13 Autonomic Nervous System

FIGURE: Because many pesticides are neurotoxins that can be readily absorbed through the skin and mucous membranes, caution must always be taken when using these poisons.

Clinical Case Study

A low-flying crop duster sprays a field worker. Within the hour, he develops blurry vision, excessive salivation, and a runny nose. As the minutes pass, he begins to experience nausea, vomiting, abdominal cramping, and coughing up of copious mucus. An observant paramedic called to the scene makes a diagnosis of organophosphate poisoning and promptly initiates therapy.

Can you account for each of the symptoms this man suffered by describing the normal response of individual organs to parasympathetic stimuli? Hexamethonium is a profoundly potent parasympathetic-blocking drug. What effect would this drug have on the eyes, salivary glands, and nose?

INTRODUCTION TO THE AUTONOMIC NERVOUS SYSTEM

The action of effectors (muscle tissue and glandular epithelium) is controlled to a large extent by motor neuron impulses. Skeletal muscles, which are the voluntary effectors, are regulated by somatic motor impulses. The involuntary effectors (smooth muscle tissue, cardiac muscle tissue, and glandular epithelium) are regulated by autonomic motor impulses through the autonomic nervous system.

Objective 1 Define the terms *preganglionic neuron* and *postganglionic neuron* and explain how the motor pathways of the somatic motor and autonomic motor systems differ.

Objective 2 Explain how the autonomic innervation of involuntary effectors differs from the innervation of skeletal muscle.

Objective 3 Compare single-unit smooth muscle tissue and multiunit smooth muscle tissue in terms of structure and regulation by autonomic nerve impulses.

Organization of the Autonomic Nervous System

The autonomic portion of the nervous system is concerned with maintaining homeostasis within the body by increasing or decreasing the activity of various organs in response to changing physiological conditions. Although the **autonomic nervous system (ANS)** is composed of portions of both the central nervous system and peripheral nervous system, it functions independently and without a person's conscious control.

Autonomic motor nerves innervate organs whose functions are not usually under voluntary control. The effectors that respond to autonomic regulation include **cardiac muscle tissue** (within the heart), **smooth muscle tissue** (within the viscera), and **glandular epithelium.** These effectors are part of the organs of the *viscera*, of blood vessels, and of specialized structures within other organs. The involuntary effects of autonomic innervation contrast with the voluntary control of skeletal muscles by way of somatic motor innervation.

The traditional distinction between the somatic system and the autonomic nervous system is based on the fact that the former is under conscious control whereas the latter is not. Recently, however, it has been discovered that we have the remarkable ability to consciously influence autonomic activity using techniques such as biofeedback and meditation. This "discovery" comes as old news to Indian yogis, who have been exploiting this ability for generations.

Unlike the somatic motor system, in which impulses are conducted along a single axon from the spinal cord to the neuromuscular junction, the *autonomic* motor pathway involves two neurons in the motor transmission of impulses (table 13.1). The first of these autonomic motor neurons has its cell body in the gray matter of the brain or spinal cord. Rather than directly innervating the effector organ, the axon of this neuron synapses with a second neuron within an *autonomic ganglion*. (A ganglion is a collection of neuron cell bodies outside the CNS.) The first neuron is thus called a **preganglionic,** or presynaptic, **neuron.** The second neuron in this pathway, called a **postganglionic,** or

viscera: L. *viscera,* internal organs
autonomic: Gk. *auto,* self; *nomos,* law
ganglion: Gk. *ganglion,* a swelling or knox

CHAPTER 13

TABLE 13.1 **Comparison of Somatic Motor and Autonomic Motor Innervations**

Feature	Somatic Motor Innervation	Autonomic Motor Innervation
Effector organs (target sites)	Skeletal muscle tissue	Cardiac muscle tissue, smooth muscle tissue, and glandular epithelium
Presence of ganglia	No ganglia	Cell bodies of postganglionic autonomic neurons located in paravertebral, prevertebral, and terminal ganglia
Number of neurons from CNS to effector organs	One	Two
Structure of neuromuscular junction	Motor end plates at axon terminals	No specialization of postsynaptic membrane; all areas of smooth muscle fibers contain receptor proteins for neurotransmitters
Effect of action potentials on muscle fibers	Excitatory only	Either excitatory or inhibitory
Type of nerve fibers	Fast-conducting, thick (9–13 μm), and myelinated	Slow-conducting; preganglionic fibers lightly myelinated but thin (3 μm); postganglionic fibers unmyelinated and very thin (about 1.0 μm)
Effect of denervation (temporary or permanent disruption of action potentials)	Flaccid paralysis and atrophy	Minimal effect on muscle tone and function; target tissues show denervation hypersensitivity

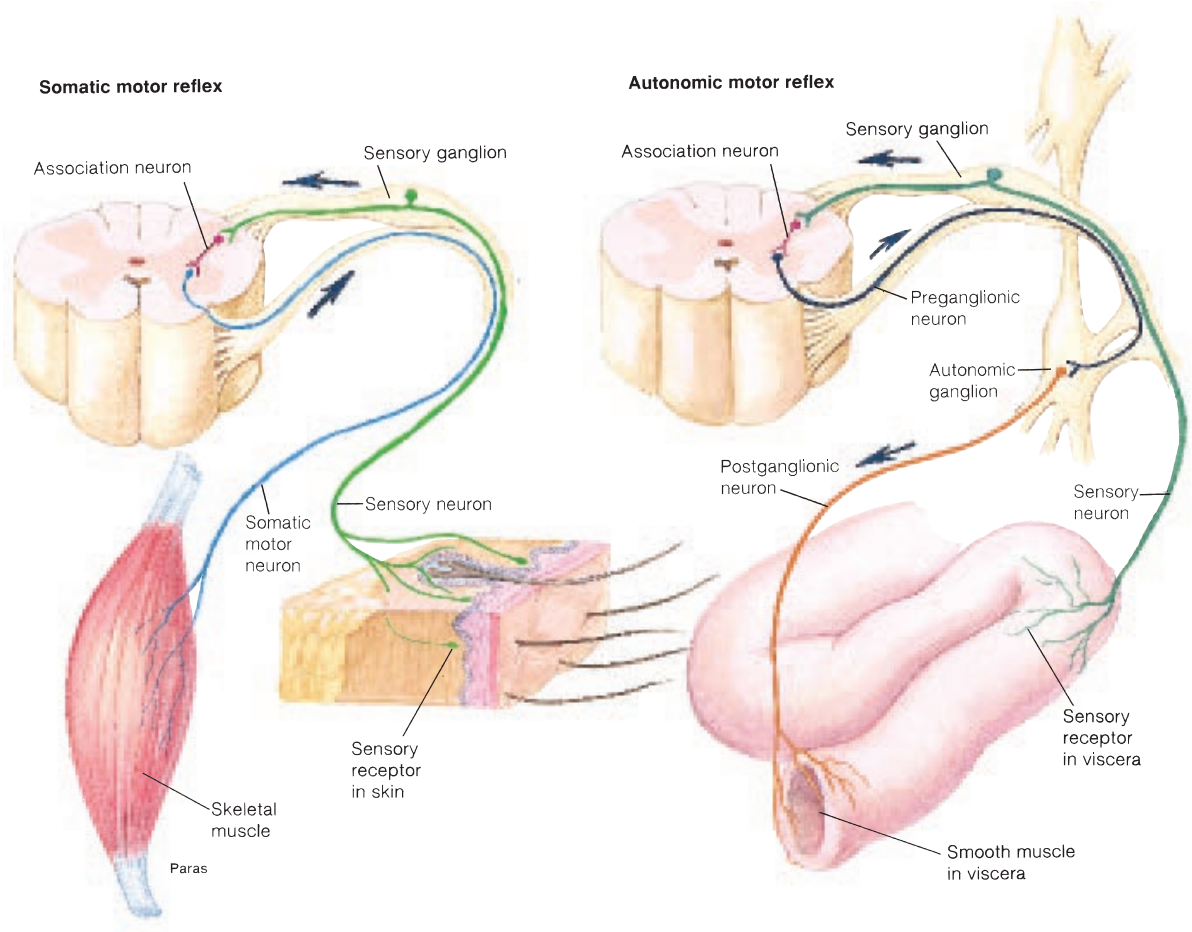


FIGURE 13.1 A comparison of a somatic motor reflex and an autonomic motor reflex.

postsynaptic, **neuron,** has an axon that extends from the autonomic ganglion and synapses with the cells of an effector organ (fig. 13.1).

Preganglionic autonomic neurons originate in the midbrain and hindbrain and from the upper thoracic to the fourth sacral portions of the spinal cord, with the exception of the area between L3 and S1. Autonomic ganglia are located in the head, neck, and abdomen. Chains of autonomic ganglia also parallel the spinal cord along each side. The origin of the preganglionic neurons and the location of the autonomic ganglia help to differentiate the **sympathetic** and **parasympathetic divisions** of the autonomic system, discussed in later sections of this chapter.

Visceral Effector Organs

Unlike skeletal muscles, which enter a state of flaccid paralysis when their motor nerves are severed, the involuntary effectors are somewhat independent of their innervation. Smooth muscles maintain a resting tone (tension) in the absence of nerve stimulation. Damage to an autonomic nerve, in fact, makes its target muscle more sensitive than normal to stimulating agents.

In addition to their intrinsic (built-in) muscle tone, cardiac muscle and many smooth muscles contract rhythmically, even in the absence of nerve stimulation, in response to action potentials initiated by the muscles themselves. Autonomic nerves also maintain a resting tone in the sense that they maintain a baseline firing rate that can be either increased or decreased. Changes in tonic neural activity produce changes in the intrinsic activity of the effector organ. A decrease in the excitatory input to the heart, for example, will slow its rate of beat.

Cardiac Muscle

Like skeletal muscle fibers, cardiac muscle fibers are striated. The long, fibrous skeletal muscle fibers, however, are structurally and functionally separated from each other, whereas the cardiac fibers are short, branched, and interconnected by **intercalated** (*in-ter'kă-lāt-ed*) **discs.**

Action potentials that originate at any point in the mass of cardiac fibers called the **myocardium** (*mi''o-kar'de-um*) can spread to all cells in the mass that are joined by intercalated discs. Because all of the cells in the myocardium are physiologi-

TABLE 13.2 Comparison of Single-Unit and Multiunit Smooth Muscles

Feature	Single-Unit Smooth Muscle	Multiunit Smooth Muscle
Location	Gastrointestinal tract (causes peristalsis); uterus (uterine contractions); ureters (cause peristalsis); arterioles (cause vasoconstriction).	Arrector pili muscles (cause hair to become verticle in hair follicles); ciliary muscle (controls shape of lens); pupillary muscles or iris (control diameter of pupil); ductus deferentia (cause movement of sperm); large arteries (cause diastolic blood pressure).
Origin of electrical activity	Spontaneous activity of myogenic fibers	Not spontaneously active; neurogenic action potentials
Type of stimuli	Action potentials	Graded depolarizations
Response to stretch	By contraction; not dependent on action potentials	No inherent response
Presence of gap junctions	Numerous gap junctions join all fibers together electrically	Few (if any) gap junctions
Type of muscle contraction	Slow and sustained	Slow and sustained

cally joined, the myocardium behaves as a single functional unit, or a *functional syncytium* (*sin-sish′e-um*). Unlike skeletal muscles, which can produce graded contractions with a strength that depends on the number of motor units activated, the heart contracts with an *all-or-none contraction*.

Furthermore, whereas skeletal muscle fibers require stimulation by action potentials through somatic motor neurons before they can contract, cardiac muscle fibers are able to produce action potentials automatically. Thus, cardiac muscle fibers are *myogenic* (*mi″ŏ-jen′ik*), which means that they contract intrinsically independent from stimulation from action potentials. Cardiac action potentials normally originate in a specialized group of cells called the *pacemaker* (see fig. 16.11). However, the rate of this spontaneous depolarization, and thus the rate of the heartbeat, is regulated by autonomic innervation.

Smooth Muscles

Smooth (visceral) muscle tissue is arranged in circular layers around the walls of blood vessels, bronchioles (small air passages in the lungs), and in the sphincter muscles of the GI tract. However, both circular and longitudinal smooth muscle layers are found in the tubular GI tract, the ureters (which transport urine), the ductus deferentia (which transport sperm), and the uterine tubes (which transport ova). The alternate contraction of circular and longitudinal smooth muscle layers produces **peristaltic waves** that propel the contents of these tubes in one direction.

Smooth muscle fibers do not contain sarcomeres (which account for striations in skeletal and cardiac muscle). Smooth muscle fibers do, however, contain a great deal of actin and some myosin, which produces a ratio of thin-to-thick myofilaments of about 16:1 (in striated muscles the ratio is 2:1).

The long length of myosin myofilaments and the fact that they are not organized into sarcomeres helps the smooth muscles function optimally. Smooth muscles must be able to exert tension even when greatly stretched—in the urinary bladder, for example, the smooth muscle cells may be stretched up to two and a half times their resting length. Skeletal muscles, by contrast, lose their ability to contract when the sarcomeres are stretched to the point where actin and myosin no longer overlap.

Single-Unit and Multiunit Smooth Muscles

Smooth muscles are often grouped into two functional categories: **single-unit** and **multiunit.** Single-unit smooth muscles have numerous gap junctions (electrical synapses) between adjacent cells that weld them together electrically; thus, they behave as a single unit. Multiunit smooth muscles have few, if any, gap junctions; thus, the individual cells must be stimulated separately by autonomic action potentials through motor neurons. This is similar to the control of skeletal muscles, in which numerous motor units are activated.

Single-unit smooth muscles display *pacemaker activity*, in which certain cells stimulate others in the mass. Single-unit smooth muscles also display intrinsic, or *myogenic*, electrical activity and contraction in response to stretch. For example, the stretch induced by an increase in the luminal contents of a small artery or a section of the GI tract can stimulate myogenic contraction. Such contraction does not require stimulation by autonomic nerves. By contrast, contraction of multiunit smooth muscles requires nerve stimulation. Single-unit and multiunit smooth muscles are compared in table 13.2.

Autonomic Innervation of Smooth Muscles

The neural control of skeletal muscles and that of smooth muscles differ markedly. A skeletal muscle fiber has only one junction with a somatic nerve fiber, and the receptors for the neurotransmitter are localized at the neuromuscular junction in the membrane of the skeletal muscle fiber. By contrast, the entire surface of smooth muscle fibers contains neurotransmitter

myogenic: Gk, *mys*, muscle; *genesis*, origin

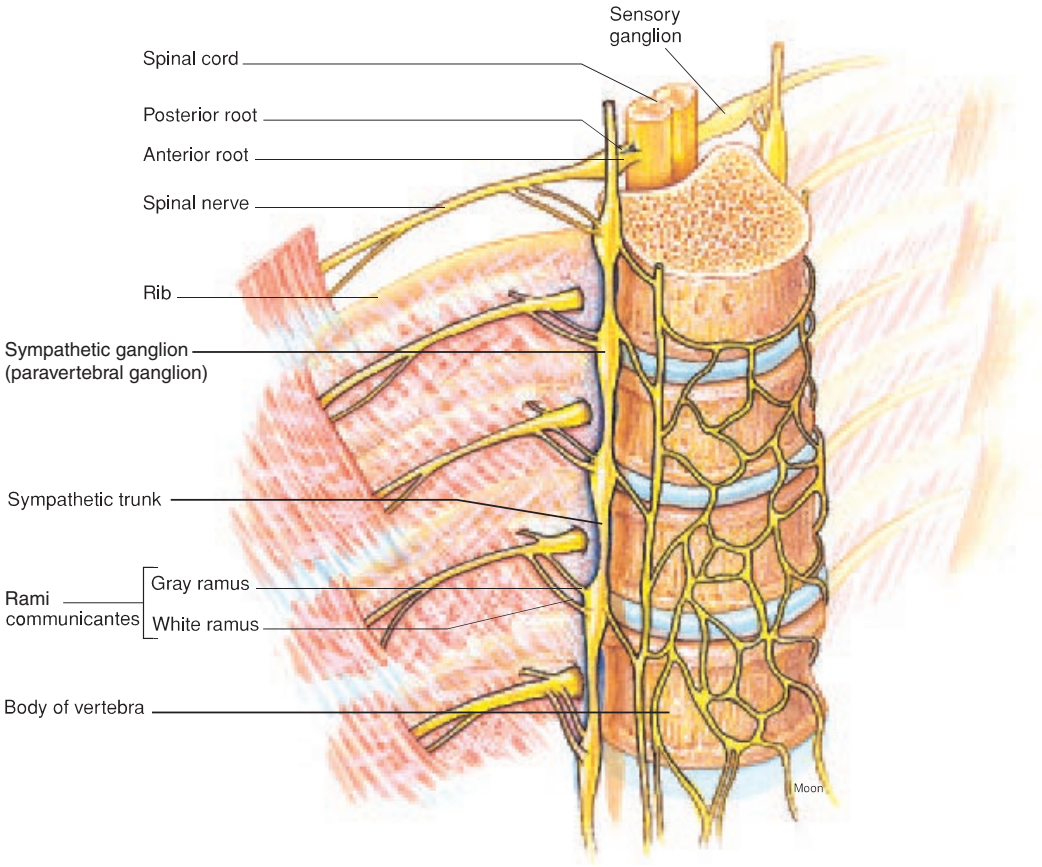


FIGURE 13.2 The sympathetic trunk of paravertebral ganglia showing its relationship to the vertebral column and spinal cord.

receptor proteins. Neurotransmitter molecules are released along a stretch of an autonomic nerve fiber that is located some distance from the smooth muscle fibers. The regions of the autonomic fiber that release transmitters appear as bulges, or *varicosities*, and the neurotransmitters released from these varicosities stimulate a number of smooth muscle fibers.

Knowledge Check

1. How does the neural regulation of cardiac and smooth muscle fibers differ from that of skeletal muscle fibers? How are these three types of muscle tissue affected by the experiment removal of their innervation?
2. Define the terms *preganglionic* and *postganglionic neurons* in the ANS and use a diagram to illustrate how motor innervation differs in somatic and autonomic nerves.
3. Distinguish between single-unit and multiunit smooth muscles. Explain how the two categories are regulated differently by action potentials through autonomic nerves.

STRUCTURE OF THE AUTONOMIC NERVOUS SYSTEM

Both the sympathetic and parasympathetic divisions of the autonomic nervous system consist of preganglionic neurons with cell bodies located in the CNS and postganglionic neurons with cell bodies located outside of the CNS in ganglia. However, the specific origin of the preganglionic neurons and the location of the ganglia differ in the two subdivisions of the autonomic nervous system.

Objective 4 Describe the origin of preganglionic sympathetic neurons and the location of sympathetic ganglia.

Objective 5 Explain the relationship between the sympathetic division of the ANS and the adrenal medulla.

Objective 6 Describe the origin of the preganglionic parasympathetic neurons and the location of the parasympathetic ganglia.

Objective 7 Describe the distribution of the vagus nerve and comment on its significance within the parasympathetic division of the ANS.

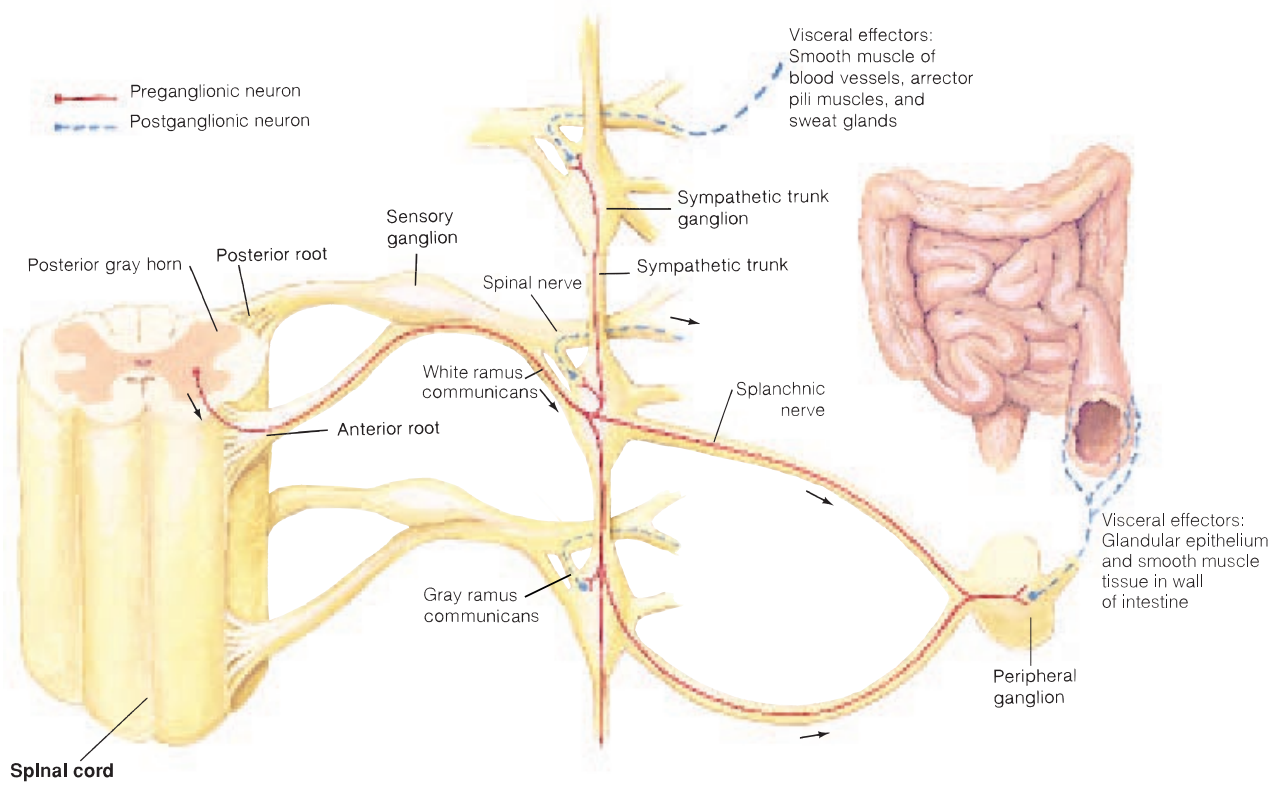


FIGURE 13.3 Sympathetic trunk ganglia, the sympathetic trunk, and rami communicantes of the sympathetic division of the ANS. (Solid lines indicate preganglionic neurons and dashed lines indicate postganglionic neurons.)

CHAPTER 13

Sympathetic (Thoracolumbar) Division

The **sympathetic division** is also called the *thoracolumbar division* of the ANS because its preganglionic neurons exit the vertebral column from the first thoracic (T1) to the second lumbar (L2) levels. Most sympathetic neurons, however, separate from the somatic motor neurons and synapse with postganglionic neurons within chains of sympathetic trunk ganglia located on either side of the vertebral column (fig. 13.2).

Because the preganglionic sympathetic neurons are myelinated and thus appear white, the "side branches" to the sympathetic ganglia are called **white rami communicantes** (*ra′mi kŏ′′myoo-nĭt-kan′tēz*—singular, *ramus communicans*) (fig. 13.3). Some of these preganglionic sympathetic neurons synapse with postganglionic neurons located at their same level in the chain of sympathetic ganglia. Other preganglionic neurons travel up or down within the sympathetic chain before synapsing with postganglionic neurons. Because the postganglionic sympathetic neurons are unmyelinated and thus appear gray, they form the **gray rami communicantes.** Postganglionic axons in the gray rami extend directly back to the anterior roots of the spinal nerves and travel distally within the spinal nerves to innervate their effector organs.

Within the sympathetic trunk ganglia, *divergence* is apparent as preganglionic neurons branch to synapse with numerous postganglionic neurons located at different levels in the chain. *Convergence* is apparent also when a postganglionic neuron receives synaptic input from a large number of preganglionic neurons. The divergence of impulses from the spinal cord to the ganglia and the convergence of impulses within the ganglia usually results in the *mass activation* of almost all the postganglionic neurons. This explains why the sympathetic division is usually activated as a unit and affects all of its effector organs at the same time.

Many preganglionic neurons that exit the spinal cord in the upper thoracic level travel through the sympathetic chain into the neck, where they synapse in cervical sympathetic ganglia (fig. 13.4). Postganglionic neurons from here innervate the smooth muscles and glands of the head and neck.

Peripheral Ganglia

Many preganglionic neurons that exit the spinal cord below the level of the diaphragm pass through the sympathetic trunk without synapsing. Beyond the sympathetic trunk, these preganglionic neurons form **splanchnic** (*splank′nik*) **nerves** (fig. 13.3). Preganglionic

ramus: L. *ramus*, a branch

splanchnic: Gk. *splanchno*, relating to viscera

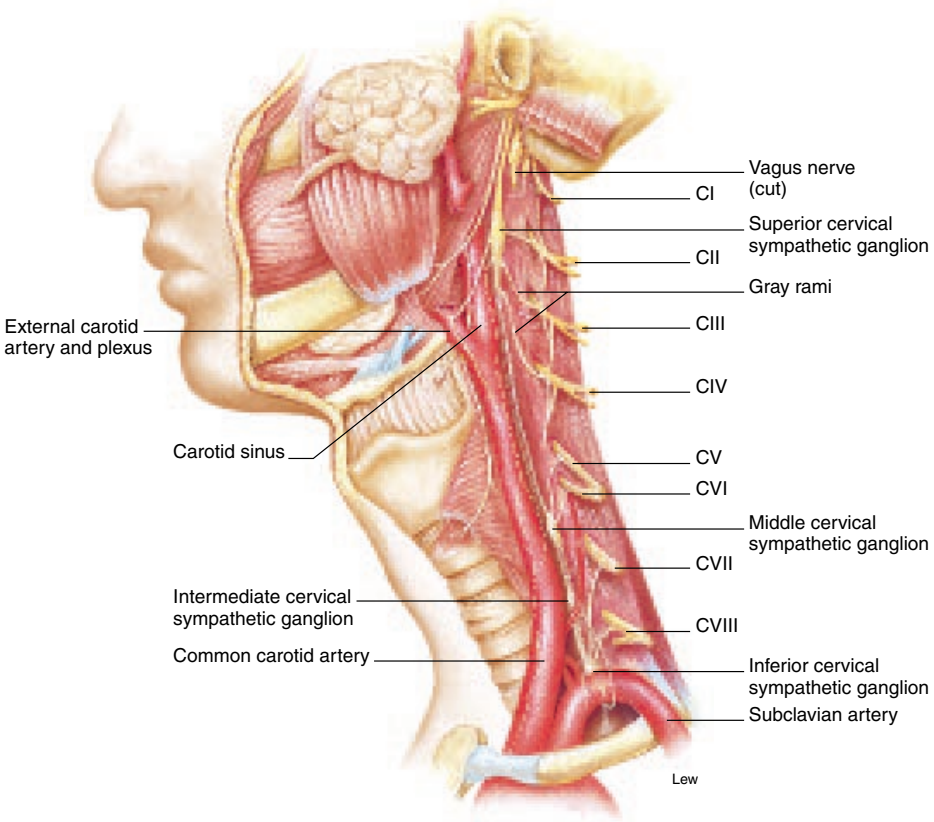


FIGURE 13.4 The cervical sympathetic ganglia.

neurons in the splanchnic nerves synapse in peripheral ganglia, which include the **celiac** (*se′le-ak*), **superior mesenteric** (*mes′′enter′ik*), and **inferior mesenteric ganglia** (figs. 13.5 and 13.6).

The *greater splanchnic nerve* arises from preganglionic sympathetic neurons T4–T9 and synapses in the celiac ganglion. These neurons contribute to the *celiac (solar) plexus*. Postganglionic neurons from the celiac ganglion innervate the stomach, spleen, pancreas, liver, small intestine, and kidneys. The *lesser splanchnic nerve* terminates in the superior mesenteric ganglion. Postganglionic neurons from here innervate the small intestine and colon. The *lumbar splanchnic nerve* synapses in the inferior mesenteric ganglion, and the postganglionic neurons innervate the distal colon and rectum, urinary bladder, and genital organs.

Adrenal Glands

The paired adrenal glands are located above each kidney (see fig. 13.5). Each adrenal is composed of two parts: an outer **adrenal cortex** and an inner **adrenal medulla.** These two parts are actually two functionally different glands with different embryonic origins, different hormones, and different regulatory mechanisms (see chapter 14). The adrenal cortex secretes steroid hormones; the adrenal medulla secretes the hormone **epinephrine** (*ep′′ĭ-nef′rin*) (adrenaline) and, to a lesser degree, **norepinephrine** when it is stimulated by the sympathetic system.

The adrenal medulla is a modified sympathetic ganglion whose cells are derived from postganglionic sympathetic neurons. The cells of the adrenal medulla are innervated by preganglionic sympathetic neurons originating in the thoracic level of the spinal cord; they secrete epinephrine into the blood in response to sympathetic stimulation. The effects of epinephrine are complementary to those of the neurotransmitter norepinephrine, which is released from postganglionic sympathetic nerve endings.

Parasympathetic (Craniosacral) Division

The **parasympathetic division** is also known as the *craniosacral division* of the autonomic system. This is because its preganglionic neurons originate in the brain (specifically, the midbrain, pons, and medulla oblongata of the brain stem) and in the second through fourth sacral segments of the spinal cord. These preganglionic parasympathetic neurons synapse in ganglia that are lo-

adrenal: L. *ad*, to; *renes*, kidney
cortex: L. *cortex*, bark
medulla: L. *medulla*, marrow

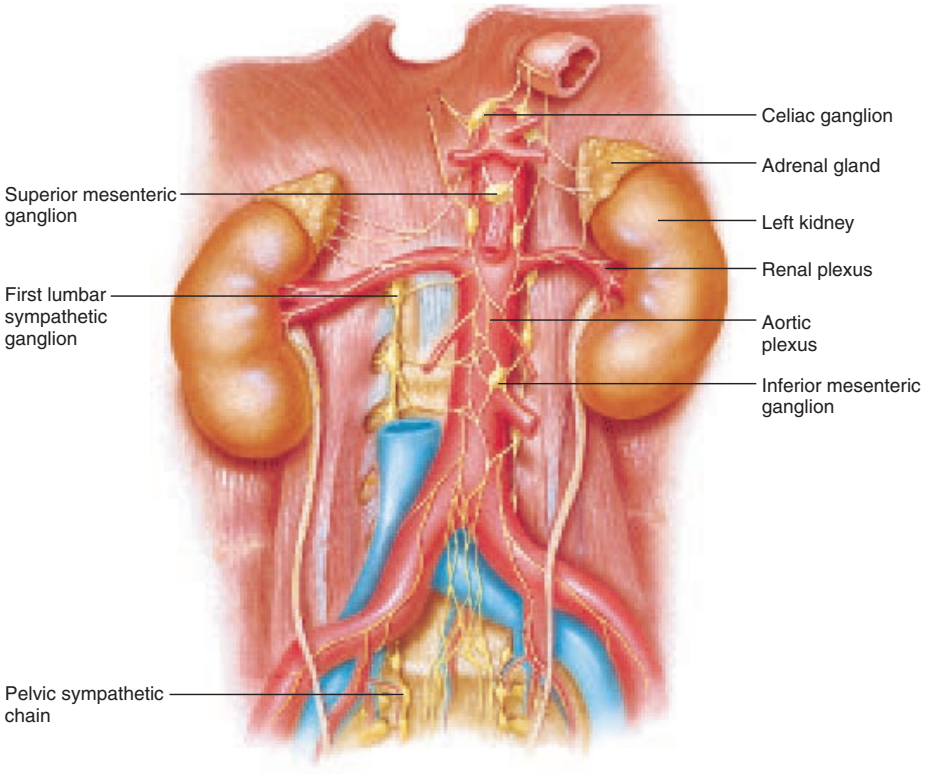


FIGURE 13.5 Peripheral sympathetic plexuses and ganglia of the abdomen.

cated next to (or actually within) the organs innervated. These parasympathetic ganglia, which are called **terminal ganglia,** supply the postganglionic neurons that synapse with the effector cells.

Tables 13.3 and 13.4 show the comparative structures of the sympathetic and parasympathetic divisions. It should be noted that, unlike sympathetic neurons, most parasympathetic neurons do not travel within spinal nerves. Cutaneous effectors (blood vessels, sweat glands, and arrector pili muscles) and blood vessels in skeletal muscles thus receive sympathetic but not parasympathetic innervation.

Four of the twelve pairs of cranial nerves contain preganglionic parasympathetic neurons. These are the oculomotor (III), facial (VII), glossopharyngeal (IX), and vagus (X) nerves. Parasympathetic neurons within the first three of these cranial nerves synapse in ganglia located in the head; neurons in the vagus nerve synapse in terminal ganglia located in many regions of the body.

The oculomotor nerve contains somatic motor and parasympathetic neurons that originate in the oculomotor nuclei of the midbrain. These parasympathetic neurons synapse in the **ciliary ganglion,** whose postganglionic neurons innervate the ciliary muscle and constrictor muscles in the iris of the eye. Preganglionic neurons that originate in the pons travel in the facial nerve to the **pterygopalatine** (*ter″ĭ-go-pal′ă-tē*) **ganglion,** which sends postganglionic neurons to the nasal mucosa, pharynx, palate, and lacrimal glands. Another group of neurons in the facial nerve terminate in the **submandibular ganglion,** which sends postganglionic neurons to the submandibular and sublingual glands. Preganglionic neurons of the glossopharyngeal nerve synapse in the **otic ganglion,** which sends postganglionic neurons to innervate the parotid gland.

Nuclei in the medulla oblongata contribute preganglionic neurons to the very long vagus nerves, which provide the most extensive parasympathetic innervation in the body (see fig. 12.11). As the paired vagus nerves pass through the thorax, they contribute to the *cardiac plexus* and the *pulmonary plexuses* within the mediastinum. Branches of the pulmonary plexuses accompany blood vessels and bronchi into the lungs. Below the pulmonary plexuses, branches of the vagus nerves merge to form the *esophageal plexuses*.

At the lower end of the esophagus, vagal neurons collect to form an **anterior** and **posterior vagal trunk,** each composed of neurons from both vagus nerves. The vagal trunks enter the abdominal cavity through the esophageal hiatus (opening) in the diaphragm. Neurons from the vagal trunks innervate the stomach on the anterior and posterior sides. Branches of the vagus nerves within the abdominal cavity also contribute to the *celiac plexus* and *plexuses of the abdominal aorta*.

vagus: L. *vagus*, wandering

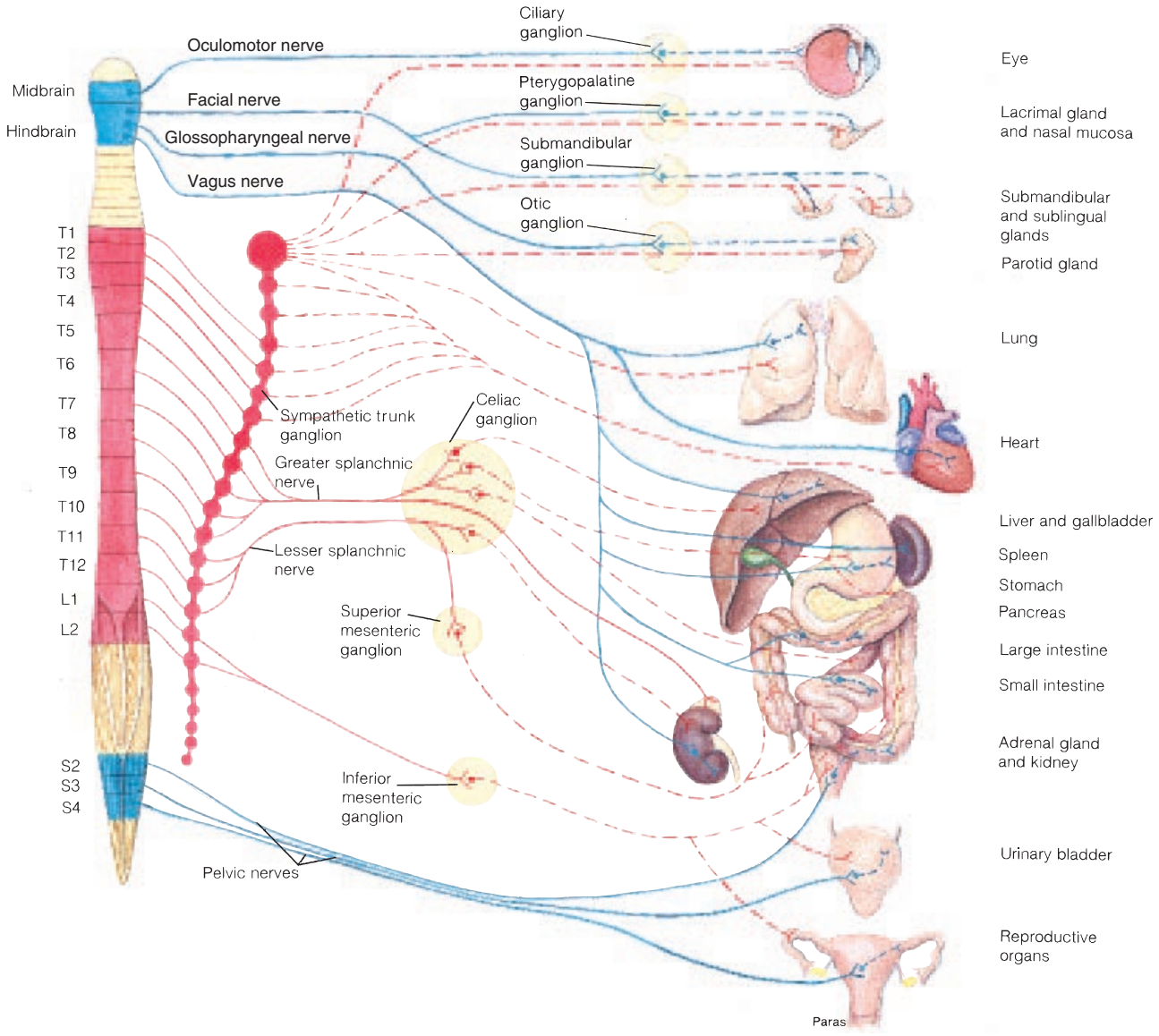


FIGURE 13.6 The autonomic nervous system. The sympathetic division is shown in red; the parasympathetic, in blue. Solid lines indicate preganglionic neurons and dashed lines indicate postganglionic neurons.

TABLE 13.3 The Sympathetic (Thoracolumbar) Division of the Autonomic Nervous System

Body Structures Innervated	Spinal Origin of Preganglionic Neurons	Origin of Postganglionic Neurons
Eye	C8, T1	Cervical ganglia
Head and neck	T1–T4	Cervical ganglia
Heart and lungs	T1–T5	Upper thoracic ganglia
Upper extremity	T2–T9	Lower cervical and upper thoracic ganglia
Upper abdominal viscera	T4–T9	Celiac and superior mesenteric ganglia
Adrenal gland	T10, T11	Adrenal medulla
Urinary and reproductive systems	T12–L2	Celiac and inferior mesenteric ganglia
Lower extremity	T9–L2	Lumbar and upper sacral ganglia

TABLE 13.4 The Parasympathetic (Craniosacral) Division of the Autonomic Nervous System

Nerve	Origin of Preganglionic Neurons	Location of Terminal Ganglia	Effector Organs
Oculomotor nerve	Midbrain (brain)	Ciliary ganglion	Eye (smooth muscles in iris and ciliary body)
Facial nerve	Pons (brain)	Pterygopalatine and submandibular ganglia	Lacrimal, mucous, and salivary glands in head
Glossopharyngeal nerve	Medulla oblongata (brain)	Otic ganglion	Parotid gland
Vagus nerve	Medulla oblongata (brain)	Terminal ganglia in or near organ	Heart, lungs, GI tract, liver, pancreas
Sacral spinal nerves	S2–S4 (spinal cord)	Terminal ganglia near organs	Lower half of large intestine, urinary bladder, and reproductive organs

The preganglionic neurons in the vagus synapse with postganglionic neurons that are actually located *within* the innervated organs. These preganglionic neurons are thus quite long. They provide parasympathetic innervation to the heart, lungs, esophagus, stomach, pancreas, liver, small intestine, and upper half of the large intestine. Postganglionic parasympathetic neurons arise from terminal ganglia within these organs and innervate the smooth muscle tissue and glandular epithelium of these same organs.

Preganglionic neurons from the sacral levels of the spinal cord provide parasympathetic innervation to the lower half of the large intestine, the rectum, and to the urinary and reproductive systems. These neurons, like those of the vagus, synapse with terminal ganglia located within the effector organs. Parasympathetic nerves to the visceral organs thus consist of preganglionic neurons, whereas sympathetic nerves to these organs contain postganglionic neurons.

A composite view of the sympathetic and parasympathetic divisions of the ANS is provided in figure 13.6, and the comparisons are summarized in table 13.5.

Knowledge Check

4. Compare the origins of preganglionic sympathetic and parasympathetic neurons and the locations of sympathetic and parasympathetic ganglia.
5. Using a simple line drawing, illustrate the sympathetic pathway from the spinal cord to the heart. Label the preganglionic neuron, postganglionic neuron, and the ganglion.
6. Use a simple diagram to show the parasympathetic innervation of the heart. Label the preganglionic and postganglionic neurons, the nerve involved, and the terminal ganglion.
7. Describe the distribution of the vagus nerve and discuss the functional significance of this distribution.
8. Define the terms *white rami* and *gray rami* and explain why blood vessels in the skin and skeletal muscles receive sympathetic but not parasympathetic innervation.
9. Describe the structure of the adrenal gland and explain its relationship to the sympathetic division of the ANS.

TABLE 13.5 **Comparison of the Structural Features of the Sympathetic and Parasympathetic Divisions of the Autonomic Nervous System**

Feature	Sympathetic	Parasympathetic
Location of cell bodies of preganglionic neurons	Thoracolumbar portion of spinal cord	Midbrain, hindbrain, and sacral portion of spinal cord
Location of ganglia	Chain of paravertebral ganglia and prevertebral ganglia	Terminal ganglia in or near effector organs
Distribution of postganglionic neurons	Throughout the body	Mainly limited to the head and viscera
Divergence of impulses from pre- to postganglionic neurons	Great divergence (1 preganglionic may activate 20 postganglionic neurons)	Little divergence (one preganglionic only activates a few postganglionic neurons)
Mass discharge of system as a whole	Usually	Not normally

FUNCTIONS OF THE AUTONOMIC NERVOUS SYSTEM

The actions of the autonomic nervous system, together with the effects of hormones, help to maintain a state of dynamic constancy in the internal environment. The sympathetic division gears the body for action through adrenergic effects; the parasympathetic division conserves the body's energy through cholinergic effects. Homeostasis thus depends, in large part, on the complementary and often antagonistic effects of sympathetic and parasympathetic innervation.

Objective 8 List the neurotransmitters of the preganglionic and postganglionic neurons of the sympathetic and parasympathetic divisions.

Objective 9 Describe the effects of acetylcholine released by postganglionic parasympathetic neurons.

Objective 10 Explain the antagonistic, complementary, and cooperative effects of sympathetic and parasympathetic innervation.

The sympathetic and parasympathetic divisions of the ANS (fig. 13.6) affect the visceral organs in different ways. Mass activation of the sympathetic division prepares the body for intense physical activity in emergencies; the heart rate increases, blood glucose rises, and blood is diverted to the skeletal muscles (away from the visceral organs and skin). These and other effects are listed in table 13.6. The theme of the sympathetic division is aptly summarized in the phrase **fight or flight.**

The effects of parasympathetic nerve stimulation are in many ways opposite to the effects of sympathetic stimulation. The parasympathetic division, however, is not normally activated as a whole. Stimulation of separate parasympathetic nerves can result in slowing of the heart, dilation of visceral blood vessels, and increased activity of the GI tract (table 13.6). The different responses of visceral organs to sympathetic and parasympathetic nerve activity is due to the fact that the postganglionic neurons of these two divisions release different neurotransmitters.

Neurotransmitters of the Autonomic Nervous System

The neurotransmitter released by most postganglionic sympathetic neurons is **norepinephrine** (noradrenaline). Transmission at these synapses is thus said to be **adrenergic** (*ad''rĕ-ner'jik*). There are a few exceptions to this rule: some sympathetic neurons that innervate blood vessels in skeletal muscles, as well as sympathetic neurons to sweat glands, release acetylcholine (are cholinergic).

Acetylcholine (*ă-sēt't-ko'lēn*) **(ACh)** is the neurotransmitter of all preganglionic neurons (both sympathetic and parasympathetic). Acetylcholine is also the transmitter released by all parasympathetic postganglionic neurons at their synapses with effector cells (fig. 13.7). Transmission at the autonomic ganglia and at synapses of postganglionic neurons is thus said to be **cholinergic** (*ko''lĭ-ner'jik*). In other words, a *cholinergic fiber* is a neuron that secretes ACh at the terminal end of its axon.

Responses to Adrenergic Stimulation

Adrenergic stimulation—by epinephrine in the blood and by norepinephrine released from sympathetic nerve endings—has both excitatory and inhibitory effects. The heart, dilatory muscles of the iris, and the smooth muscles of many blood vessels are stimulated to contract. The smooth muscles of the bronchioles and of some blood vessels, however, are inhibited from contracting; adrenergic chemicals, therefore, cause these structures to dilate.

cholinergic: Gk. *chole*, bile; *ergon*, work

CHAPTER 13

TABLE 13.6 Effects of Autonomic Nerve Stimulation on Various Effector Organs

Effector	Organ Sympathetic Effect	Parasympathetic Effect
Eye		
Iris (pupillary dilator muscle)	Dilation of pupil	—
Iris (pupillary constrictor muscle)	—	Constriction of pupil
Ciliary muscle	Relaxation (for far vision)	Contraction (for near vision)
Glands		
Lacrimal (tear)	—	Stimulation of secretion
Sweat	Stimulation of secretion	—
Salivary	Decreased secretion; saliva becomes thick	Increased secretion; saliva becomes thin
Stomach	—	Stimulation of secretion
Intestine	—	Stimulation of secretion
Adrenal medulla	Stimulation of hormone secretion	—
Heart		
Rate	Increased	Decreased
Conduction	Increased rate	Decreased rate
Strength	Increased	—
Blood vessels	Mostly constriction; affects all organs	Dilation in a few organs (e.g., penis)
Lungs		
Bronchioles	Dilation	Constriction
Mucous glands	Inhibition of secretion	Stimulation of secretion
GI tract		
Motility	Inhibition of movement	Stimulation of movement
Sphincters	Closing stimulated	Closing inhibited
Liver	Stimulation of glycogen hydrolysis	—
Adipocytes (fat cells)	Stimulation of fat hydrolysis	—
Pancreas	Inhibition of exocrine secretions	Stimulation of exocrine secretions
Spleen	Stimulation of contraction	—
Urinary bladder	Muscle tone aided	Stimulation of contraction
Arrector pili muscles	Stimulation of hair erection, causing goose bumps	—
Uterus	If pregnant, contraction; if not pregnant, relaxation	—
Penis	Ejaculation	Erection (due to vasodilation)

Responses to Cholinergic Stimulation

Somatic motor neurons, postganglionic parasympathetic neurons, and all preganglionic autonomic neurons are cholinergic—they use acetylcholine as a neurotransmitter. The cholinergic effects of somatic motor neurons and preganglionic autonomic neurons are always excitatory. The cholinergic effects of postganglionic parasympathetic neurons are usually excitatory, with some notable exceptions; the parasympathetic neurons innervating the heart, for example, cause slowing of the heart rate.

The drug *muscarine (mus'kă-rēn)*, a poison derived from certain mushrooms, mimics the cholinergic effects of parasympathetic nerves in the heart, smooth muscles, and glands by stimulating the acetylcholine receptors located in these organs. This drug, however, does not affect the cholinergic receptors of skeletal muscle or those of autonomic ganglia. The acetylcholine receptors of visceral organs are therefore said to be *muscarinic*.

The muscarinic effects of ACh are specifically inhibited by the drug *atropine,* derived from the deadly nightshade plant (*Atropa belladonna*). Indeed, extracts of this plant were used by women during the Middle Ages to dilate their pupils (atropine inhibits parasympathetic stimulation of the iris). This was thought to enhance their beauty (in Italian, *bella* = beautiful, *donna* = woman). Atropine is used clinically today to dilate pupils during eye examinations, to reduce secretions of the respiratory tract prior to general anesthesia, and to inhibit spasmodic contractions of the lower GI tract.

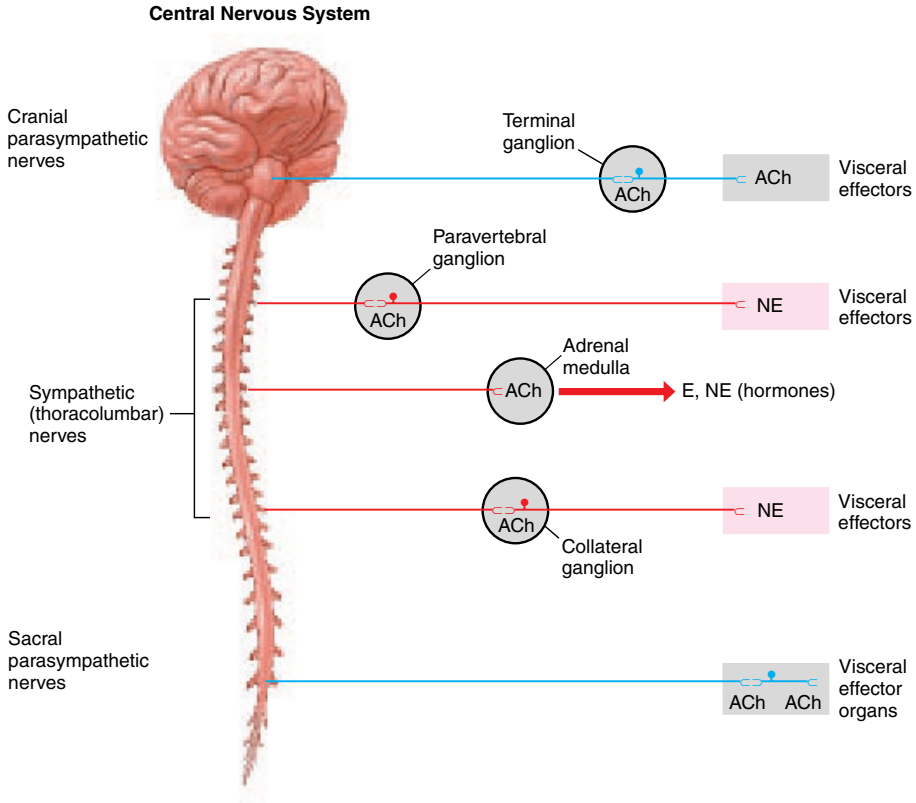


FIGURE 13.7 Neurotransmitters of the autonomic motor system (ACh = acetylcholine, NE = norepinephrine, E = epinephrine). Those nerves that release ACh are called cholinergic; those that release NE are called adrenergic. The adrenal medulla secretes both epinephrine (85%) and norepinephrine (15%) as hormones into the blood.

CHAPTER 13

Organs with Dual Innervation

Many organs receive dual innervation—they are innervated by both sympathetic and parasympathetic neurons. When this occurs, the effects of these two divisions may be antagonistic, complementary, or cooperative.

Antagonistic Effects

The effects of sympathetic and parasympathetic innervation on the sinoatrial (SA) node ("pacemaker") of the heart (see fig. 16.11) is the best example of the antagonism of these two systems. In this case, sympathetic and parasympathetic neurons innervate the SA node. Adrenergic stimulation from sympathetic neurons increases the heart rate, whereas cholinergic stimulation from parasympathetic neurons inhibits the SA node, which decreases the heart rate. Antagonism is also seen in the GI tract, where sympathetic nerves inhibit and parasympathetic nerves stimulate intestinal movements and secretions.

The effects of sympathetic and parasympathetic stimulation on the diameter of the pupil of the eye are analogous to the reciprocal innervation of flexor and extensor skeletal muscles by somatic motor neurons. This is because the iris contains antagonistic muscle layers. Contraction of the pupillary dilator muscle, which is stimulated by impulses through sympathetic nerve endings, causes dilation; contraction of the pupillary constrictor muscle, which is innervated by parasympathetic nerve endings, causes constriction of the pupil (fig. 13.8).

Complementary Effects

The effects of sympathetic and parasympathetic stimulation on salivary gland secretion are complementary. The secretion of watery saliva is stimulated by impulses through parasympathetic nerves, which also stimulate the secretion of other exocrine glands in the GI tract. Impulses through sympathetic nerves stimulate the constriction of blood vessels throughout the GI tract. The resultant decrease in blood flow to the salivary glands causes the production of a thicker, more viscous saliva.

Cooperative Effects

The effects of sympathetic and parasympathetic stimulation on the urinary and reproductive systems are cooperative. Erection of the penis, for example, is due to vasodilation resulting from action potentials through parasympathetic nerves; ejaculation is due to action potentials through sympathetic nerves. Although the contraction of the urinary bladder is myogenic (independent of nerve stimulation),

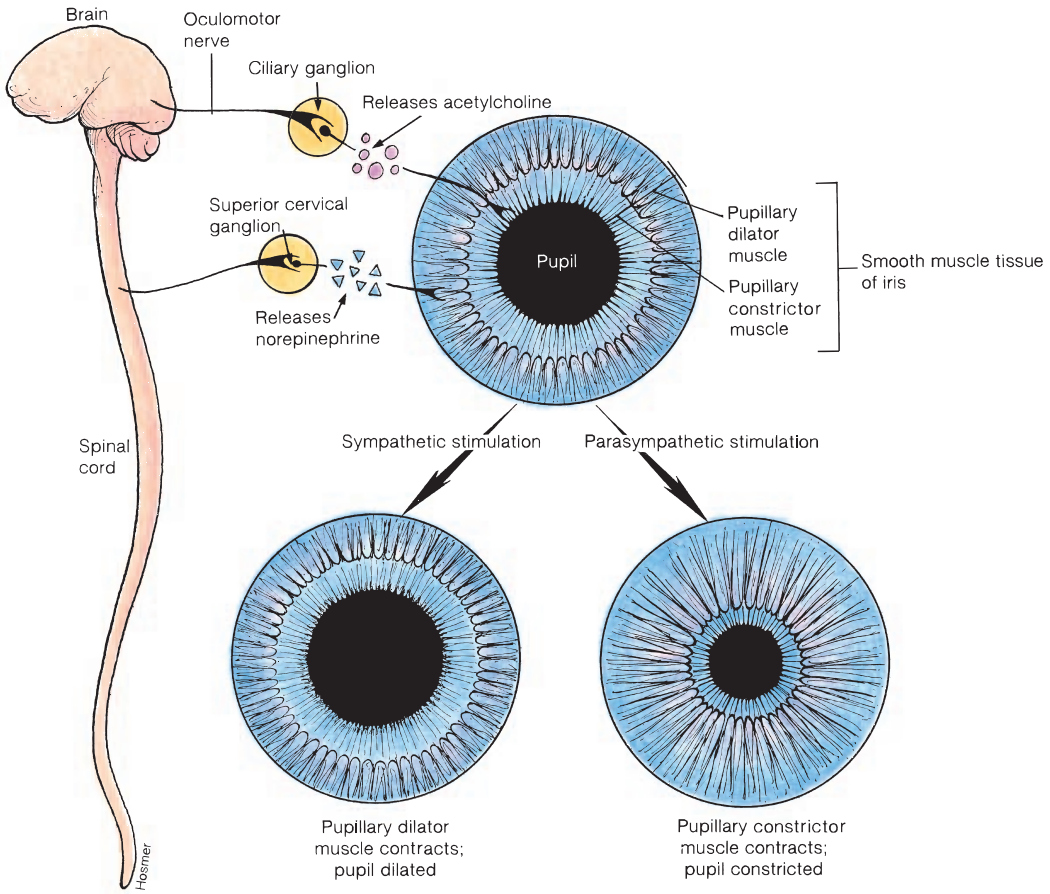


FIGURE 13.8 Reciprocal sympathetic and parasympathetic innervation of smooth muscle tissue within the iris of the eye. Stimulation through sympathetic nerves causes the dilator muscle to contract, which dilates (enlarges) the size of the pupil. Stimulation through the parasympathetic nerves causes the constrictor muscle to contract, which constricts (decreases) the size of the pupil.

it is promoted in part by the action potentials through parasympathetic nerves. This *micturition* (*mik''tŭ-rish'un*) or urination, urge and reflex is also enhanced by action potentials through sympathetic nerves, which increases the tone of the urinary bladder muscles. Emotional states that are accompanied by high sympathetic nerve activity may thus result in reflex urination at urinary bladder volumes that are normally too low to trigger this reflex.

Organs without Dual Innervation

Although most organs are innervated by both sympathetic and parasympathetic nerves, some—including the adrenal medulla, arrector pili muscles, sweat glands, and most blood vessels—receive only sympathetic innervation. In these cases, regulation is achieved by increases or decreases in the "tone" (firing rate) of the sympathetic neurons. Constriction of blood vessels, for example, is produced by increased sympathetic activity, which stimulates adrenergic receptors, and vasodilation results from decreased sympathetic nerve activity.

Sympathetic activity is required for proper thermoregulatory responses to heat. In a hot room, for example, decreased sympathetic activity produces dilation of the blood vessels in the surface of the skin, which increases cutaneous blood flow and provides better heat radiation. During exercise, on the other hand, there is increased sympathetic activity, which causes constriction of the blood vessels in the skin of the limbs and stimulation of sweat glands in the trunk.

The eccrine sweat glands in the trunk secrete a watery fluid in response to sympathetic stimulation. Evaporation of this dilute sweat helps to cool the body. The eccrine sweat glands also secrete a chemical called **bradykinin** (*brad''ĭ-ki'nin*) in response to sympathetic stimulation. Bradykinin stimulates dilation of the surface blood vessels near the sweat glands, helping to radiate heat. At the conclusion of exercise, sympathetic activity is reduced and blood flow to the surface of the limbs is increased, which aids in the elimination of metabolic heat. Notice that all of these thermoregulatory responses are achieved without the direct involvement of the parasympathetic division.

TABLE 13.7 **Some Vagal Reflexes Involving Peripheral Receptors and Nuclei in the Medulla Oblongata**

Organs	Receptors	Reflex Effects	Organs	Receptors	Reflex Effects
Lungs	Stretch receptors	Further inhalation inhibited; increase in cardiac rate and vasodilation	Aorta (cont.)	Baroreceptors	Stimulated by increased blood pressure—produces a reflex decrease in heart rate
	Type J receptors	Stimulated by pulmonary congestion—produces feelings of breathlessness and causes a reflex fall in cardiac rate and blood pressure	Heart	Atrial stretch receptors	Antidiuretic hormone secretion thus increasing the volume of urine excreted
				Stretch receptors in ventricles	Produces a reflex decrease in heart rate and vasodilation
Aorta	Chemoreceptors	Stimulated by rise in CO_2 and fall in O_2—produces increased rate of breathing, rise in heart rate, and vasoconstriction	GI tract	Stretch receptors	Feelings of satiety, discomfort, and pain

Knowledge Check

10. Define the terms *adrenergic* and *cholinergic* and use these terms to describe the neurotransmitters of different autonomic neurons.
11. Describe the effects of the drug *atropine* and explain these effects in terms of the actions of the parasympathetic division.
12. Explain how the sympathetic and parasympathetic divisions can have antagonistic, cooperative, and complementary effects. Give an example of each of these effects.

CHAPTER 13

CONTROL OF THE AUTONOMIC NERVOUS SYSTEM BY HIGHER BRAIN CENTERS

Visceral functions are largely regulated by autonomic reflexes. In most autonomic reflexes, sensory input is directed to brain centers, which in turn regulate the activity of descending pathways to preganglionic autonomic neurons. The neural centers that directly control the activity of autonomic nerves are influenced by higher brain areas, as well as by sensory input.

Objective 11 Describe the area of the brain that most directly controls the activity of autonomic nerves. Also describe the higher brain areas that influence autonomic activity.

Objective 12 Explain how the activity of the autonomic nervous system and the activity of the endocrine system can be coordinated.

Objective 13 Explain how autonomic functions can be affected by emotions.

Medulla Oblongata

The **medulla oblongata** of the brain stem is the structure that most directly controls the activity of the ANS. Almost all autonomic responses can be elicited by experimental stimulation of the medulla oblongata, which contains centers for the control of the circulatory, respiratory, urinary, reproductive, and digestive systems. Much of the sensory input to these centers travels through the sensory neurons of the vagus nerves. The reflexes that result are listed in table 13.7.

Hypothalamus

The **hypothalamus** (fig. 13.9 and 11.24), located just above the pituitary gland, is the overall control and integration center of the ANS. By means of motor fibers to the brain stem and posterior pituitary, and also by means of hormones that regulate the anterior pituitary, the hypothalamus serves to orchestrate somatic, autonomic, and endocrine responses during various behavioral states.

Experimental stimulation of different areas of the hypothalamus can evoke the autonomic responses characteristic of aggression, sexual behavior, eating, or satiety. Chronic stimulation of the lateral hypothalamus, for example, can make an animal eat and become obese, whereas stimulation of the medial hypothalamus inhibits eating. Other areas contain osmoreceptors that stimulate thirst and the secretion of antidiuretic hormone (ADH) from the posterior pituitary.

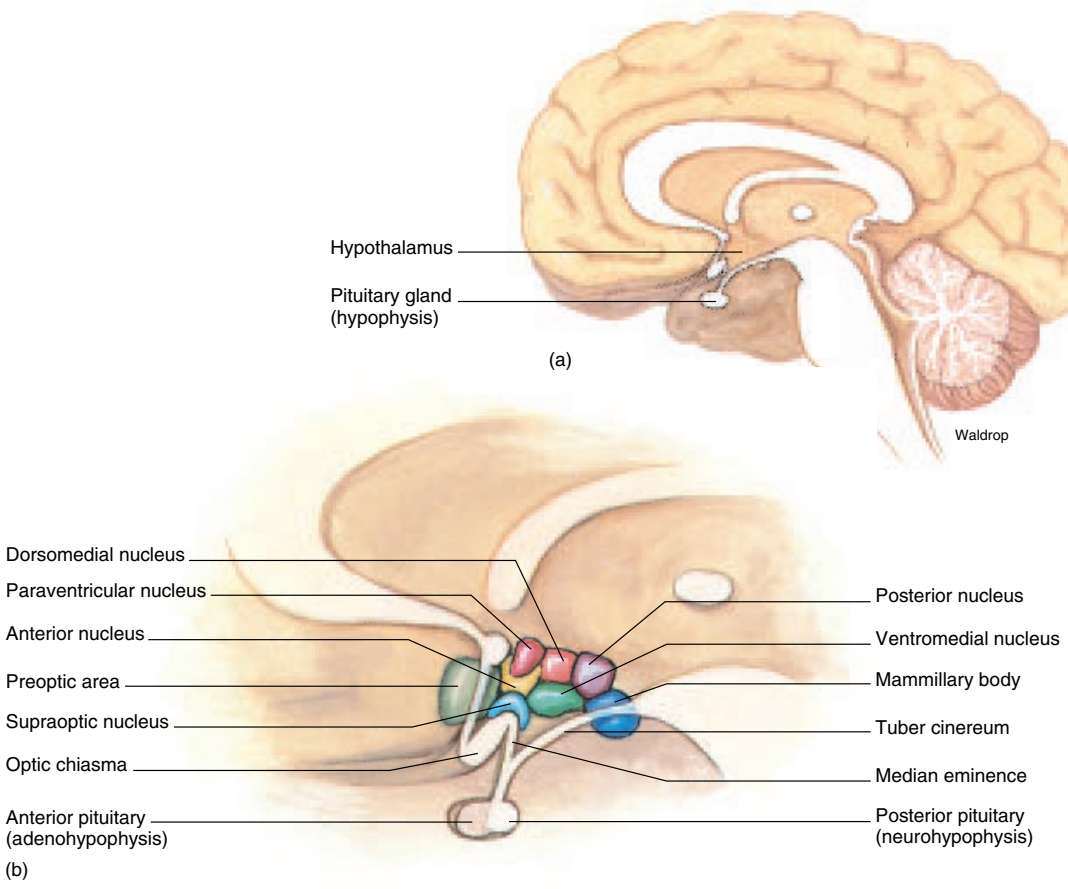


FIGURE 13.9 (*a*) The position of the hypothalamus relative to the pituitary gland within the diencephalon of the brain. (*b*) An enlargement of the hypothalamus to diagrammatically show the hypothalamic nuclei and the anterior and posterior parts of the pituitary gland.

The hypothalamus is also where the body's thermostat is located. Experimental cooling of the preoptic-anterior hypothalamus causes shivering (a somatic response) and nonshivering thermogenesis (a sympathetic response). Experimental heating of this hypothalamic area results in hyperventilation (stimulated by somatic motor nerves), vasodilation, salivation, and sweat gland secretion (stimulated by autonomic nerves).

The coordination of sympathetic and parasympathetic reflexes by the medulla oblongata is thus integrated with the control of somatic and endocrine responses by the hypothalamus. The activities of the hypothalamus are in turn influenced by higher brain centers.

Limbic System, Cerebellum, and Cerebrum

The **limbic system** is a group of fiber tracts and nuclei that form a ring (limbus) around the brain stem. It includes the cingulate gyrus of the cerebral cortex, the hypothalamus, the fornix (a fiber tract), the hippocampus, and the amygdaloid nucleus (fig. 13.10). These structures, which were derived early in the course of vertebrate evolution, were once called the *rhinencephalon (ri''nen-sefă-lon)* or "smell brain," because of their importance in the central processing of olfactory information.

In primates, these structures are autonomic nervous system centers involved in such basic emotional drives as anger, fear, sex, and hunger, and in short-term memory. Complex circuits between the hypothalamus and other parts of the limbic system (illustrated in fig. 13.10) contribute visceral responses to emotions, including blushing, pallor, fainting, and "butterflies in the stomach."

Experimental and clinical observations have demonstrated that the autonomic correlates of motion sickness—nausea, sweating, and cardiovascular changes—are eliminated by cutting the motor tracts of the cerebellum. This confirms that impulses from the cerebellum to the medulla oblongata influence activity of the ANS. In addition, the frontal and temporal lobes of the cerebral cortex influence lower brain areas as part of their involvement in emotion and personality.

limbic: L. *limbus*, edge or border

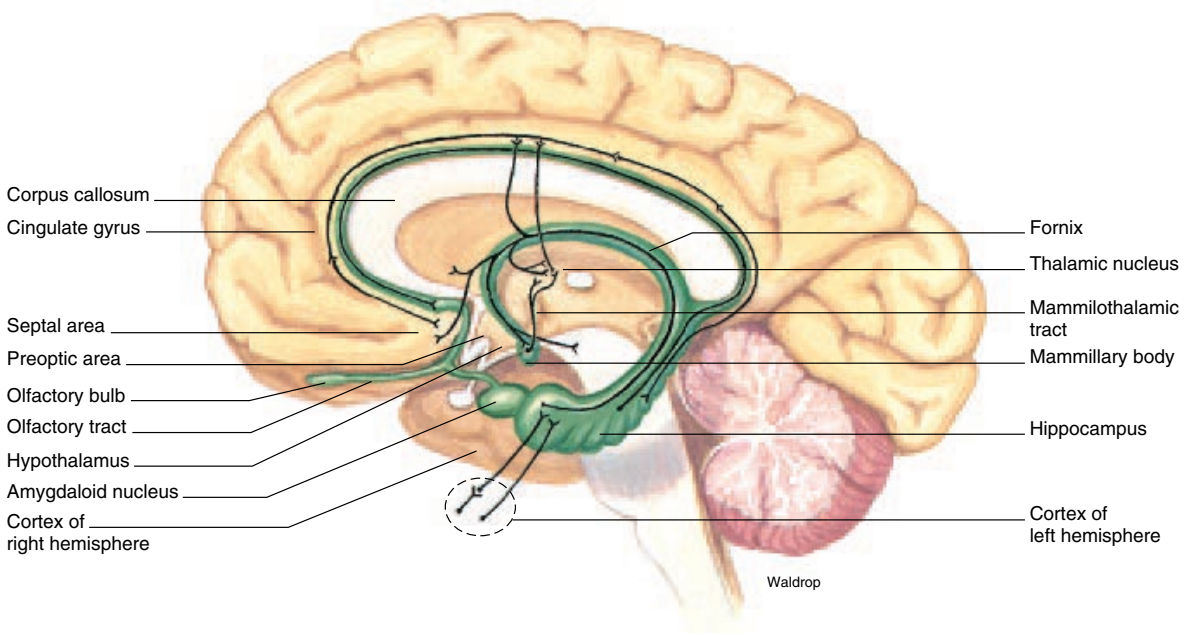


FIGURE 13.10 The limbic system and the pathways that interconnect the structures of the limbic system. (Note that the left temporal lobe of the cerebral cortex has been removed.)

One of the most dramatic examples of the role of higher brain areas in personality and emotion is the famous crowbar accident of 1848. A 25-year-old railroad foreman, Phineas P. Gage, was tamping gunpowder into a hole in a rock with a metal rod, when the gunpowder suddenly exploded. The rod—3 feet, 7 inches long and 1 1/4 inches thick—was driven through his left eye and through his brain, finally emerging through the back of his skull.

After a few minutes of convulsions, Gage got up, rode a horse three-quarters of a mile into town, and walked up a long flight of stairs to see a doctor. He recovered well, with no noticeable sensory or motor deficits. His associates, however, noted striking personality changes. Before the accident Gage was a responsible, capable, and financially prudent man. Afterward, he was much less inhibited socially, engaging, for example, in gross profanity (which he had never done previously). He also seemed to be tossed about by chance whims. Eventually, Gage was fired from his job, and his old friends remarked that he was "no longer Gage."

Knowledge Check

13. Describe the role of the medulla oblongata in the regulation of the ANS.
14. Describe the role of the hypothalamus in the regulation of the autonomic nervous system and endocrine system.
15. What mechanisms are involved when a person blushes? What structures are involved in this response?

CLINICAL CONSIDERATIONS

Autonomic Dysreflexia

Autonomic dysreflexia, a serious condition producing rapid elevations in blood pressure that can lead to stroke (cerebrovascular accident), occurs in 85% of people with quadriplegia and others with spinal cord lesions above the sixth thoracic level. Lesions to the spinal cord first produce the symptoms of spinal shock, characterized by the loss of both skeletal muscle and autonomic reflexes. After a period of time, both types of reflexes return in an exaggerated state; the skeletal muscles may become spastic because of the absence of higher inhibitory influences, and the visceral organs experience denervation hypersensitivity. Patients in this state have difficulty emptying their urinary bladders and must often be catheterized.

Noxious stimuli, such as overdistension of the urinary bladder, can result in reflex activation of the sympathetic nerves below the spinal cord lesion. This produces goose bumps, cold skin, and vasoconstriction in the regions served by the spinal cord below the level of the lesion. The rise in blood pressure resulting from this vasoconstriction activates pressure receptors that transmit impulses along sensory neurons to the medulla ob-

longata. In response to this sensory input, the medulla oblongata directs a reflex slowing of the heart and vasodilation. Because descending impulses are blocked by the spinal lesion, however, the skin above the lesion is warm and moist (because of vasodilation and sweat gland secretion), whereas it is cold below the level of spinal cord damage.

Clinical Case Study Answer

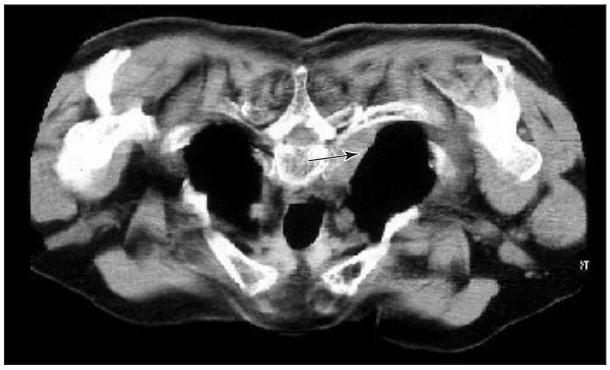
The syndrome of organophosphate toxicity consists of symptoms of dangerously enhanced parasympathetic activity. Death may result from suffocation if the victim is unable to clear his airway secretions. Therapy includes the parasympathetic-receptor antagonist atropine and pralidoxime, which reactivates the enzyme cholinesterase.

CLINICAL PRACTICUM 13.1

A 70-year-old World War II veteran comes to your office complaining that his left arm has been hurting for about 10 days, and his forearm and hand seem to be a bit weak. He can't recall injuring it, and it seems to be getting worse. You ask about his health in general and learn he has lost 15 pounds in the last year, and he has a long-standing cough that he can't seem to get rid of. You also learn he has smoked most of his life.

During the physical exam you confirm the muscle weakness in his arm. You also notice his left eyelid droops, and his left pupil is constricted. He tells you his eyelid just started doing that the other day.

You tell him you think you know what's causing the pain in his arm. He's surprised when you order a chest X-ray to confirm a problem that seems to be in his arm.



QUESTIONS:

1. Given this man's history, what is the most likely cause of the indicated lung density indicated with an arrow on the accompanying radiograph?
2. How can a lung lesion cause symptoms in the arm?
3. How do you explain the drooping eyelid and the constructed pupil? (Consider the autonomic activities of these structures.)

CHAPTER 13

Chapter Summary

Introduction to the Autonomic Nervous System (pp. 435–438)

1. The autonomic nervous system (ANS) is a functional division of the nervous system; it is composed of portions of the central nervous system (CNS) and portions of the peripheral nervous system (PNS).
2. Preganglionic autonomic neurons originate in the brain or spinal cord; postganglionic neurons originate in ganglia outside the CNS.
3. Smooth muscle, cardiac muscle, and glands receive autonomic innervation.
   (a) The involuntary effectors are somewhat independent of their innervation and become hypersensitive when their innervation is removed.
   (b) Myocardial cells are interconnected by electrical synapses, or gap junctions, to form a functional syncytium with independent SA node activity.
   (c) Single-unit smooth muscles are characterized by gap junctions and SA node activity; multiunit smooth muscles have few, if any, gap junctions, and thus their individual cells must be stimulated separately by neurons.

Structure of the Autonomic Nervous System (pp. 438–443)

1. Preganglionic neurons of the sympathetic (thoracolumbar) division originate in the spinal cord (T1–L2).
   (a) Many of these neurons synapse with postganglionic neurons, whose cell bodies are located in a trunk of sympathetic ganglia outside the spinal cord.
   (b) Some preganglionic neurons synapse in peripheral ganglia; included in these are the celiac, superior mesenteric, and the inferior mesenteric ganglia.

(c) Some preganglionic neurons innervate the adrenal medulla, which secretes epinephrine (and some norepinephrine) into the blood in response to this stimulation.

2. Preganglionic parasympathetic neurons originate in the brain and in the sacral levels of the spinal cord.
   (a) Preganglionic parasympathetic neurons contribute to the oculomotor, facial, glossopharyngeal, and vagus nerves.
   (b) Preganglionic neurons of the vagus nerve are very long and synapse in terminal ganglia located next to or within the innervated organ; short postganglionic neurons then innervate the effector cells.
   (c) The vagus nerves provide parasympathetic innervation to the heart, lungs, esophagus, stomach, liver, small intestine, and upper half of the large intestine.
   (d) Parasympathetic outflow from the sacral levels of the spinal cord innervates terminal ganglia in the lower half of the large intestine, the rectum, and the urinary and reproductive systems.

Functions of the Autonomic Nervous System (pp. 444–448)

1. The effects of sympathetic and parasympathetic activity, together with those of hormones, help maintain homeostasis. The sympathetic division activates the body to "fight or flight" through adrenergic effects; the parasympathetic division conserves and restores the body's energy through cholinergic effects.
2. All preganglionic autonomic neurons are cholinergic (use acetylcholine as a neurotransmitter).
   (a) All postganglionic parasympathetic neurons are cholinergic.
   (b) Most postganglionic sympathetic neurons are adrenergic (use norepinephrine at their synapses).
   (c) Sympathetic neurons that innervate sweat glands and those that innervate blood vessels in skeletal muscles are cholinergic.
3. Adrenergic effects include stimulation of the heart, vasoconstriction in the viscera and skin, bronchodilation, and glycogenolysis in the liver.
4. Cholinergic effects of parasympathetic nerves are promoted by the drug muscarine and inhibited by atropine.
5. In organs with dual innervation, the effects of the sympathetic and parasympathetic divisions can be antagonistic, complementary, or cooperative.
   (a) The effects are antagonistic in the heart and pupils.
   (b) The effects are complementary in the regulation of salivary gland secretion; they are cooperative in the regulation of the reproductive and urinary systems.
6. In organs without dual innervation (such as most blood vessels), regulation is achieved by increases or decreases in sympathetic nerve activity.

Control of the Autonomic Nervous System by Higher Brain Centers (pp. 448–450)

1. Visceral sensory input to the brain may result in the activity of the descending pathways to the preganglionic autonomic neurons. The centers in the brain that control autonomic activity are influenced by higher brain areas, as well as by sensory input.
2. The medulla oblongata of the brain stem is the structure that most directly controls the activity of the ANS.
   (a) The medulla oblongata is in turn influenced by sensory input and by input from the hypothalamus.
   (b) The hypothalamus orchestrates somatic, autonomic, and endocrine responses during various behavioral states.
3. The activity of the hypothalamus is influenced by input from the limbic system, cerebellum, and cerebrum; these interconnections provide an autonomic component to changes in body position, emotion, and various expressions of personality.

CHAPTER 13

Review Activities

Objective Questions

1. Which of the following statements about the superior mesenteric ganglion is *true?*
   (a) It is a parasympathetic ganglion.
   (b) It is a paravertebral sympathetic ganglion.
   (c) It is located in the head.
   (d) It contains postganglionic sympathetic neurons.
2. The pterygopalatine, ciliary, submandibular, and otic ganglia are
   (a) collateral sympathetic ganglia.
   (b) cervical sympathetic ganglia.
   (c) parasympathetic ganglia that receive neurons from the vagus nerves.
   (d) parasympathetic ganglia that receive neurons from the third, seventh, and ninth cranial nerves.
3. Parasympathetic ganglia are located
   (a) in a trunk parallel to the spinal cord.
   (b) in the posterior roots of spinal nerves.
   (c) next to or within the organs innervated.
   (d) in the brain.
4. The neurotransmitter of preganglionic sympathetic neurons is
   (a) norepinephrine.
   (b) epinephrine.
   (c) acetylcholine.
   (d) dopamine.
5. The preganglionic neurons of the sympathetic division of the autonomic nervous system originate in
   (a) the midbrain and the medulla oblongata.
   (b) the entire spinal nerve complex.
   (c) the first cervical (C1) to the first lumbar (L1) vertebrae.
   (d) the first thoracic (T1) to the second lumbar (L2) vertebrae.
6. Which of the following neurons release norepinephrine?
   (a) preganglionic parasympathetic neurons
   (b) postganglionic parasympathetic neurons
   (c) postganglionic sympathetic neurons in the heart
   (d) postganglionic parasympathetic neurons in sweat glands
   (e) all of the above

7. The actions of sympathetic and parasympathetic neurons are cooperative in
   (a) the heart.
   (b) the reproductive system.
   (c) the digestive system.
   (d) the eyes.
8. Which of the following is *not* a result of parasympathetic nerve stimulation?
   (a) increased movement of the GI tract
   (b) increased mucus secretion
   (c) constriction of the pupils
   (d) constriction of visceral blood vessels
9. Atropine blocks parasympathetic nerve effects. It would therefore result in
   (a) dilation of the pupils.
   (b) a decrease in mucus secretion.
   (c) a decrease in GI tract movement.
   (d) an increase in heart rate.
   (e) all of the above.
10. The area of the brain that is most directly involved in the reflex control of the autonomic system is
    (a) the hypothalamus.
    (b) the cerebral cortex.
    (c) the medulla oblongata.
    (d) the cerebellum.

Essay Questions

1. Compare the sympathetic and parasympathetic divisions in terms of ganglia location and nerve distribution.
2. Explain the structural and functional relationship between the sympathetic division of the ANS and the adrenal glands.
3. Compare the effects of adrenergic and cholinergic stimulation on the cardiovascular and digestive systems.
4. Explain how effectors that receive only sympathetic innervation are regulated by the ANS.
5. Explain why a person may sweat more profusely immediately after exercise than during exercise.

Critical-Thinking Questions

1. Shock is the medical condition that occurs when body tissues do not receive enough oxygen-carrying blood. It is characterized by low blood flow to the brain, leading to decreased levels of consciousness. Why would a patient with a cervical spinal cord injury be at risk of going into shock?
2. Imagine yourself at the starting block of the 100–meter dash of the Olympics. The gun is about to go off in the biggest race of your life. What is your autonomic nervous system doing at this point? How are your organs reacting?
3. Suppose you lift the wrist of a man who has fainted to feel for a pulse. How does his skin feel? How would you characterize his pulse? What specific role would the autonomic nervous system have in producing these effects?
4. Why would someone be given a prescription for atropine if they had gastritis? Why would the person's mouth feel dry after taking this drug?
5. Most agents used in chemical warfare affect the autonomic nervous system. Nerve gas, for example, stimulates activity of the parasympathetic division of the ANS to such an extent that it causes rapid death. Based on your knowledge of the autonomic nervous system, can you predict the type of symptoms a nerve-gas victim might suffer?
6. Give evidence for the argument that the autonomic nervous system is somewhat misnamed.

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