PART 1

General Principles of the Nervous System

CHAPTER 1

Introduction to the Nervous System

The human nervous system is an extremely efficient, compact, fast, and reliable computing system, yet it weighs substantially less than most computers and performs at an incredibly greater capacity. It has the capability of performing tasks that are far beyond the abilities of any computer yet devised. The present textbook discusses not only the anatomy of the central nervous system but also its function. In case the reader wonders why one should study neuroanatomy, it should be recalled that it is our central nervous system more than anything else about us that makes us what we are, human beings.

The nervous system is subdivided, *morphologically,* into two compartments, the **central nervous system** (**CNS**) and the **peripheral nervous system** (**PNS**). The CNS is composed of the brain and spinal cord whereas the PNS is composed of cranial and spinal nerve fibers and ganglia, and emanates from and is a physical extension of the CNS. *Functionally*, the nervous system is also subdivided into two components, the **somatic nervous system**, which is under the individual's conscious control, and the **autonomic nervous system**, which controls the myriad of activities in conjunction with the voluntary nervous system. The autonomic nervous system is a tripartite organization, in that it has a **sympathetic**, a **parasympathetic**, and an **entreric** component. Simply stated, the first initiates the "flight or fight or freeze" response, the second is concerned with the body's vegetative activities, whereas the enteric nervous system is involved in regulating the process of digestion. It must be understood, however, that the interplay of these three systems maintains **homeostasis**. The autonomic nervous system acts upon three cell types to perform its functions, namely cells of glands, smooth muscle, and cardiac muscle. Moreover, the nervous system has two other functional components, **sensory** and **motor**. The sensory component collects information and transmits it to the CNS (and is therefore called **afferent**), where the information is sorted, analyzed, and processed. Generally speaking, the motor component delivers the results of the analysis away from the CNS (and is therefore called **efferent**) to the effector organs, that is, muscles (all three types: skeletal, smooth, and cardiac) and glands, resulting in a response to the stimulus.

Discussion of the topics of neuroanatomy requires that the student be familiar with some of the specialized terminology

A Textbook of Neuroanatomy, Second Edition. Maria A. Patestas and Leslie P. Gartner

Terms	Definition
Arcuate	Arc-like, resembles a segment of a circle
Bilateral	On both sides
Brainstem	Originally this term referred to the entire brain with the exception of the telencephalon; most neuroanatomists refer to the medulla oblongata, pons, and midbrain as the brainstem
Caudal	Toward the tail (proceeding to a lower position; the opposite of rostral)
Column	A large bundle (also funiculus) of ascending or descending nerve fibers, composed of several different fasciculi (e.g., dorsal column of the white matter of the spinal cord)
Commissure	A bundle of nerve fibers that run horizontally, connecting the right and left sides of the central nervous system (e.g., anterior commissure)
Contralateral	The opposite side (e.g., in many instances the right side of the brain receives information from and controls the left side, *contralateral*, of the body
Cortex	The periphery of a structure; the opposite of medulla
Decussation	The level in the central nervous system where paired fiber tracts cross from one side of the body to the other (e.g., pyramidal decussation)
Exteroceptor	A sensory receptor that provides information to the central nervous system concerning the external environment
Fasciculus	A bundle (also tract) of ascending or descending nerve fibers within the central nervous system (e.g., fasciculus cuneatus)
Fiber	A long, thin structure; refers to an axon or a collection of axons
Fovea	A depression or a pit (e.g., fovea centralis of the retina)
Funiculus	A large bundle (also column) of ascending or descending nerve fibers, composed of several different fasciculi (e.g., dorsal funiculus of the white matter of the spinal cord)
Ganglion	A collection of nerve cell bodies in the peripheral nervous system (although it is used occasionally in reference to a collection of nerve cell bodies in the central nervous system, e.g., basal ganglia)
Glomerulus	Structures with a spherical configuration (e.g., synaptic glomeruli in the olfactory bulb)
Infundibulum	A funnel-like structure (e.g., infundibulum of the hypophysis)
Interoceptor	A sensory receptor that provides information to the central nervous system concerning the body's internal environment
Ipsilateral	The same side (e.g., in some instances the right side of the brain receives information from and controls the right side, *ipsilateral*, of the body)
Lamina	A layer of a specific material such as the layering of nerve cell bodies in the spinal cord
Myelin	A fatty substance that surrounds certain axons; composed of spiral layers of the cell membranes of Schwann cells (in the peripheral nervous system) and of oligodendroglia (in the central nervous system)
Neurite	A collective term for axons and dendrites
Neuropil	A complex of axons, dendrites, and processes of neuroglia that form a web-like network between nerve cell bodies of the gray matter
Nucleus	Core; in a cell it is the region of the cell that houses the chromosomes; in the central nervous system it is a collection of nerve cell bodies
Operculum	A cover or lid (e.g., parietal operculum of the cerebrum that overhangs and partially masks the insula)
Peduncle	A massive collection of nerve fiber bundles that connect the cerebrum and the cerebellum to the brainstem
Perikaryon	The cell body of a neuron (i.e., a neuron without its dendrites and axon); also referred to as soma
Plexus	The interwoven arrangements of nerve fibers that serve a specific region (e.g., brachial plexus, L. "braid")
Project	When one group of nerve cells relay their information to a second group of nerve cells, it is said that the first group "projects" to the second group (e.g., the hippocampal formation projects to the hypothalamus)
Proprioceptor	Sensory nerve endings in muscles, joints, and tendons that inform the central nervous system concerning the position and movements of the regions of the body in space (e.g., muscle spindle)
Raphe	A seam or midline structure (e.g., raphe nuclei of the reticular formation)
Rostral	Toward the nose (proceeding toward a higher position; the opposite of caudal)
Tract	A bundle (also fasciculus) of ascending or descending nerve fibers within the central nervous system (e.g., tractus solitarius)

Table 1.1 ● Common terms in neuroanatomy.

of the subject matter. One of the problems that students have in studying neuroanatomy is that there may be numerous terms applied to the same or similar structures. It is important, therefore, to begin the discussion of this subject matter by listing and defining in Table 1.1 some, but not all, of the terminology the student will encounter.

CELLS OF THE CENTRAL NERVOUS SYSTEM

Neurons

Neurons are the functional units of the central nervous system

The functional unit of the nervous system is the cell known as the **neuron**. Although there are several types of neurons (detailed in Chapter 3) they all have similar structures and functions. Most important is that neurons are specialized in that they are capable of receiving, conducting, and transmitting impulses to each other as well as to muscle cells and cells of glands. Neurons have processes known as **dendrites** and usually that is where they receive information. They also have a single process, known as an **axon**, and it is via that single process that they transmit information to other neurons and to effector organs. Thus dendrites conduct information toward the **cell body**, whereas axons conduct information away from the cell body. Neurons usually communicate with each other as well as with other cells at **synapses**, where **neurotransmitter substances** are released from the axon terminal of the first neuron and bind to receptor molecules on the surface of the second neuron (or muscle/gland cell). Neurons may also communicate with each other via **gap junctions** which are exceptionally small aqueous pores in the cell membranes of each of two adjacent cells. These pores are aligned with each other in such a way that they permit the movement of small secondary messenger molecules from the cytoplasm of one cell (the **signaling cell**) into the cytoplasm of the neighboring cell (the **target cell**), initiating a requisite response in the target cell.

Neuroglia

Neuroglia constitute several categories of non-neuronal cells, namely microglia, macroglia, and ependymal cells

Additional cells, known as **neuroglia**, constitute several categories of non-neuronal supporting cells. Those in the central nervous system are known as **ependymal cells**, **macroglia**, and **microglia**. The first two are derived from cells of the neural tube, whereas microglia are **macrophages** whose origins are monocyte precursors of the bone marrow.

Ependymal cells form a simple cuboidal epithelium that lines the central canal of the spinal cord and the ventricles of the brain. Additionally, these cells also participate in the formation of the choroid plexus, vascular tufts of tissue that manufacture cerebrospinal fluid. **Macroglia** is a collective term for the protoplasmic astrocytes, fibrous astrocytes, and oligodendroglia. **Protoplasmic astrocytes** support neurons in the gray matter, form a subpial barrier, and envelop capillaries of the CNS. **Fibrous astrocytes** are located in the white matter and appear to function in a similar fashion to protoplasmic astrocytes. Astrocytes also function in scavenging ions and neurotransmitter substances from the extracellular spaces. They also assist neurons in their role of transmitting impulses from one neuron to the other by regulating the presence of neurotransmitter substances as well as releasing **gliotransmitter substances** (e.g., ATP and glutamate that appear to restrain synaptic transmission) in the vicinity of synapses.

Oligodendroglia form myelin sheaths around axons and also surround dendrites and cell bodies of neurons in the CNS. **Schwann cells** are located in the PNS and they function in forming myelin around axons of the PNS. They also envelop unmyelinated axons.

CENTRAL NERVOUS SYSTEM

The central nervous system is composed of the large, anteriorly situated brain and smaller, cylindrically shaped spinal cord

The **central nervous system** is a complex, hollow tube, whose rostral end, the **brain**, is enlarged and folded in an elaborate manner, whereas its caudal end, the **spinal cord**, is a long, tubular structure (Fig. 1.1). The brain is housed in the cranial cavity and, at the foramen magnum, is continuous with the spinal cord, which is housed in the vertebral canal. The **dorsal** surface of the spinal cord is closer to the spinous processes of the vertebrae, whereas its **ventral** surface is closer to the bodies of the vertebrae. Since the CNS, as well as most of the body, is bilaterally symmetrical, the **sagittal** (midsagittal, according to some) plane bisects it into right and left halves. Positioning toward the sagittal plane is considered to be the **medial** direction and away from the sagittal plane is the **lateral** direction.

Brain

The brain is subdivided into five regions: the telencephalon, diencephalon, mesencephalon, metencephalon, and myelencephalon

The **brain** is subdivided into five major regions, the largest being the **telencephalon**, which is composed of the cerebral hemispheres. The other four regions are: the **diencephalon**, whose component parts are the epithalamus, thalamus, hypothalamus, and subthalamus; the **mesencephalon**, consisting of the cerebral peduncles (tegmentum and crus cerebri) and the tectum (superior and inferior colliculi); the **metencephalon**, including the pons and cerebellum; and the **myelencephalon** (medulla oblongata). Frequently the medulla oblongata, mesencephalon, and the pons are collectively termed the **brainstem**. The lumen of the CNS is a narrow slit, which is known as the **central canal** in the spinal cord. However, the lumen is expanded into a system of **ventricles** in the brain and these ventricles are filled with cerebrospinal fluid. Twelve pairs of cranial nerves emerge from the brain to supply motor, sensory, parasympathetic innervation, and proprioceptive information for the head and neck and much of the viscera of the body.

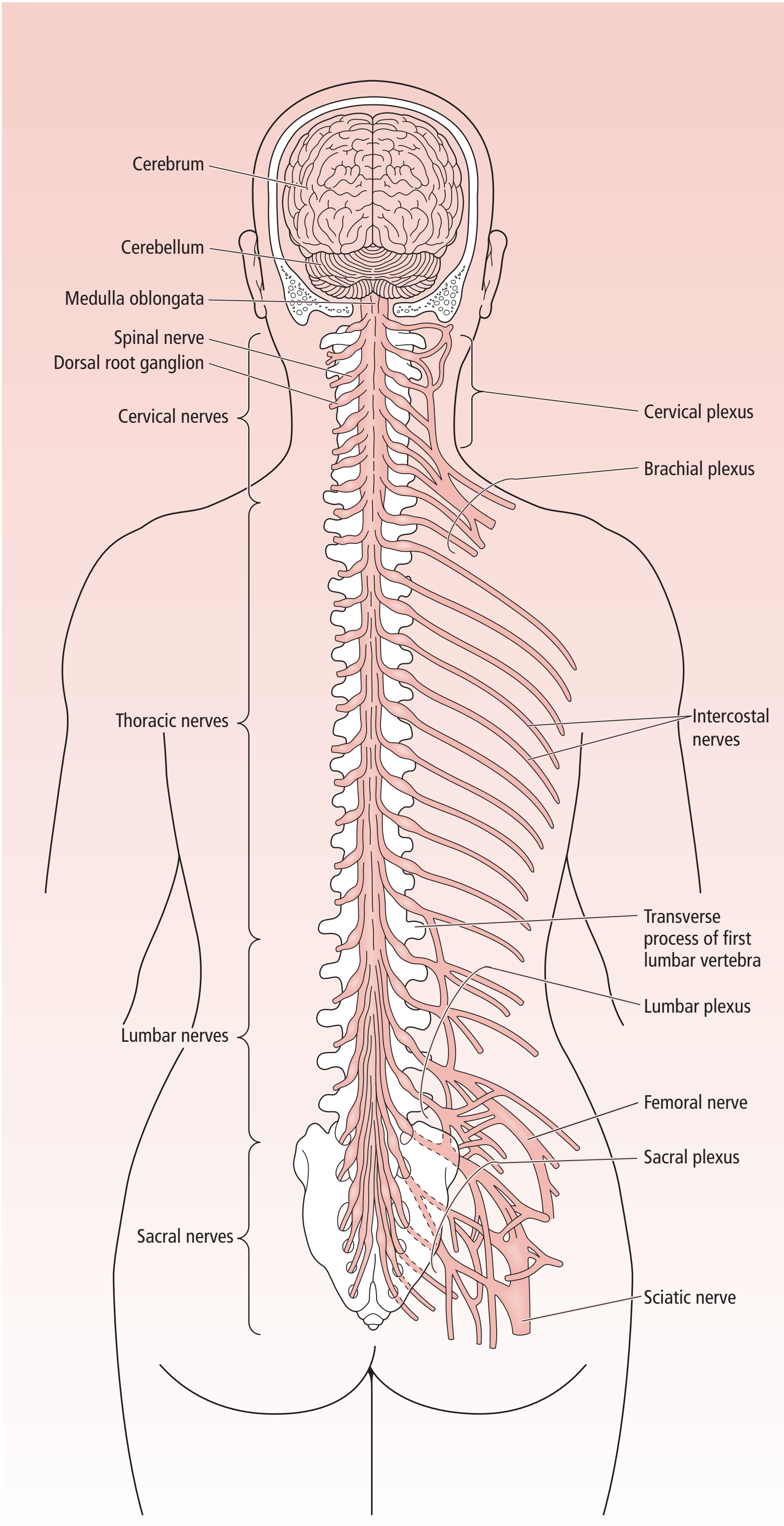

Figure 1.1 ● The brain, spinal cord, spinal nerves, and major somatic plexuses. Note that the back of the skull as well as the spinal processes of the vertebrae have been removed and that the dura mater and the arachnoid have been opened up so that the spinal cord may be viewed in its entire length.

Spinal cord

The spinal cord is a cylindrical structure whose neurons are arranged in such a fashion that the motor functions are ventrally positioned and the sensory functions are dorsally positioned

The **spinal cord** (Fig. 1.2) is concentric more or less cylindrical aggregate of nervous tissue, where a cylinder of white matter surrounds a central cylinder of gray matter. The neurons of the spinal cord are arranged in such a fashion that those concerned with somatic motor function are located in the **ventral horn** and their axons leave via the ventral rootlets. These are accompanied by axons of the preganglionic sympathetic neurons, located in the **lateral horn** of the spinal cord in all the thoracic and upper two or three lumbar segments, and axons of preganglionic parasympathetic neurons located in the lateral horn of the sacral spinal cord. The **dorsal horn** of the spinal cord is the location where central processes of unipolar neurons of dorsal root ganglia enter the spinal cord via dorsal rootlets bringing sensory information to the CNS. **Interneurons** connect two types of neurons to each other (e.g., unipolar sensory neurons of the dorsal root ganglia to motor neurons of the ventral horn). Thus, interneurons have the capability of facilitating or inhibiting a motor response to a sensory stimulus. For example, if one pricks one's finger the reflex response is to pull the finger away from the offending stimulus; however, if a health professional sticks one's finger for a blood test, the interneuron, receiving that information from higher levels in the central nervous system, inhibits the withdrawal of the finger.

The white matter of the spinal cord is composed of ascending and descending tracts of nerve fibers that connect regions of the CNS to each other. Ventral and dorsal roots at each level of the spinal cord join one another to form the spinal nerves that leave the spinal cord at regular intervals, a condition that is indicative of its segmentation. Each dorsal root displays a swelling, a dorsal root ganglion, housing the soma of the unipolar (pseudounipolar) neurons.

Gray matter and white matter

Gray matter is composed of neuron cell bodies, clusters of which within the CNS are known as nuclei; white matter is recognized by the presence of myelinated axons

The nerve cell bodies of the CNS are grouped into large aggregates, known as **gray matter**. Gray matter may be arranged into multilayered sheaths, as in the **cerebral cortex**, or as a smaller collection of nerve cell bodies, known as a **nucleus** (or occasionally, and technically incorrectly, a ganglion, e.g., basal ganglia). There are two major categories of neurons, (1) those whose axons leave the CNS and (2) those whose axons remain within the CNS. The first group, called **principal cells** by some neuroanatomists, are generally motoneurons (somatic or autonomic); the second group, known as **interneurons** relay information from one neuron (or one group of neurons) to a second neuron (or second group of neurons) within the CNS (e.g., the interneuron of a reflex arc).

White matter is composed of neuroglia and processes of neurons, many of whose axons are wrapped in a myelin

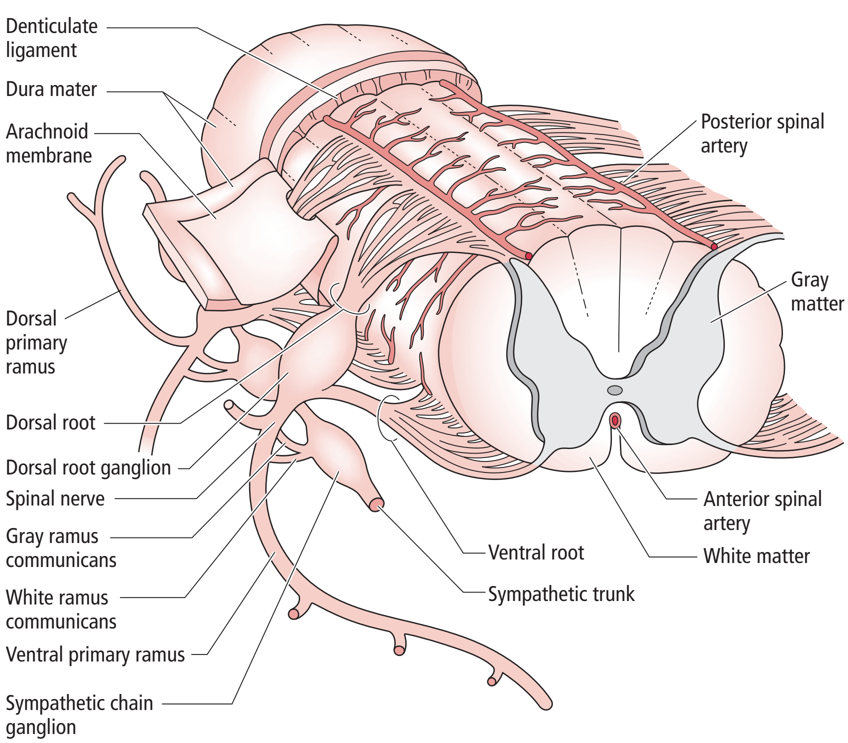

Figure 1.2 ● The spinal cord, its meninges, spinal nerves, and sympathetic chain ganglia.

sheath, which in a living individual has a white color. These axons are collected into small bundles, known as **fasciculi**, or large bundles, called **funiculi** (L. *funiculus*, "cord"). Certain larger fiber bundles are named **tracts**, **brachia** (L. armlike processes), **peduncles** (foot-like processes) or **capsules**, whereas axons that cross the midline to connect identical structures on opposing sides are known as **commissures**. The most massive commissure of the CNS is the **corpus callosum**, which connects the two cerebral hemispheres of the brain**.** Axons that travel up or down the CNS and cross the midline from one side to the other are said to **decussate** at the point of crossing over.

PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system is a continuation of the CNS; it is composed of clusters of nerve cell bodies, known as ganglia, as well as of bundles of axons and central processes, known as nerves

The **peripheral nervous system** is composed of cranial nerves, spinal nerves, their associated ganglia, and nerve fibers and ganglia of the autonomic nervous system. It must be understood that the PNS is in physical continuity with the CNS, in fact cell bodies of many of the nerve fibers (axons) of the PNS are located in the CNS.

Somatic nervous system

The somatic nervous system is composed of the 12 pairs of cranial nerves and their ganglia as well as of the 31 pairs of spinal nerves and their dorsal root ganglia

There are 12 pairs of cranial nerves, identified both by name as well as by Roman numerals I through XII. All cranial nerves, with the exception of the vagus (CN X), serve structures in the head and neck only. The vagus nerve innervates structures in the head and neck, but also serves many of the thoracic and abdominal viscera, for example, the heart and alimentary tract. Those cranial nerves that have sensory components possess sensory ganglia housing the cell bodies of unipolar neurons whose single process bifurcates into a central and a peripheral process. The central process of a unipolar neuron enters the brain, whereas its peripheral process goes to a sensory receptor. There are no synapses occurring in these sensory ganglia.

There are 31 pairs of spinal nerves (8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal), attesting to the segmentation of the spinal cord (see Fig. 1.1). The cell bodies of sensory neurons (unipolar neurons) are located in the dorsal root ganglia (sensory ganglia). Again, it must be remembered that just as in the sensory ganglia of the cranial nerves there are *no synapses* occurring in the dorsal root ganglia. The single process of each neuron bifurcates and the short central process joins other central processes to form dorsal rootlets that enter the spinal cord. The peripheral process goes to a sensory receptor, which, when stimulated, causes depolarization of the peripheral process; the wave of depolarization spreads to the central process, which transmits the stimulus either to an interneuron (in a three neuron reflex arc) or to a motoneuron (in a two neuron reflex arc, e.g., the patellar reflex). Although this description is true for reflex arcs, it must be realized that in most instances the incoming information is transmitted to higher levels in the brain and is processed either cognitively or subconsciously, or both, rather than just relying on simple spinal reflex phenomena which do not involve the brain. These motoneurons are multipolar neurons whose cell bodies are located in the ventral horn of the spinal cord and serve *skeletal muscle cells only*. Their axons leave via the ventral rootlets that join the dorsal rootlets to form the **spinal nerve**.

Each spinal nerve bifurcates to form a smaller **dorsal primary ramus** and a larger **ventral primary ramus**. Dorsal primary rami supply sensory and motor innervation to the back, whereas ventral primary rami supply the lateral and anterior portion of the trunk. Ventral rami that supply the thorax and abdomen usually remain as separate nerves, whereas those of the cervical and lumbosacral regions join each other to form **plexuses** from which individual nerve bundles arise to serve the head, neck (cervical plexus), and upper and lower extremities (cervical and lumbosacral plexuses). Each spinal nerve receives sensory information from the skin of the segment, or **dermatome**, of the body that it serves. The entire body is mapped into a number of dermatomes; however, there are overlaps in the innervation, so that a single dermatome is supplied by more than one spinal nerve. Such overlaps prevent the total anesthesia of a particular dermatome if the dorsal rootlets of the spinal nerve supplying it are damaged.

Autonomic nervous system

The autonomic nervous system regulates the activities of smooth muscle, cardiac muscle, and glands, and is divided into three components: the sympathetic, parasympathetic, and enteric nervous systems

The autonomic nervous system is a motor system, but unlike somatic motoneurons, it does *not* serve skeletal muscle cells, instead it innervates visceral muscle (cardiac muscle cells, smooth muscle cells), and secretory cells of glands (see Chapter 10, Autonomic Nervous System). Additionally, whereas a somatic motoneuron **directly** innervates its muscle cell (Fig. 1.3), in the autonomic nervous system the neuron whose cell body is located in the CNS (**preganglionic** or **presynaptic neuron**) synapses with a second neuron (**postganglionic** or **postsynaptic neuron**) located in a ganglion in the PNS. It is the axon of the *postganglionic neuron* that synapses with the cardiac muscle cell, smooth muscle cell, or secretory cell of a gland. Thus the autonomic nervous system is said to be a two cell system, and synapses *always occur* within an autonomic ganglion (Fig. 1.3). The axon of the preganglionic neuron is myelinated and is known as the **preganglionic fiber**. The axon of the postganglionic neuron is not myelinated, and is known as the **postganglionic fiber**.

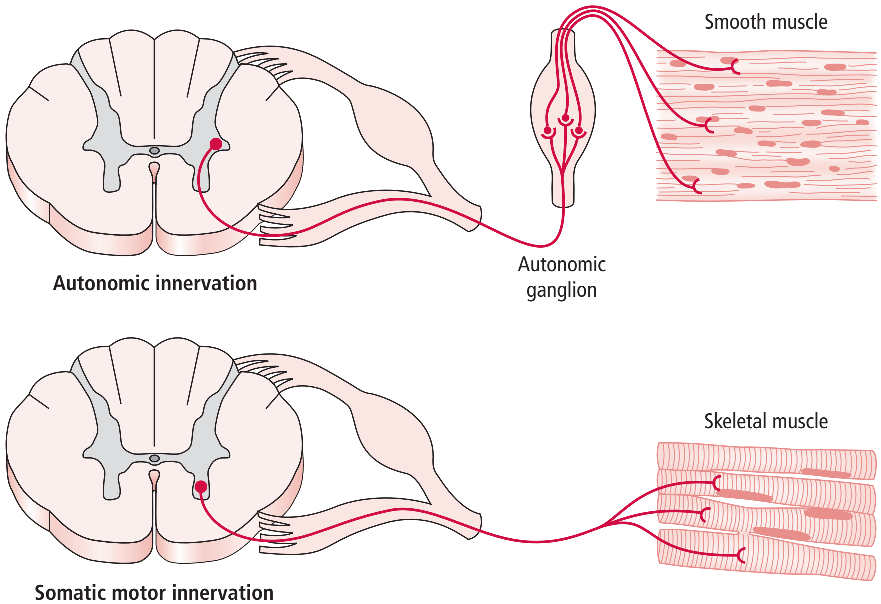

Figure 1.3 ● Diagram demonstrating the difference between autonomic innervation (top) and somatic motor innervation (bottom). Observe that two neurons are present in the autonomic supply, whereas a single motoneuron is present in the somatic motor system.

The autonomic nervous system is responsible for the maintenance of **homeostasis**, and is composed of three functional components: sympathetic, parasympathetic, and enteric. The **sympathetic** component prepares the body for "fight or flight or freeze," whereas the **parasympathetic** component prepares the body for a vegetative state (e.g., digestion). The **enteric nervous system** is situated completely within the wall of the digestive tract and controls the entire process of digestion. Although the sympathetic and parasympathetic components of the autonomic nervous system do modulate its activities, the enteric nervous system can function quite well on its own if the connections of the sympathetic and parasympathetic components are cut off from it.

Cell bodies of preganglionic sympathetic neurons are located in the lateral horn of the thoracic and upper lumbar spinal cord (T1 to L2, 3), whereas those of the preganglionic parasympathetic neurons are located in the brain (and their axons travel with CN III, VII, IX, and X) and the lateral horn of the sacral spinal cord (S2–S4). Postganglionic cell bodies of sympathetic neurons are usually located near the spinal cord, just lateral to the vertebral column; within the **sympathetic chain ganglia**; or a little farther away, in **collateral ganglia**. The cell bodies of *postganglionic parasympathetic neurons*, however, are located in ganglia that are in the vicinity of the viscera being innervated.

The cell bodies of the sensory neurons that supply the viscera are located in the dorsal root ganglia of spinal nerves or in the sensory ganglia of cranial nerves, along with the somatic sensory neurons. However, their peripheral processes accompany the preganglionic autonomic fibers into their respective ganglia, but do *not* synapse in those ganglia. Moreover, these peripheral fibers continue to accompany the postganglionic autonomic fibers to the same destinations. In spite of their route, these sensory neurons are *not* considered to be a part of the autonomic nervous system. Sensory information relayed by these autonomic sensory nerves are not registered as part of the conscious experience, and even pain sensations are experienced as "referred pain" in somatic regions of the body (e.g., **angina pectoris**, where pain sensations arising in the heart muscle are experienced as pressure in the chest, back, and arm, regions served by the same segmental spinal nerve).

QUESTIONS TO PONDER

1. What is the relationship between the central and peripheral nervous systems?

2. What is meant by the "fight or flight or freeze" response?

3. Why are there more oligodendroglia than neurons in the central nervous system?

4. What single characteristic is the major difference between microglia and the other neuroglia of the central nervous system?

5. What is the major difference between a two-neuron reflex arc and a three-neuron reflex arc, aside from the simplistic fact that one has an extra neuron associated with it?