NEURAL TISSUE  
(NEUROPHYSIOLOGY)  
PART I (A): NEURONS & NEUROGLIA

Neural Tissue

- Contains 2 kinds of cells:
  - neurons:
    - cells that send and receive signals
  - neuroglia (glial cells):
    - cells that support and protect neurons

Neuron Types

- Sensory Neurons
  - Conveys information to CNS
    - Touch, temperature, senses, movement, ..
- Motor Neurons
  - Carry commands to effector (muscle, organs, ..)
- Interneurons
  - Only in brain & spinal cord
  - Interconnector between neurons
  - Determines where information goes (reflex, command, ..)

What is the structure of a typical neuron, and the function of each component?

Anatomy of the Neuron

- Cell Body
  - Contains basic organelles
- Dendrites
  - Receives signals coming to cell body
- Axon
  - Single large extension from cell body
  - Carries signals to effector (organ, neuron, ..)
- Synaptic Terminals
  - Endpoint of axons
  - Contains neurotransmitters for communications

Nerves: Bundles of Axons

- ‘Information Highway’
  - To-and-From Brain
- Contains many types of neurons
- Covered by connective tissue
- Contains blood vessels
NEURAL TISSUE
(NEUROPHYSIOLOGY)
PART I (B): SCHWANN CELLS & NEURON REPAIR

Neuroglia

- Many types
- Covers vessels in brain
  - Forms blood-brain barrier
- Ingests debris and foreign invaders
- Schwann cells - myelin sheath

Myelin

- Made by Schwann cells
- Increases speed of action potentials
- Myelin insulates axons
- Makes nerves appear white
- Nodes:
  - also called nodes of Ranvier

White Matter and Gray Matter

- White matter:
  - regions of CNS with many myelinated nerves
- Gray matter:
  - unmyelinated areas of CNS

Peripheral Nerve Regeneration

- Distal portion of axon dies
- Macrophage microglia remove debris
- Schwann cells:
  - form path for new growth
  - wrap new axon in myelin
- Axon re-growth through schwann cell ‘scaffolding’

Nerve Regeneration in CNS

- Limited by chemicals released by astrocytes that:
  - block growth
  - produce scar tissue
  - impede debris removal
NEURAL TISSUE
(NEUROPHYSIOLOGY)
PART II (A): RESTING MEMBRANE POTENTIAL

How is resting potential created and maintained?

Ion Movements and Electrical Signals

- All cell membranes produce electrical signals by ion movements
- Transmembrane potential is particularly important to neurons

Resting Membrane Potential

- Voltage of the cell at ‘rest’
  - -70 mV
- Separation of charges (like a battery)
  - Sodium (Na+)
  - Potassium (K+)
  - Chloride (Cl-)
- Pumps and shuttle systems
  - Offset the ‘leakage’

Membrane Potential (Voltage)

- Na+ is abundant outside cell
- K+ is abundant inside cell
- Cl- is abundant outside cell
- Difference in charges across the membrane determines the voltage
- Resting membrane potential is ~ -70 mV

Alterations of Membrane Potential

- Channel activity
  - Voltage
  - Chemical
  - Passive
- Pump activity

Ion Channels

- Pores in cell membrane
  - Allow movement of certain ions in/out of cell
- Some are ‘gated’ for regulation
  - Allow passage only at certain times
- Some are ‘leaky’
  - Allow passage continuously
Ion Channels: Ion Specific

- Sodium (Na+) Channels
  - Only allow Na+ to pass
  - Voltage-gated or chemically-gated
  - Important role in depolarization and refractory (recovery) period duration

- Potassium (K+) Channels
  - Only allow K+ to pass
  - Voltage-gated or chemically-gated
  - Important role in repolarization
  - Many, many different types

Ion Channels: Types (Classes)

- Passive
  - Resting membrane potential

- Voltage-Gated
  - Action potential

- Chemically-Gated
  - Synaptic potential

- Mechanically-Gated
  - Touch, vision, etc.

3 Conditions of Gated Channels

- Closed
  - “Ready to open”

- Open
  - Allowing ions to cross membrane

- Closed & Locked
  - “Inactivated”

Pumps in the Membrane

- Sodium-potassium pump:
  - powered by ATP
  - carries 3 Na+ out and 2 K+ in
  - maintains resting potential (-70 mV)
How is the resting membrane potential altered?

Graded Potentials
- Also called local potentials
- Any stimulus that opens a gated channel:
  - Hyperpolarization (IPSP)
  - Depolarization (EPSP) = sub-threshold stimulus

Depolarization
- Decreasing the negativity of the resting membrane potential
- Result of opening a sodium channel
- Positive ions move in, not out of cell
  - This makes the cell more positive

Hyperpolarization
- Increasing the negativity of the resting membrane potential
- Result of opening a potassium channel
- Positive ions move out, not into cell
  - This makes the cell more negative
**NEURAL TISSUE**
*(NEUROPHYSIOLOGY)*
**PART II (B): ACTION POTENTIAL**

**Action Potential: Phases**

- **Initial Depolarization Signal**
  - Must reach -55 mV or nothing will happen
- **Depolarization Phase**
  - Cell rapidly becomes more positive
  - Peak occurs at +30 mV
- **Repolarization Phase**
  - Cell becomes less positive (return to normal)
- **Undershoot**

**Action Potential: Depolarization**

- Cell becomes ‘less negative enough’
  - Reaching ‘threshold’
- Cell membrane voltage goes from
  - 70 mV to -55 mV (+15 mV change)
- **Na+ channels open (+feedback loop)**
  - Na+ rushes into cell
  - Cell becomes more positive
  - Opens more Na+ channels
  - At 0 mV, Na+ channels inactivate
  - Peak of action potential at +30 mV

**Action Potential: Repolarization**

- **K+ channels open (voltage-gated)**
  - K+ leaves cell
  - Cell becomes more negative
  - Resting membrane potential restored
- Na+ channels are still ‘inactivated’ (closed & locked)

**Action Potential: Overshoot**

- Too much K+ leaves cell
  - Cell becomes hyperpolarized
    - Hyperpolarized = opposite of depolarized
- Na+ / K+ pump restores gradient
  - Na+ pumped out of cell
  - K+ pumped into cell
Steps in the Generation of Action Potentials

• Depolarization to threshold
  - -70 mV to -55 mV
  - Achieved by a depolarizing graded potential
• -55 mV threshold achieved
  - Opening of V-gated Na+ channels
  - Inner membrane changes from negative to positive
• +30 mV
  - V-gated Na+ channels close and inactivate
  - V-gated K+ channels open, allowing K+ out
  - Repolarization begins
  - Cell becomes more negative
• -70 mV
  - V-gated K+ channels begin to close
  - Na+ / K+ pump restores gradient
• -90 mV
  - V-gated K+ channels finish closing:
    • membrane is hyperpolarized
• -70 mV
  - membrane potential is restored

2 Divisions of the Refractory Period

• Absolute refractory period:
  - sodium channels closed & inactivated
  - another action potential isn’t possible
• Relative refractory period:
  - membrane potential almost normal
  - during the ‘overshoot’ phase
  - very large stimulus can initiate action potential

Propagation of Action Potentials

• moves action potentials generated in axon hillock toward axon terminal
  - a series of repeated action potentials
• Continuous
  - Unmyelinated axon
• Saltatory
  - Myelinated axon
Continuous Propagation
1. Action potential in segment 1
   • Depolarizes membrane to +30 mV
2. Local current
   • Depolarizes second segment to threshold
3. Second segment develops action potential
   • First segment enters refractory period
4. Local current depolarizes next segment
   • Cycle repeats
   • Action potential travels in 1 direction (1 m/sec)

Saltatory Propagation
• Propagation of action potential along myelinated axons
• Faster and uses less energy than continuous propagation
• Local current “jumps” from node to node
• Depolarization occurs only at nodes
How do neurons communicate with each other or with other cells of the body?

**Synapse**
- Area where a neuron communicates with another cell
- Presynaptic cell:
  - neuron that sends message
- Postsynaptic cell:
  - cell that receives message
- Synaptic cleft:
  - small gap that separates the two cells

**The Synaptic Knob**
- Expanded end of axons
  - Contains synaptic vesicles of neurotransmitters

**Neurotransmitters**
- Are chemical messengers
- Are released at presynaptic membrane
- Affect receptors of postsynaptic membrane
- Are broken down by enzymes
- Are reassembled at synaptic knob
NEURAL TISSUE
(NEUROPHYSIOLOGY)
PART III (B): GRADED POTENTIALS

Synaptic Activity
• An activated neuron activates a 2nd neuron:
  - presynaptic neuron releases neurotransmitters to postsynaptic neuron (or other postsynaptic cell)
  - The postsynaptic neuron received the neurotransmitter
  - Neurotransmitters cause a graded potential
    • IPSP or EPSP

2 Classes of Neurotransmitters
• Excitatory neurotransmitters:
  - cause depolarization of postsynaptic membranes
  - EPSP (promote action potentials)
• Inhibitory neurotransmitters:
  - cause hyperpolarization of postsynaptic membranes
  - IPSP (suppress action potentials)

The Effect of a Neurotransmitter
• On a postsynaptic membrane:
  - depends on the receptor
  - not on the neurotransmitter
• e.g., acetylcholine:
  - usually promotes action potentials
  - but inhibits cardiac neuromuscular junctions

Events at a ‘Generic’ Synapse
1. Action potential depolarizes synaptic knob
2. Exocytosis of vesicles filled with a neurotransmitter
3. Neurotransmitter binds to receptors on postsynaptic membrane
4. Neurotransmitters are broken down by enzymes
### NEURAL TISSUE
#### (NEUROPHYSIOLOGY)
#### PART IV: NEUROTRANSMITTERS

**Neurotransmitter Types**

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<td>GABA</td>
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<td>Glutamate</td>
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**Small-Molecule Transmitters**

- Synthesized in pre-synaptic knob
- Recycled vesicles and neurotransmitters

#### Acetylcholine (ACh)

- Neuro-muscular junction
- Memory
- Pathology
  - Alzheimer’s disease
  - Myasthenia gravis
  - Botulism
- Drugs
  - Nicotine (affects nicotinic receptors for Ach)
  - Curare (block nicotinic receptors for Ach)

#### Norepinephrine (NE)

- aka: noradrenalin
- Brain
  - Elevates mood, “feel good”
  - Can also increase aggressive behavior
- Sympathetic nervous system
  - Excitatory and Inhibitory effects
- Drugs
  - Monoamine oxidase inhibitors (block NE, dopamine, serotonin reuptake)
  - Amphetamines (↑ NE release)
  - Cocaine & Antidepressants (block NE reuptake)
**Dopamine**

- **Brain**
  - Emotions, “feel good”
  - Muscle coordination
- **Pathology**
  - ADHD
  - Parkinson’s disease
- **Drugs**
  - L-Dopa (↑ dopamine release)
  - Monoamine oxidase inhibitors (block NE, dopamine, serotonin reuptake)
  - Amphetamines (↑ dopamine release)
  - Cocaine & Antidepressants (block dopamine reuptake)

**Serotonin**

- **Brain, Spinal Cord, and GI tract**
  - Inhibitory effects
  - Role in sleep and mood
- **Pathology**
  - Depression, insomnia
  - Appetite, Nausea
- **Drugs**
  - Selective serotonin reuptake inhibitors (block serotonin reuptake)
    - Prozac
  - Monoamine oxidase inhibitors (block NE, dopamine, serotonin reuptake)

**Glutamate**

- **Brain and Spinal Cord**
  - Excitatory effects
  - Learning and Memory
- **Pathology**
  - Involved in stroke damage by killing cells surrounding ischemic area
- **Drugs**
  - Alcohol (blocks glutamate receptors)
    - Impairs learning and memory
    - Slows brain functions
Gamma-aminobutyric Acid

- aka: GABA
- Brain and Spinal Cord
  - Inhibitory effects
- Pathology
  - Epilepsy
- Drugs
  - Alcohol (↑ GABA effects)
  - Valium (↑ GABA levels)
  - Epilepsy medications (↑ GABA levels)

Neuropeptides

- Peptides: chain of amino acids
- Synthesized in cell body
  - Packaged into vesicles
- Transported to axon nerve endings
  - Few cm/day
- Not recycled

Endorphins

- Brain and Spinal Cord
  - Inhibitory effects
    - Inhibits Substance P
  - Natural opiate
    - Endogenous form of morphine & heroin
  - Intense exercise
    - Increases endorphin levels “runner’s high”
- Drugs
  - Morphine and heroin (stimulate endorphin receptors)

Substance P

- Dorsal root ganglia of spinal cord
  - Pain neurons synapse on ganglia
  - Slow to build up
  - Slow to be destroyed