Histology (Cells) of the Nervous System

• 2 major categories of cells are found in the nervous system:
• 1. **Nerve cells (neurons)** – carry impulses and are electrically excitable.
• 2. **Glial cells (neuroglia)** - do not carry impulses, not electrically excitable.

• We will discuss glial cells first.
• **Glial Cells (Neuroglia):** These cells do not carry electrical impulses as they are **not electrically excitable.** There are several types of glial cells with a number of different functions. About 50:1 ratio of glial to neurons, and make up half the mass of the brain.
Glial (Neuroglia) Cells

- **Glial cells found in CNS:**
  1. Astrocytes - most abundant, nutrient providers.
  2. Oligodendroglia - myelin sheaths.
  3. Microglia - phagocytes.
  4. Ependymal - ciliated semipermeable cells lining central cavity.

- **Glial Cells found in PNS:**
  1. Satellite cells - surround cell bodies.
  2. **Schwann cells** - produce myelin around axons.
Some of the many **functions of glial cells** are as follows:

• 1. Supportive of neurons - a "nerve glue". Like C.T.
• 2. Important in neuron nutrition.
• 3. Synthesize myelin.
• 4. Phagocytic.
• Most brain tumors (gliomas) arise from the actively dividing glial cells (neurons do not divide).
Component Parts of A Neuron

• **Nerve Cells (Neurons):** The nerve cells serve to carry electrical impulses. They are electrically excitable.

• There are several structural neuron cell types but we will discuss a generalized type.

• Many types of nerve cells are found in the body. A typical neuron possesses the following characteristic features:

1. **Cell body**
2. **Axon**
3. **Axon terminal**
4. **Direction of impulse**
Generalized Nerve Cell (Neuron) Component Parts and Function

1. **Dendrites**
   a. Serve to conduct information toward the nerve cell body.
   b. Are typically multiple and highly branched
   c. Are generally shorter than axon
   d. Are irregular in size (diameter)

2. **Cell body** - contains the nucleus of the cell.
Generalized Nerve Cell (Neuron) Component Parts and Function

3. **Axon**
   - a. Serves to **conduct the impulse away from the nerve cell body**.
   - b. Generally single but may have many branches to axon terminal.
   - c. Longer, may be three feet (1 meter) in length.
   - d. Of uniform diameter.

4. **Axon terminal** (terminal bouton).
Generalized Nerve Cell (Neuron) Component Parts and Function

4. **Axon terminal** (terminal bouton).
   - An axon terminal is the neuron ending.
   - It contains **synaptic vesicles** that contain **neurotransmitter** (chemical messenger) that carries the nervous system message from one neuron to the next across a gap between the neurons known as a synapse or from the neuron to a muscle cell across a gap known as the myoneural junction (neuromuscular junction).
Myelinated Axons

- Some neurons are **myelinated**.
- **Myelin** is a segmented sheath of fatty tissue = **white matter** that **serves to increase the speed of the nerve impulse**.
- Each segment of myelin is produced by a single glial cell (**Schwann Cell**) that is wrapped around the neuron (up to 100 times).
- The areas between the myelin are known as **nodes of Ranvier**.
Myelinated Axons

- The myelin causes the **impulse to jump** from one node of Ranvier to the next instead of traveling along the nerve cell membrane ion by ion.
  - The jumping or skipping of the impulse that occurs in myelinated fibers is known as **saltatory conduction** and **carries information much faster** than in nonmyelinated neurons = gray matter which exhibit **continuous conduction**.
  - Because the cytoplasm of the axon is electrically conductive, and because the myelin inhibits charge leakage through the membrane, depolarization at one node of Ranvier is sufficient to elevate the voltage at a neighboring node to the threshold for action potential initiation. (see next slides)
- The **greater the diameter of the myelinated neuron**, the faster will be it’s velocity of conduction - up to **120 meters per second**!
Myelinated Axons

- **Saltatory conduction** can be compared with a line of marbles pushing on each other - when poking the marble in one end then each marble only moves slightly, but this small effect on the marble in the other end is almost instantaneous, like a one-way Newton's cradle. So the signal moves at the speed of light between each node.
- Thus in myelinated axons, action potentials do not propagate as waves, but recur at successive nodes and in effect "hop" along the axon, by which process they travel faster than they would otherwise. This process is outlined as the charge will passively spread to the next node of Ranvier to depolarize it to threshold which will then trigger an action potential at the next node.
Saltatory Conduction = to Jump from node to node = faster
Myelinated = White Matter **

Continuous Conduction = from ion to ion = slower
Nonmyelinated = Gray Matter **

Myelinated = White Matter **

Saltatory conduction = Faster

Continuous conduction = Slower
Multiple Sclerosis

- **Multiple Sclerosis** results from a disease of the myelin sheath of the CNS and spinal cord.
- There is a **progressive demyelination** process (you lose the myelinated sheath).
- The **loss of myelin** causes a decrease in the velocity of conduction of the nerve impulse which can greatly affect coordination.
- There is a permanent scarring of the nerve tissue as the phospholipids which make up the cell membrane of the neuron are attacked.
- Clinically, multiple sclerosis symptomology includes:
  1. Numbness (when sensory neurons are effected).
  2. Vision loss
  3. Uncoordinated movements.
- **MS is an autoimmune disease**, where a person’s own immune system produces antibodies that cause oligodendrocytes in CNS to be attacked by cytotoxic immune cells.
Why a cold pack to reduce pain?

- **Temperature** also affects the conduction of nerve impulses.
- A cold pack will help relieve some pain as pain nerves are partially blocked by the cold.
Types of Neurons

- There are many different types of neurons in the body, some of which we will discuss later.

- For now we will limit our discussion to **3 types of neurons**:
  1. **Afferent (sensory) neurons** serve to bring the impulse or information **toward the brain**
  2. **Efferent (motor) neurons** carry information out and **away from the brain**.
  3. **Interneurons (association or connector or internuncial)** connect sensory to motor neurons.

- 99% of the neurons of the body are interneurons.
Physiological Properties of Neurons (Reviewed)

• **Threshold** - minimum strength (voltage) of a stimulus required to depolarize a neuron (create an AP). This is usually about \(-55\) mV (membrane depolarizes about 15-20 mV). This point is reached by the flow of \(\text{Na}^+\) in across the membrane in sufficient numbers per time.

**This starts the domino effect of rapid depolarization leading to an action potential**
Step 1

1A. Na⁺Chem gate opened by ACH

1st wave of Na⁺ in

1B. Na⁺ Voltage gate opens at -55mV

2nd wave of Na⁺ in

Step 2

2A. K⁺ voltage gate opens

K⁺ out
Physiological Properties of Neurons (Reviewed)

- **Summation** - many subthreshold stimuli may act together in an additive way to cause depolarization.

(a) Spatial summation

(b) Temporal summation
Physiological Properties of Neurons (Reviewed)

• **All or None Response** - The response of a neuron to a stimulus is either maximal or not at all.

• In other words, an action potential (AP) happens completely or not at all.

• (If you do not knock over the first domino, nothing happens.)

• If enough Na+ enters the cell, AP will occur, if not, no AP.
Physiological Properties of Neurons (Reviewed)

• **Refractory Period** - The refractory period is a “resting period” for the neuron following depolarization. During the refractory period the neuron does not respond to normal stimuli.

• Following depolarization, there is a period of time called an **absolute refractory period** during which a second stimulus, no matter how strong, will not elicit a response on the part of the neuron. The Na+ gates are open or inactive.

• Following the absolute refractory period there is a period of time during which a stronger than normal stimulus will elicit a response, this is called the **relative refractory period**. The K+ gates are open and the Na+ gates have been reset.
Refactory Period = Resting Period

**absolute refractory period** - time during which a second stimulus, no matter how strong, will not elicit a response on the part of the neuron.

**relative refractory period** - Following the absolute refractory period there is a period of time during which a stronger than normal stimulus will elicit a response.
Physiological Properties of Neurons (Reviewed)

- **Accommodation** - a rise in the threshold of a neuron due to repeated stimulation, therefore it takes a greater stimulus to elicit a response. (not in text)

- In laymen’s terms there is a “deadening of the nerve”. Synonyms for accommodation would be **habituation** and **tolerance**.

- For example, constant repeated exposure to a specific drug, alcohol, or even noise may cause, in time, a reduced effect of that stimulus. In other words, to achieve the same “high”, you may need more of a specific drug.
The Nervous System Message

• The nervous system message is electrochemical in nature.
• 1. The nerve impulse passes through the neuron as an electrical message, and
• 2. Across the synapse as a chemical message.
• The chemical that carries the message across the synapse = neurotransmitter.
• The nervous system message travels along distinct pathways = nerves. (Unlike endocrine system where message travels via blood).
• A nerve is a bundle of neurons (actually bundle of axons or dendrites) bound together by C.T. like the wire strands in an electrical cable.
The Synapse

- **The Chemical Synapse**

  The synapse is an area *functional* but not *anatomical* (structural) continuity between one neuron and another. Therefore there is no structural connection. The neurotransmitter serves to functionally connect the presynaptic neuron to the postsynaptic neuron as it diffuses across the synapse.
Physiological Properties of the Synapse

1. **One way conduction** - Because only one end of the neuron contains synaptic vesicles with neurotransmitter, the chemical message can only travel from the axon terminal of the presynaptic neuron to the dendrites of postsynaptic neuron.
Physiological Properties of the Synapse

2. **Facilitation (or excitatory postsynaptic potential (EPSP))**
   - When an excitatory presynaptic neuron synapses with a postsynaptic neuron that causes depolarization.
     - The release of excitatory neurotransmitter to the postsynaptic neuron excites the membrane and cause the membrane potential to move towards 0mV (more positive) so it moves the potential closer to triggering an action potential.
     - This usually caused by a Na+ channel opening in the membrane.
   - When the **threshold for the postsynaptic neuron is lowered** for some reason making it easier for the information to pass (generate an AP). These effects can last for minutes to hours.
   - This may be **due to repeated use and is of interest in terms of learning, memory, and conditioning.**
Physiological Properties of the Synapse

3. **Inhibition (or inhibitory postsynaptic potential (IPSP))** - Inhibition is the opposite of facilitation. The threshold of a postsynaptic neuron is increased. When an inhibitory presynaptic neuron synapses with a postsynaptic neuron that causes hyperpolarization.
   • Inhibition is the opposite of facilitation.
   • The neurons is releasing an inhibitory neurotransmitter causing further hyperpolarization of the membrane.
     • This usually caused by opening a K+ or Cl- channel.
     • The subtracts from any graded potential produced by a excitatory synapse. It competes against an excitatory neuron to create an action potential.
   • So, a greater excitatory stimulus is necessary for the message (AP) to continue.
   • A greater stimulus is necessary for the message (AP) to continue.

**Summary of Facilitation and Inhibition**:
• Presynaptic facilitation and inhibition effects can last for minutes to hours.
• They are of interest in terms of learning and memory.
Physiological Properties of the Synapse

4. **Synaptic delay** - The speed of the nervous system message slows at the synapse because the electrical AP is converted to a chemical signal (neurotransmitter) and then back to an AP. This is a 0.5 ms delay.

- The velocity of the electrical message may be as high as 120 meters per second along the neuron but chemical message slows to 0.5-1.0 m/s at the synapse.

- Therefore, the fewer the number of synapses to get the message from one place to another, the faster it will travel.
Physiological Properties of the Synapse

5. **Summation** - Summation occurs when many presynaptic neurons converge on a single postsynaptic neuron (spatial summation) or a single presynaptic neuron repeatedly fires in rapid succession (temporal summation).

- You may have many subthreshold stimuli that work in an additive way to produce enough neurotransmitter to meet the threshold of the postsynaptic neuron.

- Example: The typical CNS neuron receives input from 1000-10,000 synapses.
Physiological Properties of the Synapse

- **Many drugs** have great effects on synapses, we have discussed some of these.
- **Aspirin** causes sensory (pain) inhibition by raising the threshold of conduction of impulses near the hypothalamus (pain center).
- **pH** - Increased pH (basic condition, alkalosis) serves to increase the ease of transmission, while lowering the pH (acidic condition, acidosis) serves to depress transmission.
- **O₂** - **Hypoxia** (low oxygen levels) can lead to cessation of synaptic activity.
Types of Neurotransmitters

1. **Acetylcholine (ACh)** - Very common throughout the body (CNS and PNS). Example: Used in somatic and ANS motor divisions. It is continually broken down by acetylcholine esterase (AChE).
   - Excitatory in neuromuscular junctions where it activates muscles, but in inhibitory at parasympathetic heart synapses where it slow cardiac muscle activity.
Types of Neurotransmitters

- **Norepinephrine** - Found in CNS and PNS. Can be excitatory or inhibitory depending on receptor.
- Found in CNS for roles in arousal from sleep, dreaming, mood.
- Found in the PNS (postsynaptic neurons of the sympathetic division of the nervous system). Also a hormone secreted from the adrenal medulla to fortify a sympathetic response via the vascular system.

- The chemical structure of amphetamines is similar enough to mimic norepinephrine.
  - Therefore when a person takes amphetamines they exhibit a sympathetic nervous system response that includes increased heart and respiratory rate, dilated pupils, etc.

- Unlike acetylcholine which is continually broken down by acetylcholine esterase, norepinephrine is removed from the receptor sites and transported back across the synapse and back into the synaptic vesicles to be used again and again.
- **Cocaine** is a drug which blocks the transport of norepinephrine back across the synapse.
  - Therefore it makes sense that a person under the influence of cocaine will exhibit a sympathetic nervous system response.
Types of Neurotransmitters

- **3. Serotonin** - Found in the CNS and it mainly inhibitory.
  - Found in the CNS involved in mood control, appetite, sleep induction, temperature regulation.
  - Serotonin is a neurotransmitter involved with behavior and has been implicated in many psychotic disorders including depression and others with hallucinatory symptoms.
  - People with depression exhibit serotonin deficiency and schizophrenia exhibit high levels (or dopamine too).
  - People with depression exhibit serotonin deficiency and with schizophrenia exhibit high levels.
  - **Prozac**, a commonly used antidepressant, is known to inhibit CNS neuronal serotonin uptake. This leaves more serotonin in the synapse to have lasting effects.
  - Mescaline, a drug found in peyote cactus, and LSD are known to block serotonin receptor sites therefore bringing about hallucinations.
Types of Neurotransmitters

4. **Dopamine** - Found in the brain. Can be excitatory or inhibitory depending on receptor.
   - Like norepinephrine is constantly recycled instead of being broken down.
   - **Psychotic symptoms arise in the presence of too much dopamine**. A good example is schizophrenia which includes hallucinations and delusions.
   - Some therapeutic drugs (chlorpromazine = thorazine and halprodol) work to **block dopamine receptors therefore reducing dopamine exposure**.
   - Amphetamines worsen the schizophrenic condition because they promote dopamine production by the brain.
   - **Parkinson’s Disease** - (depression of voluntary motor control) results from destruction of dopamine secreting neurons.
Types of Neurotransmitters

• 5. **GABA** (Gamma Amino Butyric Acid), an amino acid not found in proteins.
• Found only in brain. Most common inhibitory neurotransmitter, in as many as 1/3 of all brain synapses.
• It has a tendency to increase the cell membranes permeability via chemically gated Cl⁻ channels so it crosses into the cell making it more negative.
  – This makes the cell membrane even more polarized and therefore less excitable (inhibition).
• Antianxiety drugs diazepam (Valium) enhances these effects.
• It is augmented by alcohol (slowed reflex coordination) and Valium.
Types of Neurotransmitters

GABA – an inhibitory neurotransmitter

GABA is important in the case of antagonistic muscles (i.e. the biceps and the triceps). There are inhibitory neurons that work to prevent antagonistic muscles from working at the same time.

In this case the biceps receiving acetylcholine would contract and cause flexion but the triceps receiving GABA would be inhibited.

Tetanus toxin (produced by bacteria) prevents the release of inhibitory neurotransmitters in neurons allowing all muscles to contract simultaneously leading to a condition we call tetanus (lockjaw).
Types of Neurotransmitters

• **6. Endorphine** – produced by in pituitary, thalamus, hypothalamus.

• Acts a natural opioid peptide.
  – Relieves pain by inhibiting release of P substance from sensory nerves.
  – Gives a sense of ‘well being’
  – May allow you to ‘carry on’ for a time in the presence of pain.

• Produced during extensive exercise (runner’s high), excitement, pain, orgasm.
Components of a Spinal Reflex Arc

- **A reflex** is a very fast involuntary response that serves to prevent bodily harm.
- Example: Jerking your hand back from a hot flame.
- There are few synapses and the message only has to travel to the spinal cord (not the brain) for you to respond, therefore your response is very quick.
- 1. **Receptor** - a sense organ (heat receptor in this case).
- 2. **Afferent neuron** - serves to carry the information to the spinal cord.
- 3. **Interneuron** - is found within the spinal cord and connects the afferent (sensory) neuron to the efferent (motor) neuron.
- 4. **Efferent neuron** - carries the information from the spinal cord to the effector organ.
- 5. **Effector organ** - skeletal muscle (in this case) that contracts and causes you to jerk your hand back.
Components of a Spinal Reflex Arc

1. SENSORY RECEPTOR (responds to a stimulus by producing a generator or receptor potential)
2. SENSORY NEURON (axon conducts impulses from receptor to integrating center)
3. Interneuron
4. MOTOR NEURON (axon conducts impulses from integrating center to effector)
5. EFFECTOR (muscle or gland that responds to motor nerve impulses)

INTEGRATING CENTER (one or more regions within the CNS that relay impulses from sensory to motor neurons)