Lecture 2a: Structure & Function of Cells in the Nervous System

Most cells in the body - including those in the Nervous System - share many basic features, including...

**Soma** = Cell body  **Cytoplasm** = Fluid inside cell  **Extracellular Fluid** = Fluid outside cell

Organelles in cells include...

- **Nucleus** – where DNA (mostly instructions for building proteins) stored
- **Ribosomes** - Site of Protein Production
  - Proteins serve many functions (structure, transport, metabolism, membrane gates, etc)
  - DNA sends “messenger RNA” from Nucleus, mRNA attaches to Ribosomes, instructs protein production
- **Mitochondria** - Produce ATP (Adenosine triphosphate) whose breakdown frees energy to power cell functions
  - Tend to cluster where “active” (energy-requiring) processes occur
- **Membrane** - **Lipids** (fat molecules) w/hydrophobic cilia form double layered wall, 8nm thick
  - Permeable to H2O, O2, CO2, some fats; Generally impermeable to charged ions & larger molecules

**Glial Cells** – The non-neural cells of Nervous System; Many functions, but do NOT participate in Info Transfer
- “Glia” = “Glue”; hold the Membrane
- e.g. Astrocytes – Provide nutrients to Neurons, blood brain barrier, recycle NTs, remove waste, etc.
- e.g. Microglia - Proliferate in areas of brain damage, remove toxic materials
- e.g. Myelination - whole Schwann Cells wrap around axon in PNS, arms of an Oligodendrocyte in CNS
- e.g. Ependymal Cells – Line Ventricles, secrete Cerebral Spinal Fluid, beat cilia to circulate fluid
- e.g. Radial Glia - Guide migration and growth of Neurons during development (see below)

- Much smaller than most neurons (average 1/10), much more numerous (10X), so ~ 50% of brain by weight
- Unlike most Neurons, many Glial cells can regenerate (Runaway regeneration = “Glioma” brain tumor)

**Neurons** - Cells that are specialized for Information Transfer via modified 1) Processes and 2) Membrane
1) **Processes** = Elongated structures projecting from the “Soma” or cell body = **Dendrites** and **Axon**

- **Dendrites** - Site of reception of incoming message
  - From Greek “Dendron” = Tree, Usually many tapering, dividing branches, sometimes w/extra Spines
  - **Receptor Sites** along surface interact w/molecules of Neurotransmitter (NT) from other Neurons
  - Often have Ribosomes (for protein production), can be important for processing incoming message
- **Axon** - Site of release of outgoing message
  - Each Neuron has, at most, one Axon, often long, non-tapering, may be Myelinated, end may branch
  - Ends in Presynaptic Terminals (also called Terminal Buttons or End Bulbs) where NT is released
  - **Mitochondria** in Terminals for energy-requiring processes like release/re-uptake of NT, ion pumps

2) **Membrane** As in all cells, lipid membrane generally impermeable to charged ions & larger molecules
- Neuron’s special **Selective Permeability** controls which chemicals enter/leave; affects electro-chemistry
- This done via gates (“channels”) that open or close to let chemicals (charged “ions”) pass through

**The Nerve Impulse**

To understand how Neurons “communicate” we first need to recognize that Nature seeks a Balance . . .

- i.e. Any Gradient (inequality) between the chemicals inside vs. outside cell will “seek” an equilibrium

  **Concentration Gradient** - Molecules in area of greater concentration will Diffuse to area of lesser conc

  **Electrical Gradient** - Positively charged particles will move away from other positive (& towards negative) and negative will move from negative (& towards positive) = Electrostatic Pressure

- In Neurons, the distribution of charged particles (ions, w/extra + proton or - electron) in/outside cells is controlled
  - Recall how the Blood-Brain Barrier restricts what chemicals can move from bloodstream into brain
- **Membrane Potential** = Diff in charge in/outside cell, measured in millivolts (mV) using microelectrodes
- Key ions: Sodium Na+  Potassium K+  Calcium Ca++  Chloride Cl-  as well as some charged Proteins

**Resting Potential** of most Neurons = 70 mV (less positive inside / more positive outside)
- Established in part by energy-requiring Sodium/Potassium Pump, actively transports 3 Na+ out and 2 K+ in
  - After transport, Na+ gates close, Na+ trapped outside (Extracellular fluid similar to seawater, w/NaCl salt)
  - K+ gates remain semi-open, K+ tends to leak out a bit
- Since Na+ now = 10:1 outside:inside, plus overall high quantity, Na+ “wants” to enter cell (to equalize both the Chemical and Electrical Gradients), but membrane is now impermeable to Na+
- Since K+ now = 1:10 outside:inside, plus lower overall quantity than Na+, K+ “wants” to exit cell to equalize the Chemical Gradient, but inhibited by Electrical Gradient (since outside more +)
- Cell’s negatively charged protein molecules are too large to leave, and closed Ca++ gates keep Calcium out
  - Thus, Electrical Gradient also helps maintain more Cl- outside (attracted to more + ions outside)
- Resting cell is thus **Polarized** = Large electro-chemical difference between inside/out = Ready to “fire”

**Action Potential = Depolarization of Neuron = Cell “Fires” AKA “Spikes”**
- Changes in membrane permeability of Axon, propagated via **Ionic Conduction**
- Triggered by NT from other Neuron, electrical stimulation, or other (see more on Synapse, below), typically…
  - Starting at **Axon Hillock** (where Axon joins Soma), **Voltage-activated Na+ gates open**
  - Na+ rushes in, reverses local polarization (depolariizes to +50mV)
  - Na+ moving inside causes adjacent Na+ voltage-activated gates to open, & previously-open ones close
  - This depolarization sequence continues along Axon toward Terminal
  - As previous Na+ gates close, local K+ gates open wide, K+ leaves (now per both chem & elec gradients)
  - Na+ gates continue to close, and K+ to open, following behind depolarization that is moving along Axon
  - When depolarization reaches **Terminal**, Ca++ gates there open & Ca++ enters cell
  - Ca++ influx leads to **Neurotransmitter (NT) release**
  - As Membrane Potential again approaches more pos outside than in from K+ outflow, K+ gates begin to close
  - In time, **Sodium-Potassium Pump** actively restores Resting Potential (via 3Na+ out/2K+ in) => -70mV
  - And **Calcium Pump** actively rejects Ca++ from terminal – Unlike passive ion flow above, pumps req **Energy**
- During **Refractory Period**, while cell is being re-polarized, it cannot fire (or resists firing)
  - Refractory Period also prevents impulse from being propagated back along Axon toward Soma
  - by locking down gates behind, as impulse moves from hillock to terminal
  - **All-or-None Law** = In a given cell, an Action Potential always has the same amplitude and velocity, regardless of the intensity of the stimulus that triggered it
  - Nonetheless, while the amplitude of the Spike (extent of depolarization) & amt of NT released is **fixed**
    the “message” such a cell can transmit can be varied through its…
    - **Frequency of Firing** (# spikes per sec) and **Pattern of Firing** (e.g. | | | | | | | vs. || || || || )

**Myelination and Saltatory Conduction** - Increases the speed of the propagation of an Action Potential
- **Glia cells** form insulating sheaths around some axons, with small gaps (**Nodes of Ranvier**) in between sheaths
  - **Oligodendrocytes** myelinate cells in Central NS (Brain and Spinal Cord), **Schwann Cells** in Peripheral NS
- **Electrical Conduction** (flow of electrons, like in an insulted wire) occurs along myelinated segment
  - But such signal **degrades** (weakens) as it moves, needs to be re-boosted, periodically, to original strength
  - This occurs at **Nodes of Ranvier**, where electrical signal triggers the slower but stronger Ionic Conduction, which in turn triggers Electrical Conduction that moves rapidly under next sheath to next node, etc. etc.
  - **“Saltatory”** = “Jumping” Nerve Impulse in effect “jumps” from node to node as it is propagated along axon
  - Increases overall speed of impulse from 1-10 m/sec to 100-120 m/sec!
- **MS (Multiple Sclerosis)** - Disease destroys myelin: In such un-insulated axons, electrical signal quickly degrades
  - Plus, since no Na+ gates under sheath, cell cannot resort to Ionic Conduction => cannot fire

**Graded Potentials** – Releasing NT from a Neuron does NOT always requires an Action Potential !
- e.g. Some **Receptor** cells (e.g. in Retina, Cochlea) react to outside stimulus (light, sound) w/graded potential
  - Loud sound >> large amounts of NT released, **Soft sound** >> little amount of NT released
- e.g. **Lateral Inhibitors** – cells that suppress neighboring cells so central cell’s message can get through
  - Often graded: The more/less excited the principal cell, the more/less inhibition to the neighbors
- e.g. Some Neurons are very small, have short or even no Axon or Dendrites
  - Called **Local Neurons**, these cells communicate only with immediately adjacent cells
  - In these Neurons, extremely rapid **Electrical Conduction** can cause NT release
  - Since cells so small, Electrical Conduction need not travel far, does not completely degrade

- Unlike Action Potentials, Graded Potentials can **vary in amplitude** in proportion to the input stimulus
  - i.e. React a lot to strong stimulus, less to weak one
- **NT Release** also tends to be **graded** (vs. fixed amounts typically released by Action Potential)