  - sprouting of new dendrites
  - synthesis of new proteins
  - changes in synaptic contacts with other neurons
- Limited ability for regeneration (repair)
  - PNS can repair damaged dendrites or axons
  - CNS no repairs are possible
Neurogenesis in the CNS

- Formation of new neurons from stem cells was not thought to occur in humans
- 1992 a growth factor was found that stimulates adult mice brain cells to multiply
- 1998 new neurons found to form within adult human hippocampus (area important for learning)

Factors preventing neurogenesis in CNS

- inhibition by neuroglial cells, absence of growth stimulating factors, lack of neurolemmas, and rapid formation of scar tissue
Repair within the PNS

- Axons & dendrites may be repaired if
  - neuron cell body remains intact
  - schwann cells remain active and form a tube
  - scar tissue does not form too rapidly
- Chromatolysis
  - 24-48 hours after injury, Nissl bodies break up into fine granular masses
Multiple Sclerosis (MS)

- Autoimmune disorder causing destruction of myelin sheaths in CNS
- Sheaths becomes scars or plaques
- 1/2 million people in the United States
- Appears between ages 20 and 40
- Females twice as often as males
- Symptoms include muscular weakness, abnormal sensations or double vision
- Remissions & relapses result in progressive, cumulative loss of function
Epilepsy

• The second most common neurological disorder
  • affects 1% of population
• Characterized by short, recurrent attacks initiated by electrical discharges in the brain
  • lights, noise, or smells may be sensed
  • skeletal muscles may contract involuntarily
  • loss of consciousness
• Epilepsy has many causes, including:
  • brain damage at birth, metabolic disturbances, infections, toxins, vascular disturbances, head injuries, and tumors
# Neuronal Structure & Function

<table>
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<tr>
<th>Diagram</th>
<th>Structure</th>
<th>Functions</th>
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<tr>
<td>Dendrites</td>
<td>Receive stimuli through activation of chemically or mechanically gated ion channels in sensory neurons; produce generator or receptor potentials in motor neurons and association neurons; produce excitatory and inhibitory postsynaptic potentials (EPSPs and IPSPs).</td>
<td></td>
</tr>
<tr>
<td>Cell body</td>
<td>Receives stimuli and produces EPSPs and IPSPs through activation of chemically or mechanically gated ion channels.</td>
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<td>Junction of axon hillock and initial segment of axon</td>
<td>Trigger zone; integrates EPSPs and IPSPs and, if sum is a depolarization that reaches threshold, initiates action potential (nerve impulse).</td>
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<td>Axon</td>
<td>Propagates (conducts) nerve impulses from initial segment (or from dendrites of sensory neurons) to axon terminals in a self-reinforcing manner; impulse amplitude does not change as it propagates along the axon.</td>
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<td>Axon terminals and synaptic end bulbs (or varicosities)</td>
<td>Inflow of Ca(^{2+}) caused by depolarizing phase of nerve impulse triggers neurotransmitter release by exocytosis of synaptic vesicles.</td>
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- Blue: Plasma membrane includes chemically gated channels
- Green: Plasma membrane includes voltage-gated Na\(^+\) and K\(^+\) channels
Neurotransmitters

- Chemical that reacts with specific receptors to create a nerve impulse
- Acetylcholine – controls skeletal muscle actions
- Norepinephrine – “good” feeling, low levels may lead to depression
- Dopamine – “good” feeling
- Serotonin – sleep
- Histamine – alertness
- Endorphins – reduce pain
- Nitric oxide – vasodilation, memory
Types of Nerves

- Nerves are cordlike bundles of nerve fibers held together by connective tissue layers that conduct impulses
  - Sensory nerves – impulses into the brain or spinal cord
  - Motor nerves – carry impulses to muscles or glands
  - Mixed nerves – include both of the above
Nerve Pathways

- Routes that nerve impulses follow in the nervous system
- Reflex arcs are the simplest pathways that constitute reflexes.
- Reflexes are subconscious responses to stimuli within or outside the body. Help maintain involuntary actions such as heart rate, breathing rate, blood pressure and digestion
  - Knee-jerk reflex – simple, only using two neurons; helps maintain upright posture
  - Withdrawal reflex – unexpected touch to something painful; protective by limiting tissue damage
Meninges

- Membranes beneath the bony coverings of the skull and vertebral column for protection

- Three layers
  - Dura mater – outermost layer of connective tissue, blood vessels, and nerves; interior periosteum of skull bones and between lobes of brain; surround spinal cord for protection.
  - Arachnoid mater – thin membrane lacking blood vessels in the middle
  - Pia Mater – thin layer of nerves and blood vessels that nourish the cells of the brain and spinal cord; hugs surfaces of organs
  - Cerebrospinal fluid (CSF) – in between arachnoid and pia mater.
Spinal Cord

- Nerve column passing from brain into vertebral canal

- Begins at the foramen magnum and terminates at the first and second lumbar vertebrae.
Structure of Spinal Cord

- Consists of 31 segments that give rise to spinal nerves which branch to various body parts.

- Cervical enlargement is the thickening of the spinal cord in the neck region that supplies nerves to upper limbs.

- The lumbar enlargement is in the lower back giving nerves to lower limbs.

- Divided into right and left halves by the anterior median fissure and posterior median sulcus grooves.
Functions of Spinal Cord

- Two major functions: conducting nerve impulses and center for spinal reflexes
- Axons of the spinal cord provide two way communication between the brain and the body parts
- Ascending tracts carry sensory information to the brain
- Descending tracts conduct motor impulses from the brain to the muscles
- Knee-jerk and withdrawal reflexes are spinal reflexes because they pass through the spinal cord