

The Autonomic Nervous System and Visceral Sensory Neurons

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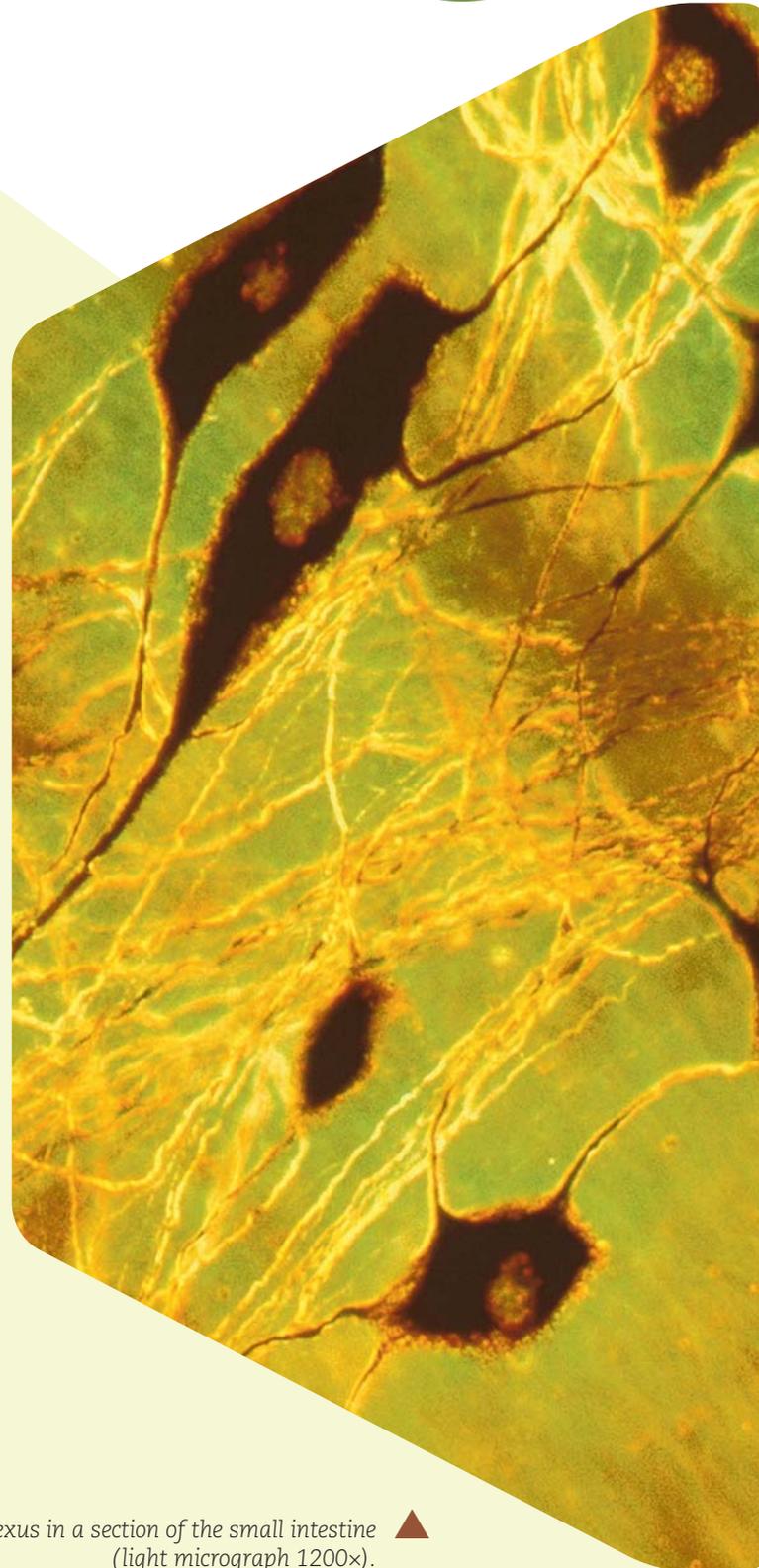
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Neurons of the myenteric plexus in a section of the small intestine (light micrograph 1200 \times). ▲

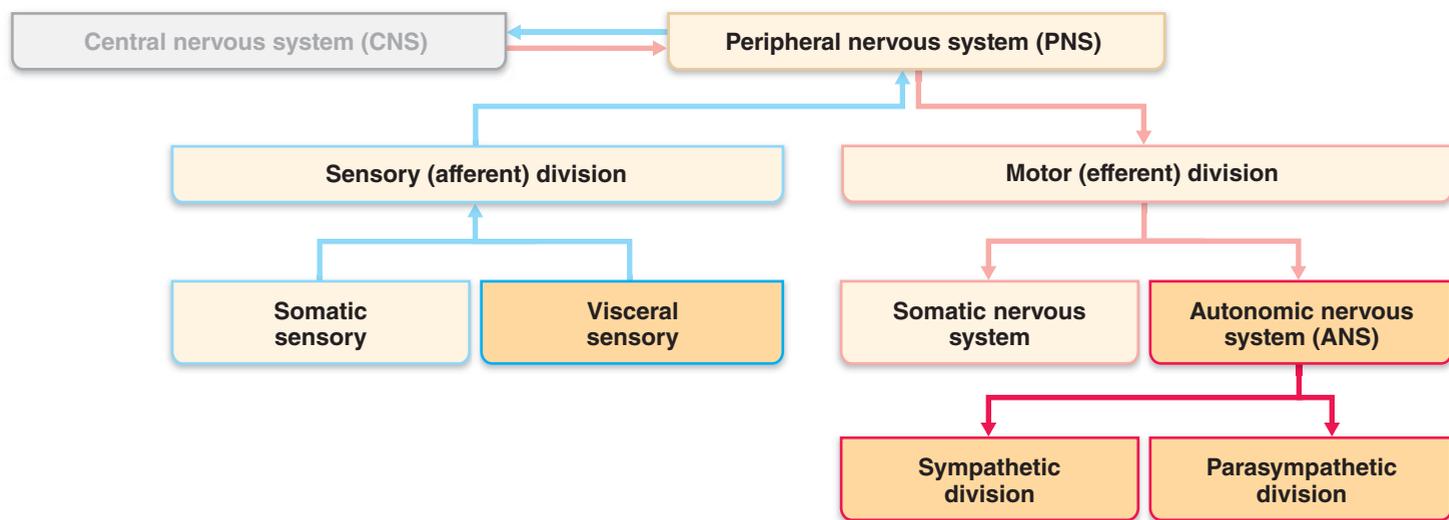


Figure 15.1 Place of the autonomic nervous system (ANS) and visceral sensory components in the structural organization of the nervous system.

Consider the following situations: You wake up at night after having eaten at a restaurant where the food did not taste quite right, and you find yourself waiting helplessly for your stomach to “decide” whether it can hold the food down. A few days later, you are driving to school after drinking too much coffee and wish in vain that your full bladder would stop its uncomfortable contractions. Later that day, your professor asks you a hard question in front of the class, and you try not to let them see you sweat—but the sweat runs down your face anyway. All of these are examples of visceral motor functions that are not easily controlled by the conscious will and that sometimes seem to “have a mind of their own.” These functions are performed by the **autonomic nervous system (ANS)**, a motor system that does indeed operate with a certain amount of independence (*autonomic* = self-governing).

OVERVIEW OF THE AUTONOMIC NERVOUS SYSTEM

learning outcomes

- ▶ Define the autonomic nervous system (ANS), and explain its relationship to the peripheral nervous system as a whole.
- ▶ Compare autonomic neurons to somatic motor neurons.
- ▶ Describe the basic differences between the parasympathetic and sympathetic divisions of the ANS.

The ANS is the system of motor neurons that innervate the smooth muscle, cardiac muscle, and glands of the body. By controlling these effectors, the ANS regulates such visceral functions as heart rate, blood pressure, digestion, and urination, which are essential for maintaining the stability of the body’s internal environment. The ANS is the *general visceral motor* division of the peripheral nervous system and is distinct from the *general somatic motor division*, which innervates the skeletal muscles (Figure 15.1).

Although this chapter focuses on autonomic (general visceral motor) functions, it also considers the **general visceral senses**.

The general visceral sensory system continuously monitors the activities of the visceral organs so that the autonomic motor neurons can make adjustments as necessary to ensure optimal performance of visceral functions.

A third component of visceral innervation, the *enteric nervous system*, also innervates smooth muscle and glands, specifically those within the digestive tract. The enteric nervous system regulates the activity of the digestive tract and functions completely independently of the CNS. Autonomic neurons to the digestive tract can influence enteric neurons by either stimulating or inhibiting their activity. This ANS influence acts as a “volume control” rather than as an “on/off” switch. The details of the enteric nervous system and its interaction with the ANS are described with the innervation of the digestive system (Chapter 23).

Before describing the ANS, we need to review two terms. A *synapse* is a junction between two neurons that communicates the message from one neuron, called the *presynaptic neuron*, to another neuron, the *postsynaptic neuron*. A *ganglion* (plural: *ganglia*) is a cluster of neuronal cell bodies in the PNS. (See Chapter 12 for review of these terms.)

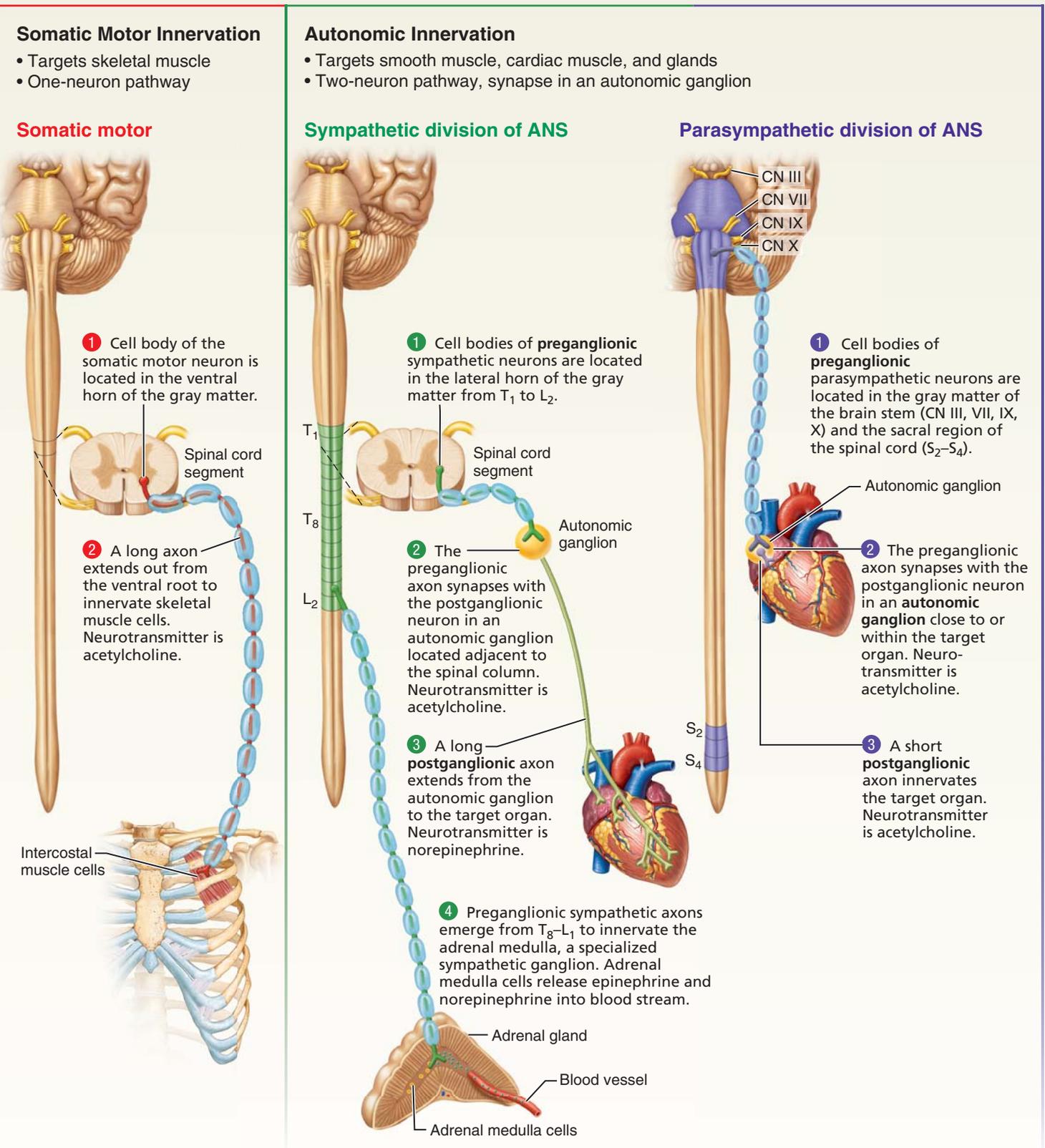
Comparison of the Autonomic and Somatic Motor Systems

Other discussions of motor innervation focus largely on the *somatic* motor system, which innervates skeletal muscles. Each somatic motor neuron runs from the central nervous system all the way to the muscle being innervated, and each motor unit consists of a single neuron plus the skeletal muscle cells that it innervates (Figure 15.2). Typical somatic motor axons are thick, heavily myelinated fibers that conduct nerve impulses rapidly.

By contrast, the comparable motor unit in the ANS includes a chain of *two* motor neurons (Figure 15.2). The first of these is called a **preganglionic neuron**. The cell body of this neuron lies within the CNS. Its axon, the **preganglionic axon** (also called a *preganglionic fiber*), synapses with the second motor neuron, the **postganglionic neuron**, in a peripheral **autonomic ganglion**. The **postganglionic axon**

Figure 15.2

Somatic motor and autonomic innervations differ anatomically in two major ways: (1) the target organs innervated and (2) the number of neurons in the pathway.



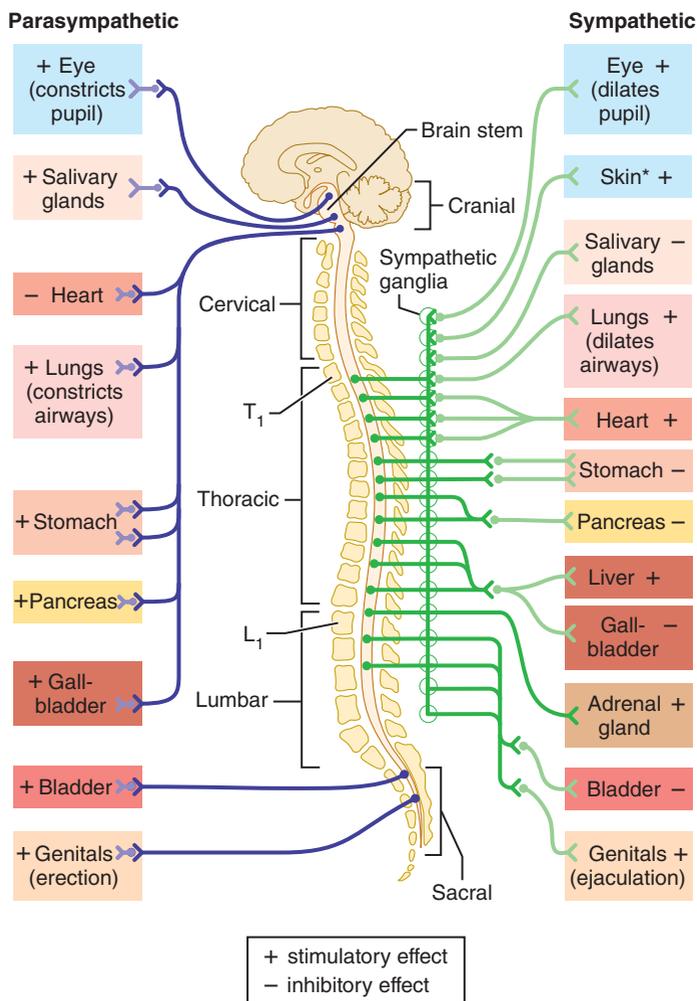


Figure 15.3 Overview of the subdivisions of the ANS. The parasympathetic and sympathetic divisions differ anatomically in (1) the sites of origin of their nerves, (2) the relative lengths of their preganglionic and postganglionic fibers, and (3) the location of their ganglia (indicated here by synapse sites).

*Although sympathetic innervation to the skin and peripheral structures is mapped to the cervical area in this diagram, all nerves to the periphery carry postganglionic sympathetic fibers.

(or *postganglionic fiber*) then extends to the visceral organs. Functionally, the preganglionic neuron signals the postganglionic neuron; the postganglionic neuron then stimulates muscle contraction or gland secretion in the effector organ. Axons of preganglionic neurons are thin, lightly myelinated fibers, whereas axons of postganglionic neurons are even thinner and are unmyelinated. Consequently, impulses are conducted through the autonomic nervous system more slowly than through the somatic motor system. It is important to emphasize that the autonomic ganglia are *motor* ganglia containing the cell bodies of motor neurons, in contrast to the dorsal root ganglia, which are *sensory* ganglia.

Divisions of the Autonomic Nervous System

The ANS has two divisions, the *sympathetic* and *parasympathetic* (par"ah-sim"pah-thet'ik) *divisions*, (Figure 15.2).

Both divisions have chains of two motor neurons that mostly innervate the same visceral organs, but they cause opposite effects: One division stimulates some smooth muscle to contract or a gland to secrete; the other division inhibits that action. The sympathetic division mobilizes the body during extreme situations such as fear, exercise, or rage. The parasympathetic division enables the body to unwind and relax and works to conserve body energy. In other words, the parasympathetic division controls routine maintenance functions, and the sympathetic division becomes active when extra metabolic effort is needed. The balance between the two divisions keeps body systems running smoothly.

The **sympathetic division** is responsible for the fight-or-flight response. Its activity is evident during vigorous exercise, excitement, or emergencies. A pounding heart, dilated (widened) eye pupils, and cold, sweaty skin are signs that the sympathetic division has been mobilized (Figure 15.3, right side). All of them help us respond to dangerous situations: The increased heart rate delivers more blood and oxygen to the skeletal muscles used for fighting or running; widened pupils let in more light for clearer vision; and cold skin indicates that blood is being diverted from the skin to more vital organs, such as the brain. Additionally, the small air tubes in the lungs (bronchioles) dilate, increasing the uptake of oxygen; oxygen consumption by the body's cells increases; and the liver releases more sugar into the blood to provide for the increased energy needs of the cells. In this way, the body's "motors are revved up" for vigorous activity. Temporarily nonessential functions, such as digestion and motility of the urinary tract, are inhibited: When you are running to catch the last bus home, digesting lunch can wait.

The sympathetic division also innervates the smooth muscle in the walls of blood vessels. Sympathetic input to the blood vessels servicing skeletal muscles rises, causing the smooth muscle of the vessels to relax. These vessels dilate, bringing more blood to the active muscles. At the same time, increased sympathetic input to the smooth muscle in other blood vessels stimulates contraction, producing **vasoconstriction**. This narrowing of vessel diameter forces the heart to work harder to pump blood around the vascular circuit. As a result, sympathetic activity causes blood pressure to rise during excitement and stress.

Unlike the sympathetic division, the **parasympathetic division** is most active when the body is at rest. This division is concerned with conserving body energy and directing vital "housekeeping" activities such as digestion and the elimination of feces and urine (Figure 15.3, left side). The buzzwords to remember are "rest and digest." Parasympathetic function is best illustrated by a person who is relaxing after dinner and reading the newspaper. Heart rate and respiratory rates are at low-normal levels, and the gastrointestinal tract is digesting food. The pupils are constricted as the eyes focus for close vision.

As you explore the sympathetic and parasympathetic divisions in detail, you will find their effects on individual visceral organs are easy to learn if you just remember fight-or-flight (sympathetic) versus rest-and-digest (parasympathetic). Furthermore, a dynamic counteraction exists between the two divisions, such that they balance each other during times when a person is neither highly excited nor completely at rest.

Table 15.1

Anatomical and Physiological Differences Between the Parasympathetic and Sympathetic Divisions

Characteristic	Sympathetic	Parasympathetic
Origin	Thoracolumbar outflow; lateral horn of gray matter of spinal cord segments T ₁ –L ₂	Craniosacral outflow: brain stem nuclei of cranial nerves III, VII, IX, and X; spinal cord segments S ₂ –S ₄
Location of ganglia	Ganglia close to CNS: alongside vertebral column (sympathetic trunk ganglia) and anterior to vertebral column (collateral ganglia)	Ganglia in or close to visceral organ served
Relative length of pre- and postganglionic axons	Short preganglionic (splanchnic nerves are exceptions); long postganglionic	Long preganglionic; short postganglionic
Rami communicantes (see p. 476)	Gray and white rami communicantes; white contain myelinated preganglionic axons; gray contain unmyelinated postganglionic axons	None
Degree of branching of preganglionic axons	Extensive	Minimal
Functional role	Prepares body to cope with emergencies and intense muscular activity; fight-or-flight response	Maintenance functions; conserves and stores energy; rest and digest response
Neurotransmitters	All preganglionic axons release ACh; most postganglionic axons release norepinephrine (adrenergic axons); postganglionic axons to sweat glands and blood vessels of skeletal muscles release ACh; neurotransmitter activity augmented by release of adrenal medullary hormones (epinephrine and norepinephrine)	All axons, preganglionic and postganglionic, release ACh (cholinergic axons)



CLINICAL APPLICATION

Autonomic Neuropathy Damage to the autonomic nerves, which may occur as a complication of diabetes, is called **autonomic neuropathy**. Damage to these nerves results in the inability to control heart rate, blood pressure, and blood sugar levels. Digestion and respiratory functions, urination, sexual response, and vision are also affected. This insidious condition may go untreated because its symptoms are widespread and commonly associated with other conditions. It can be detected via a noninvasive heart rate variability test (HRV).

In addition to these functional differences, there are anatomical and biochemical differences between the sympathetic and parasympathetic divisions (**Table 15.1**).

1. The two divisions originate from different regions of the CNS (Figure 15.2 and Figure 15.3). The sympathetic division can also be called the **thoracolumbar division** because its fibers emerge from the thoracic and superior lumbar parts of the spinal cord. The parasympathetic division can also be termed the **craniosacral division** because its fibers emerge from the brain (*cranial part*) and the sacral spinal cord (*sacral part*).
2. The sympathetic pathways have long postganglionic axons, whereas the postganglionic axons for parasympathetic pathways are comparatively short (Figure 15.2 and

Figure 15.3). All sympathetic ganglia lie near the spinal cord and vertebral column; postganglionic axons extend from these ganglia and travel to their target organs. Parasympathetic ganglia lie far from the CNS, in or near the organs innervated; therefore, the postganglionic axons are quite short.

3. Sympathetic fibers branch profusely, whereas parasympathetic fibers do not. Such extensive branching allows each sympathetic neuron to influence a number of different visceral organs, enabling many organs to mobilize simultaneously during the fight-or-flight response. Indeed, the literal translation of *sympathetic*, “experienced together,” reflects the bodywide mobilization it produces. Parasympathetic effects, by contrast, are more localized and discrete.
4. The main biochemical difference between the two divisions of the ANS involves the neurotransmitter released by the *postganglionic* axons (Figure 15.2). In the sympathetic division, most postganglionic axons release *norepinephrine* (also called *noradrenaline*); these fibers are termed *adrenergic*.^{*} The postganglionic neurotransmitter in the parasympathetic division is *acetylcholine* (*ACh*); these fibers are termed *cholinergic*. The *preganglionic* axon terminals of both divisions are always cholinergic (release ACh).

^{*}Not all postganglionic fibers in the sympathetic division are adrenergic: Those that innervate the sweat glands and blood vessels in skeletal muscle are cholinergic.

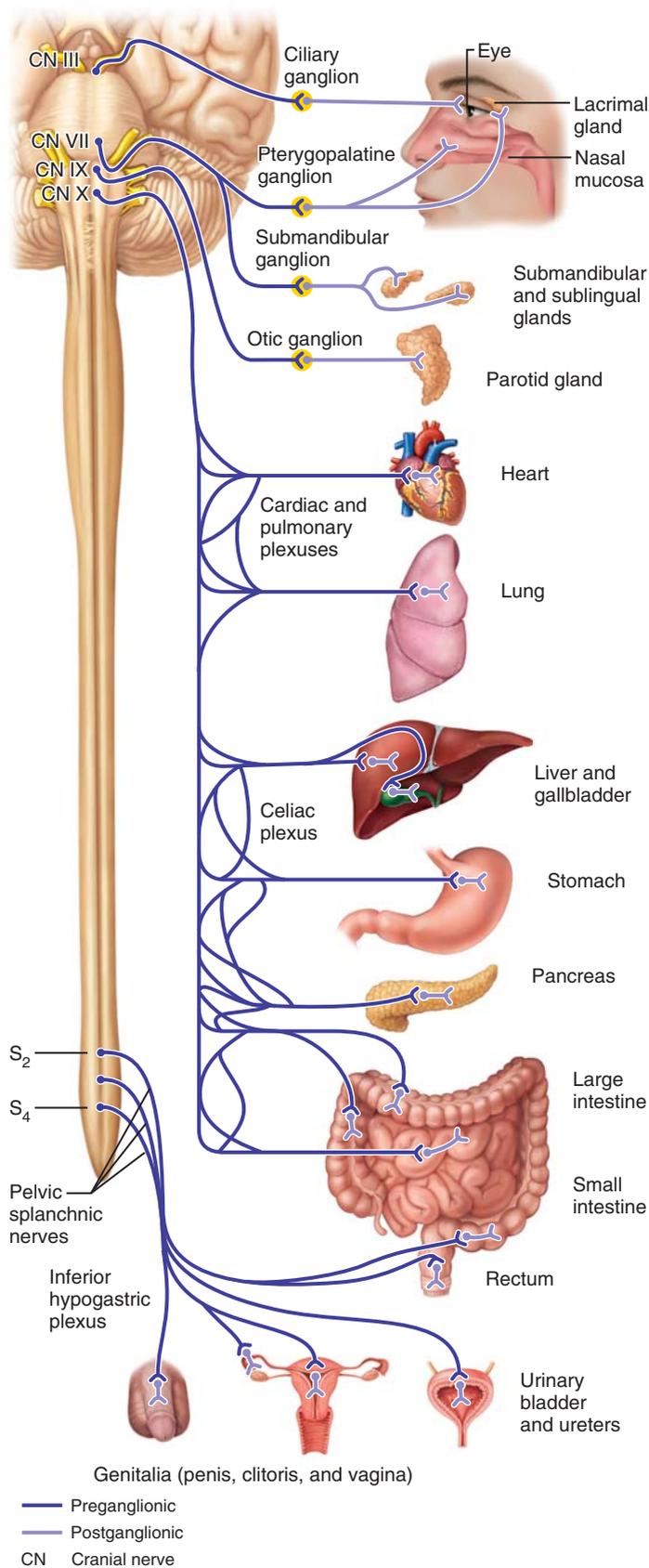


Figure 15.4 Parasympathetic division of the ANS.

The next sections give a more detailed discussion of the anatomical organization of each division.

✓ check your understanding

- 1. Which fibers in the motor division of the PNS are not myelinated?
- 2. As you are driving home from school, a car suddenly swerves toward you, forcing you to hit the brakes quickly. You feel your heart pump, and you begin to sweat a bit. Which division of the ANS has been activated?
- 3. Where are the sympathetic ganglia located? Where are most parasympathetic ganglia located?
- 4. Are visceral sensory fibers considered part of the ANS?

(For answers, see Appendix B.)

THE PARASYMPATHETIC DIVISION

learning outcomes

- ▶ Describe the pathway of parasympathetic innervation through cranial nerves and sacral spinal nerves to the visceral organs.
- ▶ Describe the effect of parasympathetic innervation on each visceral organ innervated by this division of the ANS.

The *cranial outflow* of the parasympathetic division originates from the brain and innervates organs in the head, neck, thorax, and most of the abdomen, whereas the *sacral outflow* originates from the sacral spinal cord (S_2 , S_3 , S_4) and supplies the distal portions of the digestive tract and the pelvic organs (**Figure 15.4**).

Cranial Outflow

The preganglionic axons run in the oculomotor (III), facial (VII), glossopharyngeal (IX), and vagus (X) nerves (top of **Figure 15.4**). The cell bodies of these preganglionic neurons are located in motor cranial nerve nuclei in the gray matter of the brain stem.

Oculomotor Nerve (III)

The parasympathetic fibers, the visceral motor component (VM), of the oculomotor nerve innervate smooth muscles in the eye that cause the pupil to constrict and the lens of the eye to bulge—actions that allow focusing on close objects in the field of vision. In this two-neuron pathway, the preganglionic axons in the oculomotor nerve originate from cell bodies in the *accessory oculomotor nucleus* in the midbrain (**Figure 13.7a**, p. 382); the postganglionic cell bodies lie in the **ciliary ganglion**, in the posterior part of the orbit just lateral to the optic nerve (see **Table 14.2**, p. 436).

Facial Nerve (VII)

The parasympathetic fibers (VM) of the facial nerve stimulate the secretion of many glands in the head, including the lacrimal (tear) gland above the eye; mucus-secreting glands in the nasal cavity; and two salivary glands inferior to the mouth

(the submandibular and sublingual glands). In the pathway leading to the lacrimal and nasal glands, the preganglionic neurons originate in the *lacrimal nucleus* in the pons and synapse with postganglionic neurons in the **pterygopalatine ganglion**, just posterior to the maxilla (Table 14.2, p. 439). In the pathway leading to the submandibular and sublingual glands, the preganglionic neurons originate in the *superior salivatory nucleus* in the pons and synapse with postganglionic neurons in the **submandibular ganglion**, deep to the mandibular angle.

Glossopharyngeal Nerve (IX)

The parasympathetic fibers (VM) of the glossopharyngeal nerve stimulate secretion of a large salivary gland, the parotid gland, which lies anterior to the ear. The preganglionic neurons originate in the *inferior salivatory nucleus* in the medulla and synapse with postganglionic neurons in the **otic ganglion** inferior to the foramen ovale of the skull (Table 14.2, p. 441).

The three cranial nerves considered so far (III, VII, IX) supply the entire parasympathetic innervation of the head. Note, however, that only the *preganglionic* axons run within these three nerves. These axons synapse in the ganglia described above, which are located along the path of the trigeminal nerve (V), and then the postganglionic axons travel via the trigeminal to their final destinations. This routing by way of the trigeminal nerve occurs because the trigeminal has the widest distribution within the face.

Vagus Nerve (X)

Parasympathetic fibers (VM) from the vagus innervate the visceral organs of the thorax and most of the abdomen (Figure 15.4). Note that this does not include innervation of the pelvic organs and that the vagal innervation of the digestive tube ends halfway along the large intestine. The vagus is an extremely important part of the ANS, containing nearly 90% of the preganglionic parasympathetic fibers in the body. Functionally, the parasympathetic fibers in the vagus nerve bring about typical rest-and-digest activities in visceral muscle and glands—stimulation of digestion (secretion of digestive glands and increased motility of the smooth muscle of the digestive tract), reduction in the heart rate, and constriction of the bronchi in the lungs, for example.

The preganglionic cell bodies are mostly in the *dorsal motor nucleus of vagus* in the medulla (see Fig. 13.7c, p. 382), and the preganglionic axons run through the entire length of the vagus nerve. Most postganglionic neurons are confined within the walls of the organs being innervated, and their cell bodies form *intramural ganglia* (in"trah-mu'ral; "within the walls").

The vagus nerve is essential to the functioning of many organs. As the vagus descends through the neck and trunk, it sends branches through many *autonomic nerve plexuses* to the organs being innervated (Figure 15.5). (Recall from Chapter 14 that a nerve plexus is a network of nerves.) Specifically, the vagus sends branches through the **cardiac plexus** to the heart, through the **pulmonary plexus** to the lungs, through the **esophageal plexus** to the esophagus and into the stomach wall, and through the **celiac plexus** and the

superior mesenteric plexus to the other abdominal organs (intestines, liver, pancreas, and so on). Fibers from both divisions of the ANS, parasympathetic and sympathetic, travel to the thoracic and abdominal organs through these plexuses.

Sacral Outflow

The sacral part of the parasympathetic outflow emerges from segments S₂–S₄ of the spinal cord (bottom part of Figure 15.4). Continuing where the vagus ends, it innervates the organs in the pelvis, including the distal half of the large intestine, the bladder, and reproductive organs such as the uterus, and the erectile tissues of the external genitalia. Parasympathetic effects on these organs include stimulation of defecation, voiding of urine, and erection.

The preganglionic cell bodies of the sacral parasympathetics lie in the visceral motor region of the spinal gray matter (Figure 13.27, p. 412). The axons of these preganglionic neurons run in the ventral roots to the ventral rami, from which they branch to form **pelvic splanchnic nerves** (see Figure 15.4). These nerves then run through an autonomic plexus in the pelvic floor, the **inferior hypogastric plexus** (or *pelvic plexus*; Figure 15.5) to reach the pelvic organs. Some preganglionic axons synapse in ganglia in this plexus, but most synapse in intramural ganglia in the organs. This plexus also contains fibers from both divisions of the ANS.

The specific effects of parasympathetic innervation on various organs are presented in comparison with the effects of sympathetic innervation (Table 15.2, p. 475).

check your understanding

- 5. Which spinal nerves carry parasympathetic preganglionic fibers?
- 6. What is the result of vagal stimulation of (a) the heart, (b) the small intestine, (c) the salivary glands?
- 7. Cranial nerves III, VII, and IX carry preganglionic parasympathetic fibers. Which cranial nerve carries the postganglionic fibers to the target organs innervated by these three nerves?

(For answers, see Appendix B.)

THE SYMPATHETIC DIVISION

learning outcomes

- ▶ Describe the pathways of sympathetic innervation from the spinal cord to the effector organs in the body periphery, the head, and the visceral organs.
- ▶ Describe the effect of sympathetic innervation on each effector organ.
- ▶ Explain the sympathetic function of the adrenal medulla.

Basic Organization

The sympathetic division exits from the thoracic and superior lumbar part of the spinal cord, from segments T₁ to L₂ (Figure 15.3). Its preganglionic cell bodies lie in the visceral motor region of the spinal gray matter, where they form the lateral gray horn (Figure 13.27, p. 412).

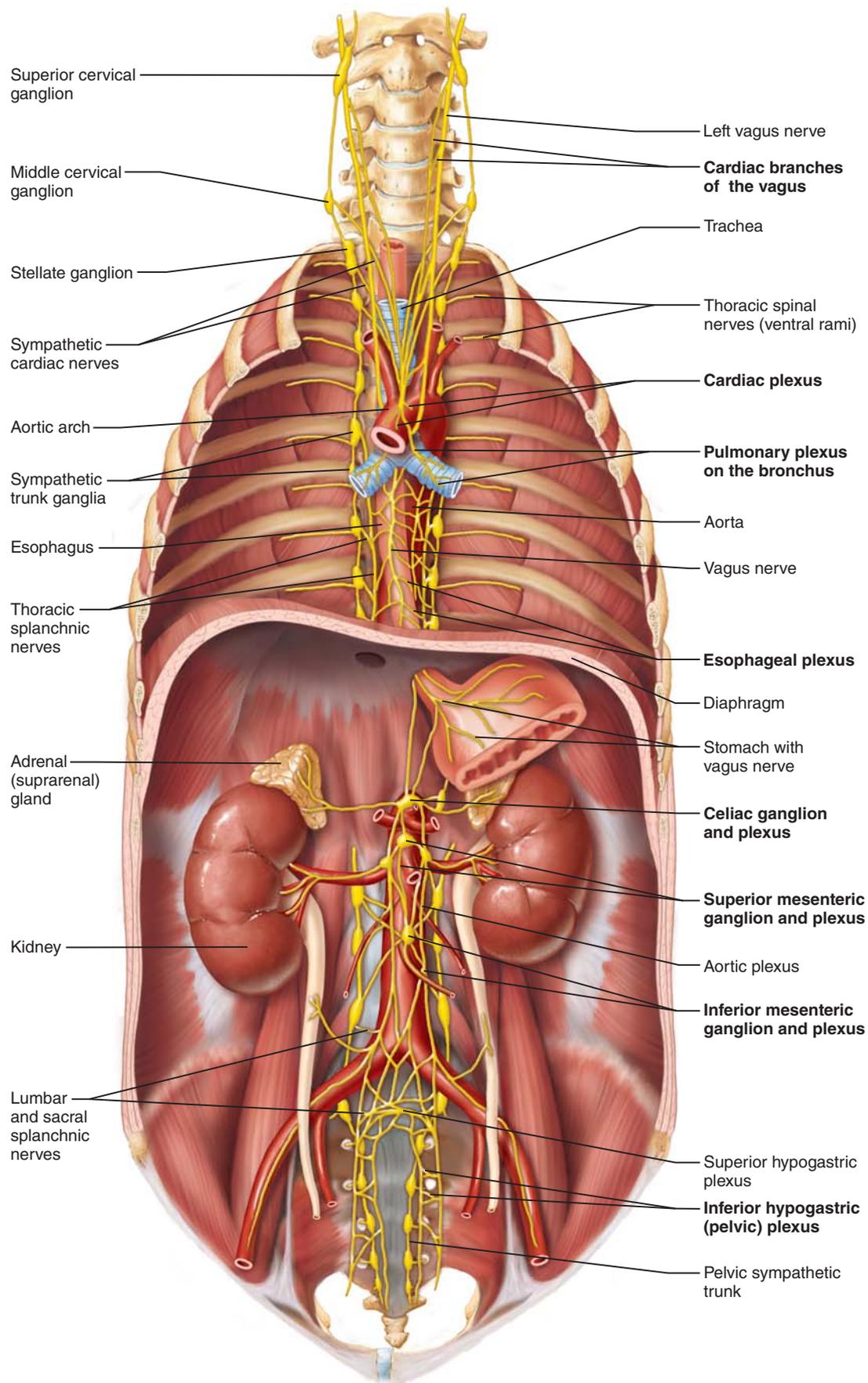


Figure 15.5 Autonomic nerves, plexuses, and ganglia. All autonomic plexuses contain both parasympathetic and sympathetic axons. The ganglia are almost exclusively sympathetic.

Table 15.2

Effects of the Parasympathetic and Sympathetic Divisions on Various Organs

Target Organ/System/Activity	Parasympathetic Effects	Sympathetic Effects
Eye (iris)	Stimulates constrictor muscles; constricts eye pupils	Stimulates dilator muscles, dilates eye pupils
Eye (ciliary muscle)	Stimulates ciliary muscles, which results in bulging of the lens for accommodation and close vision	Weakly inhibits ciliary muscles, which flatten the lens for distance vision
Glands (nasal, lacrimal, salivary, gastric, pancreas)	Stimulates secretory activity	Inhibits secretory activity; causes vasoconstriction of blood vessels supplying the glands
Sweat glands	No innervation	Stimulates copious sweating (cholinergic fibers)
Arrector pili muscles attached to hair follicles	No innervation	Stimulates to contract (erects hairs and produces goose bumps)
Heart muscle	Decreases rate; slows and steadies heart	Increases rate and force of heartbeat
Heart: coronary blood vessels	Causes vasoconstriction	Causes vasodilation
Lungs	Constricts bronchioles	Dilates bronchioles and mildly constricts blood vessels
Digestive tract organs	Increases motility (peristalsis) and amount of secretion by digestive organs; relaxes sphincters to allow movement of foodstuffs along tract	Decreases activity of glands and muscles of digestive system and constricts sphincters (e.g., anal sphincter); causes vasoconstriction
Liver	No effect	Epinephrine stimulates liver to release glucose to blood
Gallbladder	Stimulates activity (gallbladder contracts to expel bile)	Inhibits activity (gallbladder is relaxed)
Adrenal medulla	No innervation	Stimulates medulla cells to secrete epinephrine and norepinephrine into bloodstream
Kidney	No effect	Causes vasoconstriction; decreases urine output
Bladder, urethra	Causes contraction of smooth muscle of bladder wall; relaxes urethral sphincter; promotes voiding	Causes relaxation of smooth muscle of bladder wall; constricts urethral sphincter; inhibits voiding
Penis	Causes erection (vasodilation)	Causes ejaculation
Uterus	Inhibits contraction of smooth muscle of uterine wall; causes vasodilation of vessels	Stimulates contraction of smooth muscle of uterine wall; causes vasoconstriction of vessels
Vagina, clitoris	Causes erection (vasodilation) of clitoris	Causes contraction of vagina
Blood vessels	Little or no effect	Constricts most vessels and increases blood pressure; constricts vessels of abdominal viscera and skin to divert blood to muscles, brain, and heart when necessary; dilates vessels of the skeletal muscles (cholinergic fibers) during exercise
Blood coagulation	No innervation	Increases coagulation
Cellular metabolism	No innervation	Increases metabolic rate
Adipose tissue	No innervation	Stimulates lipolysis (fat breakdown)
Mental activity	No innervation	Increases alertness

The sympathetic division is more complex than the parasympathetic, in part because it innervates more organs. It supplies not only all the visceral organs in the internal body cavities but also all visceral structures in the superficial regions of the body: the sweat glands, the hair-raising arrector pili muscles of the skin, and the smooth musculature in

the walls of all arteries and veins. It is easy to remember that the sympathetic system alone innervates these structures: You know that you sweat when under stress, your hair stands up when you are terrified, and your blood pressure skyrockets (because of widespread vasoconstriction) when you get excited. The *parasympathetic* division does *not* innervate

sweat glands, arrector pili, or (with minor exceptions) blood vessels.

Another reason the sympathetic division is more complex is that it has more ganglia. The sympathetic ganglia fall into two classes: (1) *sympathetic trunk ganglia* and (2) *collateral ganglia*.

Sympathetic Trunk Ganglia

The numerous **sympathetic trunk ganglia**, located along both sides of the vertebral column from the neck to the pelvis, are linked by short nerves into long **sympathetic trunks** (*sympathetic chains*) that resemble strings of beads (Figure 15.6). The sympathetic trunk ganglia are also called *chain ganglia* and *paravertebral* (“near the vertebrae”) *ganglia*. These ganglia are joined to the ventral rami of nearby spinal nerves by **white** and **gray rami communicantes** (singular: **ramus communicans**, “communicating arm”). White rami communicantes lie lateral to gray rami communicantes.

There is approximately one sympathetic trunk ganglion for each spinal nerve. However, the number of sympathetic trunk ganglia and spinal nerves is not identical, because some adjacent ganglia fuse during development. Such fusion is most evident in the neck region, where there are eight spinal nerves but only three sympathetic trunk ganglia: the **superior**, **middle**, and **inferior cervical ganglia** (Figure 15.5). Furthermore, the inferior cervical ganglion usually fuses with the first thoracic ganglion to form the

stellate (“star-shaped”) **ganglion** in the superior thorax (Figure 15.5).

Overall, there are 22–24 sympathetic trunk ganglia per side, and a typical person may have 3 cervical, 11 thoracic, 4 lumbar, 4 sacral, and 1 coccygeal ganglia (Figure 15.5). The cervical ganglia lie just anterior to the transverse processes of the cervical vertebrae; the thoracic ganglia lie on the heads of the ribs; the lumbar ganglia lie on the anterolateral sides of the vertebral bodies; the sacral ganglia lie medial to the sacral foramina; and the coccygeal ganglion is anterior to the coccyx.

Take care not to confuse the sympathetic trunk ganglia with the *dorsal root ganglia*. The dorsal root ganglia are sensory and lie along the dorsal roots of spinal nerves in the intervertebral foramina; the sympathetic trunk ganglia are motor and lie anterior to the ventral rami of spinal nerves.

Collateral Ganglia

The **collateral ganglia**, or *prevertebral ganglia*, differ from the sympathetic trunk ganglia in at least three ways: (1) They are not paired and are not segmentally arranged; (2) they occur only in the abdomen and pelvis; and (3) they all lie anterior to the vertebral column (hence the name *prevertebral*), mostly on the large artery called the abdominal aorta. The main collateral ganglia, the *celiac*, *superior mesenteric*, *inferior mesenteric*, and *inferior hypogastric ganglia* (Figure 15.5), lie within the autonomic nerve plexuses of the same names.

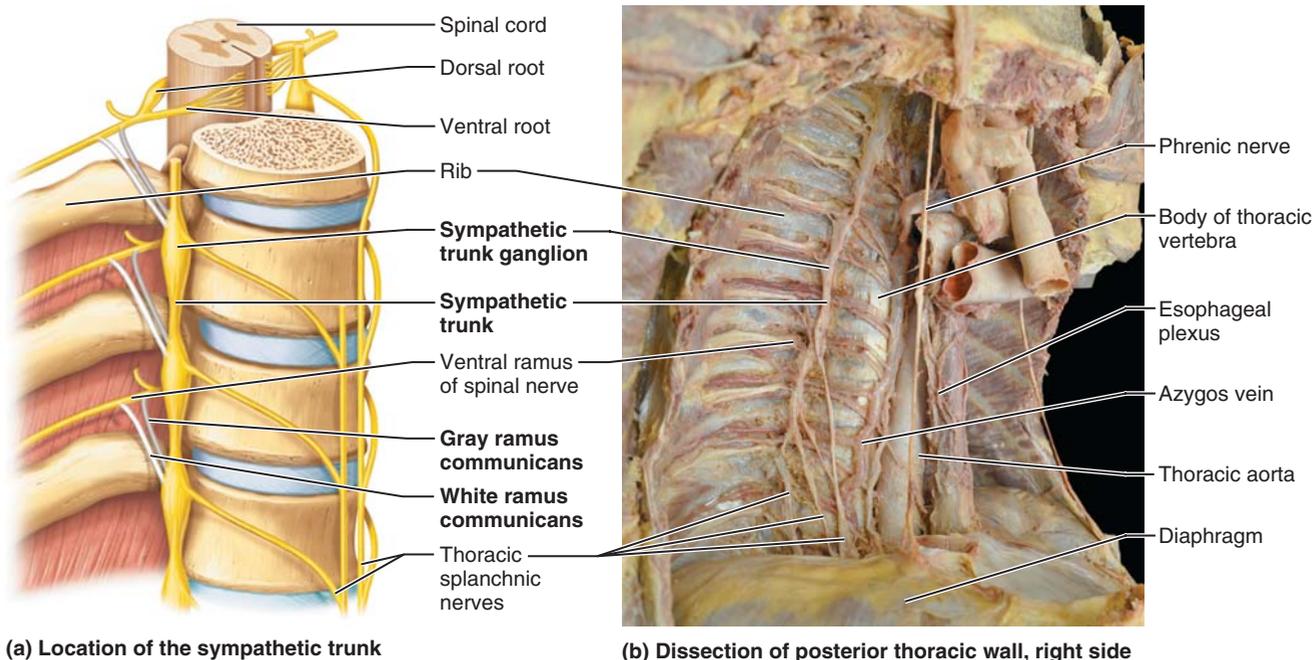


Figure 15.6 The sympathetic trunk, thoracic region.



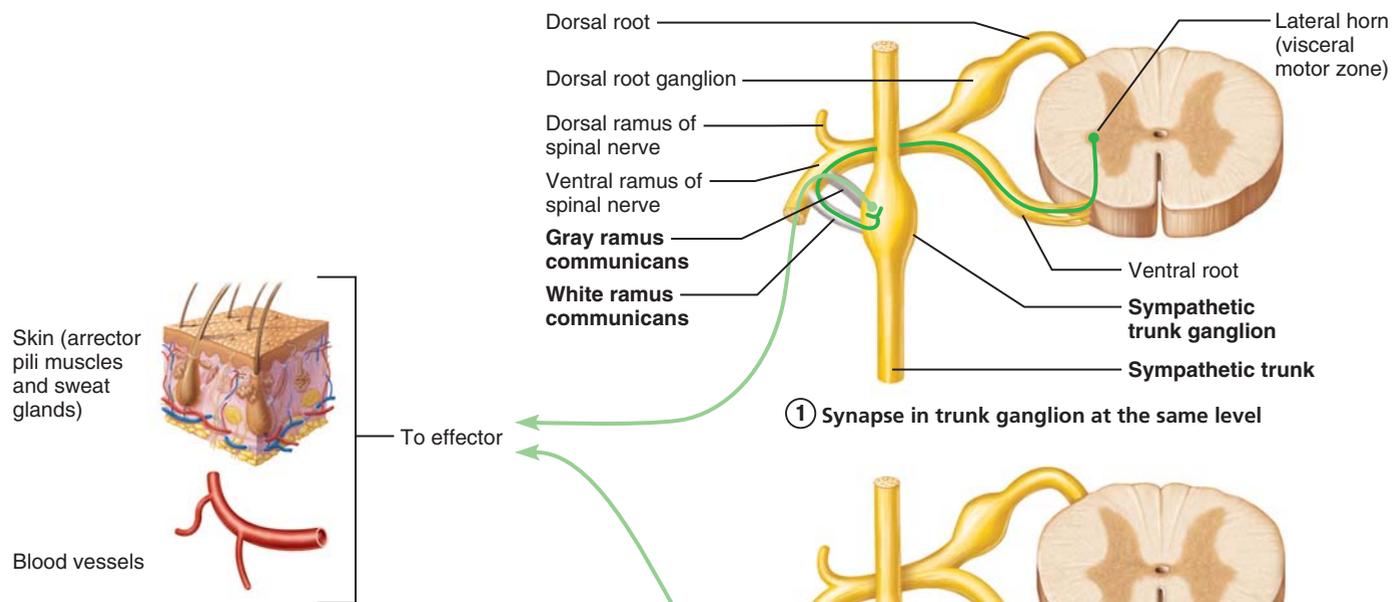


Figure 15.7 Three pathways of sympathetic innervation.

Sympathetic Pathways

In the sympathetic pathways to all body regions (**Figure 15.7**), preganglionic neurons in the thoracolumbar spinal cord send their motor axons through the adjacent ventral root into the spinal nerve, white ramus communicans, and associated sympathetic trunk ganglion. From there, these preganglionic axons follow one of three pathways:

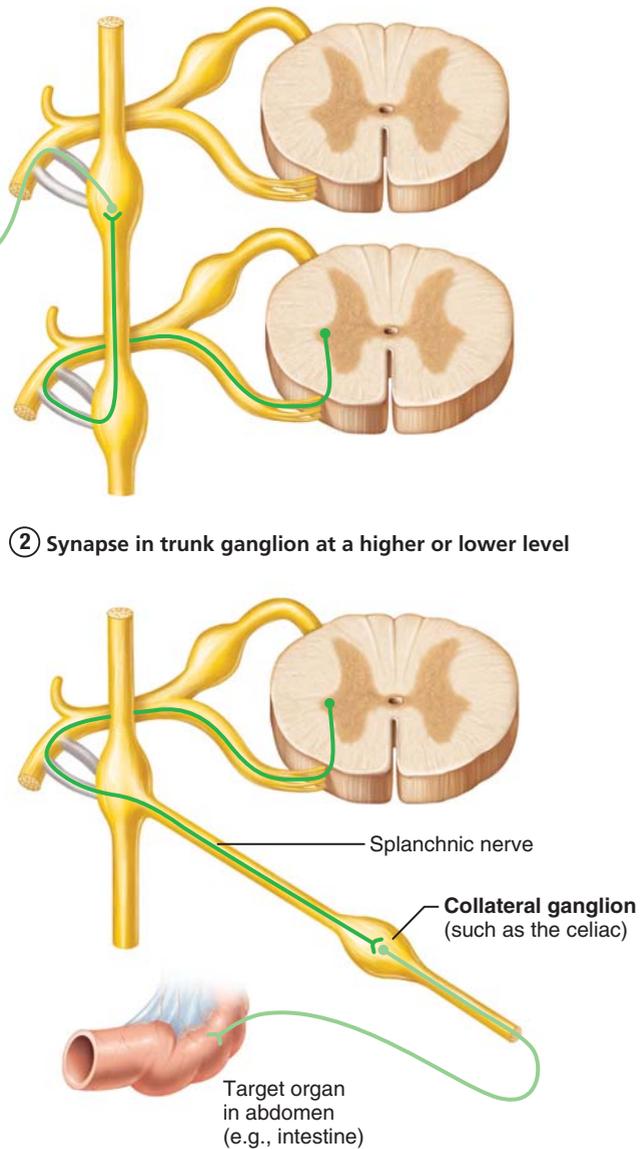
- ① The preganglionic axon synapses with a postganglionic neuron in the sympathetic trunk ganglion at the same level and exits via the gray ramus communicans into the spinal nerve at that level.
- ② The preganglionic axon ascends or descends in the sympathetic trunk to synapse in another trunk ganglion. The postganglionic fiber exits the sympathetic trunk via the gray ramus communicans at the level of the synapse.
- ③ The preganglionic axon passes through the sympathetic trunk, exits on a splanchnic nerve, and synapses in a collateral ganglion. The postsynaptic fiber extends from the collateral ganglion to the visceral organ via an autonomic nerve plexus.

Keep this overview in mind as you consider the pathways to the specific body regions in more detail.

① Synapse in trunk ganglion at the same level

② Synapse in trunk ganglion at a higher or lower level

③ Pass through sympathetic trunk to synapse in a collateral ganglion anterior to the vertebral column



Pathways to the Body Periphery

Sympathetic pathways to the body periphery innervate the sweat glands, the arrector pili muscles in the skin, and peripheral blood vessels (Figure 15.7 ① and ②). In these pathways, the preganglionic axons enter the sympathetic trunk ganglia and synapse there with ganglionic cell bodies. Because sympathetic outflow from the CNS occurs only on thoracic and lumbar spinal nerves, some of the preganglionic axons travel superiorly or inferiorly in the sympathetic trunk to synapse in regions outside the area of outflow, thus supplying the head, pelvis, and limbs. From the sympathetic trunk ganglion, the postganglionic axons travel in a *gray ramus communicans* to the spinal nerve. The axons then follow branches of the dorsal and ventral rami of the spinal nerve to the skin, where they supply the arrector pili and sweat glands. Anywhere along this path, the postganglionic axons can “jump onto” nearby blood vessels—and then follow and innervate those vessels.

At this point, the difference between the two types of rami communicantes becomes clear.

- The *white rami* contain all the *preganglionic* axons traveling to the sympathetic trunk ganglion. White rami are white because preganglionic axons are myelinated. They occur only in the region of sympathetic outflow from the spinal cord — on sympathetic trunk ganglia between T₁ and L₂.
- The *gray rami* contain only the *postganglionic* axons headed for peripheral structures. Gray rami are gray because postganglionic axons are nonmyelinated. They occur on all the sympathetic trunk ganglia because sweat glands, arrector pili, and blood vessels must be innervated in *all* body segments.

Pathways to the Head

In the sympathetic innervation of the head (Figure 15.8), the preganglionic axons originate in the first four thoracic segments of the spinal cord (T₁–T₄). From there, these axons ascend in the sympathetic trunk to synapse in the superior cervical ganglion. From this ganglion, the postganglionic axons associate with large arteries that carry them to glands, smooth muscle, and vessels throughout the head. Functionally, these sympathetic fibers (1) inhibit the lacrimal, nasal, and salivary glands (the reason fear causes dry mouth), (2) stimulate the muscle in the iris that dilates the pupil in the eye, and (3) stimulate the *superior tarsal muscle*, a smooth muscle in the upper eyelid that prevents drooping of the eyelid whenever the eyes are open. This muscle also lifts the eyelid to open the eyes wide when one is frightened.

Pathways to the Thoracic Organs

In the sympathetic innervation of thoracic organs (Figure 15.8), the preganglionic axons originate at spinal levels T₁–T₆. Some of these axons synapse in the nearest sympathetic trunk ganglion, and the postganglionic axons run directly to the organ being supplied. Fibers to the lungs and esophagus take this direct route, as do some axons to the heart. Along the way, the postganglionic axons pass through the pulmonary, esophageal, and cardiac plexuses (Figure 15.5).



CLINICAL APPLICATION

Horner's Syndrome *Horner's syndrome* is a condition that follows damage to the sympathetic trunk in the inferior neck region on one side of the body. The symptoms, which occur on the affected side only, result from a loss of sympathetic innervation to the head and the dominance of parasympathetic effects. They include drooping of the upper eyelid (ptosis), pupil constriction, flushing of the face, and inability to sweat. Horner's syndrome can indicate the presence of disease or infection in the neck.



Left eye showing typical signs of Horner's syndrome

Many of the sympathetic fibers to the *heart*, however, take a less direct path. The preganglionic axons ascend in the sympathetic trunk to synapse in the cervical ganglia of the sympathetic trunk. From there, the postganglionic axons descend through the cardiac plexus and into the heart wall. Many nerves to the heart (a thoracic organ) arise in the neck because the heart develops in the neck region of the embryo (discussed in Chapter 19, “Development of the Heart” section).

Functionally, the thoracic sympathetic nerves increase the heart rate and dilate the blood vessels that supply the heart wall (so that the heart muscle itself receives more blood). They also dilate the respiratory air tubes and inhibit the muscle and glands in the esophagus, effects that are integral to the fight-or-flight response.

Pathways to the Abdominal Organs

In the sympathetic innervation of abdominal organs, the preganglionic axons originate in the inferior half of the thoracolumbar spinal cord (T₅–L₂; Figure 15.8). From there, these axons pass through the adjacent sympathetic trunk ganglia and travel in **thoracic splanchnic nerves** (greater, lesser, and least) to synapse in collateral ganglia in the large plexuses on the abdominal aorta. These ganglia include the **celiac** and **superior mesenteric ganglia**, along with some smaller ones. Postganglionic axons from these ganglia then follow the main branches of the aorta to the stomach, liver, kidney, spleen, and intestines (through the proximal half of the large intestine). For the most part, the sympathetic

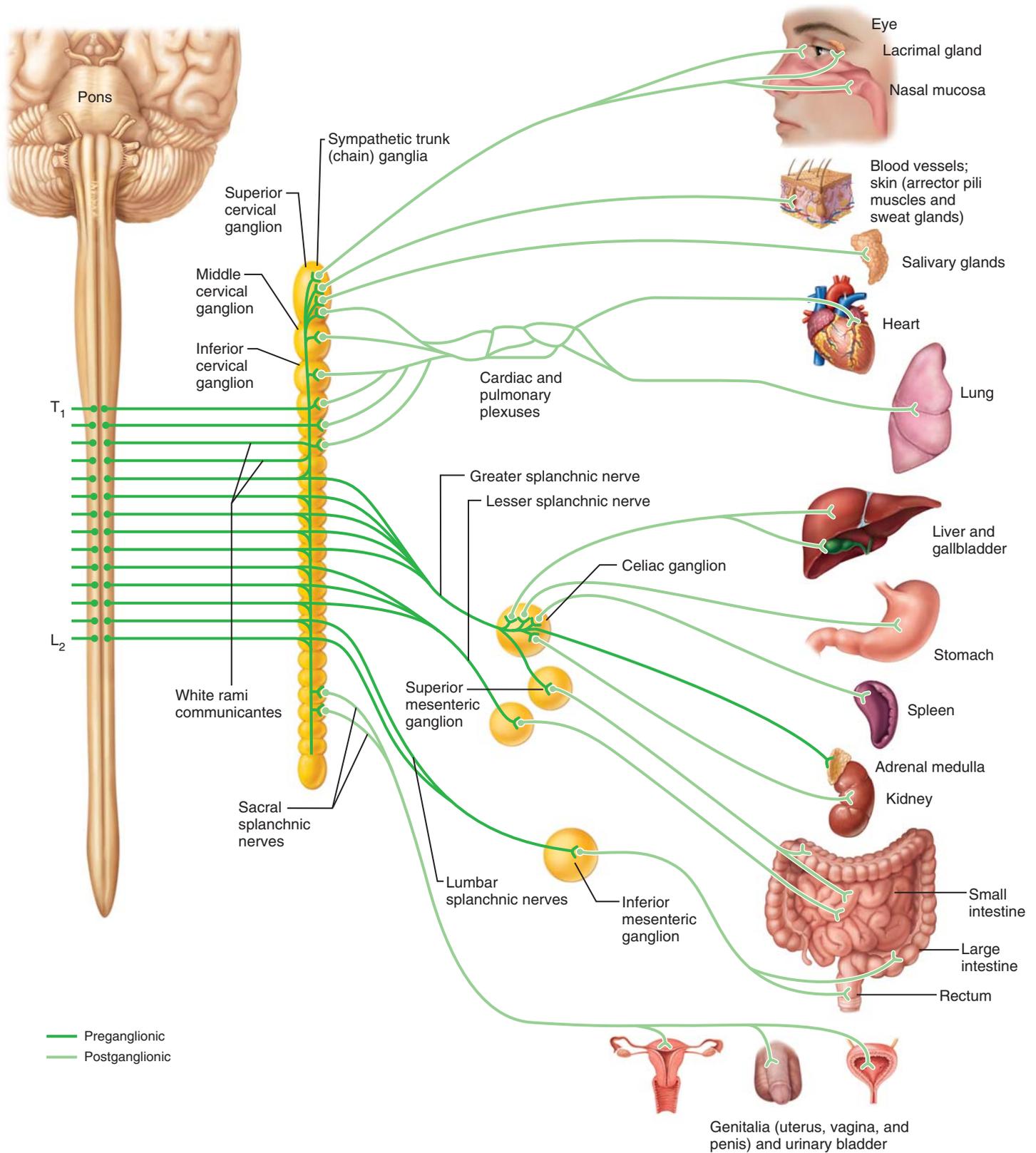


Figure 15.8 Sympathetic division of the ANS. Sympathetic innervation to peripheral structures (blood vessels, glands, and arrector pili muscles) occurs in all areas but is shown only in the cervical area.

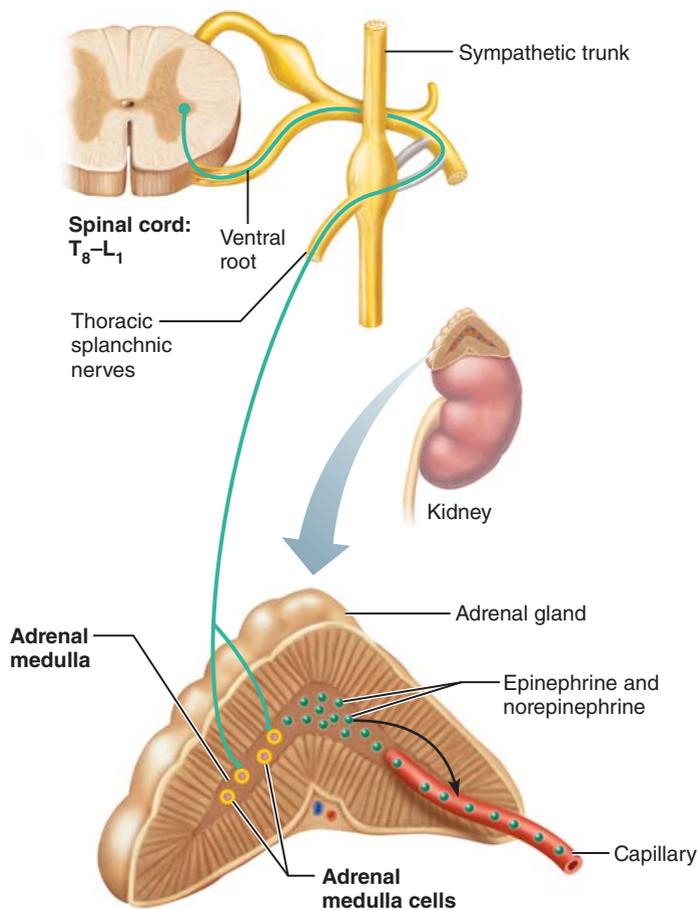


Figure 15.9 Sympathetic innervation of the adrenal medulla.

fibers *inhibit* the activity of the muscles and glands in these visceral organs.

Pathways to the Pelvic Organs

In the sympathetic innervation of pelvic organs (Figure 15.8), the preganglionic axons originate in the most inferior part of the thoracolumbar spinal cord (T_{10} – L_2), then descend in the sympathetic trunk to the lumbar and sacral ganglia of the sympathetic trunk. Some axons synapse there, and the postganglionic axons run in *lumbar* and *sacral splanchnic nerves* to plexuses on the lower aorta and in the pelvis—namely, the **inferior mesenteric plexus**, the **aortic plexus**, and the **hypogastric plexuses**. Other preganglionic axons, by contrast, pass directly to these autonomic plexuses and synapse in collateral ganglia there—the **inferior mesenteric ganglia** and **inferior hypogastric ganglia**. Postganglionic axons proceed from these plexuses to the pelvic organs, including the bladder, the reproductive organs, and the distal half of the large intestine. These sympathetic fibers inhibit urination and defecation and promote ejaculation.

The Role of the Adrenal Medulla in the Sympathetic Division

On the superior aspect of each kidney lies an **adrenal (suprarenal) gland (Figure 15.9)**. The internal portion of this gland—the **adrenal medulla**—is a major organ of the sympathetic nervous system. The adrenal medulla is a specialized sympathetic ganglion containing a collection of modified postganglionic neurons that completely lack nerve processes. These neuron-derived cells secrete great quantities of two excitatory hormones into the blood of nearby capillaries during the fight-or-flight response. The hormones secreted are norepinephrine (the chemical secreted by other postganglionic sympathetic neurons as a neurotransmitter) and greater amounts of a related excitatory molecule called **epinephrine (adrenaline)**. Once released, these hormones travel throughout the body in the bloodstream, producing the widespread excitatory effects that we have all experienced as a “surge of adrenaline.”

The cells of the adrenal medulla are stimulated to secrete by preganglionic sympathetic fibers that arise from cell bodies in the T_8 – L_1 region of the spinal cord. From there, they run in the thoracic splanchnic nerves and pass through the celiac plexus before reaching the adrenal medulla (Figure 15.8). Not surprisingly, the adrenal medulla has a more concentrated sympathetic innervation than any other organ in the body.

The effects of sympathetic innervation to various organs are presented in comparison with the effects of parasympathetic innervation (Table 15.2, p. 475).



CLINICAL APPLICATION

Stress-Induced Hypertension Continual stress can promote overactive sympathetic stimulation causing vasoconstriction that results in **hypertension**, or high blood pressure, a circulatory condition that can have a variety of contributing factors. Hypertension is always serious because (1) it increases the workload on the heart, possibly precipitating heart disease, and (2) it increases the wear and tear on artery walls. Stress-induced hypertension is treated with drugs that prevent smooth muscle cells in the walls of blood vessels from binding norepinephrine and epinephrine.

✓ check your understanding

- 8. Why are white rami communicantes located only on sympathetic trunk ganglia between T_1 and L_2 , and gray rami communicantes branch off each sympathetic trunk ganglion?
- 9. What is the general effect of sympathetic innervation to the abdominal organs?
- 10. Which types of autonomic fibers (preganglionic, postganglionic, sympathetic, parasympathetic) are located in the thoracic and abdominal autonomic plexuses?

(For answers, see Appendix B.)

VISCERAL SENSORY NEURONS

learning outcomes

- ▶ Describe the role and location of visceral sensory neurons relative to autonomic neurons.
- ▶ Explain the concept of referred pain.

The visceral division of the PNS contains sensory as well as motor (autonomic) neurons (Figure 15.1). General visceral sensory neurons monitor stretch, temperature, chemical changes, and irritation within the visceral organs. The brain interprets this visceral information as feelings of hunger, fullness, pain, or nausea. Almost all of the receptors for these visceral senses are free (nonencapsulated) nerve endings widely scattered throughout the visceral organs. Visceral sensations tend to be difficult to localize with precision: For example, people usually cannot distinguish whether gas pains originate in the stomach or in the intestine, or whether a pain in the lower abdomen originates from the uterus or the appendix.

Like somatic sensory neurons, the cell bodies of visceral sensory neurons are located in dorsal root ganglia and in the sensory ganglia of cranial nerves. The long peripheral processes of these sensory neurons accompany the autonomic motor fibers to the visceral organs. Many visceral sensory fibers accompany the parasympathetic fibers in the vagus nerve and monitor visceral sensations in the many organs served by this nerve. Other visceral sensory fibers accompany the sympathetic fibers, running from the visceral organs into the autonomic plexuses and then through the splanchnic nerves, sympathetic trunk, rami communicantes, spinal nerves, and dorsal roots. From the dorsal roots, the central processes of these sensory neurons enter the spinal cord. *Most visceral pain fibers follow this sympathetic route to the CNS.*

The pathways by which visceral sensory information is relayed through the spinal cord to the cerebral cortex are not yet fully understood. Most visceral inputs travel along the spinothalamic (and spinoreticular) pathways to the thalamus. Neurons in the thalamus relay visceral sensory information to the visceral sensory cortex in the insula lobe (p. 388) for conscious perception. Visceral sensory information also reaches and influences the visceral control centers in the hypothalamus and medulla oblongata.

Visceral *pain* exhibits an unusual feature that is worth noting: Surprisingly, one often feels no pain when a visceral organ is cut or scraped. When pieces of mucous membrane are snipped from the uterus or the intestines to be examined for cancer, for example, most patients report little discomfort. Visceral pain does result, however, from chemical irritation or inflammation of visceral organs, from spasms of the smooth muscle in these organs (cramping), and from excessive stretching of the organ. In these cases, visceral pain can be severe.

People suffering from visceral pain often perceive this pain to be somatic in origin—that is, as if it originated from the skin or outer body. This phenomenon is called **referred**

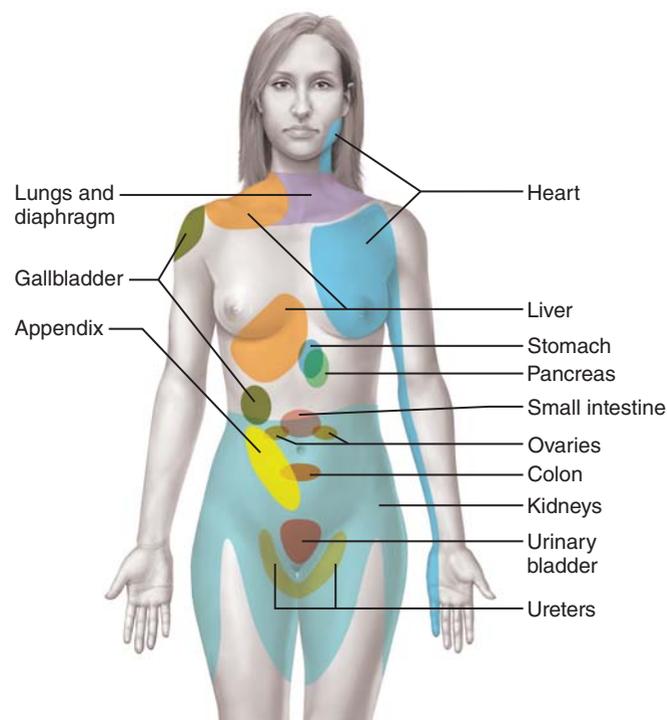


Figure 15.10 A map of referred pain. This map shows the anterior skin areas to which pain is referred from certain visceral organs.

pain. For example, heart attacks can produce referred pain in cutaneous areas of the superior thoracic wall and the medial aspect of the left arm (Figure 15.10). The cause of referred pain is not fully understood. It is known that both the affected organ and the region of the body wall to which the pain is referred are innervated by the same spinal segments. For example, both the heart and the skin area to which heart pain projects are innervated by sensory neurons from T₁ to T₅. Referred pain may result from the convergence of somatic and visceral sensory neurons on the same second-order neurons in the dorsal horn of the spinal cord.

VISCERAL REFLEXES

learning outcome

- ▶ Explain how visceral reflexes regulate some functions of visceral organs.

Visceral sensory and autonomic neurons participate in **visceral reflex arcs** (Figure 15.11) including the *defecation reflex* (illustrated in Figure 23.22, p. 703), in which the rectum is stretched by feces and the smooth muscle of the large intestine responds by contracting, and the *micturition reflex* (shown in Figure 24.15, p. 735), in which the smooth muscle in the urine-filled bladder contracts. Many visceral reflexes are simple spinal reflexes in which sensory neurons activate spinal interneurons, which in turn activate preganglionic autonomic neurons.

Other visceral reflexes involve cranial nerves and are integrated in the brain stem. One example is the baroreceptor reflex,

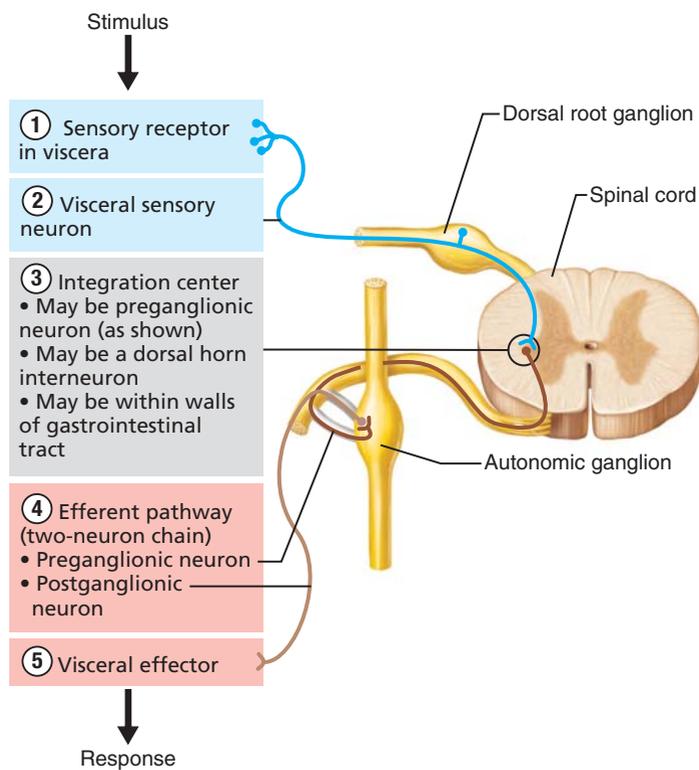


Figure 15.11 Visceral reflexes. Visceral reflex arcs have the same five elements as somatic reflex arcs.

a visceral reflex that regulates blood pressure (**Figure 15.12**). When blood pressure is elevated, baroreceptors in the carotid sinus, located at the junction of the internal and external carotid arteries, stimulate visceral sensory neurons in the glossopharyngeal nerve (cranial nerve IX). Integration in the cardiac center in the medulla stimulates the vagus nerve (cranial nerve X). Vagal stimulation of the heart decreases heart rate, and subsequently blood pressure falls.

Some visceral reflex arcs do not involve the central nervous system at all—they are strictly *peripheral reflexes*. In some of these peripheral reflexes, branches from visceral sensory fibers synapse with postganglionic motor neurons *within sympathetic ganglia*. Furthermore, complete three-neuron reflex arcs (with small sensory, motor, and intrinsic neurons) exist *entirely within the wall of the digestive tube*; these neurons are part of the *enteric nervous system* (see Chapter 23, p. 686). The peripheral reflexes carry out highly localized autonomic responses involving either small segments of an organ or a few different visceral organs. These reflexes enable the peripheral part of the visceral nervous system to control some of its own activity, making it partly independent of the brain and spinal cord. This fact further illustrates the general concept that the autonomic nervous system operates partly on its own.

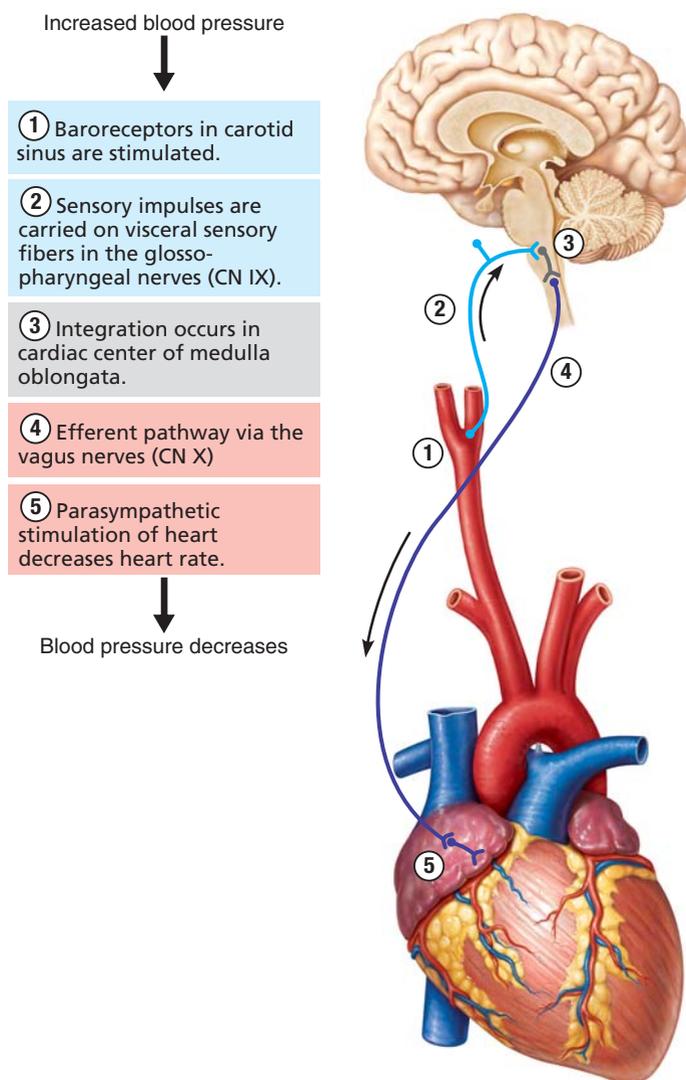


Figure 15.12 Baroreceptor reflex.



CLINICAL APPLICATION

Mass Reflex Reaction The **mass reflex reaction** affects quadriplegics and paraplegics with spinal cord injuries above the level of T₆. The cord injury is followed by a temporary loss of all reflexes inferior to the level of the injury. When reflex activity returns, it is exaggerated because of the lack of inhibitory input from higher (brain) centers. The ensuing episodes of mass reflex reaction involve surges of both visceral and somatic motor output from large regions of the spinal cord. The usual trigger for such an episode is a strong stimulus to the skin or the overfilling of a visceral organ, such as the bladder. During the mass reflex episode, the body goes into flexor spasms, the limbs move wildly, the colon and bladder empty, and profuse sweating occurs. Most seriously, sympathetic activity raises blood pressure to life-threatening levels.

CENTRAL CONTROL OF THE AUTONOMIC NERVOUS SYSTEM

learning outcome

- Explain how various regions of the CNS help to regulate the autonomic nervous system.

Though the ANS is not considered to be under direct voluntary control, many of its activities are regulated by the central nervous system. Several sources of central control exist—the brain stem and spinal cord, the hypothalamus and amygdala, and the cerebral cortex (Figure 15.13).

Control by the Brain Stem and Spinal Cord

The reticular formation of the brain stem appears to exert the most direct influence over autonomic functions. Centers in the medulla oblongata (pp. 379–380) regulate heart rate (*cardiac centers*; Figure 15.12), the diameter of blood vessels (*vasomotor center*), and many digestive activities. Also, the periaqueductal gray matter of the midbrain controls many autonomic functions, especially the sympathetic fear response during a threatening encounter (pp. 381–382).

Control of autonomic functions at the level of the spinal cord involves the spinal visceral reflexes (Figure 15.11). Note, however, that even though the defecation and urination reflexes are integrated by the spinal cord, they are subject to conscious inhibition from the brain. This enables conscious control over when and where to eliminate wastes.

Control by the Hypothalamus and Amygdaloid Body

The main *integration center* of the autonomic nervous system is the hypothalamus (Figure 15.13). In general, the medial and anterior parts of the hypothalamus direct parasympathetic functions, whereas the lateral and posterior parts direct sympathetic functions. These hypothalamic centers influence the preganglionic autonomic neurons in the spinal cord and brain, both through direct connections and through relays in the reticular formation and periaqueductal gray matter. It is through the ANS that the hypothalamus controls heart activity, blood pressure, body temperature, and digestive functions.

Recall that the amygdaloid body is the main limbic region for emotions, including fear (see p. 400). Through communications with the hypothalamus and periaqueductal gray matter, the amygdaloid body stimulates sympathetic activity, especially previously learned fear-related behavior.

Control by the Cerebral Cortex

Even though it was once thought that the autonomic nervous system was not subject to voluntary control by the cerebral cortex, people can exert some conscious control over some autonomic functions by developing control over their thoughts and emotions. For example, feelings of extreme calm achieved during meditation are associated with cerebral cortex influence on the parasympathetic centers in the hypothalamus via various limbic structures. Voluntary sympathetic

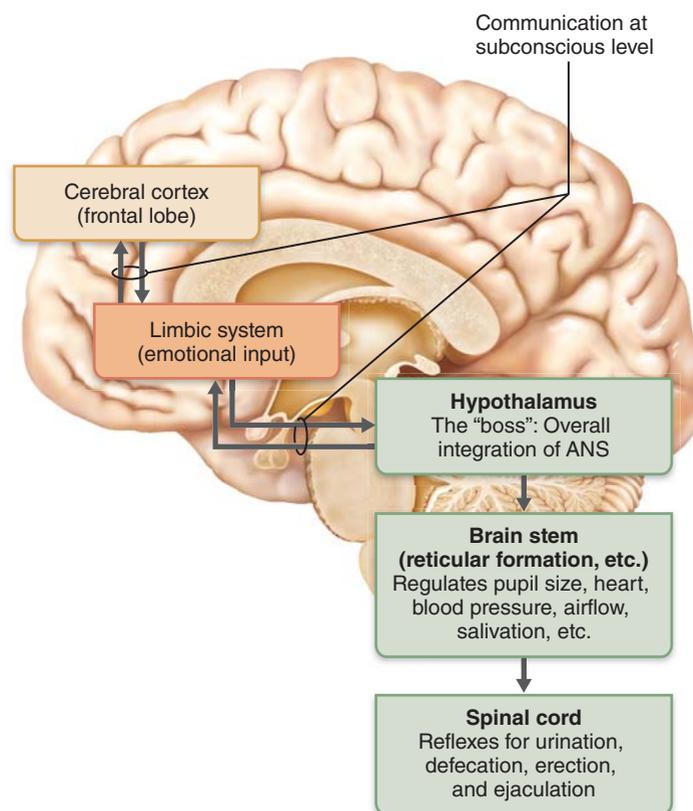


Figure 15.13 Levels of ANS control. The hypothalamus is the main integration center of the ANS. Inputs from the cerebral cortex via the limbic lobe can influence hypothalamic functioning.

activation can occur when people decide to recall a frightful experience; in this case the cerebral cortex acts through the amygdaloid body.

✓ check your understanding

- 11. Via which pathway do most visceral pain fibers travel to reach the CNS?
- 12. What is a peripheral reflex, and how does it differ from a spinal reflex?
- 13. Which region of the CNS is the main control center for the ANS?

(For answers, see Appendix B.)

DISORDERS OF THE AUTONOMIC NERVOUS SYSTEM

learning outcome

- Briefly describe some diseases of the autonomic nervous system.

Because the ANS is involved in nearly every important process that occurs within the body, it is not surprising that abnormalities of autonomic functioning can have far-reaching effects. Such abnormalities can impair elimination processes and blood delivery, and can even threaten life.



Figure 15.14 Raynaud's disease in an elderly man.

Raynaud's disease is characterized by intermittent attacks during which the skin of the fingers and toes becomes pale, then blue and painful (Figure 15.14). When such an attack ends and the vessels dilate, the fingers refill with blood and become red. Commonly provoked by exposure to cold or by emotional stress, this disease is thought to be an exaggerated, sympathetic vasoconstriction response in the affected body regions. The severity of Raynaud's disease ranges from mere discomfort to such extreme constriction of vessels that gangrene (tissue death) results. Treatment typically involves administering drugs that inhibit vasoconstriction, but in severe cases it may be necessary to remove ganglia or to cut the preganglionic sympathetic fibers serving the affected region. Raynaud's disease is rather common among the elderly, affecting 9% of all elderly women and 3% to 5% of elderly men.

Achalasia (ak"ah-la'ze-ah) of the cardia is a condition in which some defect in the autonomic innervation of the esophagus results in a loss of that organ's ability to propel swallowed food inferiorly. Additionally, the smooth muscle surrounding the inferior end of the esophagus (cardiac sphincter) remains contracted, preventing the passage of food into the stomach. (*Achalasia* means "failure to relax.") The accumulation of food stretches the esophagus to enormous width, and meals cannot be kept down. The cause of this condition, which usually appears in young adults, is not precisely understood. The preferred treatment is a longitudinal surgical incision through the muscle at the inferior end of the esophagus.

Congenital megacolon, or **Hirschsprung's disease**, is a birth defect in which the parasympathetic and enteric innervation of the distal region of the large intestine fails to develop normally because migrating neural crest cells fail to reach this region (discussed in the next section). Feces and gas accumulate proximal to the immobile bowel segment, greatly distending this area (*megacolon* = enlarged large intestine). The condition is corrected surgically by removing the inactive part of the infant's intestine.

THE AUTONOMIC NERVOUS SYSTEM THROUGHOUT LIFE

learning outcomes

- ▶ Describe the embryonic development of the ANS.
- ▶ List some effects of aging on autonomic functions.

The developmental origins of the structures of the PNS can be summarized in two statements:

- All neurons with cell bodies in the CNS are derived from the neural tube.
- All neurons with cell bodies in the PNS are derived from the neural crest.

Thus, somatic motor neurons and *preganglionic autonomic neurons* form from neuroblasts of the basal plate of the neural tube (Figure 12.16, p. 370); sensory neurons and *postganglionic autonomic neurons* form from the neural crest.

In the development of the sympathetic division (Figure 15.15), some cells migrate ventrally from the neural crest to form the sympathetic trunk ganglia. From there, other cells migrate ventrally to form both the collateral ganglia on the aorta and the adrenal medulla. The sympathetic trunk ganglia and collateral ganglia receive axons from spinal preganglionic neurons, and they in turn send postganglionic axons to the visceral organs.

In the development of the parasympathetic division, the postganglionic neurons also derive from the neural crest and reach the visceral organs by migrating along the growing preganglionic axons.

During youth, impairments of visceral nervous function are usually due to injuries to either the spinal cord or autonomic nerves. With advancing age, the efficiency of the ANS

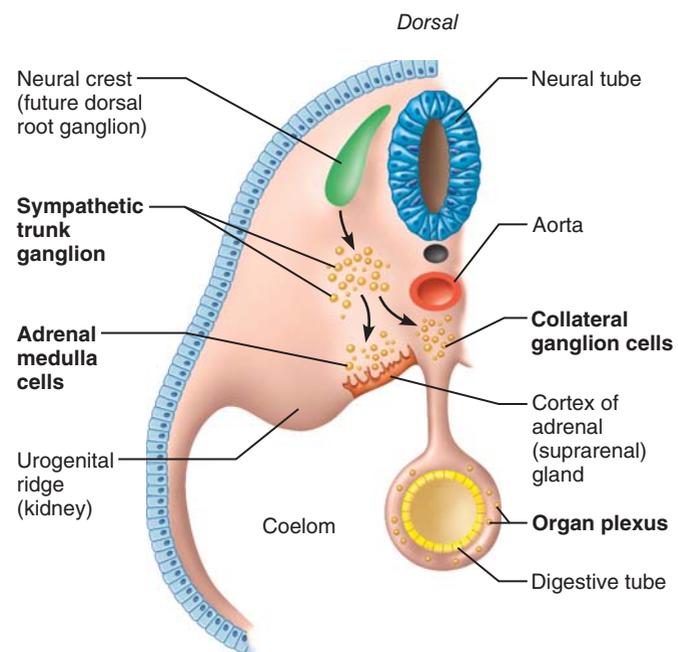


Figure 15.15 Embryonic development of some sympathetic structures, including the adrenal medulla. Transverse section through a 5-week embryo.

begins to decline. Elderly people are commonly constipated because the autonomically controlled motility of their gastrointestinal tract is reduced. Frequent eye infections can result from diminished formation of tears, which contain bactericidal enzymes, and the pupils cannot dilate as widely or as quickly. Whenever a young and healthy person rises to a standing position, the sympathetic division induces bodywide vasoconstriction, raising blood pressure so that blood can be pumped to the head and brain. The response becomes sluggish with age, so elderly people may faint if they stand up too quickly. Although these age-related problems are distressing, they usually are not life-threatening and can be easily alleviated. For example,

standing up slowly gives the sympathetic nervous system time to adjust blood pressure, eye drops are available for dry eyes, and drinking ample fluid helps alleviate constipation.

✓ check your understanding

- 14. Which embryonic tissue forms the postganglionic neurons of the ANS?
- 15. Which division of the ANS is deficient in achalasia of the cardia? Which division malfunctions in Raynaud's disease?

(For answers, see Appendix B.)



RELATED CLINICAL TERMS

Atonic bladder (a-tahn'ik; "without tone") A condition in which the bladder becomes flaccid and overfills, allowing urine to dribble out. Atonic bladder results from the temporary loss of the micturition reflex following injury to the spinal cord.

Vagotomy (va-got'o-me) Cutting or severing of a vagus nerve, often to decrease the secretion of stomach acid and other caustic digestive juices that aggravate ulcers.

CHAPTER SUMMARY

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1. The ANS is the system of motor neurons that innervates smooth muscle, cardiac muscle, and glands. It is the general visceral motor division of the PNS. The ANS largely operates below the level of consciousness.

OVERVIEW OF THE AUTONOMIC NERVOUS SYSTEM (pp. 468–472)

Comparison of the Autonomic and Somatic Motor Systems (pp. 468–470)

2. In the somatic motor division of the nervous system, a single motor neuron forms the pathway from the CNS to the skeletal muscle cells. Autonomic motor pathways, by contrast, consist of chains of two neurons: the preganglionic neuron, whose cell body is in the CNS, and the postganglionic neuron, whose cell body is in an autonomic ganglion. The postganglionic axon innervates the visceral organs.

Divisions of the Autonomic Nervous System (pp. 470–472)

3. The ANS has parasympathetic and sympathetic divisions. Both innervate many of the same organs but produce opposite effects (Table 15.2, p. 475). The sympathetic division prepares the body for "fight or flight," whereas the parasympathetic division is active during "rest and digest."

4. The parasympathetic division exits the CNS on cranial and sacral nerves and has comparatively long preganglionic axons. The sympathetic division exits on thoracic and lumbar nerves and has comparatively long postganglionic axons.
5. The two divisions differ in the neurotransmitters they release at the effector organ. Acetylcholine is released by parasympathetic postganglionic fibers, whereas norepinephrine is released by most sympathetic postganglionic fibers.

THE PARASYMPATHETIC DIVISION (pp. 472–473)

Cranial Outflow (pp. 472–473)

6. Cranial parasympathetic fibers arise in the brain stem nuclei of cranial nerves III, VII, IX, and X and synapse in ganglia in the head, thorax, and abdomen. Axons in cranial nerve (CN) III serve smooth musculature in the eye via a synapse in the ciliary ganglion. Axons in CN VII serve the submandibular, sublingual, lacrimal, and nasal glands and synapse in the submandibular and pterygopalatine ganglia. Axons in CN IX serve the parotid gland via a synapse in the otic ganglion.
7. Parasympathetic fibers in the vagus nerve (CN X) innervate organs in the thorax and most of the abdomen, including the heart, lungs, esophagus, stomach, liver, and most of the intestines. The axons in the vagus are preganglionic. Almost all postganglionic neurons are located in intramural ganglia within the organ walls.

Sacral Outflow (p. 473)

8. Sacral parasympathetic pathways innervate the pelvic viscera. The preganglionic axons exit from the visceral motor region of the gray matter of the spinal cord (S_2 – S_4) and form the pelvic splanchnic nerves. Most of these axons synapse in intramural ganglia in the pelvic organs.

THE SYMPATHETIC DIVISION (pp. 473–480)**Basic Organization** (pp. 473–476)

9. The preganglionic sympathetic cell bodies are in the lateral horn of the spinal gray matter from the level of T₁ to L₂.
10. The sympathetic division supplies some peripheral structures that the parasympathetic division does not: arrector pili, sweat glands, and the smooth muscle of blood vessels.
11. Sympathetic ganglia include 22–24 pairs of sympathetic trunk ganglia (also called chain ganglia and paravertebral ganglia), which are linked together to form sympathetic trunks on both sides of the vertebral column, and unpaired collateral ganglia (prevertebral ganglia), most of which lie on the aorta in the abdomen.

PAL Human Cadaver/Nervous System/Autonomic Nervous System**Sympathetic Pathways** (pp. 477–480)

12. Every preganglionic sympathetic axon leaves the lateral gray horn of the thoracolumbar spinal cord through a ventral root and spinal nerve. From there, it runs in a white ramus communicans to a sympathetic trunk ganglion or collateral ganglion, where it synapses with the postganglionic neuron that extends to the visceral effector. Many preganglionic axons ascend or descend in the sympathetic trunk to synapse in a ganglion at another body level.
13. In the sympathetic pathway to the *body periphery* (to innervate arrector pili, sweat glands, and peripheral blood vessels), the preganglionic axons synapse in the sympathetic trunk ganglia, and the postganglionic axons run in gray rami communicantes to the dorsal and ventral rami of the spinal nerves for peripheral distribution.
14. In the sympathetic pathway to the *head*, the preganglionic axons ascend in the sympathetic trunk and synapse in the superior cervical ganglion. From there, most postganglionic axons associate with a large artery that distributes them to the glands and smooth musculature of the head.
15. In the sympathetic pathway to *thoracic organs*, most preganglionic axons synapse in the nearest sympathetic trunk ganglion, and the postganglionic axons run directly to the organs (lungs, esophagus). Many postganglionic axons to the heart, however, descend from the cervical ganglia in the neck.
16. In the sympathetic pathway to *abdominal organs*, the preganglionic axons run in splanchnic nerves to synapse in collateral ganglia on the aorta. From these ganglia, the postganglionic axons follow large arteries to the abdominal viscera (stomach, liver, kidney, and most of the large intestine).
17. In the sympathetic pathway to *pelvic organs*, the preganglionic axons synapse in sympathetic trunk ganglia or in collateral ganglia on the aorta, sacrum, and pelvic floor. Postganglionic axons travel through the most inferior autonomic plexuses to the pelvic organs.

The Role of the Adrenal Medulla in the Sympathetic Division (p. 480)

18. The adrenal glands, one superior to each kidney, contain a medulla of modified postganglionic sympathetic neurons that secrete the hormones epinephrine (adrenaline) and norepinephrine into the blood. The result is the “surge of adrenaline” felt during excitement.
19. The cells of the adrenal medulla are innervated by preganglionic sympathetic neurons, which signal them to secrete the hormones.

VISCERAL SENSORY NEURONS (p. 481)

20. General visceral sensory neurons monitor temperature, pain, irritation, chemical changes, and stretch in the visceral organs.
21. Visceral sensory fibers run within the autonomic nerves, especially within the vagus and the sympathetic nerves. Most pain fibers from the visceral organs of the body follow the sympathetic pathway to the CNS and are carried in the spinothalamic tract to the thalamus and then to the visceral sensory cortex.
22. Visceral pain is induced by stretching, infection, and cramping of internal organs but seldom by cutting or scraping these organs. Visceral pain is referred to somatic regions of the body that receive innervation from the same spinal cord segments.

VISCERAL REFLEXES (pp. 481–482)

23. Many visceral reflexes are spinal reflexes, such as the defecation reflex. Others, such as the baroreceptor reflex, involve integration centers in the brain stem. Some visceral reflexes, however, involve only peripheral neurons.

CENTRAL CONTROL OF THE AUTONOMIC NERVOUS SYSTEM (p. 483)

24. Visceral motor functions are influenced by the medulla oblongata, the periaqueductal gray matter, spinal visceral reflexes, the hypothalamus, the amygdaloid body, and the cerebral cortex. Some people can voluntarily regulate some autonomic activities by gaining extraordinary control over their emotions.

DISORDERS OF THE AUTONOMIC NERVOUS SYSTEM (pp. 483–484)

25. Most autonomic disorders reflect problems with the control of smooth muscle. Raynaud’s disease and hypertension result from abnormalities in vascular control.

THE AUTONOMIC NERVOUS SYSTEM THROUGHOUT LIFE (pp. 484–485)

26. Preganglionic neurons develop from the neural tube. Postganglionic neurons and visceral sensory neurons develop from the neural crest.
27. The efficiency of the ANS declines in old age: Gastrointestinal motility and production of tears decrease, and the vasomotor response to standing slows.

REVIEW QUESTIONS**Multiple Choice/Matching Questions**

(For answers, see Appendix B.)

1. Which of the following does *not* characterize the ANS? (a) two-neuron motor chains, (b) preganglionic cell bodies in the CNS, (c) presence of postganglionic cell bodies in ganglia, (d) innervation of skeletal muscle.

2. For each of the following terms or phrases, write either S (for *sympathetic*) or P (for *parasympathetic*) division of the autonomic nervous system.

- _____ (1) short preganglionic axons, long postganglionic axons
 _____ (2) intramural ganglia
 _____ (3) craniosacral outflow

- ___ (4) adrenergic fibers
 - ___ (5) cervical ganglia of the sympathetic trunk
 - ___ (6) otic and ciliary ganglia
 - ___ (7) more widespread response
 - ___ (8) increases heart rate, respiratory rate, and blood pressure
 - ___ (9) increases motility of stomach and secretion of lacrimal and salivary glands
 - ___ (10) innervates blood vessels
 - ___ (11) most active when you are lolling in a hammock
 - ___ (12) most active when you are running in the Boston Marathon
 - ___ (13) gray rami communicantes
 - ___ (14) synapse in celiac ganglion
 - ___ (15) relates to fear response induced by the amygdaloid body
3. The thoracic splanchnic nerves contain which kind of axons? (a) preganglionic parasympathetic, (b) postganglionic parasympathetic, (c) preganglionic sympathetic, (d) postganglionic sympathetic.
 4. The collateral ganglia contain which kind of cell bodies? (a) preganglionic parasympathetic, (b) postganglionic parasympathetic, (c) preganglionic sympathetic, (d) postganglionic sympathetic.
 5. Preganglionic sympathetic neurons develop from (a) neural crest, (b) neural tube, (c) alar plate, (d) endoderm.
 6. Which of the following is the best way to describe how the ANS is controlled? (a) completely under control of voluntary cerebral cortex, (b) entirely controls itself, (c) completely under control of brain stem, (d) little control by cerebrum, major control by hypothalamus and amygdaloid body, and major control by spinal and peripheral reflexes.
 7. The white rami communicantes contain what kind of axons? (a) preganglionic parasympathetic, (b) postganglionic parasympathetic, (c) preganglionic sympathetic, (d) postganglionic sympathetic.
 8. Collateral sympathetic ganglia are involved with the innervation of the (a) abdominal organs, (b) thoracic organs, (c) head, (d) arrector pili, (e) all of these.

Short Answer Essay Questions

9. Is the visceral sensory nervous system part of the autonomic nervous system? Explain your answer.
10. (a) Describe the anatomical relationship of the white and gray rami communicantes to a spinal nerve, and to the dorsal and ventral rami. (b) Why are gray rami communicantes gray?
11. What effect does sympathetic activation have on each of the following structures? Sweat glands, pupils of the eye, adrenal medulla, heart, lungs, blood vessels of skeletal muscles, blood vessels of digestive viscera, salivary glands.
12. Which of the effects listed in question 11 would be reversed by parasympathetic activity?
13. A friend asks you how the parasympathetic division, which comes only from cranial and sacral regions, is able to innervate organs in the thorax and abdomen. How would you answer that question?
14. What manifestations of decreased ANS efficiency are seen in elderly people?

15. The students in anatomy class were having difficulty understanding what kind of cell bodies are located in the autonomic ganglia. Frustrated by being asked this same question repeatedly, the exasperated teaching assistant stood on a desk and yelled, "Autonomic ganglia always contain the *postganglionic* cell bodies!" Describe how that information enabled the students to work out which type of neuron has cell bodies in the (a) sympathetic trunk ganglia, (b) intramural ganglia, and (c) head ganglia (ciliary, pterygopalatine, submandibular, and otic).
16. Describe the sympathetic pathways to the (a) submandibular salivary gland, (b) bladder, (c) sweat glands in the skin, (d) adrenal medulla, (e) heart, (f) stomach.
17. Describe the parasympathetic pathways to the (a) smooth muscles in the eye, (b) bladder, (c) small intestine.
18. Describe the path of the vagus through the neck, thorax, and abdomen.
19. What structures are innervated by the *sacral* part of the parasympathetic division?
20. How do the somatic motor and visceral motor (ANS) pathways differ anatomically and functionally?

Critical Reasoning & Clinical Application Questions

1. A 1-year-old infant has a swollen abdomen and is continually constipated. On examination, a mass is felt over the distal colon, and X-ray findings show the colon to be greatly distended in that region. From the information in this chapter, identify one possible cause for these symptoms.
2. Rowena, a high-powered marketing executive, develops a stomach ulcer. She complains of a deep abdominal pain that she cannot quite locate, plus superficial pain on her abdominal wall. Exactly where on the abdominal wall is the superficial pain most likely to be located? (Refer to Figure 15.10.)
3. Constipated people often have hardened feces that can tear the inner lining of the rectum and anus during defecation. Those with tears in the skin of the anus complain of sharp pain, whereas those with tears higher up in the intestinal mucosa do not complain of such pain. How do you explain this difference?
4. A woman with a history of kidney infections was feeling pain in the skin of the lower part of her abdomen and even in her thighs. Does this make sense? Why or why not?
5. Which clinical condition has the classical symptoms of blue fingertips that later turn bright red?
6. Why does a person with a spinal cord injury have no deficits in digestive function?
7. Suppose that a mad scientist seeking to invent a death ray produces a beam that destroys a person's ciliary, pterygopalatine, and submandibular ganglia (and nothing else). List all the signs that would be apparent in the victim. Would the victim die, or would the scientist have to go back to the laboratory to try again?
8. Job-related stress is a concern for people in many occupations. One response to stress is an increase in sympathetic nerve activity. What are some health-related problems that can result from chronic sympathetic stimulation?