of the table describes how cranial nerves are tested, which is an important part of any neurologic examination. You do not need to memorize these tests, but this information may help you understand cranial nerve function. As you read through the table, also look at Figure 7.21, which shows the location of the cranial nerves on the brain's anterior surface.

Most cranial nerves are mixed nerves; however, three pairs, the optic, olfactory, and vestibulocochlear (ves-tib″u-lo-kok′le-ar) nerves, are purely sensory in function. (The older name for the vestibulocochlear nerve is *acoustic nerve,* a name that reveals its role in hearing but not in equilibrium.) I give my students the following little saying as a memory jog to help them remember the cranial nerves in order; perhaps it will help you, too. The first letter of each word in the saying (and both letters of "ah") is the first letter of the cranial nerve to be remembered: "**O**h, **o**h, **o**h, **t**o **t**ouch **a**nd **f**eel **v**ery **g**ood **v**elvet, **ah.**"

Spinal Nerves and Nerve Plexuses

The 31 pairs of human **spinal nerves** are formed by the combination of the ventral and dorsal roots of the spinal cord. Although each of the cranial nerves issuing from the brain is named specifically, the spinal nerves are named for the region of the cord from which they arise. Figure 7.22 shows how the nerves are named in this scheme.

Almost immediately after being formed, each spinal nerve divides into **dorsal** and **ventral rami** (ra′mi), making each spinal nerve only about ½ inch long. The rami, like the spinal nerves, contain both motor and sensory fibers. Thus, damage to a spinal nerve or either of its rami results both in loss of sensation and flaccid paralysis of the area of the body served. The smaller dorsal rami serve the skin and muscles of the posterior body trunk. The ventral rami of spinal nerves T_1 through T_{12} form the *intercostal nerves,* which supply the muscles between the ribs and the skin and muscles of the anterior and lateral trunk. The ventral rami of all other spinal nerves form complex networks of nerves called **plexuses,** which serve the motor and sensory needs of the limbs. The four nerve plexuses are described in Table 7.2; three of the four plexuses are shown in Figure 7.23.

Autonomic Nervous System

The **autonomic nervous system (ANS)** is the motor subdivision of the PNS that controls body activities automatically. It is composed of a special group of neurons that regulate cardiac muscle (the heart), smooth muscles (found in the walls of the visceral organs and blood vessels), and glands. Although all body systems contribute to homeostasis, the relative stability of our internal environment depends largely on the workings of the ANS. At every moment, signals flood from the visceral organs into the CNS, and the autonomic nerves make adjustments as necessary to best support body activities. For example, blood flow may be shunted to more "needy" areas, heart and breathing rate may be speeded up or slowed down, blood pressure may be adjusted, and stomach secretions may be increased or decreased. Most of this fine-tuning occurs without our awareness or attention—few of us realize when our pupils dilate or our arteries constrict—hence the ANS is also called the **involuntary nervous system.**

Somatic and Autonomic Nervous Systems Compared

Our previous discussions of motor nerves have focused on the activity of the somatic nervous system, the motor subdivision that controls our skeletal muscles. So, before plunging into a description of autonomic nervous system anatomy, we will take the time to point out some important differences between the somatic and autonomic divisions.

Besides differences in their effector organs and in the neurotransmitters released, the patterns of their motor pathways differ. In the somatic division, the cell bodies of the motor neurons are inside the CNS, and their axons (in spinal nerves) extend all the way to the skeletal muscles they serve. The autonomic nervous system, however, has a chain of *two* motor neurons. The first motor neuron of each pair is in the brain or spinal cord. Its axon, the **preganglionic axon** (literally, the "axon before the ganglion"), leaves the CNS to synapse with the second motor neuron in a ganglion outside the CNS. The axon of this neuron, the
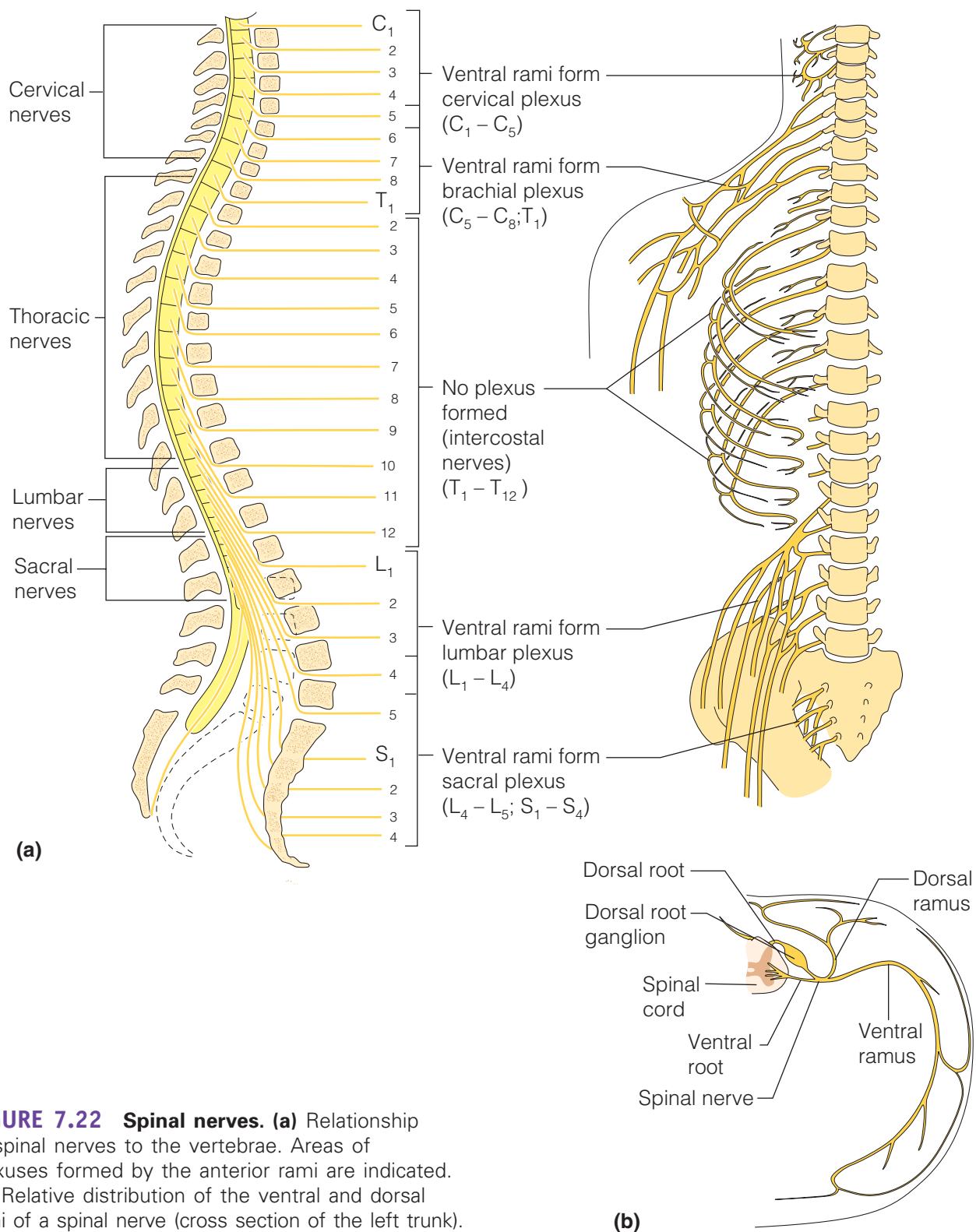
Cervical nerves

Thoracic nerves

Lumbar nerves

Sacral nerves

C_1
2
3
4
5
6
7
8
T_1
2
3
4
5
6
7
8
9
10
11
12
L_1
2
3
4
5
S_1
2
3
4

Ventral rami form cervical plexus $(C_1 - C_5)$

Ventral rami form brachial plexus $(C_5 - C_8; T_1)$

No plexus formed (intercostal nerves) $(T_1 - T_{12})$

Ventral rami form lumbar plexus $(L_1 - L_4)$

Ventral rami form sacral plexus $(L_4 - L_5; S_1 - S_4)$

(a)

Dorsal root

Dorsal root ganglion

Spinal cord

Ventral root

Spinal nerve

Dorsal ramus

Ventral ramus

(b)

FIGURE 7.22   Spinal nerves. (a) Relationship of spinal nerves to the vertebrae. Areas of plexuses formed by the anterior rami are indicated. **(b)** Relative distribution of the ventral and dorsal rami of a spinal nerve (cross section of the left trunk).

TABLE 7.2   Spinal Nerve Plexuses
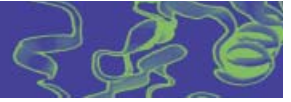
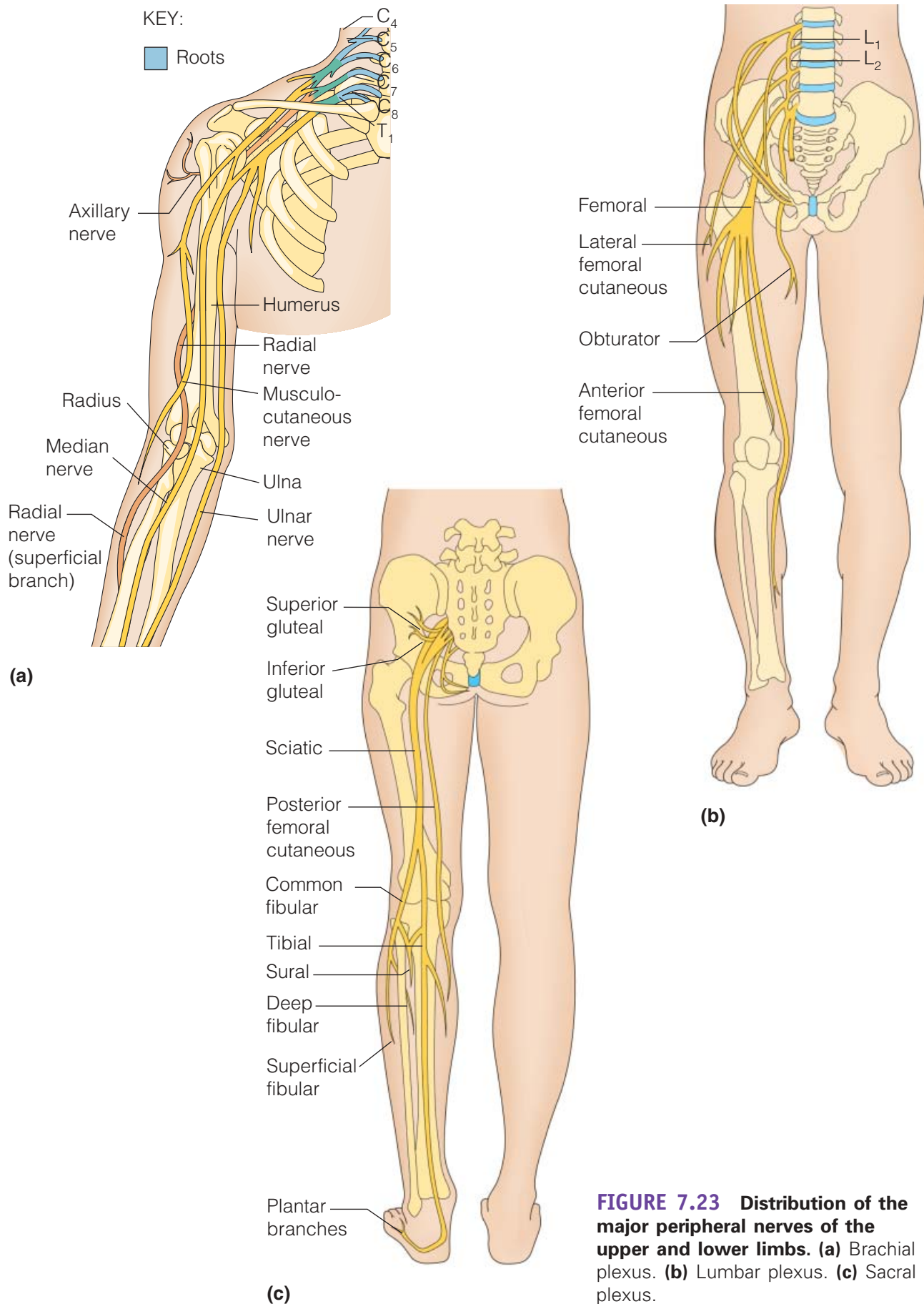| Plexus	Origin (from ventral rami)	Important nerves	Body areas served	Result of damage to plexus or its nerves
Cervical	C_1–C_5	Phrenic	Diaphragm and muscles of shoulder and neck	Respiratory paralysis (and death if not treated promptly)
Brachial	C_5–C_8 and T_1	Axillary	Deltoid muscle of shoulder	Paralysis and atrophy of deltoid muscle
		Radial	Triceps and extensor muscles of the forearm	Wristdrop—inability to extend hand at wrist
		Median	Flexor muscles of forearm and some muscles of hand	Decreased ability to flex and abduct hand and flex and abduct thumb and index finger—therefore, inability to pick up small objects
		Musculocutaneous	Flexor muscles of arm	Decreased ability to flex forearm on arm
		Ulnar	Wrist and many hand muscles	Clawhand—inability to spread fingers apart
Lumbar	L_1–L_4	Femoral (including lateral and anterior cutaneous branches)	Lower abdomen, buttocks, anterior thighs, and skin of anteromedial leg and thigh	Inability to extend leg and flex hip; loss of cutaneous sensation
		Obturator	Adductor muscles of medial thigh and small hip muscles; skin of medial thigh and hip joint	Inability to adduct thigh
Sacral	L_4–L_5 and S_1–S_4	Sciatic (largest nerve in body; splits to common fibular and tibial nerves)	Lower trunk and posterior surface of thigh (and leg)	Inability to extend hip and flex knee; sciatica
		• Common fibular (superficial and deep branches)	Lateral aspect of leg and foot	Footdrop—inability to dorsiflex foot
		• Tibial (including sural and plantar branches)	Posterior aspect of leg and foot	Inability to plantar flex and invert foot; shuffling gait
		Superior and inferior gluteal	Gluteus muscles of hip	Inability to extend hip (maximus) or abduct and medially rotate thigh (medius)

KEY:

□ Roots

C4
C5
C6
C7
C8
T1

Axillary nerve

Humerus

Radial nerve

Musculo-cutaneous nerve

Radius

Median nerve

Ulna

Ulnar nerve

Radial nerve (superficial branch)

(a)

Femoral

Lateral femoral cutaneous

Obturator

Anterior femoral cutaneous

L1
L2

(b)

Superior gluteal

Inferior gluteal

Sciatic

Posterior femoral cutaneous

Common fibular

Tibial

Sural

Deep fibular

Superficial fibular

Plantar branches

(c)

FIGURE 7.23 **Distribution of the major peripheral nerves of the upper and lower limbs. (a)** Brachial plexus. **(b)** Lumbar plexus. **(c)** Sacral plexus.

Q *Transmission of nerve impulses along ANS pathways is generally much slower than along somatic fibers. Why?*
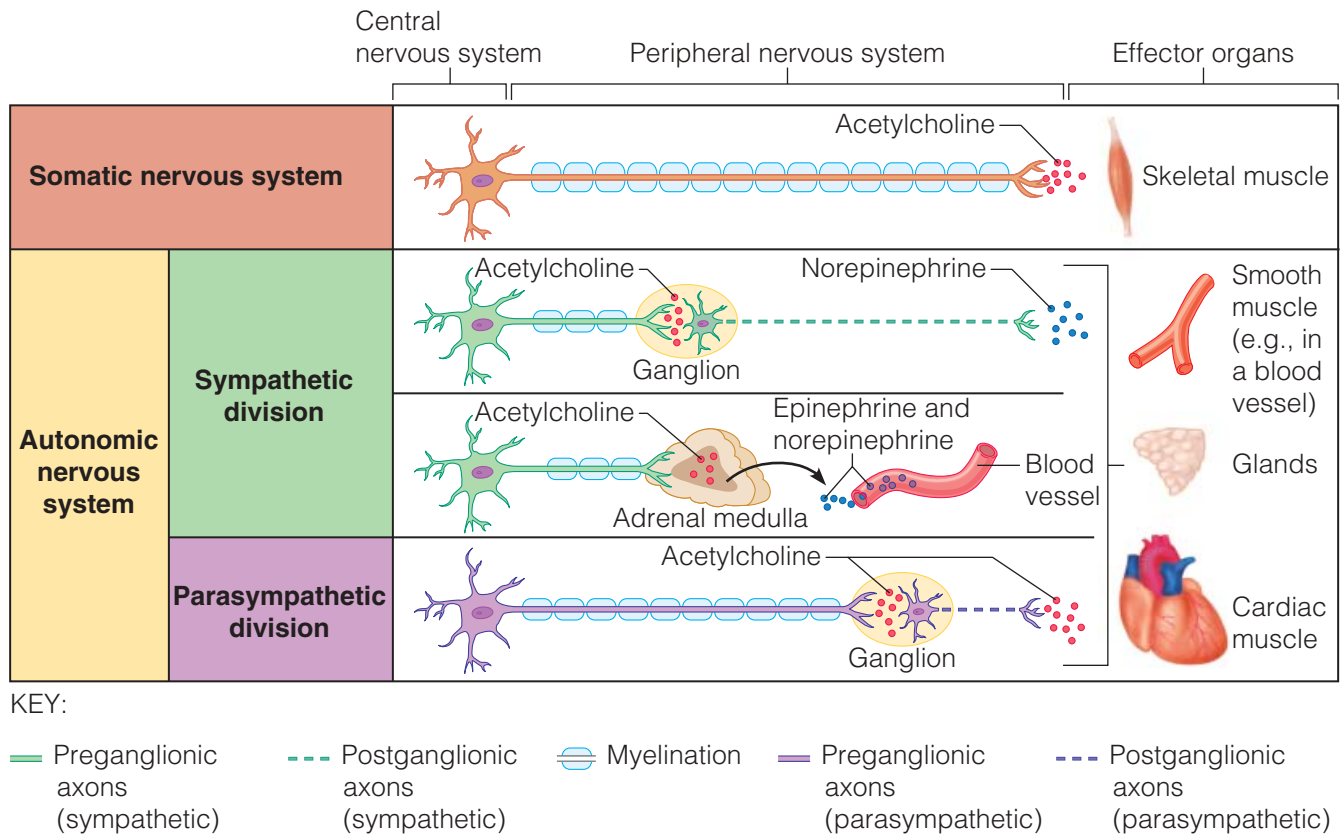

FIGURE 7.24 Comparison of the somatic and autonomic nervous systems.

postganglionic axon, then extends to the organ it serves. These differences are summarized in Figure 7.24.

The autonomic nervous system has two arms, the sympathetic and the parasympathetic (Figure 7.25). Both serve the same organs but cause essentially opposite effects, counterbalancing each other's activities to keep body systems running smoothly. The **sympathetic division** mobilizes the body during extreme situations (such as fear, exercise, or rage), whereas the **parasympathetic division** allows us to "unwind" and conserve energy. These differences are examined in more detail shortly, but first we will consider the structural characteristics of the two arms of the ANS.

A *Postganglionic fibers of the ANS are unmyelinated fibers which conduct much more slowly than the myelinated fibers that are typical of somatic nerve fibers.*
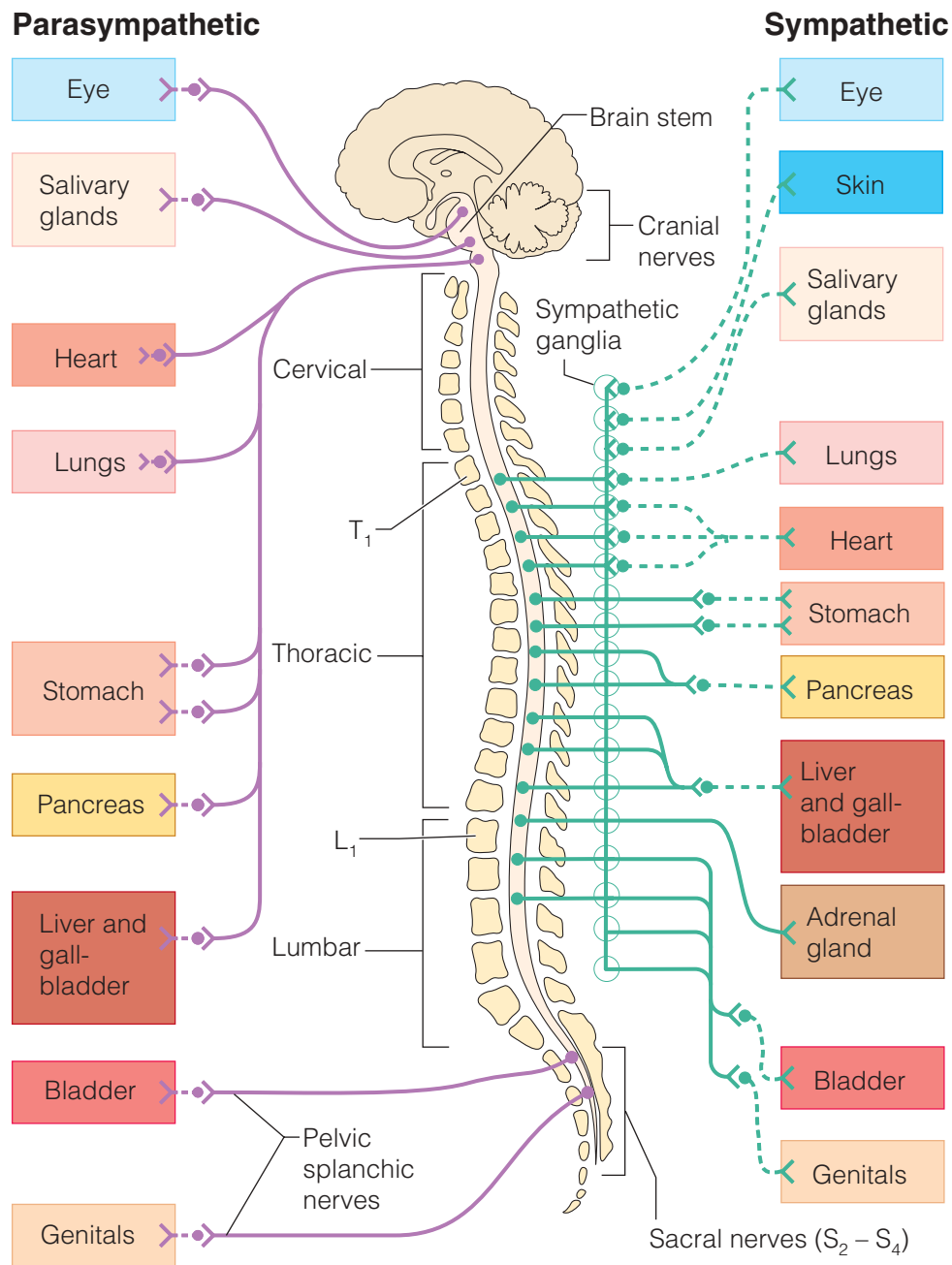
Anatomy of the Parasympathetic Division

The first neurons of the parasympathetic division are located in brain nuclei of several cranial nerves—III, VII, IX, and X (the vagus being the most important of these) and in the S_2 through S_4 levels of the spinal cord (see Figure 7.25). The neurons of the cranial region send their axons out in cranial nerves to serve the head and neck organs. There they synapse with the second motor neuron in a **terminal ganglion.** From the terminal ganglion, the postganglionic axon extends a short distance to the organ it serves. In the sacral region, the preganglionic axons leave the spinal cord and form the *pelvic splanchnic* (splank′nik) *nerves,* also called the *pelvic nerves,* which travel to the pelvic cavity. In the pelvic cavity, the preganglionic axons synapse with the second motor neurons in terminal ganglia on, or close to, the organs they serve.

FIGURE 7.25   **Anatomy of the autonomic nervous system.**
Parasympathetic fibers are shown in purple, sympathetic fibers in green.
Solid lines represent preganglionic fibers; dashed lines indicate
postganglionic fibers.

Anatomy of the Sympathetic Division

The sympathetic division is also called the *thora-columbar* (tho″rah-ko-lum′bar) *division* because its first neurons are in the gray matter of the spinal cord from T_1 through L_2 (see Figure 7.25). The preganglionic axons leave the cord in the ventral root, enter the spinal nerve, and then pass through a **ramus communicans,** or small communicating branch, to enter a **sympathetic chain ganglion** (Figure 7.26). The **sympathetic chain,** or **trunk,** lies alongside the vertebral column on each side. After it reaches the ganglion, the axon may synapse with the second neuron in the sympathetic chain at the same or a different level (the
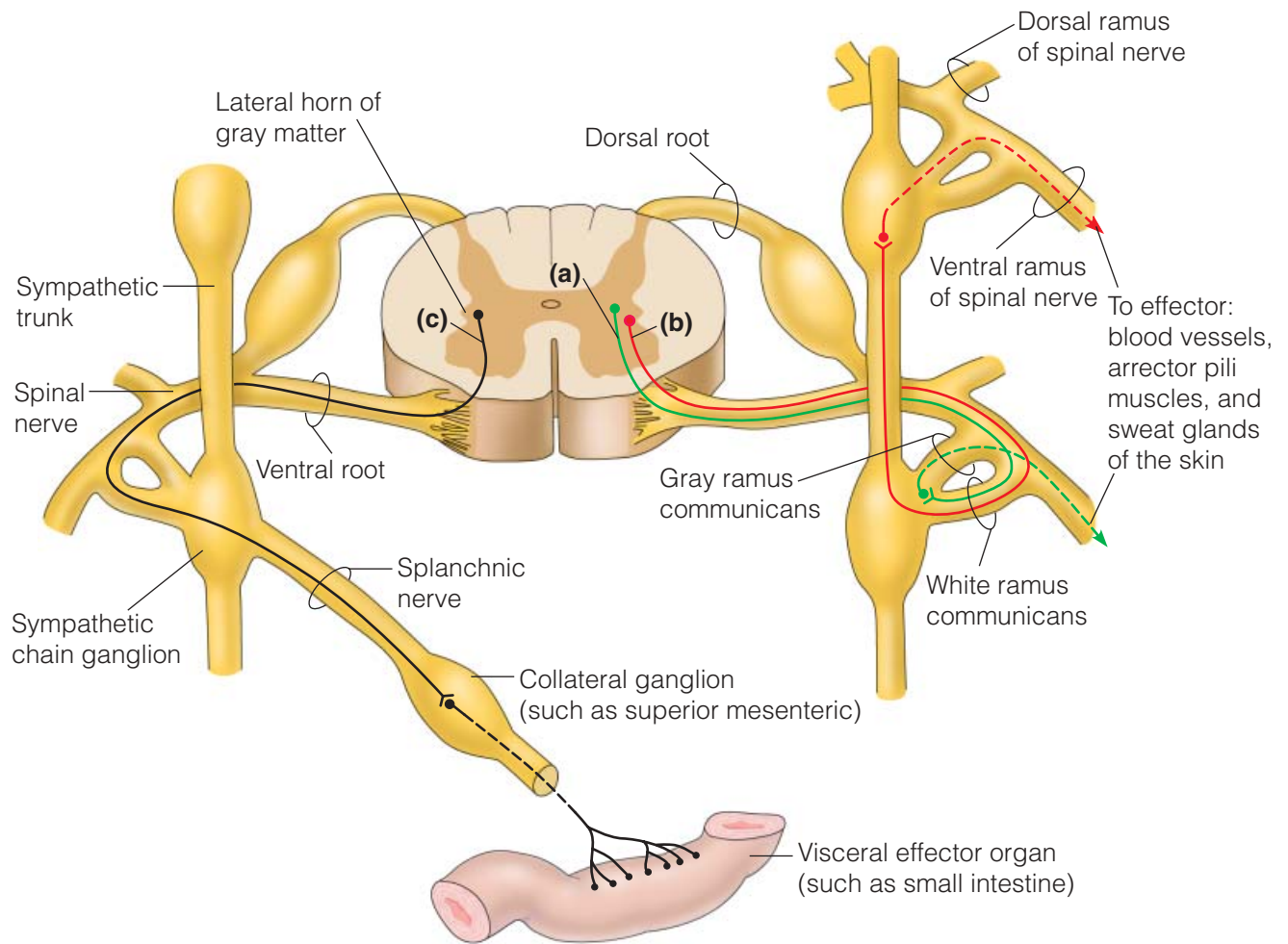
FIGURE 7.26   Sympathetic pathways. (a) Synapse in a sympathetic chain ganglion at the same level. **(b)** Synapse in a sympathetic chain ganglion at a different level. **(c)** Synapse in a collateral ganglion anterior to the vertebral column.

postganglionic axon then reenters the spinal nerve to travel to the skin), or the axon may pass through the ganglion without synapsing and form part of the **splanchnic nerves.** The splanchnic nerves travel to the viscera to synapse with the second neuron, found in a **collateral ganglion** anterior to the vertebral column. The major collateral ganglia—the celiac and the superior and inferior mesenteric ganglia—supply the abdominal and pelvic organs. The postganglionic axon then leaves the collateral ganglion and travels to serve a nearby visceral organ.

Now that the anatomical details have been described, we are ready to examine ANS functions in a little more detail.

Autonomic Functioning

Body organs served by the autonomic nervous system receive fibers from both divisions. Exceptions are most blood vessels and most structures of the skin, some glands, and the adrenal medulla, all of which receive only sympathetic fibers (Table 7.3). When both divisions serve the same organ they cause antagonistic effects, mainly because their postganglionic axons release different neurotransmitters (see Figure 7.24). The parasympathetic fibers, called *cholinergic* (ko″lin-er′jik) *fibers,* release acetylcholine. The sympathetic postganglionic fibers, called *adrenergic* (ad″ren-er′jik) *fibers,* release norepinephrine (nor″ep-ĭ-nef′rin). The preganglionic

TABLE 7.3   Effects of the Sympathetic and Parasympathetic Divisions of the Autonomic Nervous System

Target organ/system	Parasympathetic effects	Sympathetic effects
Digestive system	Increases smooth muscle mobility (peristalsis) and amount of secretion by digestive system glands; relaxes sphincters	Decreases activity of digestive system and constricts digestive system sphincters (for example, anal sphincter)
Liver	No effect	Causes glucose to be released to blood
Lungs	Constricts bronchioles	Dilates bronchioles
Urinary bladder/urethra	Relaxes sphincters (allows voiding)	Constricts sphincters (prevents voiding)
Kidneys	No effect	Decreases urine output
Heart	Decreases rate; slows and steadies	Increases rate and force of heartbeat
Blood vessels	No effect on most blood vessels	Constricts blood vessels in viscera and skin (dilates those in skeletal muscle and heart); increases blood pressure
Glands—salivary, lacrimal	Stimulates; increases production of saliva and tears	Inhibits; result is dry mouth and dry eyes
Eye (iris)	Stimulates constrictor muscles; constricts pupils	Stimulates dilator muscles; dilates pupils
Eye (ciliary muscle)	Stimulates to increase bulging of lens for close vision	Inhibits; decreases bulging of lens; prepares for distant vision
Adrenal medulla	No effect	Stimulates medulla cells to secrete epinephrine and norepinephrine
Sweat glands of skin	No effect	Stimulates to produce perspiration
Arrector pili muscles attached to hair follicles	No effect	Stimulates; produces "goose bumps"
Penis	Causes erection due to vasodilation	Causes ejaculation (emission of semen)
Cellular metabolism	No effect	Increases metabolic rate; increases blood sugar levels; stimulates fat breakdown

axons of *both* divisions release acetylcholine. To emphasize the *relative* roles of the two arms of the ANS, we will focus briefly on situations in which each division is "in control."

Sympathetic Division   The **sympathetic division** is often referred to as the "fight-or-flight" system.

Its activity is evident when we are excited or find ourselves in emergency or threatening situations, such as being frightened by street toughs late at night. A pounding heart; rapid, deep breathing; cold, sweaty skin; a prickly scalp; and dilated eye pupils are sure signs of sympathetic nervous system activity. Under such conditions, the sympathetic

nervous system increases heart rate, blood pressure, and blood glucose levels; dilates the bronchioles of the lungs; and brings about many other effects that help the individual cope with the stressor. Dilation of blood vessels in skeletal muscles (so that one can run faster or fight better) and withdrawal of blood from the digestive organs (so that the bulk of the blood can be used to serve the heart, brain, and skeletal muscles) are other examples.

The sympathetic nervous system is working at full speed not only when you are emotionally upset, but also when you are physically stressed. For example, if you have just had surgery or run a marathon, your adrenal glands (activated by the sympathetic nervous system) would be pumping out epinephrine and norepinephrine (see Figure 7.24). The effects of sympathetic nervous system activation continue for several minutes until its hormones are destroyed by the liver. Thus, although sympathetic nerve impulses themselves may act only briefly, the hormonal effects they provoke linger. The wide-spread and prolonged effects of sympathetic activation help explain why we need time to "come down" after an extremely stressful situation.

The sympathetic division generates a head of steam that enables the body to cope rapidly and vigorously with situations that threaten homeostasis. Its function is to provide the best conditions for responding to some threat, whether the best response is to run, to see better, or to think more clearly.

⚠ Homeostatic Imbalance

Some illnesses or diseases are at least aggravated, if not caused, by excessive sympathetic nervous system stimulation. Certain individuals, called Type A people, always work at breakneck speed and push themselves continually. These are people who are likely to have heart disease, high blood pressure, and ulcers, all of which may result from prolonged sympathetic nervous system activity or the rebound from it. ▲

Parasympathetic Division The **parasympathetic division** is most active when the body is at rest and not threatened in any way. This division, sometimes called the "resting-and-digesting" system, is chiefly concerned with promoting normal digestion and elimination of feces and urine and with conserving body energy, particularly by decreasing demands on the cardiovascular system. (This explains why it is a good idea to relax after a heavy meal so that digestion is not inhibited or disturbed by sympathetic activity.) Its activity is best illustrated by a person who relaxes after a meal and reads the newspaper. Blood pressure and heart and respiratory rates are being regulated at low normal levels, the digestive tract is actively digesting food, and the skin is warm (indicating that there is no need to divert blood to skeletal muscles or vital organs). The eye pupils are constricted to protect the retinas from excessive damaging light, and the lenses of the eyes are "set" for close vision. We might also consider the parasympathetic division as the "housekeeping" system of the body.

An easy way to remember the most important roles of the two ANS divisions is to think of the parasympathetic division as the **D** (digestion, defecation, and diuresis [urination]) division and the sympathetic division as the **E** (exercise, excitement,

Prove It Yourself

Improve Your Memory

Can you improve your ability to learn and remember new information? Yes! The following techniques take advantage of the brain's storage and retrieval mechanisms:

- **Concentrate.** This may seem obvious, but paying attention increases brain activity and epinephrine levels, thereby promoting consolidation of information into long-term memory.
- **Minimize interference.** Go where it is quiet. A noisy environment will impair your ability to concentrate.
- **Break down large amounts of information into smaller topics.** Give yourself time to review each topic, and take a break in between.
- **Rephrase material in your own words.** Restate the information in a way that makes sense to you personally.
- **Test yourself.** Create outlines or diagrams. Try to define key terms before looking up their definitions. Use practice and review questions when they are available.

Short-term memory involves quick bursts of action potentials. Every time you read, think about, or test yourself on a concept, more neurons fire. By studying new material actively and repeatedly, you trigger additional action potentials and improve long-term retention because the neural synapses are reinforced by use.