

Chapter 9 - Nervous System

9.1 Introduction (Figs. 9.1-9.2)

- A. The nervous system is composed of neurons and neuroglia.
 - 1. Neurons transmit nerve impulses along nerve fibers to other neurons.
 - 2. Nerves are made up of bundles of nerve fibers.
 - 3. Neuroglia carry out a variety of functions to aid and protect components of the nervous system.
- B. Organs of the nervous system can be divided into the central nervous system (CNS), made up of the brain and spinal cord, and the peripheral nervous system (PNS), made up of peripheral nerves that connect the CNS to the rest of the body.

9.2 General Functions of the Nervous System

- A. The nervous system provides sensory, integrative, and motor functions to the body.
 - 1. Motor functions can be divided into the consciously controlled somatic nervous system and the unconscious autonomic system.
- B. Sensory receptors at the ends of peripheral nerves gather information and convert it into nerve impulses.
- C. Sensory impulses are integrated in the brain as perceptions
- D. Conscious or subconscious decisions follow, leading to motor functions via effectors.

9.3 Neuroglia (Fig. 9.3)

- A. Classification of Neuroglial Cells
 - 1. Neuroglial cells fill spaces, support neurons, provide structural frameworks, produce myelin, and carry on phagocytosis. Four are in the CNS and the last in the PNS.
 - 2. Microglial cells are small cells that phagocytize bacterial cells and cellular debris.
 - 3. Oligodendrocytes form myelin in the brain and spinal cord.
 - 4. Astrocytes are near blood vessels and support structures, aid in metabolism, and respond to brain injury by filling in spaces.
 - 5. Ependyma cover the inside of ventricles and form choroid plexuses within the ventricles.
 - 6. Schwann cells are the myelin-producing neuroglia of the peripheral nervous system.

9.4 Neurons

- A. Neuron Structure (Figs. 9.4-9.5)
- B. A neuron has a cell body with mitochondria, lysosomes, a Golgi apparatus, chromatophilic substance (Nissl bodies) containing rough endoplasmic reticulum, and neurofibrils.
- C. Nerve fibers include a solitary axon and numerous dendrites.
 - 1. Branching dendrites carry impulses from other neurons (or from receptors) toward the cell body.
 - 2. The axon transmits the impulse away from the axonal hillock of the cell body and may give off side branches.
 - 3. Larger axons are enclosed by sheaths of myelin provided by Schwann cells and are myelinated fibers.
 - a. The outer layer of myelin is surrounded by a neurilemma (neurilemmal sheath) made up of the cytoplasm and nuclei of the Schwann cell.
 - b. Narrow gaps in the myelin sheath between Schwann cells are called nodes of Ranvier.
 - 4. The smallest axons lack a myelin sheath and are unmyelinated fibers.
 - 5. White matter in the CNS is due to myelin sheaths in this area.
 - 6. Unmyelinated nerve tissue in the CNS appears gray.
 - 7. Peripheral neurons are able to regenerate because of the neurilemma but the CNS axons are myelinated by oligodendrocytes thus lacking neurilemma and usually do

not regenerate.

D. Classification of Neurons

1. Neurons can be grouped in two main ways: on the basis of structural differences (bipolar, unipolar, and multipolar neurons), and by functional differences (sensory neurons, interneurons, and motor neurons).
 - a. Multipolar neurons have many nerve fibers arising from their cell bodies and are commonly found in the brain and spinal cord.
 - b. Bipolar neurons are found in the eyes, nose, and ears, and have a single axon and a single dendrite extending from opposite sides of the cell body.
 - c. Unipolar neurons are found in ganglia outside the CNS and have an axon and a dendrite arising from a single short fiber extending from the cell body.
 - d. Sensory neurons (afferent neurons) conduct impulses from peripheral receptors to the CNS and are usually unipolar, although some are bipolar neurons.
 - e. Interneurons are multipolar neurons lying within the CNS that form links between other neurons.
 - f. Motor neurons are multipolar neurons that conduct impulses from the CNS to effectors.

9.5 The Synapse (Fig. 9.8)

- A. Nerve impulses travel from neuron to neuron along complex nerve pathways.
- B. The junction between two communicating neurons is called a synapse; there exists a synaptic cleft between them across which the impulse must be conveyed.
- C. Synaptic Transmission (Figs. 9.9-9.10)
 1. The process by which the impulse in the presynaptic neuron is transmitted across the synaptic cleft to the postsynaptic neuron is called synaptic transmission.
 2. When an impulse reaches the synaptic knobs of an axon, synaptic vesicles release neurotransmitter into the synaptic cleft.
 3. The neurotransmitter reacts with specific receptors on the postsynaptic membrane.

9.6 Cell Membrane Potential

- A. A cell membrane is usually polarized, with an excess of negative charges on the inside of the membrane; polarization is important to the conduction of nerve impulses.
- B. Distribution of Ions (Fig. 9.11)
 1. The distribution of ions is determined by the membrane channel proteins that are selective for certain ions.
 2. Potassium ions pass through the membrane more readily than do sodium ions, making potassium ions a major contributor to membrane polarization.
- C. Resting Potential (Figs. 9.12a,b - 9.10)
 1. Due to active transport, the cell maintains a greater concentration of sodium ions outside and a greater concentration of potassium ions inside the membrane.
 2. The inside of the membrane has excess negative charges, while the outside has more positive charges.
 3. This separation of charge, or potential difference, is called the resting potential.
- D. Potential Changes (Fig 9.13a)
 1. Stimulation of a membrane can locally affect its resting potential.
 2. When the membrane potential becomes less negative, the membrane is depolarized.
 3. If sufficiently strong depolarization occurs, a threshold potential is achieved as ion channels open.
 4. At threshold, action potential is reached.
 5. Action potential may be reached when a series of subthreshold stimuli summate and reach threshold

- E. Action Potential (Figs. 9.13b,9.14b,c,d)
 - 1. At threshold potential, membrane permeability to sodium suddenly changes in the region of stimulation.
 - 2. As sodium channels open, sodium ions rush in, and the membrane potential changes and becomes depolarized.
 - 3. At the same time, potassium channels open to allow potassium ions to leave the cell, the membrane becomes repolarized, and resting potential is reestablished.
 - 4. This rapid sequence of events is the action potential.
 - 5. The active transport mechanism then works to maintain the original concentrations of sodium and potassium ions.

9.7 Nerve Impulses (Fig. 9.15, Table 9.1)

- A. A nerve impulse is conducted as action potential is reached at the trigger zone and spreads by a local current flowing down the fiber, and adjacent areas of the membrane reach action potential.
- B. Impulse Conduction (Fig. 9.4)
 - 1. Unmyelinated fibers conduct impulses over their entire membrane surface.
 - 2. Myelinated fibers conduct impulses from node of Ranvier to node of Ranvier, a phenomenon called saltatory conduction.
 - 3. Saltatory conduction is many times faster than conduction on unmyelinated neurons.
- C. All-or-None Response
 - 1. If a nerve fiber responds at all to a stimulus, it responds completely by conducting an impulse (all-or-none response).
 - 2. Greater intensity of stimulation triggers more impulses per second, not stronger impulses.

9.8 Synaptic Transmission

- A. Excitatory and Inhibitory Actions
 - 1. Neurotransmitters that increase postsynaptic membrane permeability to sodium ions may trigger impulses and are thus excitatory.
 - 2. Other neurotransmitters may decrease membrane permeability to sodium ions, reducing the chance that it will reach threshold, and are thus inhibitory.
 - 3. The effect on the postsynaptic neuron depends on which presynaptic knobs are activated.
- B. Neurotransmitters (Table 9.2)
 - 1. At least 50 kinds of neurotransmitters are produced by the nervous system, most of which are synthesized in the cytoplasm of the synaptic knobs and stored in synaptic vesicles.
 - 2. When an action potential reaches the synaptic knob, calcium ions rush inward and, in response, some synaptic vesicles fuse with the membrane and release their contents to the synaptic cleft.
 - 3. Enzymes in synaptic clefts and on postsynaptic membranes rapidly decompose the neurotransmitters after their release.
 - 4. Destruction or removal of neurotransmitter prevents continuous stimulation of the postsynaptic neuron.

9.9 Impulse Processing

- A. How impulses are processed is dependent upon how neurons are organized in the brain and spinal cord.
- B. Neuronal Pools
 - 1. Neurons within the CNS are organized into neuronal pools with varying numbers of cells.
 - 2. Each pool receives input from afferent nerves and processes the information

according to the special characteristics of the pool.

- C. Facilitation
 - 1. A particular neuron of a pool may receive excitatory or inhibitory stimulation; if the net effect is excitatory but subthreshold, the neuron becomes more excitable to incoming stimulation (a condition called facilitation).
- D. Convergence (Fig 9.16a)
 - 1. A single neuron within a pool may receive impulses from two or more fibers (convergence), which makes it possible for the neuron to summate impulses from different sources.
- E. Divergence (Fig. 9.16b)
 - 1. Impulses leaving a neuron in a pool may be passed into several output fibers (divergence), a pattern that serves to amplify an impulse.

9.10 Types of Nerves (Fig. 9.17)

- A. A nerve is a bundle of nerve fibers held together by layers of connective tissue.
- B. Nerves can be sensory, motor, or mixed, carrying both sensory and motor fibers.

9.11 Nerve Pathways

- A. The routes nerve impulses travel are called pathways, the simplest of which is a reflex arc.
- B. Reflex Arcs (Fig. 9.18)
 - 1. A reflex arc includes a sensory receptor, a sensory neuron, an interneuron in the spinal cord, a motor neuron, and an effector.
- C. Reflex Behavior (Figs. 9.19-9.20; Table 9.4)
 - 1. Reflexes are automatic, subconscious responses to stimuli that help maintain homeostasis (heart rate, blood pressure, etc.) and carry out automatic responses (vomiting, sneezing, swallowing, etc.).
 - 2. The knee-jerk reflex (patellar tendon reflex) is an example of a monosynaptic reflex (no interneuron).
 - 3. The withdrawal reflex involves sensory neurons, interneurons, and motor neurons.
 - a. At the same time, the antagonistic extensor muscles are inhibited.

9.12 Meninges (Figs. 9.21a,b-9.22)

- A. The brain and spinal cord are surrounded by membranes called meninges that lie between the bone and the soft tissues.
- B. The outermost meninx is made up of tough, white dense connective tissue, contains many blood vessels, and is called the dura mater.
 - 1. It forms the inner periosteum of the skull bones.
 - 2. In some areas, the dura mater forms partitions between lobes of the brain, and in others, it forms dural sinuses.
 - 3. The sheath around the spinal cord is separated from the vertebrae by an epidural space.
- C. The middle meninx, the arachnoid mater, is thin and lacks blood vessels.
 - 1. It does not follow the convolutions of the brain.
 - 2. Between the arachnoid and pia maters is a subarachnoid space containing cerebrospinal fluid.
- D. The innermost pia mater is thin and contains many blood vessels and nerves.
 - 1. It is attached to the surface of the brain and spinal cord and follows their contours.

9.13 Spinal Cord (Fig. 9.23)

- A. The spinal cord begins at the base of the brain and extends as a slender cord to the level of the intervertebral disk between the first and second lumbar vertebrae.
- B. Structure of the Spinal Cord (Figs. 9.24, 9.35)
 - 1. The spinal cord consists of 31 segments, each of which gives rise to a pair of spinal nerves.
 - 2. A cervical enlargement gives rise to nerves leading to the upper limbs, and a lumbar

- enlargement gives rise to those innervating the lower limbs.
- 3. Two deep longitudinal grooves (anterior median fissure and posterior median sulcus) divide the cord into right and left halves.
- 4. White matter, made up of bundles of myelinated nerve fibers (nerve tracts), surrounds a butterfly-shaped core of gray matter housing interneurons.
- 5. A central canal contains cerebrospinal fluid.
- C. Functions of the Spinal Cord (Figs. 9.25-9.26)
 - 1. The spinal cord has two major functions: to transmit impulses to and from the brain, and to house spinal reflexes.
 - 2. Tracts carrying sensory information to the brain are called ascending tracts; descending tracts carry motor information from the brain.
 - 3. The names that identify nerve tracts identify the origin and termination of the fibers in the tract.
 - 4. Many spinal reflexes also pass through the spinal cord.

9.14 Brain (Fig. 9.27)

- A. The brain is the largest, most complex portion of the nervous system, containing 100 billion multipolar neurons.
- B. The brain can be divided into the cerebrum (largest portion and associated with higher mental functions), the diencephalon (processes sensory input), the cerebellum (coordinates muscular activity), and the brain stem (coordinates and regulates visceral activities).
- C. Structure of the Cerebrum (Fig. 9.28)
 - 1. The cerebrum is the largest portion of the mature brain, consisting of two cerebral hemispheres.
 - 2. A deep ridge of nerve fibers called the corpus callosum connects the hemispheres.
 - 3. The surface of the brain is marked by convolutions, sulci, and fissures.
 - 4. The lobes of the brain are named according to the bones they underlie and include the frontal lobe, parietal lobe, temporal lobe, occipital lobe, and insula.
 - 5. A thin layer of gray matter, the cerebral cortex, lies on the outside of the cerebrum and contains 75% of the cell bodies in the nervous system.
 - 6. Beneath the cortex lies a mass of white matter made up of myelinated nerve fibers connecting the cell bodies of the cortex with the rest of the nervous system.
- D. Functions of the Cerebrum
 - 1. The cerebrum provides higher brain functions, such as interpretation of sensory input, initiating voluntary muscular movements, memory, and integrating information for reasoning.
 - 2. Functional Regions of the Cerebral Cortex (Figs. 9.25-9.26, 9.28)
 - a. The functional areas of the brain overlap, but the cortex can generally be divided into motor, sensory, and association areas.
 - b. The primary motor areas lie in the frontal lobes, anterior to the central sulcus and in its anterior wall.
 - c. Broca's area, anterior to the primary motor cortex, coordinates muscular activity to make speech possible.
 - d. Above Broca's area is the frontal eye field that controls the voluntary movements of the eyes and eyelids.
 - e. The sensory areas are located in several areas of the cerebrum and interpret sensory input, producing feelings or sensations.
 - f. Sensory areas for sight lie within the occipital lobe.
 - g. Sensory and motor fibers alike cross over in the spinal cord or brain stem so centers in the right hemisphere are interpreting or controlling the left side of the body, and vice versa.
 - h. The various association areas of the brain analyze and interpret sensory

- impulses and function in reasoning, judgment, emotions, verbalizing ideas, and storing memory.
 - i. Association areas of the frontal lobe control a number of higher intellectual processes.
 - j. A general interpretive area is found at the junction of the parietal, temporal, and occipital lobes, and plays the primary role in complex thought processing.
 - 3. Hemisphere Dominance (Fig. 9.27)
 - a. Both cerebral hemispheres function in receiving and analyzing sensory input and sending motor impulses to the opposite side of the body.
 - b. Most people exhibit hemisphere dominance for the language-related activities of speech, writing, and reading.
 - c. The left hemisphere is dominant in 90% of the population, although some individuals have the right hemisphere as dominant, and others show equal dominance in both hemispheres.
 - d. The non-dominant hemisphere specializes in nonverbal functions and controls emotions and intuitive thinking.
 - e. The basal ganglia are masses of gray matter located deep within the cerebral hemispheres that relay motor impulses from the cerebrum and help to control motor activities by producing inhibitory dopamine.
 - f. Basal ganglia include the caudate nucleus, the putamen, and the globus pallidus.
- E. Ventricles and Cerebrospinal Fluid (Figs. 9.30-9.31)
 - 1. The ventricles are a series of connected cavities within the cerebral hemispheres and brain stem.
 - 2. The ventricles are continuous with the central canal of the spinal cord, and are filled with cerebrospinal fluid.
 - 3. Choroid plexuses, specialized capillaries from the pia mater, secrete cerebrospinal fluid.
 - a. Most cerebrospinal fluid arises in the lateral ventricles.
 - 4. Cerebrospinal fluid has nutritive as well as protective (cushioning) functions.
- F. Diencephalon (Figs. 9.29, 9.32b)
 - 1. The diencephalon lies above the brain stem and contains the thalamus and hypothalamus.
 - 2. Other portions of the diencephalon are the optic tracts and optic chiasma, the infundibulum (attachment for the pituitary), the posterior pituitary, mammillary bodies, and the pineal gland.
 - 3. The thalamus functions in sorting and directing sensory information arriving from other parts of the nervous system, performing the services of both messenger and editor.
 - 4. The hypothalamus maintains homeostasis by regulating a wide variety of visceral activities and by linking the endocrine system with the nervous system.
 - a. The hypothalamus regulates heart rate and arterial blood pressure, body temperature, water and electrolyte balance, hunger and body weight, movements and secretions of the digestive tract, growth and reproduction, and sleep and wakefulness.
 - 5. The limbic system, in the area of the diencephalon, controls emotional experience and expression.
 - a. By generating pleasant or unpleasant feelings about experiences, the limbic system guides behavior that may enhance the chance of survival.
- G. Brainstem (Figs. 9.27 & 9.32)

1. The brain stem, consisting of the midbrain, pons, and medulla oblongata, lies at the base of the cerebrum, and connects the brain to the spinal cord.
2. Midbrain
 - a. The midbrain, located between the diencephalon and pons, contains bundles of myelinated nerve fibers that convey impulses to and from higher parts of the brain, and masses of gray matter that serve as reflex centers.
 - b. The midbrain contains centers for auditory and visual reflexes.
3. Pons
 - a. The pons, lying between the midbrain and medulla oblongata, transmits impulses between the brain and spinal cord, and contains centers that regulate the rate and depth of breathing.
4. Medulla Oblongata (Fig. 9.26,9.27)
 - a. The medulla oblongata transmits all ascending and descending impulses between the brain and spinal cord.
 - b. The medulla oblongata also houses nuclei that control visceral functions, including the cardiac center that controls heart rate, the vasomotor center for blood pressure control, and the respiratory center that works, along with the pons, to control the rate and depth of breathing.
 - c. Other nuclei in the medulla oblongata are associated with coughing, sneezing, swallowing, and vomiting.
5. Reticular Formation
 - a. Throughout the brain stem, hypothalamus, cerebrum, cerebellum, and basal ganglia, is a complex network of nerve fibers connecting tiny islands of gray matter; this network is the reticular formation.
 - b. Decreased activity in the reticular formation results in sleep; increased activity results in wakefulness.
 - c. The reticular formation filters incoming sensory impulses.
- H. Cerebellum (Figs. 9.27, 9.32-9.33)
 1. The cerebellum is made up of two hemispheres connected by a vermis.
 2. A thin layer of gray matter called the cerebellar cortex lies outside a core of white matter.
 3. The cerebellum communicates with other parts of the central nervous system through cerebellar peduncles.
 4. The cerebellum functions to integrate sensory information about the position of body parts and coordinates skeletal muscle activity and maintains posture.

9.15 Peripheral Nervous System (Table 9.5)

- A. The peripheral nervous system (PNS) consists of the cranial and spinal nerves that arise from the central nervous system and travel to the remainder of the body.
- B. The PNS is made up of the somatic nervous system that oversees voluntary activities, and the autonomic nervous system that controls involuntary activities.
- C. Cranial Nerves (Fig. 9.34; Table 9.6)
 1. Twelve pairs of cranial nerves arise from the underside of the brain, most of which are mixed nerves.
 2. The 12 pairs are designated by number and name and include the olfactory, optic, oculomotor, trochlear, trigeminal, abducens, facial, vestibulocochlear, glossopharyngeal, vagus, accessory, and hypoglossal nerves.
 3. Refer to Figure 9.34 and Table 9.6 for cranial nerve number, name, type, and function.
- D. Spinal Nerves (Fig. 9.35)
 1. Thirty-one pairs of mixed nerves make up the spinal nerves.
 2. Spinal nerves are grouped according to the level from which they arise and are

- numbered in sequence, beginning with those in the cervical region.
3. Each spinal nerve arises from two roots: a dorsal, or sensory, root, and a ventral, or motor, root.
4. The main branches of some spinal nerves form plexuses.
5. Cervical Plexuses
 - a. The cervical plexuses lie on either side of the neck and supply muscles and skin of the neck.
6. Brachial Plexuses
 - a. The brachial plexuses arise from lower cervical and upper thoracic nerves and lead to the upper limbs.
7. Lumbrosacral Plexuses
 - a. The lumbrosacral plexuses arise from the lower spinal cord and lead to the lower abdomen, external genitalia, buttocks, and legs.

9.16 Autonomic Nervous System

- A. The autonomic nervous system has the task of maintaining homeostasis of visceral activities without conscious effort.
- B. General Characteristics
 1. The autonomic nervous system includes two divisions: the sympathetic and parasympathetic divisions, which exert opposing effects on target organs.
 - a. The parasympathetic division operates under normal conditions.
 - b. The sympathetic division operates under conditions of stress or emergency.
- C. Autonomic Neurons (Fig 9.36)
 1. In the autonomic motor system, motor pathways include two fibers: a preganglionic fiber that leaves the CNS, and a postganglionic fiber that innervates the effector.
 2. Sympathetic Division (Fig. 9.37)
 - a. Fibers in the sympathetic division arise from the thoracic and lumbar regions of the spinal cord, and synapse in paravertebral ganglia close to the vertebral column.
 - b. Postganglionic axons lead to an effector organ.
 3. Parasympathetic Division (Figs. 9.38)
 - a. Fibers in the parasympathetic division arise from the brainstem and sacral region of the spinal cord, and synapse in ganglia close to the effector organ.
- D. Autonomic Neurotransmitters(Fig. 9.39; Table 9.7)
 1. Preganglionic fibers of both sympathetic and parasympathetic divisions release acetylcholine.
 2. Parasympathetic postganglionic fibers are cholinergic fibers and release acetylcholine.
 3. Sympathetic postganglionic fibers are adrenergic and release norepinephrine.
 4. The effects of these two divisions, based on the effects of releasing different neurotransmitters to the effector, are generally antagonistic.
- E. Control of Autonomic Activity
 1. The autonomic nervous system is largely controlled by reflex centers in the brain and spinal cord.
 2. The limbic system and cerebral cortex alter the reactions of the autonomic nervous system through emotional influence.