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
- Cell processes = dendrites & axons
Axons and Dendrites

- Axons conduct impulses away from cell body
- Dendrites conducts impulses towards the cell body
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
Oligodendrocytes

- Most common glial cell type
- Each forms myelin sheath around more than one axons in CNS
- Analogous to Schwann cells of PNS
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
  - slow, small diameter fibers
  - only surrounded by neurilemma but no myelin sheath wrapping
Myelination in PNS

- Schwann cells myelinate (wrap around) axons in the PNS during fetal development
- Schwann cell can only myelinate 1 axon
- Schwann cell cytoplasm & nucleus forms outermost layer of neurolemma with inner portion being the myelin sheath
- Tube guides growing axons that are repairing themselves
Myelination in the CNS

- Oligodendrocytes myelinate axons in the CNS
- Broad, flat cell processes wrap about CNS axons, but the cell bodies do not surround the axons
- No neurilemma is formed
- Little regrowth after injury is possible due to the lack of a distinct tube or neurilemma
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 surface & is found in clusters called nuclei inside the CNS
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
  – nerve cells have more K+ than Na+ leakage channels
  – as a result, membrane permeability to K+ is higher
  – explains restoring membrane potential of -70mV in nerve tissue

• Gated channels open and close in response to a stimulus results in neuron excitability
  – voltage-gated open in response to change in voltage
  – ligand-gated open & close in response to particular chemical stimuli (hormone, neurotransmitter, ion)
  – mechanically-gated open with mechanical stimulation
Gated Ion Channels

(a) Voltage-gated ion channel
- Voltage $= -70$ mV
- K$^+$ channel closed
- Extracellular fluid
- Change in membrane potential
- Voltage $= -50$ mV

(b) Ligand-gated ion channel
- Acetylcholine
- Cation channel open
- Chemical stimulus
Resting Membrane Potential

• Negative ions along inside of cell membrane & positive ions along outside
  – potential energy difference at rest is -70 mV
  – cell is “polarized”

• Resting potential exists because
  – concentration of ions different inside & outside
    • extracellular fluid rich in Na+
    • cytosol full of K+
  – membrane permeability differs for Na+ and K+
    • 50-100 greater permeability for K+
    • inward flow of Na+ can’t keep up with outward flow of K+
    • Na+/K+ pump removes Na+ as fast as it leaks in
Graded Potentials

- Small deviations from resting potential of -70mV
  - hyperpolarization = membrane has become more negative
  - depolarization = membrane has become more positive
How do Graded Potentials Arise?

• Source of stimuli
  – mechanical stimulation of membranes with mechanical gated ion channels (pressure)
  – chemical stimulation of membranes with ligand gated ion channels (neurotransmitter)

• Graded potential
  – ions flow through ion channels and change membrane potential locally
  – amount of change varies with strength of stimuli (graded)

• Flow of current (ions) is local change only
Action Potential

- Series of rapidly occurring events that change and then restore the membrane potential of a cell to its resting state
- Ion channels open, Na+ rushes in (depolarization), K+ rushes out (repolarization)
- All-or-none principal = with stimulation, either happens one specific way or not at all (lasts 1/1000 of a second)
- Travels (spreads) over surface of cell without dying out
Depolarizing Phase of Action Potential

- Chemical or mechanical stimulus caused a graded potential to reach at least (-55mV or threshold)
- Voltage-gated Na+ channels open & Na+ rushes into cell
- Positive feedback process
Repolarizing Phase of Action Potential

- When threshold potential of -55mV is reached, voltage-gated K+ channels open
- K+ channel opening is much slower than Na+ channel opening which caused depolarization
- When K+ channels finally do open, the Na+ channels have already closed (Na+ inflow stops)
- K+ outflow returns membrane potential to -70mV
- If enough K+ leaves the cell, it will reach a -90mV membrane potential and enter the after-hyperpolarizing phase
- K+ channels close and the membrane potential returns to the resting potential of -70mV
Refractory Period of Action Potential

- Period of time during which neuron can not generate another action potential
The Action Potential: Summarized

- Resting membrane potential is -70 mV
- Depolarization is the change from -70 mV to +30 mV
- Repolarization is the reversal from +30 mV back to -70 mV)
Propagation of Action Potential

• An action potential spreads (propagates) over the surface of the axon membrane
  – as Na+ flows into the cell during depolarization, the voltage of adjacent areas is effected and their voltage-gated Na+ channels open
  – self-propagating along the membrane

• The traveling action potential is called a nerve impulse
Local Anesthetics

• Prevent opening of voltage-gated Na+ channels
• Nerve impulses cannot pass the anesthetized region
• Novocaine and lidocaine
Continuous versus Saltatory Conduction

• Continuous conduction (unmyelinated fibers)
  – step-by-step depolarization of each portion of the length of the axolemma

• Saltatory conduction (myelinated fibers)
  – depolarization only at nodes of Ranvier where there is a high density of voltage-gated ion channels
  – current carried by ions flows through extracellular fluid from node to node
  – travels faster
Saltatory Conduction

- Nerve impulse conduction in which the impulse jumps from node to node
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
Comparison of Graded & Action Potentials

• Origin
  – GPs arise on dendrites and cell bodies
  – APs arise only at trigger zone on axon hillock

• Types of Channels
  – AP is produced by voltage-gated ion channels
  – GP is produced by ligand or mechanically-gated channels

• Conduction
  – GPs are localized (not propagated)
  – APs conduct over the surface of the axon
Comparison of Graded & Action Potentials

• Amplitude
  – amplitude of the AP is constant (all-or-none)
  – graded potentials vary depending upon stimulus

• Duration
  – The duration of the GP is as long as the stimulus lasts (several msec to minutes)
  – The duration of AP is shorter (0.5 to 2 msec)

• Refractory period
  – The AP has a refractory period due to the nature of the voltage-gated channels, and the GP has none.
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
      – axodendritic -- from axon to dendrite
      – axosomatic -- from axon to cell body
      – axoaxonic -- from axon to axon
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
- One-way information transfer
Excitatory & Inhibitory Potentials

• The effect of a neurotransmitter can be either excitatory or inhibitory
  – a depolarizing postsynaptic potential is called an EPSP
    • it results from the opening of ligand-gated Na+ channels
    • the postsynaptic cell is more likely to reach threshold
  – an inhibitory postsynaptic potential is called an IPSP
    • it results from the opening of ligand-gated Cl- or K+ channels
    • it causes the postsynaptic cell to become more negative or hyperpolarized
    • the postsynaptic cell is less likely to reach threshold
Removal of Neurotransmitter

- **Diffusion**
  - move down concentration gradient
- **Enzymatic degradation**
  - acetylcholinesterase
- **Uptake by neurons or glia cells**
  - neurotransmitter transporters
    - Prozac = serotonin reuptake inhibitor
Small-Molecule Neurotransmitters

• 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
  – 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 – emotional response, addictive behavior, pleasurable experiences, regulating skeletal muscle tone
    • serotonin -- control of mood, temperature regulation, & induction of sleep
  – removed from synapse & recycled or destroyed by enzymes
Small-Molecule Neurotransmitters (3)

- **ATP**
  - excitatory in both CNS & PNS
  - released with other neurotransmitters (ACh & NE)

- **Gases (nitric oxide or NO)**
  - formed from amino acid arginine by an enzyme
  - formed on demand and acts immediately
    - diffuses out of cell that produced it to affect neighboring cells
Neuropeptides

• 3-40 amino acids linked by peptide bonds
• Substance P -- enhances our perception of pain
• Pain relief
  – endorphins -- pain-relieving effect by blocking the release of substance P
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
Repair within the PNS

• By 3-5 days,
  – wallerian degeneration occurs (breakdown of axon & myelin sheath distal to injury)
  – retrograde degeneration occurs back one node

• Within several months, regeneration occurs
  – neurolemma on each side of injury repairs tube (schwann cell mitosis)
  – axonal buds grow down the tube to reconnect (1.5 mm per day)
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