Biology 219 – Human Physiology

Neurons and Neural Signals

I. Neurons and the Nervous System

Functions of the nervous system: sensation, communication, integration, control

neurons - functional cells of the nervous system;
- excitable cells - generate electrical signals (changes in membrane potential)
- communicate information in the form of electrical and chemical signals

Structure of Neurons

cell body contains the nucleus and most organelles
dendrites branch from the cell body, receive signals from other cells through synapses
axon extends from the cell body, conducts action potentials
axon hillock - region where axon joins the cell body
initial segment adjacent to the axon hillock is the trigger zone for AP
axon terminals - contain vesicles with neurotransmitter, form synapses with other cells

Nervous System Organization

1. Central Nervous System (CNS) - Brain and Spinal Cord.
2. Peripheral Nervous System (PNS) - nerves, ganglia and sensory receptors
   a. Afferent Division - input sensory information to the CNS
   b. Efferent Division - output motor signals from CNS to effector organs

Functional types of neurons

1. sensory (afferent) neurons - input to CNS from sensory receptors;
dendrites located at receptors, axons in nerves, cell bodies in ganglia outside the CNS
2. motor (efferent) neurons - output from CNS to effectors (muscles, glands)
cell bodies and dendrites in the CNS, axons in nerves
3. interneurons - located entirely within the CNS; most abundant and diverse types

II. Neural Signals

A. Graded Potentials
   • small, localized changes in membrane potential
   • formed at the cell body and dendrites
   • can be depolarization (↑) or hyperpolarization (↓)
   • spread passively and weaken with distance
   • size depends on stimulus strength
B. **Action Potentials** (= nerve impulses)

- large change in membrane potential
- actively conducted along the axon
- rapid *depolarization* followed by *repolarization*
- “all or none” - constant size, does not depend on stimulus strength

**Phases of the action potential**

1. **Depolarization (rising) phase**
   - triggered by an initial depolarizing stimulus, must be above *threshold* to form an AP
   - **voltage-gated Na⁺ channels** open
     - *activation gate* opens in response to initial depolarization
     - → rapid Na⁺ inflow → depolarization → more activation gates open (*positive feedback*)

2. **Repolarization (falling) phase**
   - voltage-gated Na⁺ channels close
   - *inactivation gate* closes when depolarization reaches a peak (∼ +30 mV)
   - **voltage-gated K⁺ channels** open
     - → rapid K⁺ outflow → repolarization

3. **Hyperpolarization (undershoot) phase**
   - voltage-gated K⁺ channels remain open, high K⁺ permeability results in *hyperpolarization*
   - resting states of channels and resting potential restored at the end of undershoot phase

**Properties of action potentials**

1. *threshold* - stimulus must be greater than a certain strength to evoke an AP
2. "*all or none"* - once threshold is reached, size of the AP is constant regardless of stimulus
3. *regenerative* - AP is regenerated and does not decrease in strength along the axon
4. *refractory period* - short delay following an AP before another AP can be formed
   - absolute refractory period (ARP) - another AP cannot be formed
   - relative refractory period (RRP) - a stronger stimulus is required to get another AP

**Importance of refractory period:**
- Refractory period prevents AP from traveling backward along the axon
- During the RRP, a stronger stimulus can result in increased *frequency* of APs

*Stimulus intensity is coded by the frequency of APs.*

**Conduction of action potentials**

a. unmyelinated axons
   - AP depolarization spreads a short distance down the axon (local current flow)
   - depolarization stimulates formation of AP farther down the axon
   - axons are “leaky” to Na⁺ and K⁺; need to regenerate AP often along the axon
     → slow conduction speed
   - increasing axon diameter increases conduction speed

b. myelinated axons
   - *myelin sheath* formed by Schwann cells in the PNS, oligodendrocytes in CNS
   - insulates the axon, reduces leakage of Na⁺ and K⁺
   - *nodes of Ranvier* - gaps in myelin sheath are sites of AP regeneration
   - AP "jumps" from node to node (*saltatory conduction*)
     → very fast conduction speed (> 100 m/s)
Ion Channels and the Action Potential

0. Resting Potential

- K⁺ Leak Channel
- Voltage-gated Na⁺ Channel
- Voltage-gated K⁺ Channel

ECF: 

ICF: K⁺ Channel: OPEN CLOSED CLOSED

1. Depolarization Phase of A.P.

ECF: 

ICF: K⁺ Channel: OPEN OPENS CLOSED

2. Repolarization Phase of A.P.

ECF: 

ICF: K⁺ inactivation gate Channel: OPEN CLOSES OPENS

3. Hyperpolarization Phase of A.P.

ECF: 

ICF: K⁺ gates reset Channel: OPEN CLOSED OPEN, slowly closes