The Nervous System and Sense Organs

ASSIGNMENT 4

Read in your textbook, *Clinical Anatomy and Physiology for Veterinary Technicians,* pages 314–336. Then read Assignment 4 in this study guide.

Introduction

The *nervous system* is the body's control center. Commands issued by the brain are carried by nerves to the rest of the body, where a variety of tasks are performed in response to the nervous stimulation. Signals are carried by nerves back to the brain, where the information provided is processed or stored, and a response is formulated. Some neurological functions don't require the brain but instead involve *reflexes*—signals that pass between nerves in the spinal cord.

The nervous system carries out voluntary tasks, such as walking, and involuntary tasks, such as breathing. The nervous system is a vital part of the body—so vital, in fact, that it has its own protective enclosures, the skull and the spinal column.

In this part of your course, you'll learn about the anatomic and functional organization of the nervous system, how the nerves carry signals to and from the brain, and how different nerve signals affect different body functions.

Major Divisions of the Nervous System

The nervous system has several divisions based on function, anatomy, or both. One way to divide the nervous system is into two basic anatomic areas:

1. The *central nervous system (CNS),* which consists of the brain and spinal cord and their associated structures

2. The *peripheral nervous system,* which is comprised of the nerves traveling from the brain or spinal cord to the target organs and back

The central nervous system acts as a central processing unit for the body. The peripheral nervous system acts as the messenger, carrying signals generated by the central nervous system to the target organs, or carrying signals from sensory nerves back to the central nervous system.

Another way to describe the nervous system is to divide it into two basic functional groupings: the voluntary, or somatic, nervous system, and the involuntary, or autonomic, nervous system. The *somatic nervous system* carries out conscious activities, such as walking, eating, and so on, as well as activities that are somewhat unconscious, like posture. The *autonomic nervous system* performs functions that don't require conscious thought, such as breathing, blood pressure, and heart rate. These divisions overlap to some extent anatomically—autonomic and somatic nerves are found in both the central and peripheral nervous systems.

A third way to categorize the nervous system in terms of its functions is to evaluate the method by which it receives and responds to signals. The three main function categories are (1) sensory, (2) integrating, and (3) motor functions. The *sensory* parts of the nervous system *sense* changes from within or outside the body. Those signals are *integrated* to produce some response. *Motor* responses involve movements of the body, such as secretion from a gland or movement of a muscle.

You can also describe the nervous system based on whether the nerves are afferent or efferent. The term *afferent* indicates that the nerve impulse is traveling to the spinal cord and brain, and the term *efferent* indicates that the nerve impulse is traveling away from the spinal cord and brain. In the peripheral nervous system, afferent pathways originate from sensory organs, while efferent pathways go to organs and cause reactions. For example, if you place your hand on a hot surface, you feel the heat and immediately remove your hand from the surface. The nerves that sensed the heat in your hand and carried the impulse to your central nervous

system form an afferent pathway. The nerves that carried the impulse from your central nervous system and caused your hand to move form an efferent pathway.

Neuron Structure

The basic structural and functional unit of the nervous system is the *neuron,* or *nerve cell,* that's found in various configurations throughout the nervous system (see Figure 13-1 on page 315 of your textbook). Neurons are organized into pathways that carry signals to and from various areas of the body, or coordinate signals within the nervous system. All neurons have the same basic features. However, depending on the location and function of the neuron, these features are modified to suit the purpose of that particular neuron.

Two important types of neurons that will be discussed here are *sensory neurons,* which carry signals of touch, taste, etc. to the brain, and *motor neurons,* which carry instructions from the brain to the muscles, causing them to move. There are two types of motor neurons: upper motor neurons and lower motor neurons. *Lower motor neurons* are located in the peripheral nervous system. *Upper motor neurons* carry signals that initiate body movement from nuclei in the brain. Also of interest are *interneurons,* which carry signals between neurons.

The central portion of the neuron is called the *cell body,* or *cyton;* this is where the nucleus is located. The cytoplasm within the cell body is called the *perikaryon.* Because neurons are very active cells, they have a large number of endoplasmic reticula, mitochondria, and Golgi apparatuses within the perikaryon.

Two types of cell extensions project from the cell body*:* an axon and one or more dendrites. *Dendrites* are the highly branched cell receptors that either sense the environment or receive signals from other neurons. The *axon* is a cylindrical projection extending from the cell body, usually in the direction opposite that of the dendrites. The axon transmits

signals from the cell body to other neurons or to target organs such as muscles. Only one axon is present in each neuron.

At the end of the axon are one or more small branches that end in a slightly disk-shaped bulb called the *synaptic knob,* or *terminal bouton,* which lies adjacent to the cell membrane of the next cell in the pathway. The electrical signal in the neuron starts at the dendrites, travels to the cell body, and then passes through the axon to the synaptic knobs, where it initiates a signal in the next cell in the pathway, whether that cell is a neuron or a muscle cell.

The *synapse* is the junction of the synaptic knobs of one neuron with the dendrites or cell body of the adjacent neuron. When a nerve terminates at a skeletal muscle fiber, the junction of the nerve and the muscle fiber is called the *neuromuscular junction.*

Cell Locations

Most neuron cell bodies are located within the brain or spinal cord. The nerves in the peripheral nervous system are primarily dendrites or axons extending from these cell bodies. Some cell bodies are located outside the central nervous system in clusters of cell bodies called *ganglia* (singular: *ganglion*), while the cell bodies of some neurons used for the specialized sensory organs are located within those organs.

Surrounding the axons of many peripheral neurons are *Schwann cells,* which provide structural and metabolic support to the neurons. The Schwann cells make up a protective covering over the axon called the *myelin sheath,* which consists of layers of Schwann cell cytoplasm and a cell membrane (see Figure 13-3 on page 316 of your textbook). These neurons are said to be myelinated. *Myelinated* nerve fibers are wrapped up in many layers of the cytoplasm of the Schwann cell, which spirals around the axon to envelop it. The myelin sheath thins between Schwann cells, exposing some of the axon to the extracellular environment; these sites are called the *nodes of Ranvier.* Collectively, the myelin sheath and the nodes of Ranvier function to improve the transmission speed of the electrical impulse through the

axon. Some neurons aren't wrapped up in a myelin sheath. Such neurons are called *nonmyelinated* neurons. Transmission is generally slower through nonmyelinated nerve fibers than through myelinated nerve fibers.

The axon ends by forming a flared, bulblike structure called a *synaptic knob*. Within the synaptic knob are synaptic vesicles, which are packages of chemicals called *neurotransmitters*. Neurotransmitters are responsible for passing the signal from one neuron to the next.

The membrane covering the end of the synaptic knob is called the *presynaptic membrane*. The postsynaptic membrane is the surface of the adjacent dendrite or muscle cell membrane. The two membranes are separated by a gap called the *synaptic cleft*. The postsynaptic membrane serves as the receptor for the nerve impulse traveling across the synaptic cleft.

Physiology

The primary purpose of a neuron is to transmit an electrical signal that acts either to signal other neurons or to cause a change in a target organ, such as a muscle or gland. Transmission of an electrical signal is dependent on differences between the electrical charges on either side of the neuron cell membrane. This difference is known as the *membrane potential.*

The membrane potential of a nerve cell is established in two ways. The first is by the diffusion of ions across the cell membrane. The membrane is selectively permeable to ion diffusion—some ions can diffuse while others can't. The second is by active transport of selected ions across the cell membrane. Active transport is achieved by molecules embedded in the cell membrane. These molecules are called the *sodium-potassium pump* (see Figure 13-4 on page 318 of your textbook).

Sodium can't easily diffuse across the cell membrane, so the sodium-potassium pump actively transports sodium out of the cell and potassium into the cell. Thus, in its resting *(polarized)* state, the neuron contains a high concentration of

potassium ions relative to the outside of the cell. Sodium ion concentration is lower inside the cell. This creates a difference in electrical charge on each side of the membrane.

When neurons are stimulated by other neurons or by sensations (touch, heat, etc.), specialized ion channels within the membrane are triggered. Initially, the sodium channel opens and sodium floods into the cell as a result of both the concentration and electrical gradients. This channel is open only briefly. The result of the movement of sodium into the cell is a loss of the electrical potential, or *polarity,* between the two sides of the membrane. This is referred to as *depolarization.* As the sodium channel closes, the potassium channel opens. In response to both the concentration and electrical gradients, potassium now quickly diffuses across the channel, resulting in repolarization of the membrane.

Depolarization is the change in membrane potential that occurs when a nerve is stimulated. *Repolarization* is the reestablishment of normal resting membrane potential. The process of depolarization and repolarization is called the *action potential.* Depolarization doesn't occur over the entire neuron at one time. Instead, depolarization occurs in a series of segmental depolarizations, like a wave, along the neuron's length. The depolarization of one segment of the cell membrane begins to change the electrical charge in the adjacent segment of cell membrane, which activates the channels in the adjacent segment, triggering depolarization.

Depolarization can occur in only one direction, because a segment undergoing repolarization can't undergo depolarization until the resting membrane potential is reestablished. Action potentials travel down the entire length of a neuron in a period much less than one second, a speed that enables rapid response to stimuli by muscles and glands.

This information is useful in understanding how the process can go wrong. For example, decreased extracellular potassium levels decrease the resting membrane potential, making the cell membrane less excitable. The neurons fail to fire properly, causing weakness or loss of sensation. High levels of calcium can alter the resting membrane potential, which also decreases the excitability of the neuron. Certain drugs used as local anesthetics for minor surgical procedures block

the channels through which ions pass during the depolarization or repolarization process. The nerve fails to fire, and no pain sensation is transmitted to the brain.

The speed of electrical signal transmission along some neurons is enhanced by the myelin sheath as well as by the nodes of Ranvier. Electrical signals travel along myelinated axons via a method called *saltatory conduction.* In this process, the electrical impulse "jumps" from one node of Ranvier to the next without depolarization and repolarization taking place along the entire length of the axon cell membrane. The myelin sheath acts as an "insulator," preventing ion transport between the extracellular fluid and the cytoplasm of the neuron. Ion transport can therefore occur only at the nodes of Ranvier.

Saltatory conduction is useful because it speeds up the process of nerve impulse conduction by five to seven times. Less ion transport is needed to create the impulse since only the nodes are depolarized, not the entire cell membrane. This causes the depolarization process to occur more quickly. Another advantage of saltatory conduction is that it uses less energy to repolarize the cell membrane, since repolarization needs to occur only at the nodes of Ranvier.

Action potentials that reach the synaptic knob cause fusion of synaptic vesicles with the presynaptic membrane. The contents of the synaptic vesicles, called *neurotransmitters,* are released into the synaptic cleft. The neurotransmitter molecules cross the synaptic cleft and bind to the postsynaptic membrane, causing a chemical change in the membrane. These chemical changes can be either excitatory or inhibitory, depending on the type of receptor protein on the postsynaptic membrane. Thus, the same neurotransmitter can excite one neuron but inhibit another neuron.

Excitatory neurotransmitters open the ion channels in the postsynaptic membrane, initiating the action potential. Inhibitory neurotransmitters stabilize the cell membrane channels and prevent ion transport, thereby decreasing the neuron's excitability. Most electrical activity in the nervous system is a balance between excitatory and inhibitory signals

that creates smooth muscle movements. Without this balance, movements would be jerky, excessively strong, or excessively weak.

Most neurotransmitters are synthesized within the cytoplasm of the synaptic knob and absorbed into the synaptic vesicles. Several different neurotransmitters are present in the nervous system. Some of the more important neurotransmitters include the following:

- Acetylcholine
- Norepinephrine
- Gamma-aminobutyric acid (GABA)
- Dopamine
- Enkephalins
- Serotonin

Most of these neurotransmitters are found in the central nervous system. The peripheral nervous system has only two—norepinephrine and acetylcholine. *Norepinephrine* is secreted in several areas of the brain. In the peripheral nervous system, it's secreted only by neurons of the sympathetic nervous system. Norepinephrine may be excitatory or inhibitory.

Acetylcholine is also secreted in various areas of the central nervous system. In the peripheral nervous system, it's secreted by somatic motor neurons controlling skeletal muscle fibers and by neurons of the parasympathetic nervous system. The effect of acetylcholine is usually excitatory.

After the neurotransmitter binds to the postsynaptic membrane, enzymes break it down, limiting the excitation or inhibition of the neuron. Therefore, to cause continued excitation or inhibition, the presynaptic membrane must continue to release neurotransmitters. This release occurs only if the presynaptic neuron is undergoing continual stimulation.

Central Nervous System

The *central nervous system (CNS)* is composed of the brain and the spinal cord. Before we cover these two major divisions of the CNS, let's review the microscopic composition of CNS tissue. Examined grossly, central nervous system tissue is composed of two major types: gray matter and white matter. *Gray matter* is composed of aggregates of brain neuron cell bodies, while *white matter* is composed of the axons and dendrites of these neurons.

These two types of nervous tissue are visibly separate. In the brain, the outer layer is gray matter, while the inner layer is white matter. Oddly enough, in the spinal cord, the opposite is true—the white matter is on the outside, while the gray matter constitutes the core of the spinal cord.

The central nervous system has very little connective tissue, except in the external coverings known as the *meninges.* Covering the surface of the brain or spinal cord tissue is a layer called the *pia mater.* The middle layer is the *arachnoid,* and the outermost layer of meninges is the *dura mater* (see Figure 13-10 on page 326 of your textbook). The arachnoid and the dura mater aren't directly connected. A very thin space called the *subdural space* lies between them and is filled with a minute amount of fluid under normal conditions.

The dura mater of the brain fuses with the *periosteum* (inside layer) of the skull so that no space exists between them, and the dura is held firmly in place. However, in the spinal cord, the dura is connected only loosely to the periosteum of the vertebrae, and the epidural space lies between them. The epidural space is filled with fibrous tissue, fat tissue, and veins.

Organization of the Brain

The brain is situated in the skull and is composed of several parts, each with its own unique structures and functions. The divisions are based either on the fetal derivation of each brain portion or on the brain's gross appearance.

The cerebrum, or cerebral cortex, comprises the bulk of the brain in domestic animals and humans. The cerebellum, diencephalons, and brain stem comprise the other three brain sections (see Figure 13-8 on page 324 of your textbook).

Cerebrum

The *cerebrum* is shaped like a half-sphere, somewhat longer than it's wide. It's located in the rostral portion of the skull's braincase. A groove called the *longitudinal fissure,* or the *central sulcus,* partially divides the cerebrum in half along the medial plane. Each half of the cerebrum created by the central sulcus is called a *hemisphere.* The hemispheres, right and left, control different activities. The activities controlled by each hemisphere have been extensively studied in humans, partly by the effect that injuries to particular areas of the brain have on behavior, memory, sensation, and so on. Mapping of these functions in animals hasn't been as extensive.

The cerebral hemispheres have a very wrinkled look, due to numerous indentations and convolutions winding across the external surface. Each one of these indentations is called a *sulcus* (plural: *sulci*). The raised tissue between the sulci is called a *gyrus* (plural: *gyri*).

At the rostral and ventral surface of the brain is a projection of brain tissue called the *olfactory lobe,* which receives and processes sensory signals from the nose. Compared with humans, animals have a larger olfactory lobe relative to the total cerebral mass, which reflects their keener sense of smell.

Deep within each hemisphere is a cavity known as a *lateral ventricle,* where cerebrospinal fluid is produced. The ventricle roof is a section of tissue called the *corpus callosum,* the fibers that connect the two halves of the brain. The cerebrospinal fluid acts as a cushion between the brain and the skull.

Cerebellum and Diencephalon

The *cerebellum* is a roughly spherical bundle of brain tissue with an even more convoluted surface than the cerebrum. It's located caudal to the cerebrum and dorsal to the brain stem. The cerebellum is attached to the brain stem by columns of nerve fibers on each side. The cerebellum functions to maintain balance and coordination. The *diencephalon* ("between brains") acts as a passageway between the brain stem and cerebrum. The three major components of the diencephalon are the thalamus, hypothalamus, and pituitary.

Brain Stem

The *brain stem* forms the connection between the brain and spinal cord and is composed of three anatomic areas:

1. Midbrain
2. Pons
3. Medulla oblongata

The brain stem plays a role in the autonomic nervous system and is the site of origination of most of the cranial nerves.

Spinal Cord

The *spinal cord,* the second major component of the central nervous system, lies within the vertebral canal formed by openings in the vertebra of the spine. The spinal cord is a long, tapering column of nerve tissue arranged mostly in bundles of axons running lengthwise along the body.

Branching away from the spinal cord at regular intervals are the *spinal nerves,* which are part of the peripheral nervous system. Spinal nerves generally exit from the spinal cord in the spaces between the vertebrae.

The spinal cord must be able to flex with the movements of the spine, so the attachment between the dura mater of the spinal cord and the vertebrae is relatively loose. The spinal column "floats" in a cushion of cerebrospinal fluid in the subarachnoid space and fatty tissue in the epidural space.

Internally, the spinal cord is similar to the brain, but the positions of the white matter and gray matter are reversed. Within the spinal cord's gray matter are also *interneurons,* nerve cells that connect one cell body in the gray matter to another cell body in the gray matter. These nerve cells coordinate signals between different areas of the spine or from a sensory neuron to a motor neuron.

Tracts of axons running up and down the spinal cord make up the bulk of the white matter. Axons with similar functions, and which begin and/or end in the same locations, are grouped together in different areas in the white matter.

Blood-Brain Barrier

The *blood-brain barrier* separates the capillaries in the brain from the nervous tissue. The capillaries in the brain are unique in that they don't have the wide pores of capillaries found elsewhere in the body. This barrier prevents many substances from readily passing from the blood into the brain.

Anatomy of the Peripheral Nervous System

The *peripheral nervous system* includes all the neurons that aren't functional parts of the central nervous system. Parts of some neurons in the peripheral nervous system lie within the spinal cord or brain tissue but terminate quickly within those areas.

There are two parts of the peripheral nervous system that are anatomically and functionally distinct—the spinal nerves and the cranial nerves. The *spinal nerves* enter or exit the spinal cord at regular intervals along the spine. They supply muscle cells in the body, sensory areas of the body, and glands. The *cranial nerves* are located in or immediately near the head. Most of them enter and exit the brain stem.

Two functional pathways exist in both divisions of the peripheral nervous system. A sensory pathway carries signals regarding touch, pain, temperature, stretch, and so on, to the CNS. A motor pathway carries signals from the CNS to

muscles. These pathways share the same path for part of their course but diverge near the origin and termination of their nerves.

Spinal Nerves

Let's examine the spinal nerves first. Spinal sensory nerves begin in a peripheral location such as a muscle fiber, the skin, or an internal organ. Dendrites of these nerves are specially designed to initiate nerve signals in response to certain stimuli, such as heat, cold, and touch. The dendrite of the sensory nerve joins axons from motor nerves in the same area to form the spinal nerve, which travels a specific path through the body until it reaches the spine.

Spinal nerves divide near the spine into a dorsal root and a ventral root, which enter the spinal cord at the dorsolateral and ventrolateral sides, respectively. Sensory nerve dendrites travel through the dorsal root and end in the dorsal root *ganglion* (plural: *ganglia*), a cluster of sensory neuron cell bodies that lies next to the spinal cord. A string of ganglia lies parallel to the spinal cord on each side. The motor nerve axon branches away from the sensory nerve dendrites at the muscle level and terminates at the neuromuscular junction. Thus, when the spinal cord is damaged, depending on what area is damaged, there may be loss of motor function, sensory function, or both.

Specific Anatomy of the Spinal Nerves

The significant spinal nerves you should know are those involved with the brachial plexus and the lumbosacral plexus, which we'll examine in detail next.

The *brachial plexus* is found medial to the scapula on each side of the body. It's formed from the fusion of the ventral branches of several spinal nerves and is involved with controlling the thoracic limbs. The nerves exiting the brachial plexus are named based on where they travel or what muscles they control. Some of these nerves are as follows:

- The *axillary nerve* supplies the muscles that flex the shoulder and the skin over the cranial surface of the elbow.

- The *radial nerve* is the largest brachial plexus nerve. It supplies the lateral surface of the humerus and the cranial-lateral surface of the foreleg and foot.
- The *median nerve* supplies the medial surface of the foreleg and the palmar surface of the foot.
- The *ulnar nerve* supplies the caudal surface of the foreleg and palmar surface of the foot (overlapping with the median nerve).

Nerve supply to the pelvic limbs primarily arises from the lumbosacral plexus. The three major nerves coming from the lumbosacral plexus are the femoral nerve, the obturator nerve, and the ischiatic (also called the *sciatic*) nerve.

The *femoral nerve* supplies the cranial muscles of the femur and sensory nerves to the medial surface of the thigh and foreleg. The *obturator nerve* supplies primarily the muscles of the medial thigh. The biggest lumbosacral plexus nerve is the *ischiatic,* which passes over the hip joint and travels down the caudal-lateral surface of the thigh, supplying the caudal thigh muscles.

Cranial Nerves

Now that you've read about spinal nerve anatomy, you need to learn about the anatomy of the cranial nerves supplying the head (see Tables 13-1 and 13-2 on pages 327–328 in your textbook). The arrangement of pathways in the cranial nerve division is similar to that of the spinal nerves. Sensory nerve dendrites terminate in ganglia located in or near the brain. The axons of sensory nerves terminate on cell bodies or dendrites located in specific nuclei in the brain stem, where signals are generated in response to the sensation.

Motor neurons of the cranial nerve system originate in nuclei in the brain stem, where they receive signals from *sensory neurons,* or *interneurons.* The axons pass out of the brain stem to terminate at neuromuscular junctions in muscles of the head and neck. The cranial nerve system can be distinguished from the spinal nerve system by the fact that not all cranial nerves carry both sensory and motor nerve pathways; some carry only one or the other.

Specific Anatomy of the Cranial Nerves

Cranial nerves are arranged in a roughly linear sequence along the brain stem, much as the spinal nerves are arranged in series along the spinal cord. There are some exceptions to this.

Twelve pairs of cranial nerves are present in all domestic animals. They're numbered in Roman numerals I through XII (1 through 12) from rostral to caudal in the order of attachment to the brain. Cranial nerves may contain both sensory and motor neuron fibers or only one type of fiber, unlike spinal nerves, which always have both fiber types. Knowledge of the arrangement and purpose of the cranial nerves can be very useful in localizing brain lesions to a specific area.

The first cranial nerves are the *olfactory nerves,* which are actually a bundle of nerve fibers originating in the lining of the nasal cavity. The cell bodies are within the lining of the nose, and axons eventually end in the olfactory bulb of the brain. The olfactory nerves carry signals to the brain regarding the sense of smell; no motor neurons are involved.

The second cranial nerve is the *optic nerve,* which originates in the retina of the eye, where the cell bodies are located. Axons of these cells join in what's roughly the center of the retina at the optic disk. The axons then pass out of the back of the eye as the optic nerve.

Optic nerves from each side join at the base of the cerebrum, just rostral to the hypothalamus and pituitary gland. Some of the fibers cross over to the opposite side, which allows for better binocular vision. The optic nerve is sensory only and carries visual signals to the brain from the eye.

Third in line is the *oculomotor nerve,* which carries only motor fibers of two types: motor fibers to the muscles controlling most of the movements of the eye, and motor fibers that cause the pupillary muscles to constrict, making the pupil smaller in size.

Oculomotor nerve signals can cause the eye to rotate laterally (along an axis drawn through the center of the pupil) or can turn the eye ventrally, dorsally, or medially. The oculomotor

nerve travels from the brain stem to the eye socket to supply the muscles around the eye, the upper eyelid, and the muscle fibers of the pupil.

The *trochlear nerve* is the fourth cranial nerve; it carries nerve fibers to a single muscle around the eye that causes the eye to rotate medially (opposing some of the function of the oculomotor nerve).

Both motor and sensory nerve fibers travel in the fifth cranial nerve, the *trigeminal nerve,* which is the largest cranial nerve. Motor nerves arise in nuclei in the pons and pass to the muscles involved with chewing. Three branches of the trigeminal nerve control these functions:

The sixth cranial nerve, the *abducent nerve,* has motor nerves to muscles that retract the eyeball deeper into the socket or rotate the eye laterally.

Seventh in line is the *facial nerve,* which primarily performs motor functions involving facial muscles (controlling facial expressions), muscles of the eye, tear glands, some of the salivary glands, and the nasal glands. It also carries sensory signals from the tongue responsible for taste in the rostral two-thirds of the tongue.

The eighth cranial nerve, the *vestibulocochlear nerve,* is unique among the cranial nerves because it carries two types of sensory signals from the ear. One sensory signal is that of hearing, while the other provides the body with signals regarding motion and sense of balance. Both types of signals connect with the brain stem at the level of the medulla.

Muscles of the pharynx and soft palate are controlled by motor nerve fibers of the ninth cranial nerve, the *glossopharyngeal nerve.* The glossopharyngeal nerve also controls secretion from some of the salivary glands. Sensory fibers of the glossopharyngeal nerve are responsible for the sense of taste from the caudal one-third of the tongue, and for the sense of touch from the tongue and pharynx.

The tenth cranial nerve, the *vagus nerve,* includes both motor and sensory fibers. Motor fibers in the vagus connect to organs within the thorax and abdomen and control the muscles of the pharynx, larynx, and esophagus. Sensory fibers of

the vagus nerve connect to abdominal and thoracic organs, and to the pharynx and larynx; they also carry taste signals from the caudal tongue.

The eleventh cranial nerve is the *accessory nerve,* which carries only motor nerves that control certain muscles of the neck and thoracic limbs. These fibers arise from the cranial cervical spinal cord. Unlike other cranial nerves, the accessory nerve doesn't connect directly to the brain.

Finally, the twelfth cranial nerve, the *hypoglossal nerve,* controls muscles of the tongue and some muscles of the neck.

Autonomic Nervous System

General Organization

There are two anatomically and functionally distinct divisions of the autonomic nervous system found in the body—the *sympathetic nervous system* and the *parasympathetic nervous system.* These divisions have in common a similar organizational plan. Fibers in the brain or spinal cord send out axons via peripheral nerves like those already discussed, and these axons terminate on another neuron in a cluster of nerve cell bodies called a *ganglion* (plural: *ganglia*). Ganglia are located throughout the body.

Neurons in the ganglia send out axons to the target organ, terminating at a neuromuscular junction or, in some cases, other neurons. Thus, each autonomic pathway has two neurons between the central nervous system and the target organ—a *preganglionic* neuron between the CNS and the ganglion, and a *postganglionic* neuron between the ganglion and the target organ. You'll learn about the specific anatomy of each division in the following sections.

Sympathetic Nervous System

Preganglionic neuron cell bodies of the sympathetic nervous system are confined to the thoracic and lumbar regions of the spinal cord. The axons of the preganglionic neuron travel a short distance from the spinal cord as part of the corresponding spinal nerve before branching out and ending at one of

the vertebral ganglia that lie in a chain ventrolateral to the vertebrae. Vertebral ganglia are connected to each other and form a continuous string of nervous tissue called the *sympathetic ganglion chain.*

Postganglionic fibers travel one of several routes to reach their goal. They may

- Enter nearby spinal nerves to travel to a specific organ
- Travel from a vertebral ganglion directly to the target organ
- Leave a vertebral ganglion to travel to a plexus of nerves

A multitude of sympathetic fibers are distributed throughout the body, nearly as extensively as arteries. Many ganglia have specific names that you don't need to be familiar with at this time.

Parasympathetic Nervous System

Preganglionic neuron cell bodies of the parasympathetic system are found in the brain stem and in the sacral region of the spinal cord. This distribution gives rise to the term craniosacral as a synonym for the parasympathetic division. The *preganglionic axons* in the head travel as part of the third, seventh, ninth, and tenth cranial nerves. All of these travel to areas of the head—except for the tenth, the vagus nerve. This nerve supplies nerve fibers to smooth muscles in the cervical (pharynx, larynx, and esophagus), abdominal, and thoracic regions.

The sacral preganglionic axons travel out of the spinal cord to the lumbosacral plexus. From the lumbosacral plexus, the preganglionic fibers travel to their target organs. *Parasympathetic ganglia* are located near or within the target organ. The *postganglionic axons* are thus relatively short, unlike those of the sympathetic division, which are longer.

Physiology of the Autonomic Nervous System

The *autonomic nervous system,* divided into the sympathetic and parasympathetic divisions, controls operations that aren't under voluntary control. The ability to perform certain functions without thought enables an animal to spend more time and energy performing voluntary functions. If you had to think about breathing and controlling your heart rate all of the time, you wouldn't have time to do anything else!

Many involuntary functions are vital functions, such as breathing, control of heart rate, control of blood pressure, and secretion of certain glandular products. Although these functions are termed involuntary, they can be influenced by the somatic nervous system. For example, you can hold your breath; some people can even control their heart rate and blood pressure.

However, when they're not under voluntary control, the autonomic nervous system takes over these functions to keep the body alive. One situation in which the autonomic nervous system becomes important is stress. Under stress, the heart rate tends to increase, blood pressure rises, and the rate and depth of respiration increase, all as a result of autonomic nervous system stimulation.

The sympathetic and parasympathetic nervous systems may both act on the same target organ, but they tend to cause opposing effects. The *sympathetic nervous system* causes dilation of the pupil, secretion of sweat glands, increased heart rate, increased contraction of heart muscle, dilation of bronchi, decreased contractions of the gastrointestinal walls, constriction of some blood vessels, dilation of other blood vessels, increased adrenal gland activity, increased metabolism, and increased muscle strength.

The *parasympathetic nervous system* generally causes constriction of the pupil, secretion of certain glands, decreased heart rate, decreased heart muscle contraction, constriction of bronchi, and increased gastrointestinal motility (movement).

As you can see, even within the sympathetic nervous system, differing effects on the same organ are elicited by stimulation of different types of sympathetic receptors. You may also notice that not all organs are innervated by both autonomic systems. For example, the adrenal gland is innervated only by the sympathetic nervous system.

All preganglionic neurons secrete *acetylcholine* as their neurotransmitter. Parasympathetic postganglionic neurons also secrete acetylcholine. Sympathetic postganglionic neurons primarily secrete norepinephrine (also called *noradrenaline*), although some also secrete acetylcholine. Neurons that secrete acetylcholine are called *cholinergic neurons,* while neurons that secrete norepinephrine are called *adrenergic neurons.*

Of interest is the fact that the adrenal medulla secretes a hormone called *epinephrine,* or *adrenaline,* a modified version of norepinephrine. Epinephrine is released from the adrenal gland under stimulation by the sympathetic nervous system. Since epinephrine acts on receptors in target organs much like norepinephrine, adrenal secretion augments the direct neurotransmitter effects of the sympathetic nervous system. The difference is that adrenal secretion is slower to act than neurotransmitter release of norepinephrine and is more prolonged. Receptors at the target organs also differ.

Three different receptor subtypes are present in the sympathetic nervous system. They're designated *alpha, beta-1,* and *beta-2.* Norepinephrine primarily stimulates alpha receptors, while epinephrine stimulates all receptor types equally well. Therefore, the response of an organ depends on the type and concentration of receptors in that organ as well as the chemical signal it receives.

Cholinergic receptors are also divided into two subtypes, named by the effect different toxins have on the functions of these neurons—muscarinic and nicotinic receptors. *Muscarinic receptors* are found in the target organs of the parasympathetic nervous system and in the target organs of the cholinergic postganglionic neurons of the sympathetic nervous system. *Nicotinic receptors* are found in the synapse between the preganglionic and postganglionic neurons of

both the parasympathetic and sympathetic nervous systems, as well as at the neuromuscular junctions in skeletal muscles.

In general, the sympathetic nervous system causes increased heart rate and strength of contraction, dilation of bronchi, increased blood pressure, increased glucose synthesis, decreased gastric and intestinal secretions, and dilated pupils. The parasympathetic nervous system causes decreased heart rate and strength of contraction, constriction of bronchi, increased gastrointestinal and salivary secretions, and constriction of pupils.

Reflexes and the Reflex Arc

Reflexes are involuntary motor movements initiated by specific sensory input. They're physiologic defense mechanisms that function in both the somatic and autonomic nervous systems. All reflexes originate from a sensory receptor. An example of a reflex is the knee-jerk reflex, technically called the *patellar reflex,* in which the knee joint is rapidly extended when the patellar ligament is struck. Walking, standing, and maintaining balance are also partially reflexive in nature.

Sensory pathways send impulses to areas of the central nervous system that initiate motor responses. In other words, the sensory pathways provide information on who, what, why, where, when, and how (or how much) to the central nervous system to allow it to form an appropriate response. Sensations detected by the body can be classified into eleven categories:

1. Touch
2. Pressure
3. Stretch
4. Sound
5. Balance (equilibrium)
6. Temperature
7. Pain

8. Sight
9. Taste
10. Smell
11. Chemical levels in the body

Some of these sensations detect changes in the external environment, while others detect changes in the internal environment, within the body.

Receptors are nerve endings that detect these changes. Each receptor detects only one or two types of stimuli, because the cell membrane design allows it to respond only to specific stimuli. There are five categories of receptors.

Once detected by receptors, sensory stimuli must be transmitted to the central nervous system. You've already seen that spinal nerves contain sensory as well as motor pathways. The dendrites of the sensory neurons travel via the dorsal root of the spinal nerve, stopping at the dorsal root ganglion, where the cell body is located. The axon then enters the spinal cord via the remaining portion of the dorsal root.

Once in the spinal cord, the neuron synapses with other neurons that either travel up the spinal cord to the brain, or travel within the spinal cord to synapse with yet other neurons. Some of the neurons on the receiving end of the synapse are motor neurons. When the sensory neuron stimulates the motor neuron, the motor neuron stimulates the muscle to carry out its specific activity, without any input or interaction with the brain. This nerve-to-nerve interaction is called a *reflex arc.*

The reflex arc allows a faster response than would communication with the brain. For example, sometimes you snatch your hand away from a hot stove before you even realize what you're doing. If the painful stimulus had to travel all the way from your hand to your brain, and the instruction to move your hand had to travel all the way back, you might be badly burned before the instruction was carried out. The reflex arc is the body's way of protecting itself by acting first, and thinking later.

Other neurons carry sensory signals to the brain. Sensory nerve signals pass through the thalamus to an area of the cerebrum called the *sensory cortex,* where signals are recognized. Another area of the cortex called the *somatic association area* receives signals from the sensory cortex and helps the brain interpret the sensory information, allowing you to recognize complex objects.

Before proceeding to the next assignment, take a moment to complete *Self-Check 4.* Remember, you can check your answers by turning to the back of this study guide.

Self-Check 4

Questions 1–5: Match the terms in the left-hand column with their definitions in the right-hand column.

_____ 1. Perikaryon	a. Largest cranial nerve
_____ 2. Dendrite	b. Carries nerve impulse from cell body to synaptic
_____ 3. Trigeminal	c. Cytoplasm of neuron
_____ 4. Myelin sheath	d. Carries nerve impulse to cell body
_____ 5. Axon	e. Improves speed of nerve conduction

6. A _____ is an indentation in brain tissue, while a _____ is the raised tissue between the indentations.

7. Name the two divisions of the autonomic nervous system.

_____

_____

(Continued)

Self-Check 4

8. Name the three tissue layers of the meninges.

_____

_____

_____

9. Name the three divisions of the brain stem.

_____

_____

_____

10. _____ are chemicals that cross the synapse when stimulated by an electrical impulse.

Check your answers with those on page 132.

ASSIGNMENT 5

Read in your textbook, *Clinical Anatomy and Physiology for Veterinary Technicians,* pages 337–355, 429–435, 459–460, 465, and 475. Then read Assignment 5 in this study guide.

Sense Organs

Now that you've learned about the nervous system, you need to learn about the *special senses* animals possess that enable them to function efficiently in their environment. In the previous section, you learned that sensory pathways are involved in sending impulses to areas of the central nervous system that initiate motor responses. There are five general senses and five special senses. The senses are part of the nervous system but are sufficiently specialized to be examined

separately (see Table 14–1 on page 338 of your textbook). Specialized dendrites located throughout the body act as sensory receptors. When stimulated, these dendrites transmit impulses to the nervous system. The receptors are able to respond to four types of stimuli:

1. Mechanical
2. Thermal
3. Electromagnetic
4. Chemical

General Senses

The receptors for the general senses are widely distributed throughout the body. Hunger, thirst, and the feeling of fullness in hollow organs, such as the urinary bladder and stomach, are considered *visceral senses.* The sensations of touch, pressure, temperature, and pain also have widely distributed receptors. Touch and pressure are referred to as *tactile senses. Temperature receptors* provide information to the nervous system about changes in body temperature. *Superficial temperature receptors* are located in the skin and sense changes in skin temperature. *Central temperature receptors* are located within the hypothalamus of the brain and monitor the body's internal temperature.

Pain receptors are the most numerous sensory receptors in the body. They're located in nearly every part of the body, except the brain. Pain receptors are capable of responding to a wide variety of stimuli and trigger the protective mechanisms of the nervous system.

Proprioception

Structures within the nervous system are also responsible for detecting the position of the feet and body, a function called *proprioception.* A variety of receptors in the skeletal muscles, tendons, ligaments, and joints are involved in monitoring the position of the body and its parts and relaying that information to the nervous system. Proprioceptive signals arrive from the legs through the spinal cord. Sensory signals concerning

the placement of the limbs and body travel up the nerve, innervating that area to the spinal ganglia. The signal eventually travels via the thalamus to the sensory cortex, so the animal knows how its feet and body are positioned. Similar signals, concerning the positioning of facial muscles, eyelids, and so on, travel in the cranial nerves.

The cerebellum is the part of the brain primarily concerned with equilibrium and coordination. When any motor activity is initiated by the motor cortex, signals are also sent to the cerebellum, which sends signals back to the motor cortex via the thalamus. These cerebellar signals inhibit or promote activity of the upper motor neurons in the cortex, which fine-tunes the motor activity. If the cerebellum weren't present to perform this fine-tuning, all actions would be very jerky or uncoordinated. Since the cerebellum receives all types of proprioceptive signals from all over the body, it has information about the position of the limbs and body that it can use to tell the cerebral cortex how to modify its signals.

A veterinarian can test for proprioception by flipping an animal's foot over so that it's standing on the top of its foot. A normal animal quickly flips the foot back into the normal position. Animals with a *proprioceptive deficit* continue to stand on the top of the foot. If proprioception is severely affected in more than one leg, the animal may not be able to stand. Trauma, infection, inflammation, intervertebral disk disease, parasite migration, tumors, and disruption of blood flow are all potential causes of proprioceptive disorders.

Special Senses

The *special senses* are organized into discrete sensory organs located in the head. They're responsible for the senses of taste, smell, hearing, vision, and equilibrium. The special senses are crucial to an animal's survival because they provide the animal with information about the environment. Animals must have this information to formulate a proper response to their environment. The importance of these senses is evident because of the degree of specialization of the tissues developed for these senses.

Taste

Taste buds are a type of *chemoreceptor,* a sensory organ that detects chemical stimuli, and are located mostly in the tongue. The sense of taste is referred to as the *gustatory sense.* On the dorsal surface of the tongue, taste buds line the sides of small raised bumps called *papillae* (singular: *papilla*). The papillae are partially embedded into the tissue of the tongue and are surrounded by a moatlike trough (see Figure 14-2 on page 343 of your textbook). Four taste sensations are recognized in humans—*sweet, sour, bitter,* and *salty.* The different types of tastes you can detect derive from varying combinations of these four basics.

Different tastes are recognized in the taste buds of different areas of the tongue. Although different areas of the tongue detect various tastes, there are no known structural differences between taste buds. The sense of taste generated by the taste buds is augmented by the sense of smell, as well as by receptors for touch and temperature in the mouth.

Axons of nerves carrying signals from the taste buds travel to the brain stem. There they connect with neurons that send out either reflex signals or sensory signals to the sensory cortex for conscious perception of taste. Reflex actions that result from smell include salivation, gastrointestinal secretions (of stomach acid, digestive enzymes, and so on), swallowing, and chewing. Offensive taste signals can cause nausea and salivation, probably through conscious and unconscious (reflex) pathways.

Smell

The sense of smell—the *olfactory sense*—is organized in two specific patches of epithelial cells in the upper part of the nasal passages. The nasal cavities are lined with a specialized type of epithelium called *olfactory epithelium,* along with supporting epithelial cells. The supporting epithelial cells possess long, thin cilia projecting into the lumen. They provide mechanical and nutritional support to the olfactory cells.

The olfactory cells of the respiratory epithelium are a type of chemoreceptor somewhat like the taste buds of the tongue. Mucus within the nasal passages dissolves odor molecules,

creating a chemical stimulus. Contact between that chemical stimulus and the olfactory cilia generates an electrical impulse in the olfactory cells. This impulse travels along the olfactory nerve to specialized areas in the central nervous system. Signals are sent from these areas to the sensory cortex for conscious perception of smell, and to the hypothalamus and brain stem for reflex actions (salivation, gastrointestinal secretions, and so on) similar to those induced by the sense of taste.

Animals have a much keener sense of smell than humans do. Where you might smell "spaghetti and meatballs," an animal would smell starch, salt, tomatoes, beef, oregano, cheese, and all the ingredients of the dish separately. Humans take advantage of this ability when they train dogs for search and rescue, drug detection, etc.

Hearing

Hearing is the *auditory sense.* The ear can be divided into three areas: the *external ear,* the *middle ear,* and the *inner ear.* The external ear is further divided into the *pinna,* the *external auditory canal,* and the *tympanic membrane (eardrum).*

External Ear

The pinna is shaped like a cone. It's composed of a piece of cartilage known as the *auricular cartilage,* which is covered with a layer of skin. Different animals and different breeds have ears with unique shapes, depending on the shape and flexibility of the *auricular cartilage.* Some ears are erect, while others hang down on each side of the head. At rest, the concave inner surface of the pinna faces laterally, while the convex outer surface faces medially. The function of the external ear is to funnel sound toward the middle ear.

Near the head, the auricular cartilage forms a complete ring, which is the external boundary of the auditory canal. The cartilage proceeds in a vertical direction for a short distance, forming the *vertical canal.* Then it makes a roughly right-angle turn in most domestic animals to form the *horizontal canal.* To see deep into the external ear canal, you must pull the pinna laterally away from the head, temporarily bending the cartilage straight.

Lining the external ear canal is a layer of epithelium that's an extension of the external skin. Glands in the epithelium secrete *cerumen,* or ear wax. Sometimes hairs are found in the lining of the ear canal. The combination of hair and cerumen can lead to an accumulation of debris in the canal that can establish conditions ripe for bacterial growth. The resulting infection of the external ear canal is known as *otitis externa.*

The external ear ends and the middle ear begins at the *tympanic membrane,* or eardrum. The tympanic membrane consists of tissue stretching across the opening into the middle ear. The tympanic membrane is slightly depressed in the middle when viewed from the outside because it's pulled inward by tension on the membrane exerted by the bones of the middle ear.

Middle Ear

The middle ear is lined with soft tissue and contains three tiny bones called the *auditory ossicles.* These bones transmit sound waves to the auditory sensory organ in the inner ear. The *malleus* is the outermost of the three bones—and the only one that contacts the eardrum. It's also called the *hammer,* because it hits upon the next bone, the *incus,* commonly called the *anvil.* The third bone in line is the *stapes,* which is also called the *stirrup* because its shape resembles a stirrup used in horseback riding.

These bones stretch in a line from the tympanic membrane at the lateral side of the middle ear to the *oval window* (also called the *vestibular window*). The oval window is an opening in the temporal bone of the skull at the medial side of the middle ear that leads into the inner ear.

Opposite the tympanic membrane on the medial surface of the middle ear is an opening into the *auditory tube,* commonly called the *Eustachian tube* in humans, which travels rostrally to the nasopharynx. This tube keeps the air pressure inside the ear consistent with that outside the body. When your ears "pop" in an airplane, it's because pressure has been building inside the ear and then suddenly equalizes through the auditory tube.

Another small opening in the wall of the middle ear, the round window, also called the *cochlear window,* lies between the oval window and the auditory tube. This window serves as another opening in the temporal bone leading into the inner ear.

The ventral part of the middle ear below the tympanic membrane and auditory canal is called the *tympanic bulla* (plural: *bullae*), a round, normally hollow cavity surrounded by a thin layer of bone. The entire surface of the middle ear is lined with ciliated columnar epithelium.

Inner Ear

Completely encased in a thick portion of the temporal bone are the structures of the inner ear. The inner ear consists of a membranous system of saclike structures and a mazelike system of ducts in the bone filled with a fluid called *perilymph*. The ducts and saclike structures are organized into three basic structures: the *cochlea,* which is responsible for detection of sound; the semicircular canals; and the vestibule (see Figure 14-5 on page 347 of your textbook). The latter two are also involved in maintaining balance.

The cochlea is rostral to the semicircular canals and vestibule. The cochlea is spiral-shaped, gradually decreasing in size until finally coming to a dead end at the *apex,* or *cupula.* In the middle of these spirals is the *modiolus,* a hollow core containing the cochlear nerve.

Along the outer edge of the cochlea is a part of the membranous system called the *cochlear duct*. This contains a fluid called *endolymph.* Lying along the cochlear duct is a layer of sensory epithelium called the *organ of Corti*. The organ of Corti consists of supporting epithelial cells, a tectorial membrane, and hair cells that are the receptor cells of hearing.

The *vestibule* is a hollow oval organ that communicates with the cochlea rostrally and with the semicircular canals caudally. On the lateral surface of the vestibule is the vestibular window, which is sealed by the base of the stapes. The bony portion of the vestibule is filled with perilymph. Within the perilymph lie membranous structures known as the *utricle* and the *saccule*. Both are involved with the sense of balance.

The saccule is roughly spherical, connects with the cochlear duct, and is filled with endolymph. The utricle and the saccule each contain a sensory organ called a *macula* (plural: *maculae*). Each macula is a focal, thickened area of epithelium containing supporting cells and ciliated hair cells much like those of the organ of Corti in the cochlea. The specialized cilia of these cells are embedded in a gelatinous covering called the *otolithic membrane,* on the surface of which are small crystals called *otoliths.* The structures of the maculae are designed to detect the head's motion and position. Movement of the head causes the otoliths to pull against the hairs, which send signals to the brain.

The semicircular canals lie on the opposite side of the vestibule from the cochlea. Each *semicircular canal* is a tube with two openings into the vestibule and is positioned at nearly a right angle to the other two canals. One of the canals lies horizontally, while the other two lie vertically. The membranous portion of each semicircular canal is the semicircular duct, which is filled with endolymph and is surrounded by perilymph. Each semicircular canal is continuous with the utricle at each end, but one end of each canal is dilated into a structure called the *ampulla* (plural: *ampullae*).

On one side of the wall of the duct in the ampulla is a crest of thickened connective tissue called the *crista ampullaris.* The surface of this crest is lined with a layer of hair cells, similar to those in the utricle and saccule, covered with a gelatinous mass called the *cupula.* The cupula is similar to the otolithic membrane in a macula. These structures aid in perception of balance.

Physiology of Hearing

Sound is essentially caused by vibrations in the air created by alternate compression and decompression of air. Hearing involves converting the mechanical process of sound into neurological signals that can be translated by the brain as sounds—music, voices, and so on.

Sound is funneled by the pinna into the external ear canal, where the *tympanic membrane* vibrates in response to the vibrations in the air. These vibrations are transmitted in turn to the three ossicles of the middle ear—first the *malleus,* then the *incus,* and finally the *stapes.* The base of the stapes fills

the oval window in the vestibule. As the stapes vibrates, the vibrations are transmitted to the perilymph, then to the endolymph of the *cochlear duct,* and to the *organ of Corti.*

The *tectorial membrane* vibrates over the cilia of the hair cells. This vibration initiates a change in the cell membrane that creates an electrical impulse in the cochlear nerves. This impulse is then transmitted to the central nervous system.

Varying stimulation in different areas of the cochlea is interpreted by the brain as sounds of different pitch. Low frequencies stimulate the apex of the cochlea more, while high frequencies stimulate the base of the cochlea more. Vibrations in the temporal bone can also create vibrations in the perilymph and organ of Corti, leading to auditory signals, which explains the ability to detect sounds from vibrations induced by heavy machinery even when no sound waves from the machinery actually reach the ear.

Physiology of Balance

The inner ear is important in maintaining a sense of balance, or *equilibrium,* and also in the detection of head movement. In the inner ear, the structures of importance are the *utricle,* the *saccule,* and the *semicircular canals.* Gravity pulls on the *otoliths* on the otolithic membrane surface. The force tugging on the otoliths in turn pulls on the *otolithic membrane,* and thus on the hair cells of the *maculae.*

Under normal conditions, nerve impulses are generated continuously by the force of gravity. If the position of the head changes, the force pulling on the otoliths changes, resulting in bending or straightening of the cilia, which changes the frequency of nerve impulses generated. Different hair cells are oriented in slightly different directions, so each one detects movement or changes in position differently. These varied signals allow the brain to interpret the position or movement of the head precisely.

The utricle in particular is very important in helping maintain the proper upright position when walking. Any acceleration in any direction causes the otoliths, which have more inertia than the surrounding fluid, to shift, which sends a signal to the brain. The central nervous system can then send signals to the rest of the body to prevent the animal from falling over.

Head rotation is detected more by the semicircular ducts, which are oriented in planes at right angles to each other. This arrangement allows each canal to detect a different direction of rotation. As the head turns, the semicircular ducts move, but the endolymph, which has inertia, doesn't—at first. The cupula bends as the endolymph moves over it. Deflection of the cupula deflects the cilia on the hair cells of the crista ampullaris, generating nerve impulses to the brain interpreted as rotation of the head. When you spin around and then stop, you become dizzy because the fluid in your ears is still moving, making your brain think you're still spinning. But your eyes don't see movement, so the brain gets confused and you feel dizzy.

Vision

Eyes are very specialized organs that convert the energy of light into signals to the brain that are then interpreted as sight. Each eye is roughly spherical in shape, with a round slight outward bulge in the surface (see Figure 14-9 on page 350 of your textbook).

The eye consists of three layers. The outermost layer is composed of the *cornea,* a transparent layer of tissue that allows light to enter the eye, and the *sclera,* which is seen as the opaque, white part of the eye surrounding the cornea and pupil. External muscles controlling the eye movements attach to the sclera, which constitutes the bulk of this outer layer. The cornea is located only at the front of the eye where the light enters—like a window. The junction between the sclera and the cornea is called the *limbus* and is slightly depressed.

The second (middle) layer of the eye is the *uvea,* which contains large numbers of blood vessels. The uvea contains three parts: the ciliary body, the choroid, and the iris. The *ciliary body* encircles the outer edge of the lens and is attached to the lens via the suspensory ligament. The *choroid* of most mammals contains a highly reflective area called the *tapetum* that aids in night vision.

The last and innermost layer of the eye is the *retina,* also called the *nervous layer,* which contains the neurons responsible for detection of light stimuli. The retina lines the interior of the eye everywhere except near the ciliary body. There's no

retina lining the back of the lens, the ciliary body, the suspensory ligament, or the cornea. Axons of the neurons in the retina gather together at a single spot on the retina, the *optic disk,* which forms the optic nerve that exits the eye at a point on the caudal and slightly ventral surface of the eye.

Together, the lens, suspensory ligament, and the ciliary body divide the eye into two chambers—the *aqueous chamber,* the smaller anterior chamber, and the *vitreous chamber,* the larger posterior chamber. The iris lies just in front of the lens and divides the aqueous chamber into anterior and posterior chambers. The *iris* contains smooth muscle cells and opens and closes to let more or less light into the eye. (The opening in the iris is called the *pupil*.) The iris also has pigments that give eyes their color.

The entire eye is called the *orbit*. The orbit is supported in a socket formed by the bones of the skull and is surrounded by fatty connective tissue. Eyelids protect the eye. The skin of the outer surface of the eyelid turns inward toward the eye and becomes the *conjunctiva,* a layer of epithelium that secretes mucus and lines both the inner surface of the eyelids and the cranial surface of the sclera. The *lacrimal gland* secretes tears that moisten the eye and help wash away debris. Tears drain into the nasal cavity via a tiny tube called the *nasolacrimal duct,* found near the medial corner of the eye, where the upper and lower eyelids meet.

The lens is composed of multiple layers of long, thin epithelial cells, called *lens fibers,* arranged to be transparent. Lens fibers lack nuclei but aren't dead. Their cell membranes are fused so there's little or no extracellular material. *Cataracts* are a common problem in which the lens fibers are altered to become opaque, blocking light from reaching the retina. Blindness results when the cataracts are sufficiently opaque, and surgery must be performed to restore vision.

Aqueous fluid in the anterior portion of the eye is a watery fluid somewhat similar in composition to cerebrospinal fluid. It's secreted by the ciliary processes of the ciliary body and supplies nutrients to the corneal cells. Aqueous fluid is reabsorbed by the *canal of Schlemm,* a duct located at the angle of the cornea and the iris.

A balance between production and absorption of aqueous fluid exists such that a constant pressure is maintained within the aqueous chamber. This pressure is called *intraocular pressure* and helps support the cornea from within. *Glaucoma* is a disease of the eye in which the drainage of aqueous humor is obstructed or decreased, causing increased intraocular pressure and pain. If glaucoma becomes severe, the retina may be damaged and blindness may ensue.

The vitreous chamber is filled with the *vitreous body,* a mass of gelatinous material called *vitreous humor.* The vitreous body helps support the retina, lens, and ciliary body from within.

Retina

The *retina* is a highly complex tissue designed for receiving light and converting it into neurological signals. The retina is composed of multiple layers. These layers consist either of cell bodies of neurons, or of the dendrites and axons of these neurons. The arrangement of the retinal cells may seem a little backward to you at first. The outermost layer consists of pigmented cells lying next to the choroid. The next layer of cells is composed of receptor neurons called *rods* or *cones,* which sense light stimuli and are named by the rod and cone shape of the receptor dendrites. Both rods and cones have dendrites with multiple, overlapping, and stacked layers of cell membranes at the tip. These membranes contain a light-absorbing pigment called *rhodopsin* in the rod cells, and a pigment called *iodopsin* that's sensitive to various colors in the cone cells.

The density and distribution of rod and cone cells in various areas of the retina varies in different species. Rods and cones determine the animal's degree of night vision as well as color vision. The dendrites of the rod and cone cells are actually near the outer pigmented layer. The cell bodies and their axons project in toward the eye's center, where the axons synapse with the next layer of cells in the retina, the integrating neurons.

The *integrating neurons* carry the signal from the rod or cone cells to the innermost layer of cells, the ganglion cell layer. Ganglion cells send axons called *optic-nerve fibers* that travel parallel to the inner surface of the retina until they reach the optic disk, where they form the fibers of the optic nerve that travel from the eye to the brain.

Formation of a Visual Image

Vision is the culmination of several types of processes that translate the electromagnetic energy of light into images in the brain. The first process is a physical one. Light enters the eye at the cornea, which refracts (bends) the waves of light to focus the light waves at the retina.

The amount of light that actually reaches the retina is determined by the pupil's diameter, which is under the control of the autonomic nervous system. In dim light, the sympathetic nervous system triggers the myoepithelial cells in the iris to contract, dilating the pupil and allowing more light to enter the eye. In bright light, the parasympathetic nervous system causes the smooth muscles of the iris to contract, constricting the pupil.

Light passing through the cornea is refracted further by the lens. The lens refraction is much less than that of the cornea, so refraction caused by the lens is used to fine-tune the refraction of light needed for sharp focus. The degree of refraction of light is determined by the amount of tension placed on the borders of the lens by the suspensory ligament and the ciliary body. As smooth-muscle fibers in the ciliary body contract, the suspensory ligament pulls on the borders of the lens, making the lens flatten out.

As the ciliary body muscles relax, tension on the lens decreases, and it naturally returns to a more rounded shape. A more flattened lens refracts light less, and vice versa. Light normally passes through the aqueous and vitreal fluids without being refracted.

Light reaching the retina passes through the inner layers of the retina until it reaches the outer layer containing the rods and cones. Here it interacts in a physical-chemical process with the pigments on the dendrite membranes of the rod and cone cells. Interaction of light with these pigments creates a

charge in the pigment molecule. This charge in turn initiates an action potential in the cell membrane of the dendrite. The nerve send a signal to the ganglion cells, through the optic disk to the optic nerve, and then to the brain.

Rods are stimulated under conditions of low light, providing night vision. Cones are stimulated in brighter light, providing day vision, and are responsible for detecting colors. *Nocturnal* animals—those that move about primarily at night—have a higher percentage of rods than *diurnal* animals—those that move about in the day.

Animals with more color vision have a greater percentage of cones than do animals that see in black and white. Most domestic animals are relatively color blind compared with humans and primates. Some animals (and all people) have an area of the retina (the *area centralis*) where vision is the sharpest because of its very high concentration of rods and cones. This area is usually located dorsolateral to the optic disk.

The cornea can suffer from scratches, abrasions, and ulcers where the surface epithelium is eroded away. If a corneal ulcer becomes severe, the underlying membrane bulges forward through the corneal defect. Viruses and trauma are the most common causes of corneal diseases. Antibiotics or surgery are needed to correct corneal defects.

Visual pathways in the brain are somewhat complex. First, light rays cross over in the lens prior to reaching the retina. In other words, in the left eye, light from the right side falls on the lateral surface of the retina while light from the left side of the body falls on the retina's medial surface. In the right eye, light from the left falls on the lateral surface while light from the right falls on the medial surface of the retina. In both eyes, light coming from the ventral direction falls on the retina's dorsal surface while light coming from the dorsal direction falls on the ventral retina. The end result of light crossing over is an image falling on the retina that's upside-down and backward compared with the actual image.

The right and left optic nerves carry signals from the eyes and meet at the *optic chiasm,* a bundle of nerve fibers that lies at the base of the cerebrum just cranial to the hypothalamus and pituitary gland. Nerve fibers from the lateral retina

of each eye continue on to the brain on the same side via the optic tract. However, nerve fibers from the medial surface of the retina actually cross over to the opposite side and travel via the *optic tract* to the brain on the side opposite the eye from which those fibers originated.

The amount of crossing over determines the degree of binocular vision that the animal possesses. *Binocular vision* is what gives humans "3-D" vision. Hunting animals such as dogs and cats have more crossing over, and thus better binocular vision, than herd animals such as cows and sheep. The advantage of binocular vision is the ability to determine depth and distance, thereby improving tracking of a target. Animals whose eyes are set on the sides of the head rather than the front of the head have *monocular vision.* The lateral position of the eyes enables the animal to see a wider field of vision, which is important for those that need to keep an eye out for predators. However, they have poor depth perception.

Visual signals travel through the optic tracts to an area of the brain called the *occipital cortex,* located in the caudal part of the cortex at the back of the head. Within the occipital cortex is an area of visual interpretation called the *visual cortex.* The visual cortex on each side of the brain has connections to the visual cortex on the opposite side of the brain, to motor areas of the cortex, to the cerebellum, to the brain stem, and indirectly to the spinal cord. These connections control eye movements and body movements in response to visual stimuli.

Birds, Reptiles, and Amphibians

The location of the brain and the control centers within the avian brain that receive nervous stimuli from the sense organs are similar to those of mammals. In birds, the control centers for vision and hearing are relatively large, whereas those for taste, touch, and smell are relatively small. Birds have a highly developed sense of vision. The shape of the eye is determined by the orbits, and the position of the eyes on the head differs among species. The avian eye is structurally similar to that of mammals. The three layers of tissue that comprise the avian eyeball are referred to as the *fibrous tunic,*

uveal tunic, and *neural tunic.* The cornea is comprised of three eyelids: an *upper lid,* a *lower lid,* and a *nictitating membrane* (see Figure 19-23 on page 433 of your textbook). This membrane is under voluntary control and is composed of thin specialized epithelial cells and striated muscles. In some species, the nictitating membrane has a clear window in its center to act as a contact lens under water. Avian ears are structurally similar to those of mammals. Some species possess specialized structures to enhance acuity of hearing. For example, nocturnal owls possess a flap of skin at the ear opening that helps funnel sounds into the ears. The senses of taste and smell aren't well developed in most species of birds. Avian skin contains sensory receptors for pain, heat, cold, and touch. In species that rely on the sense of touch to help find food, receptors for touch are located in the tongue, palate, and bill.

Significant anatomic and physiologic variations are present in the nervous system and sense organs of reptiles and amphibians, and few generalizations can be made even within related families of these species.

Now, review the material you've learned in this study guide as well as the assigned pages in your textbook for Assignments 4–5. Once you feel you understand the material, complete *Self-Check 5.* Then check your answers with those provided at the end of this study guide. If you've missed any answers, or you feel unsure of the material, review the assigned pages in your textbook and this study guide. When you're sure that you completely understand the information presented in Assignments 4–5, complete your examination for Lesson 2.

Self-Check 5

Questions 1–9: Match the terms in the left-hand column with their definitions in the right-hand column.

_____ 1. Tapetum

_____ 2. Cochlea

_____ 3. Rhodopsin

_____ 4. Endolymph

_____ 5. Tympanic membrane

a. Light-absorbing pigment

b. Fluid within the cochlear duct in the inner ear

c. Reflective portion of the choroid

d. Eardrum

e. Detects sounds

6. Name the three divisions of the ear.

_____

_____

_____

7. Name the three bones of the middle ear.

_____

_____

_____

8. The sense that detects where the feet and body are positioned is called _____.

9. The chamber in front of the lens of the eye is called the _____, while the chamber behind the lens is called the _____.

10. Name the three structures that divide the eye into two chambers.

_____

_____

_____

Check your answers with those on page 132.

Lesson 2
The Nervous System and Sense Organs

EXAMINATION NUMBER

39652300

Whichever method you use in submitting your exam answers to the school, you must use the number above.

For the quickest test results, go to
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When you feel confident that you have mastered the material in Lesson 2, go to http://www.takeexamsonline.com and submit your answers online. If you don't have access to the Internet, you can phone in or mail in your exam. Submit your answers for this examination as soon as you complete it. *Do not wait until another examination is ready.*

Questions 1–25: Select the one best answer to each question.

1. Which of the following is *true* of the depolarization of a nerve?

   A. Depolarization starts at the axon and ends at the dendrite.
   B. Ion channels that are normally closed open, allowing ions to pass through the membrane.
   C. The electrical charge of the fluid inside the nerve becomes more negative.
   D. Depolarization occurs across the entire nerve at one time.

2. The third eyelid found in some species is *correctly* referred to by which name?

   A. Nictitating membrane
   B. Meibomian gland
   C. Medical canthus
   D. Conjunctival sac

Exam Questions

3. Which of the following is *true* of neurotransmitters?

   A. Most are produced in the cytoplasm of the dendrite and migrate to the axon.
   B. The effect of acetylcholine on the heart muscles is excitatory.
   C. They're stored in synaptic vesicles in the axon.
   D. The peripheral nervous system has a wider variety of neurotransmitters than the central nervous system.

4. Which receptors are involved with the proprioception sense?

   A. The macula and otoliths in the vestibule
   B. The crista ampullaris in the semicircular canals
   C. Stretch receptors in the muscles, tendons, and ligaments
   D. Nociceptors in the muscles and joints

5. Which of the following is *true* of the sympathetic nervous system?

   A. The nerves exit the central nervous system in the head and from the lumbar spine.
   B. The only neurotransmitters it secretes are epinephrine and norepinephrine.
   C. There are three different subtypes of sympathetic nervous system receptors on target organs.
   D. Stimulation of the sympathetic nervous system generally causes a decrease in blood pressure.

6. The term *ipsilateral reflex* refers to which of the following?

   A. The reflex that causes the iris in both eyes to constrict when one eye is exposed to light
   B. The reflex that causes the opposite leg muscles to contract and support the body when one leg is lifted in a withdrawal reflex
   C. A reflex that starts on one side of the body and travels to the opposite side
   D. A reflex where the stimulus and response are both on the same side of the body

7. Which of the following is a test for a proprioception deficit?

   A. Blindfold the animal and see if it can find its way around the examining room.
   B. Flip over a foot while the animal is standing and see if the animal corrects the position.
   C. Hold one foot in the air and see if the animal falls over.
   D. Strike the patellar ligament and look for reflexive movement.

8. Which of the following is *true* of gray matter?

   A. It makes up the outer tissue layer in the brain.
   B. It's composed of axons.
   C. It transmits nerve signals from one area of the CNS to another.
   D. It's composed of dendrites.

9. Which of the following causes the greatest degree of light refraction in the eye?

A. Vitreous body
B. Aqueous body
C. Lens
D. Cornea

10. Rotation of the head is detected primarily by the

A. semicircular canals.
B. saccule.
C. utricle.
D. cochlea.

11. The _____ connects the two halves of the brain.

A. lateral ventricle
B. cerebellum
C. corpus callosum
D. diencephalon

12. Which structure contains the muscles that adjust the shape of the lens of the eye?

A. Ciliary body
B. Cornea
C. Sclera
D. Limbus

13. The reflective tapetum lucidum is formed on the

A. rods and cones.
B. choroid.
C. limbus.
D. nasolacrimal apparatus.

14. Which of the following is considered part of the visceral senses?

A. Touch
B. Pain
C. Temperature
D. Thirst

15. The axons of myelinated neurons are imbedded in a protective covering of

A. Schwann cells.
B. nodes of Ranvier.
C. synaptic knobs.
D. gray matter.

16. Norepinephrine, dopamine, and epinephrine belong to a group of neurotransmitters known as

A. glucocorticoids.
B. mineralocorticoids.
C. hormones.
D. catecholamines.

17. Cells that support neurons structurally and functionally are called

A. dendrites.
B. axons.
C. neuroglia.
D. soma.

18. Which of the following supplies a rich network of blood vessels that supply nutrients and oxygen to the superficial tissues of the brain and spinal cord?

A. Cerebrospinal fluid
B. Meninges
C. Brain stem
D. Blood-brain barrier

19. A reflex arc commonly used to assess the depth of anesthesia is the _____ reflex.

A. crosses extensor
B. pupillary light
C. withdrawal
D. stretch

20. Nociceptors are *not* found in which organ?

A. Heart
B. Brain
C. Lungs
D. Kidneys

21. The area of the brain through which sensory signals pass to the cerebrum is called the

A. hypothalamus.
B. thalamus.
C. olfactory lobe.
D. somatic association area.

22. Which of the following describes the *correct* pathway by which sound is transmitted between the ossicles of the middle ear?

A. Malleus, stapes, incus
B. Incus, malleus, stapes
C. Malleus, incus, stapes
D. Stapes, incus, malleus

23. Central temperature receptors that monitor the body's internal temperature are located within which structure of the brain?

A. Pituitary
B. Hypothalamus
C. Corpus callosum
D. Medulla oblongata

24. The *tactile sense* is the sense of

A. touch.
B. temperature.
C. hunger.
D. pain.

25. The function of mucus in the nasal cavities is to

A. dissolve odor molecules for detection by the receptor cells.
B. provide support to the receptor cells.
C. keep outside substances away from the receptor cells.
D. detect certain scents that the receptor cells can't.