Chapter 41: Cells of the Nervous System

Neuron Structure

Neurons consist of three basic parts: dendrites, cell body, and axon.

1. Each neuron has numerous **dendrites** which receive signals from other neurons.
2. The **cell body** is the “normal” part of the cell. It contains the nucleus and most of the organelles.
3. The **axon** is the long projection that carries signals from the cell body to more distant locations to pass the signal to another neuron.

Communication between neurons occurs at specific sites called synapses. They come in two varieties: chemical and electrical. Chemical synapses are the more common variety and involve neurotransmitter from the presynaptic cell binding to receptors on the postsynaptic cell. Electrical synapses occur only in the CNS, and travel via gap junctions between cell bodies. This type of transmission is very rapid.

**Glial Cells**

Glial cells are more abundant in the brain than are neurons. They provide the neurons with a cozy environment in which to function by providing them with metabolic and structural support. Two specific types of glial cells, ogliodendrocytes and Schwann cells, wrap around axons to form the myelin sheath (see below).

**Q.** How does the structure of a neuron help it accomplish its function?

**Electrical concepts and nerve impulses**

**Membrane potential**

The plasma membrane acts as a battery: it stores potential energy by separating charges. Ions cannot cross the lipid bilayer without the aid of an ion-specific channel. This property allows for ions to be unevenly distributed across the membrane:

- \([\text{Na}]_i = 10-20 \text{ mM}\)
- \([\text{Na}]_o = 140 \text{ mM}\)
- \([\text{K}]_i = 120-140 \text{ mM}\)
- \([\text{K}]_o = 3.3 \text{ mM}\)
- \([\text{Cl}]_i = 5-14 \text{ mM}\)
- \([\text{Cl}]_o = 124 \text{ mM}\)
At rest, the membrane is permeable only to K+, which diffuses out of the cell through open K+ channels. Also, the Na+/K+ pump is active: pumping 2 K+ into the cell for every 3 Na+ pumped out of the cell. Together these two elements, plus the impermeability of the cell the Na and Cl, set the resting membrane potential at approximately –70 mV (inside negative to the outside).

**Q.** Why is the sodium potassium pump “electrogenic”?

**Voltage gating**

Na+ and K+ channels are said to be voltage-gated. This means that they will remain closed until they sense that the membrane potential has reached a certain value (usually –40 mV). At this potential, the protein undergoes a conformational change that opens the channel.

The channels will briefly remain open and allow ions to pass, but quickly will be inactivated and become impermeable again (closed). This is accomplished, most likely – the method is still under investigation, by a different conformational change.

**Q.** If voltage-gated sodium channels opened at –65 mV instead of –40 mV, how would the firing pattern of a neuron change?

**Changes in membrane potential**

During an action potential the permeability of the membrane to specific ions changes at set intervals. These changes can cause the cell to either

1. depolarize – the membrane potential becomes more positive
2. hyperpolarize – the membrane potential becomes more negative

This is determined by which ions move (due to their charge) and in which direction.

1. If Na+ channels open, which way will Na+ want to move? Into the cell. Since Na+ is positively charged, this means positive charge is entering the cell. How will this affect the membrane potential? Will depolarize the cell.

2. If K+ channels open which, way will K+ want to move? Out of the cell. Since K+ is positively charged, this means positive charge is leaving the cell. How will this affect the membrane potential? Will hyperpolarize the cell.

3. If Cl- channels open which, way will Cl- want to move? Into the cell. Since Cl- is negatively charged, this means negative charge is entering the cell. How will this affect the membrane potential? Will hyperpolarize the cell.

Now compare this ionic movement to an action potential.
1. Resting potential – determined by K+ passively leaving cell (hyperpolarizing effect). This is why the resting potential is negative. Also, the Na/K pump is helping set ionic gradients.

2. Stimulus – an excitatory stimulus opens a small number of Na+ channels. Na+ enters, causing a small depolarization to about –40 mV.

3. Upswing – voltage-gated Na+ channels open, more Na+ enters, cell depolarizes rapidly to about 50 mV.

4. Downswing – Na+ channels inactivate (close), voltage-gated K+ channels open. K+ leaves the cell, hyperpolarizing it beyond the resting potential. (Voltage gated K+ channels are also activated by the depolarization to threshold, but they have a delayed opening. This is why they open after the Na+ channels.)

5. Resting potential – K+ channels close (inactivate), cell returns to resting potential.

NOTE – If a cell is hyperpolarized, it needs a larger stimulus to fire an action potential. Therefore, a hyperpolarization is inhibitory and, in most cases, will not allow another action potential to fire until resting potential has been re-established.

Q. An action potential is called an “all or none phenomena”. What does this mean?
Propagation

As Na+ ions enter through their voltage-gated channels during an action potential, they begin moving along the inside of the axon into areas of lower concentration. This serves as the “stimulus” for the Na+ channels further down the axon to begin opening and an action potential to begin at the new location. Then more Na+ enters and begins moving down the axon, etc., etc., etc.

This process goes faster in myelinated axons. Myelinated axons have no ion channels beneath the myelin, therefore the action potential “jumps” from Node of Ranvier to Node of Ranvier (saltatory conduction). The reason this is faster is that Na+ ions travel, without loss, down the axon faster than channels can open and continuously regenerate the AP.

Q. If an axon was unmyelinated, would the action potential decrease in amplitude as it traveled? Why or why not?

Synapses

Synaptic structure

1. Presynaptic membrane: has voltage-gated Ca^{2+} channels, vesicles with neurotransmitter (at the NMJ the neurotransmitter is acetethylcholine).
2. Synaptic cleft: gap between cells, at NMJ is usually 20-40 nm.
3. Postsynaptic membrane: is invaginated to prevent transmitter spreading out, has neurotransmitter receptors (some of which work thru G-proteins).
Steps in synaptic transmission:

1. AP enters the presynaptic terminal. (Na+ channels open, depolarizing terminal.)
2. Voltage-gated Ca\(^{2+}\) channels open, Ca\(^{2+}\) enters (is in higher concentration outside cell).
3. Ca\(^{2+}\) entering triggers vesicles to move to presynaptic membrane, fuse with the membrane, and dump the neurotransmitter into the cleft.
4. Neurotransmitter diffuses across cleft to postsynaptic membrane.
5. Neurotransmitter binds to receptors.
6. Binding triggers receptor/channel opening, or may activate G-protein.
7. The neurotransmitter is either broken down by enzymes (in the case of actetylcholine the enzyme is actetycholinesterase) or is taken back up by the presynaptic cell (or both).
Q. The synapse is a common target for pharmaceuticals. Describe 4 ways in which a drug can block synaptic transmission.

Summation

The post synaptic cell receives thousands of inputs from different neurons. It must integrate all of this incoming information at the axon hillock in order to make a decision whether to fire or not. This integration is called summation. There are two type of summation:

1. **temporal summation** – postsynaptic potentials that occur at the same site are added together. Thus, if the membrane is already depolarized slightly from one input when another excitatory input arrives at the same place, the two inputs will be added together to make a larger depolarization.

2. **Spacial summation** - postsynaptic potentials that occur at different sites on the dendrites but arrive at the axon hillock at the same time are added together. This sum determines whether or not the neuron will fire.
Neuronal Circuits

Sensory input (PNS) → integration (CNS) → output to effectors (PNS)

This is the basic circuit in the nervous system. Each portion represents a different set of neurons (sensory, inner, motor). Reflexes are the simplest circuits in the nervous system; i.e. they involve the fewest neurons. An example is the myotatic/"knee jerk" reflex.

Steps:
1. Tap on patellar tendon causes stretching to be detected by sensory receptors.
2. AP generated in sensory neuron travels to the spinal cord.
3. Sensory neuron synapses on two motor neurons:
   a. Motor neuron to the extensor muscles (quads) is excited, causing contraction.
   b. Motor neuron to flexor muscles (hamstrings) is inhibited, causing relaxation.
4. End result: knee is extended (kicking motion).

Q. Can reflexes be overruled by input from the brain? Please give an example.