Neural Tissue

Anatomy
- Overview of nervous system
- Neurons
  - Structure
  - Synapse
  - Axoplasmic transport
  - Classification
    - Structural
    - Functional
- Neuroglia
  - Classification
    - CNS
    - PNS
    - Myelin
- Gray versus white matter
- Neural response to injury

Physiology
- Ion movements and electrical signals
  - Transmembrane potential
  - Ion channels
  - Graded potentials
  - Action potentials (nerve impulses)
  - Propagation of action potentials
  - Anesthetics
- Synapses
  - Removal of neurotransmitters
  - Postsynaptic potentials
- Neural Integration
  - Summation
    - Spatial summation
    - Temporal summation
  - Facilitation / inhibition
- Examples of neurotransmitters / neuromodulators

Overview of Nervous System
- General Nervous System
  - Central Nervous System
    - Afferent Nerves
    - Efferent Nerves
  - Peripheral Nervous System
    - Cranial Nerves
    - Spinal Nerves
    - Autonomic Nervous System
      - Sympathetic Division
      - Parasympathetic Division
Overview of Nervous System

Neurons
Nerve Cells
transmit electochemical signals (nerve impulses)

Neuroglia
insulate, nourish, support, protect

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Structure of a Neuron

Cell body (soma) – found in clusters
- CNS: nuclei
- PNS: ganglia

Cell processes = dendrites & axons

Nerve Tissue

Nervous Tissue
Anatomy

Neurons
Neuroglia

Cell body (soma)
Nucleus with Nucleolus
Axons or Dendrites
Cell body
Cell body
Organelles
Nucleus
Nucleolus
Nissl bodies
Processes
Dendrites
Receptors
Axons
Axolemma
Collaterals
Axon hillock
Axon terminal
Synaptic end bulb
Synaptic vesicle
Neurotransmitter

Structure of a Neuron

Dendrites
“Receivers”
Conducts impulses towards the cell body
Typically short, highly branched & unmyelinated
Surfaces specialized for contact with other neurons

Axons
“Transmitters”
Conduct impulses away from cell body toward synapse
Long, thin cylindrical process of cell
Axolemma: specialized portion of plasma membrane
Axon hillock
Thickened region of cell body
Axon terminal
Synaptic end bulbs contain synaptic vesicles filled with neurotransmitters
Nervous Tissue

Neurons
Structure of a Chemical Synapse
- Specialized junction between two neurons
  - Presynaptic neuron
  - Post synaptic neuron
- Neurotransmitter
  - Chemicals released by synaptic vesicles in presynaptic neuron
  - Affect activity of postsynaptic neuron
- Synaptic cleft
- Receptors for neurotransmitter on postsynaptic neuron

Neuron Classes
- Structure
  - Multipolar
    - Anaxonic
  - Bipolar
  - Unipolar
- Function
  - Sensory (afferent)
  - Interneurons (association)
  - Motor (efferent)

A. What **structural** classification is this neuron?
B. What **functional** classification is this neuron?

Neuroglial Cells

Nerve Tissue
- Neurons
  - Nerve Cells transmit electrochemical signals (nerve impulses)
- Neuroglia
  - Insulate, nourish, support, protect
Neuroglial Cells

- Smaller cells than neurons
- Half of the volume of the CNS
- 50X more numerous
- Cells can divide
  - rapid mitosis in tumor formation (gliomas)

Neuroglial Classification

- Neurons
  - Nerve Cells
  - Transmit electrochemical signals (nerve impulses)
- Astrocytes
  - Neurotransmitter metabolism
- Oligodendrites
  - Form myelin
- Microglia
  - Phagocytic
- Ependymal Cells
  - Movement of CSF
- Neurolemmocytes
  - (Schwann Cells)
  - Form myelin sheath
  - Support, protect, nourish
- Satellite Cells
  - Support neuron cell bodies in ganglia

CNS: Astrocytes

- Most abundant
- Form blood-brain barrier by covering blood capillaries
- 3D framework for CNS
- Repair
- Guide neuron development
- Control interstitial environment
  - Absorb and recycle some neurotransmitters
  - Regulate concentration of Na⁺, K⁺, and CO₂
  - Transport of nutrients, ions, and dissolved gases between capillaries and neurons
  - Control volume of blood flow through capillaries
  - Release chemicals that enhance or suppress communication across synaptic terminals
CNS: Oligodendrocytes

- Form myelin
  - Myelin sheath
  - Internodes
  - Nodes of Ranvier
  - White matter
- Analogous to Schwann cells of PNS

CNS: Microglia

- Small cells found near blood vessels
  - Macrophages
- Migrate
- Phagocytes
  - Clear away dead cells, debris, pathogens, waste products, etc
- Aid in remodeling

CNS: Ependymal cells

- **Ependyma**: modified epithelial membrane lining cerebral cavities & central canal
  - Adult stem cells
  - Formation and circulation of cerebrospinal fluid (CSF)

Can you identify the cells?
A. 
B. 
C. 
D. 
E.
Neuroglial Classification

- Neurons: Nerve Cells that transmit electochemical signals (nerve impulses)
- Neuroglia: support, nourish, insulate, protect
  - Astrocytes: metabolize, neurotrophic
  - Oligodendrites: form myelin
  - Microglia: phagocytic
  - Ependymal Cells: form choroid plexus, secrete CSF
  - Neurolemmocytes (Schwann Cells): form myelin sheath
  - Satellite Cells: support neuron cell bodies

PNS: Satellite Cells

- Support neurons
- Flat cells surrounding neuronal cell bodies in peripheral ganglia
- Analogous to astrocytes
PNS:
Schwann Cell / Neurolemmocyte
- Form myelin sheath
- Cells encircling PNS axons
- Analogous to oligodendrocytes in CNS
- Aid in neuron repair

Myelin
- Around axon of most neurons
- Functions
  - Increases speed of conduction of a nerve impulse down the axon
  - Electrically isolates adjacent neurons
  - May direct axon regeneration following damage
- In both PNS and CNS

Myelinated Axons
- Internode
- Node of Ranvier

1. Identify the regions:
   A. 
   B.
2. Is this from the CNS or PNS and why?
Nervous Tissue

White matter = myelinated processes
Gray matter = nerve cell bodies, dendrites, axon terminals, bundles of unmyelinated axons and neuroglia

Neural Response to Injury

1. Cell body
   A. Nissl bodies disperse and move away from central location
2. Degeneration (Wallerian)
   A. Distal axon section degenerates
   B. Microglia/macrophages phagocytize debris
   C. Schwann cells proliferate and form cellular cord that follows original path of axon
Nervous Tissue

Neural Response to Injury
...continued

3. Axon bud
   A. Proximal axon section sends bud into network of Schwann cells
4. May eventually re-establish normal synaptic networks (Can take up to 2 years)
5. Possible complications
   A. Many axons may be involved in injury
   B. Subsequent scar tissue may prevent axon growth across damaged area

Nervous Tissue Physiology

Ion movements and electrical signals
- Transmembrane potential
- Ion channels
- Graded potentials
- Action potentials
- Propagation of action potentials
- Anesthetics

Synaptic activity
- Synapses
- Removal of neurotransmitters
- Postsynaptic potentials

Information processing by individual neurons
- Summation
  - Spatial summation
  - Temporal summation

Examples of neurotransmitters

Nervous Tissue Physiology

Ion Movements and Electrical Signals
(Electrophysiology)
**Transmembrane Potential**

**Polarized**

- Extracellular Fluid
- Intracellular Fluid

-70 mV

**Resting Membrane Potential**

- Extracellular Fluid

-70 mV

**Passive Forces**

- Chemical gradients
  - Concentrations of potassium and sodium

- Electrical gradients
  - Inside cell slightly negative relative to outside cell
  - Current: movement of charges to eliminate potential difference
  - Resistance: measure of how much the membrane restricts ion movement
    - Can change resistance by opening or closing ion channels

- Electrochemical gradients: the sum of the chemical and electrical forces acting on a specific ion across the cell membrane

**Electrochemical Gradient**: Sum of both concentration and gradient
Transmembrane Potential
Active Forces
Sodium-Potassium Exchange Pumps

Changes in Transmembrane Potential
Ion Channels

Leakage (nongated) channels are always open

Gated channels open and close in response to a stimulus and result in neuron excitability

Graded (Local) versus Action Potentials

45
46
47
48
Graded (Local) Potentials

- Small deviations from resting potential of \(-70\text{mV}\)
  - **hyperpolarization** = membrane has become more negative
  - **depolarization** = membrane has become more positive
- Graded/postsynaptic/receptor or generator potential
  - Ions flow through ion channels and change membrane potential locally
  - Amount of change varies with strength of stimuli
- Local current: flow of current (ions) is local change only

Action Potential

- Graded potential triggers........

**Threshold:** the transmembrane potential at which an action potential begins

**All-or-none principal:** with stimulation, either happens one specific way or not at all (lasts 1/1000 of a second)
**Action Potential**

1. Normal Resting State
2. Graded potential - threshold
3. Depolarization
4. Repolarization
5. Hyperpolarization
6. Reset
   - Reposition the ions using the sodium potassium pumps
   - Relative Refractory period

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**1. Resting**

- Both open at -55 mV

**2. Graded Potential - Threshold**

- Sodium gates close at +35 mV
- Potassium gates close at -70 mV

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**3. Depolarization**

- Both open at -55 mV

**4. Repolarization**

- Sodium gates closed, K⁺ gate fully open, K⁺ leaves cell

**5. Hyperpolarization**

- Sodium gates closed, K⁺ gate closing
6. Reposition - Back to Resting

Action Potential

Albert’s axon is repolarizing

A. Which gates are open?
B. Which gates are closed?
C. Which ions are moving?
   - Which direction (in or out of the cell)?

Refractory Period

- Refractory period: the period between the initiation of an action potential and the restoration of the normal resting potential

- Absolute refractory period: the membrane will not respond normally to stimulation

- Relative refractory period: another action potential can occur if membrane is sufficiently depolarized
Summary

Graded Potentials

Action Potentials

Neurotransmitter Release

Signal Conduction in Nerve Fibers

Conduction (propagation)
- Action potential moves forward, not backward, due to absolute refractory period

Continuous conduction:
- Unmyelinated axons
- step-by-step depolarization of each portion of the length of the axon membrane

Saltatory conduction
- Myelinated axons
- 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

Conduction

Continuous

Saltatory

Action Potential

Axon Diameter & Conduction Speed

Larger diameter, lower resistance

Classification of axons

- Type A fibers
  - Largest diameters
  - Myelinated
  - 140 m/s (300 mph)

- Type B fibers
  - Smaller diameters
  - Myelinated
  - 18 m/s (40 mph)

- Type C fibers
  - Smallest diameters
  - Unmyelinated
  - 1 m/s (2 mph)

Ex: position, balance, delicate touch, skeletal muscle control

Ex: Temperature, pain, general touch/pressure, control of smooth muscle, cardiac muscle, and glands
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**
  - GP is produced by chemical, mechanically-regulated, or light-gated channels
  - AP is produced by voltage-regulated ion channels

- **Conduction**
  - GPs are localized (not propagated)
  - APs conduct over the surface of the axon

- **Amplitude**
  - Graded potentials vary depending upon stimulus
  - Amplitude of the AP is constant (all-or-none)

- **Duration**
  - The duration of the GP is as long as the stimulus lasts
  - AP continues to the end of the axon

- **Refractory period**
  - The AP has a refractory period due to the nature of the voltage-gated channels, and the GP has none

Original Potentials

- GPs arise on dendrites and cell bodies
- APs arise only at trigger zone on axon hillock
- GPs are produced by chemical, mechanically-regulated, or light-gated channels
- APs are produced by voltage-regulated ion channels
- GPs are localized (not propagated)
- APs conduct over the surface of the axon
- Graded potentials vary depending upon stimulus
- The amplitude of the AP is constant (all-or-none)
- The duration of the GP is as long as the stimulus lasts
- The AP has a refractory period due to the nature of the voltage-gated channels, and the GP has none

Amplification Potential

- GPs are produced by chemical, mechanically-regulated, or light-gated channels
- APs are produced by voltage-regulated ion channels
- GPs are localized (not propagated)
- APs conduct over the surface of the axon
- Graded potentials vary depending upon stimulus
- The amplitude of the AP is constant (all-or-none)
- The duration of the GP is as long as the stimulus lasts
- The AP has a refractory period due to the nature of the voltage-gated channels, and the GP has none

Refractory Period

- The AP has a refractory period due to the nature of the voltage-gated channels, and the GP has none

Summary: Neuronal Structure & Function

**Diagnoses**

- Diagnosis: Nervous Tissue Physiology
- Nervous Tissue
- Synapses
- Neural Integration

**Structure**

- Neurons
  - Neurons transmit information through electrical or chemical signals
  - Neurotransmitters are released at synapses

**Functions**

- Neurons perform the following functions:
  - Generate and propagate electrical signals
  - Communicate with other neurons and muscles

**Local Anesthetics**

- Prevent opening of voltage-gated Na⁺ channels
- Nerve impulses cannot pass the anesthetized region
- Novocaine, lidocaine, procaine

**What stage is being affected?**

- Nervous Tissue Physiology
- Synapses
- Neural Integration
Nervous Tissue

Synapses

- **Electrical synapses**: direct physical contact between cells
  - Connexons
  - Gap junctions
  - Ex: brain regions involved in eye and head movement, postural reflexes, gravity dependent reflexes, and spatial orientation

- **Chemical synapses**: involve neurotransmitters

Cessation of the Signal (removal of neurotransmitter)

- **Diffusion**: move down concentration gradient
- **Degradation by enzymes**
- **Reuptake by neurons or neuroglia**
  - Neurotransmitter transporters
    - Ex: NE, dopamine, serotonin
  - Prozac = serotonin reuptake inhibitor

Postsynaptic Potentials

- **Postsynaptic potentials**: graded potentials that develop at postsynaptic membrane in response to neurotransmitter

- The effect of a neurotransmitter can be either excitatory or inhibitory

  - **Excitatory post synaptic potential (EPSP)**
    - it results from the opening of ligand-gated Na⁺ channels
    - the postsynaptic cell is more likely to reach threshold (depolarized)

  - **Inhibitory post synaptic potential (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

  - Strychnine poisoning

Chemical Synapses

- **Neurotransmitter in synaptic vesicles**
- **Receptors for neurotransmitter on postsynaptic cell**

*Try to identify numbered structures*
Summation (Integration)

- **Summation**: individual EPSPs and IPSPs combine, integrating the effects of all the graded potentials that effect a portion of the cell membrane
  - Spatial summation
    - Facilitation
    - Inhibition
  - Temporal summation

Spatial Summation

- Summation of effects of neurotransmitters released from several end bulbs onto one neuron

Summation: Facilitation and Inhibition

- Facilitation: one neuron enhances the effect of another
- Presynaptic inhibition: one neuron inhibits the effect of another

Temporal Summation

- Summation of effect of neurotransmitters released from 2 or more firings of the same end bulb in rapid succession onto a second neuron
Neural Pools and Circuits

**Neuronal pools:** functional groups of interconnected neurons

**Neural circuits** - pathway of neurons

Ex: visual info

Ex: breathing, consciousness

Ex: withdrawal, afterimage

Neurotransmitters and Related Messengers

**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
  - Learning and memory
- GABA (gamma aminobutyric acid) is inhibitory neurotransmitter for 1/3 of all brain synapses
  - Valium is a GABA agonist -- enhancing its inhibitory effect

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

- ATP and other purines (ADP, AMP, & adenosine)
  - 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
    - may play a role in memory & learning
  - first recognized as vasodilator that helps lower blood pressure

Neuropeptides

- Substance P -- enhances our perception of pain
- Opioids -- Pain relief
  - Endorphins
  - Endomorphins
  - Dynorphins
  - 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
  - *Synthetic forms: morphine, codeine, heroin, oxycodone, methadone*