

UNIT 3

CONTROL SYSTEMS

INTRODUCTION: NERVOUS AND ENDOCRINE SYSTEMS

Together the nervous and endocrine systems coordinate all body systems. The nervous system controls through nerve impulses conducted along axons of neurons. The endocrine system releases hormones which are delivered to tissues throughout the body by blood. Certain parts of the nervous system stimulate or inhibit the release of hormones and hormones may promote or inhibit nerve impulses. The nervous system causes muscular contraction or glandular secretion, the endocrine system alters metabolic activities, regulates growth and development, and guides the reproductive process. Nerve impulses are generally much faster but the responses are briefer than hormones which are slower in response time but last longer. Hormones affect target cells in three ways:

- control of enzymatic reactions
- control transport of ions or molecules across a cell membrane
- control gene expression and the synthesis of proteins.

NERVOUS TISSUE

FUNCTIONS OF THE NERVOUS SYSTEM

The nervous system functions as a sensory organ. Receptors sense changes within and external to the body and pass that information to Integrative Centers that analyze the sensory information, store data, and make decisions based on that data. Motor impulses stimulate effectors to respond to the stimuli by initiating muscular contractions or glandular secretions.

NERVOUS SYSTEM DIVISIONS

The nervous system contains the Central Nervous System (CNS), the Peripheral Nervous System (PNS), and the Autonomic nervous system. The CNS comprises the brain and spinal cord and is connected to sensory receptors, muscles, glands by the peripheral nervous system. The Peripheral Nervous System (PNS) include cranial nerves that arise in the brain and spinal nerves that arise in the spinal cord. Sensory or afferent neurons in various parts of the body bring impulses into CNS. Motor or efferent neurons send impulses from CNS to muscles and glands.

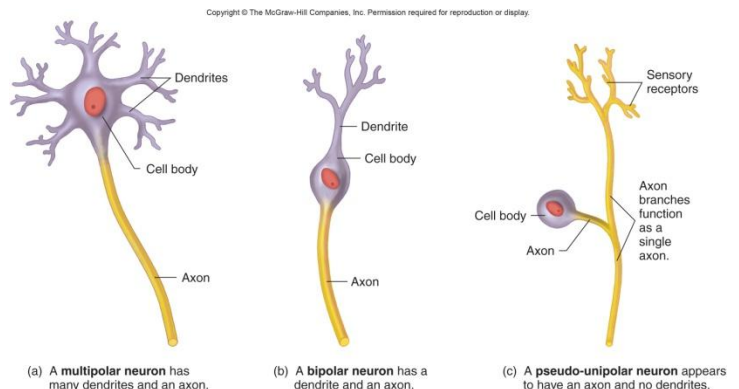
The PNS can be further subdivided into the Somatic nervous system (voluntary), the Autonomic nervous system (involuntary), and an Enteric nervous system (involuntary). In the somatic nervous system, neurons conduct impulses from cutaneous and special sense receptors to the CNS and motor neurons conduct impulses from CNS to skeletal muscle tissue. Since the Autonomic nervous system is involuntary, sensory neurons from viscera send impulses to CNS, and impulses

from CNS are sent to smooth muscles, cardiac muscles and glands. Some recent publications list a third component of the nervous system; the enteric nervous system. This system consists of a network of neurons in the walls of the digestive tract. It is usually under control of the autonomic nervous system but can function on its own integrating system. Enteric motor neurons stimulate smooth muscles to move food along the alimentary canal, secrete fluids into the GI system and secrete hormones that aid in the digestive process.

The motor part of the ANS consists of two branches, the sympathetic and parasympathetic divisions. Both of them will be discussed later.

HISTOLOGY OF NERVOUS TISSUE

Neurons are excitable cells that generate and carry electrical signals. Neurons can be classified based on structural or functional differences. The number of processes that originate from the cell body determines the structural classification: neurons are multipolar (several dendrites and one axon), bipolar (one dendrite and one main axon), pseudounipolar (one process extending from main body) or anaxonic (no apparent axon present). Most neurons in brain and spinal cord are multipolar. Pseudounipolar and bipolar neurons are always sensory. Bipolar neurons are found in retina of eye, inner ear and olfactory area of brain.



Based on direction or function, neurons are sensory (afferent) in which nerve impulses from receptors are carried to the brain or the spinal cord, interneuron or association neurons conduct impulses to other neurons (most neurons in CNS are this type), or motor (efferent) neurons that conduct impulses (effectors) from the brain or spinal cord to muscles or glands. A nerve is a bundle of axons located outside of the CNS.

Most neurons have a cell body, many dendrites, and usually a single axon. The cell body is the control center of the neuron. Dendrites conduct impulses from receptors or other neurons to the cell body. The axon conducts impulses from the neuron to the dendrites or cell body of another neuron or to an effector organ of the body at a synapse. The axon joins the cell body at the axon hillock.

The first portion of the axon is the initial segment or trigger zone where nerve impulses arise. Branches coming off the axon are called collaterals which end in a swelling called an axon terminal. This terminal contains mitochondria and membrane bound vesicles containing neurocrine molecules.

The region where the axon terminal meets its target cell is called the synapse. The presynaptic cell is the cell that delivers the signal to the synapse. The postsynaptic cell is the target cell. The space between the two cells is called the synaptic cleft.

Proteins move slowly or rapidly along the axon (axonal transport) to the synapse. A nerve fiber is a general term for any neuronal process (dendrite or axon). These processes of neurons are arranged into bundles called nerves in the PNS and tracts in the CNS. Nerve bodies in the PNS form clusters called ganglia. Axonal transport can be a fast or slow natural mechanism of intracellular transport in neurons.

CLASSIFICATION OF NEUROGLIAL CELLS

Neuroglia cells are specialized tissue cells that support neurons, attach neurons to blood vessels, produce the myelin sheath, and carry out phagocytosis. They outnumber neurons by a factor of 10-50:1. Neuroglia cells found in the CNS include [astrocytes](#), [oligodendrocytes](#), [microglia cells](#), and [ependymal cells](#). Astrocytes participate in brain development, help form the blood-brain barrier, secrete neurotrophic factors, and take up potassium neurotransmitters. Oligodendrocytes are the most common glia cells in CNS. They produce the myelin sheath. Microglia cells protect the CNS by engulfing microbes. Ependymal cells are epithelial cells that produce CSF and assist in its circulation. Neural stem cells are found in the ependymal layer.

The accepted theory has been that the neurons did all the communicating in the brain and nervous system, and that the glial cells merely nurtured the neurons. Recent research has demonstrated that glia cells communicate with one another as well as with the neurons primarily through chemical signals and that the glial cells can alter the signals at the synaptic gaps. As a result, glial cells may be critical in learning and memory functions.

Neuroglial cells found in the PNS include neurolemmocytes ([Schwann cells](#)) that produce myelin sheaths around neurons in the PNS and secrete neurotransmitters. Satellite cells support neurons in PNS. The nodes of Ranvier are sections of uninsulated membrane between Schwann cells.

Myelination is the process by which a myelin sheath is produced around the axons in the CNS and PNS. Those axons that are sheathed are called myelinated, those axons that aren't are called unmyelinated. The sheath electrically insulates the axon and increases the speed of the nerve impulse conduction. The more myelin, the faster the impulse and it is more accurate (less straying). White matter is primarily myelinated axons.

NEUROPHYSIOLOGY

Cell membranes are usually charged or polarized. This means that there is an unequal distribution of ions on either side of the membrane. Ions pass through membranes via pores or protein channels. There are two types of channels, leakage (nongated) and gated ion channels. Leakage channels are always open. Gated channels open and close in response to some stimulus. The permeability of a cell to

ions changes when ion channels in the membrane open and close. Movement of only a few ions will significantly change the membrane potential. Examples of gated channels include voltage-gated, chemically gated, mechanically gated, and light-gated. Voltage-gated ion channels in nerves and muscle plasma membranes give these cells excitability. The presence of chemically, mechanically, or light-gated ion channels in a membrane permits the appropriate stimulus to cause a graded potential.

Resting Membrane Potential

A cell that is not being stimulated to send an impulse is in a resting state. Factors that contribute to resting membrane potential include unequal distribution of ions across the plasma membrane (high concentration of sodium ions outside the cell and a high concentration of potassium inside), or a large concentration of negatively charged ions inside the cell, and the relative permeability of the plasma membrane to sodium and potassium. In a resting cell more positive ions leave the cell than enter it.

Graded potential

Graded potentials are depolarizing (polarization less negative than the resting level) or hyperpolarizing (more negative than the resting level), whose strength is directly proportional to the strength of the triggering event. A large stimulus will cause a strong graded potential, and a small stimulus will result in a weak graded potential. Graded potentials lose strength as they move through the cell. Graded potentials are produced by the opening and closing of chemically gated channels. The flow of ions through a particular channel may cause either depolarization or hyperpolarization depending on the charge of the ion and the direction of flow. Graded potentials that are strong enough eventually reach the trigger zone of the neuron. If the graded potential depolarizes the membrane to a minimum level (threshold voltage), the voltage-gated sodium channels open and an action potential is initiated. If it doesn't reach the threshold voltage, no action potential is begun. Most often graded potentials occur in the cell body or the dendrites.

Action Potential (Impulse)

A sequence of events that results first in depolarization and then repolarization is called action potential. Action potentials are large, uniform depolarization that can travel for long distances through the neuron without losing strength. Their function is rapid signaling over long distances. Excitatory postsynaptic potential (EPSPs) are depolarizing graded potentials that make a neuron more likely to fire an action potential. Inhibitory postsynaptic potentials (IPSPs) are hyperpolarizing events. If a stimulus is strong enough to generate an action potential, the impulse travels at a constant and maximum strength for the existing conditions. A stronger stimulus will not cause a stronger impulse. All the impulses conducted on an axon are the same. This is known as the all-or-none principle. Repolarization restores the resting membrane potential and allows inactivated sodium channels to revert to their resting state.

A good comparison of Graded Potentials and Action Potentials can be found in Table 12.2 of your text. It might be a good idea to refer to this table.

Refractory period

During an absolute refractory period, another impulse cannot be generated at all no matter how large the stimulus. A relative refractory period can be triggered by a suprathreshold stimulus. Action potentials cannot be summed. Refractory periods limit the rate at which signals can be transmitted and assures one-way traffic of an action potential from cell body to axon terminal. An action potential conducts (propagates) from point to point along the membrane. The traveling action potential is a nerve impulse.

These action potentials are the language of the nervous system. For example, how does your brain know if you have a light object in your hand or a heavy object? In a situation like this, special receptors detect the pressure on the skin and send action potentials to the brain. The weight of the object is "coded" into the action potential—the heavier the object, the more action potentials per second. This is called neural coding. The amount of neurotransmitter released at the axon terminal is directly related to the number of action potentials that arrive at the terminal per unit of time. An increase in signal strength increases neurotransmitter output.

Impulse conduction

A continuous conduction is a step-by-step depolarization of adjacent areas. A saltatory conduction occurs when the impulse jumps from neurofibril node to another node. This phenomenon is more energy efficient and is used in quick responses.

Factors that affect the speed of an action potential are the amount of myelination present (myelinated axons are faster), the axon diameter (bigger is faster), and temperature (warmer is faster).

Briefly in summary:

1. Resting membrane potential (-70 mV)
2. Depolarization stimulus
3. Membrane depolarizes to threshold. Voltage gated Na^+ channels open and Na^+ enters the cell. Voltage gated K^+ channels open slowly.
4. Rapid Na^+ entry depolarizes cell.
5. Na^+ channels close and slower K^+ channels open.
6. K^+ moves from within the cell to extracellular fluid.
7. K^+ channels remain open and additional K^+ leaves cell, hyperpolarizing it.
8. Voltage-gated K^+ channels close, some K^+ enters the cell through leak channels.
9. Cell returns to resting ion permeability and resting membrane potential.

Chemical/Electrical Synapses

Cell-to-Cell Communication or Transmission at Synapses

A synapse is the functional unit between one neuron and another or between a neuron and an effector such as a muscle or gland. At an electrical synapse, ionic current spreads directly from one cell to another through gap junctions. They are faster than chemical synapses, can synchronize the activity of a group of neurons or muscle fibers, and may allow two way transmissions of impulses. Electrical synapses occur mainly in the CNS, but are also found in cardiac and smooth muscle. The vast majority of synapses are chemical. At a chemical synapse, there is only one-way information, transfer from a presynaptic neuron to a postsynaptic neuron across the synaptic cleft.

1. An action potential depolarizes the axon terminal.
2. The depolarization opens voltage-gated calcium channels and calcium enters the cell.
3. Calcium triggers exocytosis of a synaptic vesicle which contains the neurotransmitter.
4. The neurotransmitter diffuses across the synaptic cleft and binds with receptors on the postsynaptic cleft.

Neurotransmitters

The nervous system secretes a variety of neurotransmitters. They can be grouped into seven classes by their structure: acetylcholine, amino acids, amino-acid derived amines, polypeptides, purines, gases, and lipids. Examples of neurotransmitters are acetylcholine (ACh), amines (norepinephrine, epinephrine, dopamine, serotonin, and histamine), amino acids (glutamate, aspartate, GABA, and glycine), and nitric oxide. Both excitatory and inhibitory neurotransmitters are present in the CNS and PNS. The same neurotransmitter may be excitatory in some locations and inhibitory in others. The response depends on the receptor of the target cell. Excitatory neurotransmitter is one that can depolarize or make less negative the postsynaptic neuron's membrane. A depolarizing postsynaptic potential is called an excitatory postsynaptic potential (EPSP). An inhibitory neurotransmitter hyperpolarizes the membrane of the postsynaptic neuron, making the inside more negative and generation of nerve impulse more difficult.

An inhibitory postsynaptic potential (IPSP) neurotransmitter is removed from the synaptic cleft in three ways, diffusion, enzymatic degradation, and uptake into cells and is necessary for normal synaptic function. Neurotransmitter activity is rapidly terminated. Certain synapses can modify the quantity of neurotransmitter released at other synapses. Presynaptic facilitation increases the amount of neurotransmitter released by a presynaptic neuron whereas presynaptic inhibition decreases the amount. Both can last for several minutes to hours and may be important in learning and memory. If several presynaptic end bulbs release their neurotransmitters at about the same time, the combined effect may generate a

nerve impulse due to summation. Summation may be spatial or temporal. The initiation of an action potential from several simultaneous graded potentials is an example of spatial summation. Temporal summation refers to graded potentials overlapping in time. Summation demonstrates a key property of neurons. When multiple signals reach a neuron, the postsynaptic integration allows the neuron to evaluate the strength and duration of the signals. If the resultant integrated signal is above the threshold the neuron fires an action potential.

Disorders associated with neurotransmitter imbalance include Alzheimer's disease, clinical depression, epilepsy, Huntington's disease, Parkinson's disease, Myasthenia gravis, Schizophrenia, and possibly SIDS.

Alteration of Impulse Conduction and Synaptic Transmission

A neuron's chemical and physical environment influences both impulse conduction and synaptic transmission. Chemical synaptic transmission may be stimulated or blocked by affecting neurotransmitter synthesis, release, removal, or the receptor site. Alkalosis, acidosis, mechanical pressure and others may all modify impulse conduction and/or synaptic transmission.

Neuronal Circuits

Neurons in the CNS are organized into different patterns called neuronal pools. Each pool differs from all others and has its own role in regulating homeostasis. A neuronal pool may contain thousands to millions of neurons. Neuronal pools are organized into circuits which can be simple series, diverging, converging, reverberating (oscillatory), or parallel after-discharge circuits. Divergence occurs when a presynaptic neuron synapses a larger number of postsynaptic neurons, whereas in convergence, a large number of presynaptic neurons synapse onto fewer postsynaptic neurons. In a reverberating circuit, the first neuron stimulates a second neuron which stimulates a third and so on. Signals are also sent back through the circuit again and again. In the parallel after-discharge circuit a presynaptic cell stimulates a group of neurons, each of which synapses with a common postsynaptic cell. These types of circuits maybe involved in mathematical calculations.

REGENERATION OF NERVOUS TISSUE

For the most part, at about 6 months of age, neuronal cells lose their ability to divide. Once a neuron is destroyed, it is permanently lost. Only some types of damage can be repaired. In the PNS, damage to myelinated axons and dendrites may be repaired if the cell body remains intact and if the neurolemmocytes remain active. In the CNS, injury to the brain or spinal cord is usually permanent to the neural cells. Mammalian tissue exhibits very limited ability to produce new neurons. Stem cell research has offered hope to those with spinal cord injuries. However, much research still needs to be done in this field.

Why is this chapter important?

The first chapter in the control systems tells us what the components and functions are associated with nervous tissue. It covers the organization of the nervous system (CNS versus PNS) and the types of neurons and neuroglia present. It also goes into nervous system physiology including membrane potentials, the differences between action potentials and graded potentials, transmission at synapses, neurotransmitters (especially acetylcholine), and the different types of neuronal circuits.