Neurons, Synapses, and Signaling

Doç. Dr. M. Borga Ergönül

Neurons are nerve cells transfer information within the body. Communication by neurons largely consists of long-distance electrical signals and short-distance chemical signals.

The special structure of neurons allows them to use pulses of **electrical current** to receive, transmit, and regulate the flow of information over **long distances** within the body.

In transferring information from **one cell to another**, neurons often rely on **chemical signals** that act over very short distances.

Most of a neuron's organelles, including its nucleus, are located in the cell body. A typical neuron has numerous highly branched extensions called dendrites. Together with the cell body, the dendrites *receive* signals from other neurons.

A neuron also has an axon, -an extension- that *transmits* signals to other cells. Axons are often much longer than dendrites, (some are over a meter long).

The coneshaped base of an axon, called the axon hillock, is typically where signals that travel down the axon are generated. Near its other end, an axon usually divides into many branches (axon terminals).

Each branched end of an axon transmits information to another cell at a junction called a synapse. The part of each axon's branch that forms this special junction is a *synaptic terminal*.

At most synapses, chemical messengers called neurotransmitters pass information from the transmitting neuron to the receiving cell.

The neurons of vertebrates and most invertebrates require supporting cells called glial cells, or glia. Glia nourish neurons, insulate the axons of neurons, and regulate the extracellular fluid (oxygen and nutrient supply) surrounding neurons. In addition, glia sometimes function in protection of neurons. Glia outnumber neurons in the mammalian brain 10- to 50-fold.

Information Processing

Information processing by a nervous system occurs in three stages:

- sensory input,

- integration,

- motor output.

Depending on its role in information processing, the shape of a neuron can vary from simple to quite complex.

Neurons that transmit information to many target cells do so through **highly branched axons**.

Similarly, neurons that have highly branched dendrites can receive input through tens of thousands of synapses in some interneurons.

In many animals, the neurons that carry out integration are organized in a **central nervous system (CNS)**. This includes the brain and a nerve cord.

The neurons that carry information into and out of the CNS constitute the **peripheral nervous system (PNS)**.

Data transmition

In neurons, as in other cells, ions are unequally distributed between the interior of cells and the surrounding fluid. As a result, **the inside of a cell is negatively charged** relative to the outside. Because the attraction of opposite charges across the plasma membrane is a source of potential energy, this charge difference, or voltage, is called the **membrane potential**. For a **resting neuron** -one that is not sending a signal- the membrane potential is called the **resting potential** and is typically between -60 and -80 mV (millivolts).

Inputs from other neurons or specific stimuli cause **changes** in the neuron’s membrane potential that act as signals, - transmitting the information. Fundamentally, the changes in membrane potential enable us to see, hear a song, or ride a bicycle.

Conduction speed

The rate at which the axons within nerves conduct action potentials governs how rapidly an animal can react to stimuli. As a consequence, natural selection often results in anatomical adaptations that increase conduction speed. One such adaptation is a wider axon.

Axon width matters because resistance to electrical current flow is inversely proportional to the cross-sectional area of a conductor (such as a wire or an axon). In the same way that a wide hose offers less resistance to the flow of water than does a narrow hose. Thus, a wide axon provides less resistance to the current associated with an action potential than does a narrow axon.

Myelin Sheath

In vertebrates, axons are insulated by a **myelin sheath**, which causes an action potential's speed to increase.

Myelin sheaths are made by glial cells in the nervous system.

During development, these specialized glia wrap axons in many layers of membrane. The membranes forming these layers are mostly lipid, which is a poor conductor of electrical current and thus a good insulator.

The majority of synapses are **chemical synapses**, which involve the release of a chemical **neurotransmitter** by the presynaptic neuron. At each terminal, the presynaptic neuron synthesizes the neurotransmitter and packages it in multiple membrane-enclosed compartments called ***synaptic vesicles***.

The arrival of an action potential at a synaptic terminal depolarizes the plasma membrane, opening voltage-gated channels that allow Ca2+ to diffuse into the terminal. The resulting rise in Ca2+ concentration in the terminal causes some of the synaptic vesicles to fuse with the terminal membrane, releasing the neurotransmitter.

Once released, the neurotransmitter diffuses across the *synaptic cleft*. Diffusion time is very short because the gap is less than 50 nm across. Upon reaching the postsynaptic membrane, the neurotransmitter binds to and activates a specific receptor in the membrane.

After release, the neurotransmitter

- May diffuse out of the synaptic cleft
- May be taken up by surrounding cells
- May be degraded by enzymes

Neurotransmitters

- Signaling at a synapse brings about a response that depends on both the neurotransmitter released from the presynaptic membrane and the receptor at the postsynaptic membrane. A single neurotransmitter may bind specifically to more than a dozen different receptors. Thus, the same neurotransmitter can produce different effects in different types of cells.
- There are five major classes of neurotransmitters: **acetylcholine, biogenic amines, amino acids, neuropeptides,** and **gases (NO, CO).**
- **Gases** such as nitric oxide and carbon monoxide are also **local regulators** in the **PNS**.

Nervous System

Nervous systems consist of circuits of neurons and supporting cells

- A **nerve net** is a series of interconnected nerve cells. There is no central pathway / or directional organization.
- The simplest animals with nervous systems, the cnidarians, have neurons arranged in nerve nets.

- In more complex animals with bilaterally symmetry, cephalization is common. Cephalization is the clustering of sensory organs at the front end of the body.
- In nonsegmented worms, (*Planaria*), a small brain and longitudinal nerve cords constitute the simplest CNS.
- More complex invertebrates, such as annelids and arthropods, have many more neurons. Their behavior is regulated by more complicated brain and by ventral nerve cords containing **ganglia**, - segmentally arranged clusters of neurons.
- Invertebrates usually have a ventral nerve cord. Whereas vertebrates have a dorsal spinal cord

Nervous system organization usually correlates with lifestyle. Among the molluscs, for example, sessile and slow-moving species, such as clams and chitons, have relatively simple sense organs and little or no cephalization.

In contrast, active predatory molluscs, such as octopuses and squids, have the most sophisticated nervous systems of any invertebrates, rivaling those of some vertebrates.

Nervous system has 2 main divisions

- CNS (Brain – Spinal Cord/Longitidunal Nerves)
- PNS (Sensory Neurons - Motor Neurons)

- PNS has 2 sub-systems

- Motor system – voluntary movement (balance, movement)
- Autonomic system – involuntary movement (breathing, digestion)

The Peripheral Nervous System

- The PNS transmits information to and from the CNS and regulates movement and the internal environment.

- In the PNS, *afferent* neurons transmit information to the CNS and *efferent* neurons transmit information away from the CNS.
- **Cranial nerves** originate in the brain and mostly terminate in organs of the head and upper body.
- **Spinal nerves** originate in the spinal cord and extend to parts of the body below the head.

- The **PNS** has two functional components: the motor system and the autonomic nervous system.
- The **motor system** carries signals to skeletal muscles and is voluntary.
- The **autonomic nervous system** regulates the internal environment in an involuntary manner.

Central Nervous System

In vertebrates nervous system consists of brain and spinal cord.

The ***central canal*** of the *spinal cord* and the ***ventricles*** of the *brain* are hollow and filled with ***cerebrospinal fluid***.

The cerebrospinal fluid is filtered from blood and functions to cushion the brain and spinal cord.

The brain and spinal cord contain;

- **Gray matter**, which consists of neuron cell bodies, dendrites, and unmyelinated axons.
- **White matter**, which consists of bundles of myelinated axons.

Brain

In vertebrates brain has 3 major regions. However, the size and complexity of each region and brain as a whole depends on the level of organization.

- Cerebral hemispheres
- Diencephalon
- Brain stem
- Cerebellum

Cerebrum

The cerebrum has right and left **cerebral hemispheres.** Each cerebral hemisphere consists of a **cerebral cortex** (gray matter) overlying white matter and basal nuclei. The right half of the cerebral cortex controls the left side of the body, and vice versa.

In humans, the cerebral cortex is the largest and most complex part of the brain.

The **basal nuclei** are important centers for planning and learning movement sequences.

The Diencephalon

- The diencephalon develops into three regions: the epithalamus, thalamus, and hypothalamus.
- The *epithalamus* includes the pineal gland and generates cerebrospinal fluid from blood.
- The **thalamus** is the main input center for sensory information to the cerebrum and the main output center for motor information leaving the cerebrum.
- The **hypothalamus** regulates homeostasis and basic survival behaviors such as feeding, fighting, fleeing, reproducing and circadian rhythms such as the sleep/wake cycle.

The Brainstem

*The **brainstem** coordinates and conducts information between spinal cord and cerebrum.*

The brainstem has three parts: the **midbrain**, the **pons**, and the **medulla oblongata.**

-The *midbrain* contains centers for receipt and integration of sensory information.

-The *pons* regulates breathing centers in the medulla.

-The *medulla oblongata* contains centers that control several functions including breathing, cardiovascular activity, swallowing, vomiting, and digestion.

The Cerebellum

- The **cerebellum** is the second largest part of the brain. It is important for coordination and error checking during motor, perceptual, and cognitive functions.
- It is also involved in learning and remembering motor skills.