Case Investigation

Sandra's grades have been improving, and she treats herself to dinner at a seafood restaurant. However, after just beginning to eat some mussels and clams gathered from the local seashore, she complains of severe muscle weakness. Paramedics are called, and when they examine Sandra, they notice that she has a droopy eyelid and that her purse contains a prescription bottle for an MAO inhibitor. When questioned, Sandra states that she had a recent Botox treatment, and the medication was prescribed to treat her clinical depression. Further investigation reveals that the shellfish were gathered from waters at the beginning of a red tide and that Sandra's blood pressure was in the normal range.

Some of the new terms and concepts you will encounter include:

- Voltage-gated channels and the action of saxitoxin
- Neurotransmitter release and the action of botulinum toxin
- Monoamine neurotransmitters and monoamine oxidase (MAO)

7.1 NEURONS AND SUPPORTING CELLS

The nervous system is composed of neurons, which produce and conduct electrochemical impulses, and supporting cells, which assist the functions of neurons. Neurons are classified functionally and structurally; the various types of supporting cells perform specialized functions.

LEARNING OUTCOMES

After studying this section, you should be able to:

- ✔ Describe the different types of neurons and supporting cells, and identify their functions.
- ✔ Identify the myelin sheath and describe how it is formed in the CNS and PNS.
- ✔ Describe the nature and significance of the blood-brain barrier.

The nervous system is divided into the **central nervous system (CNS),** which includes the brain and spinal cord, and the **peripheral nervous system (PNS),** which includes the *cranial nerves* arising from the brain and the *spinal nerves* arising from the spinal cord.

The nervous system is composed of only two principal types of cells—neurons and supporting cells. **Neurons** are the basic structural and functional units of the nervous system. They are specialized to respond to physical and chemical stimuli, conduct electrochemical impulses, and release chemical regulators. Through these activities, neurons enable the perception of sensory stimuli, learning, memory, and the control of muscles and glands. Most neurons cannot divide by mitosis, although many can regenerate a severed portion or sprout small new branches under certain conditions.

Supporting cells aid the functions of neurons and are about five times more abundant than neurons. In the CNS, supporting cells are collectively called **neuroglia,** or simply **glial cells** (from the Middle Greek *glia* = glue). Unlike neurons, which do not divide mitotically (except for particular neural stem cells; chapter 8, section 8.1), glial cells are able to divide by mitosis. This helps to explain why brain tumors in adults are usually composed of glial cells rather than of neurons.

Neurons

Although neurons vary considerably in size and shape, they generally have three principal regions: (1) a cell body, (2) dendrites, and (3) an axon (figs. 7.1 and 7.2). Dendrites and axons can be referred to generically as *processes,* or extensions from the cell body.

The **cell body** is the enlarged portion of the neuron that contains the nucleus. It is the "nutritional center" of the neuron where macromolecules are produced. The cell body and larger dendrites (but not axons) contain *Nissl bodies,* which are seen as dark-staining granules under the microscope. Nissl bodies are composed of large stacks of rough endoplasmic reticulum that are needed for the synthesis of membrane proteins. The cell bodies within the CNS are frequently clustered into groups called *nuclei* (not to be confused with the nucleus of a cell). Cell bodies in the PNS usually occur in clusters called *ganglia* (table 7.1).

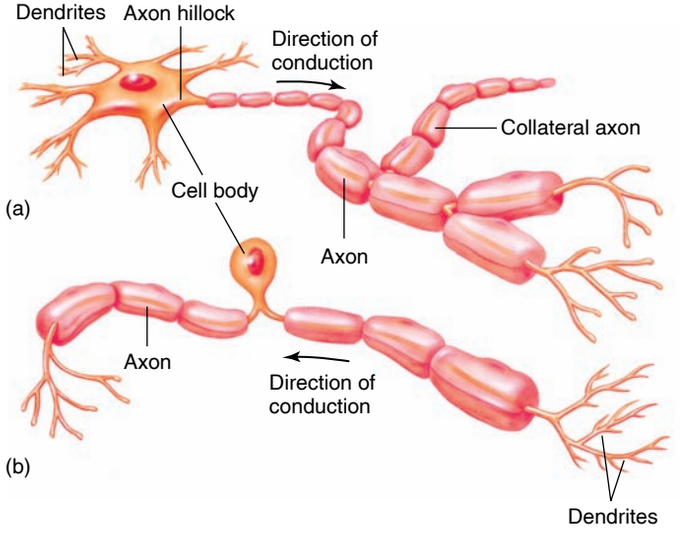

Figure 7.1 **The structure of two kinds of neurons.** A motor neuron (*a*) and a sensory neuron (*b*) are depicted here.

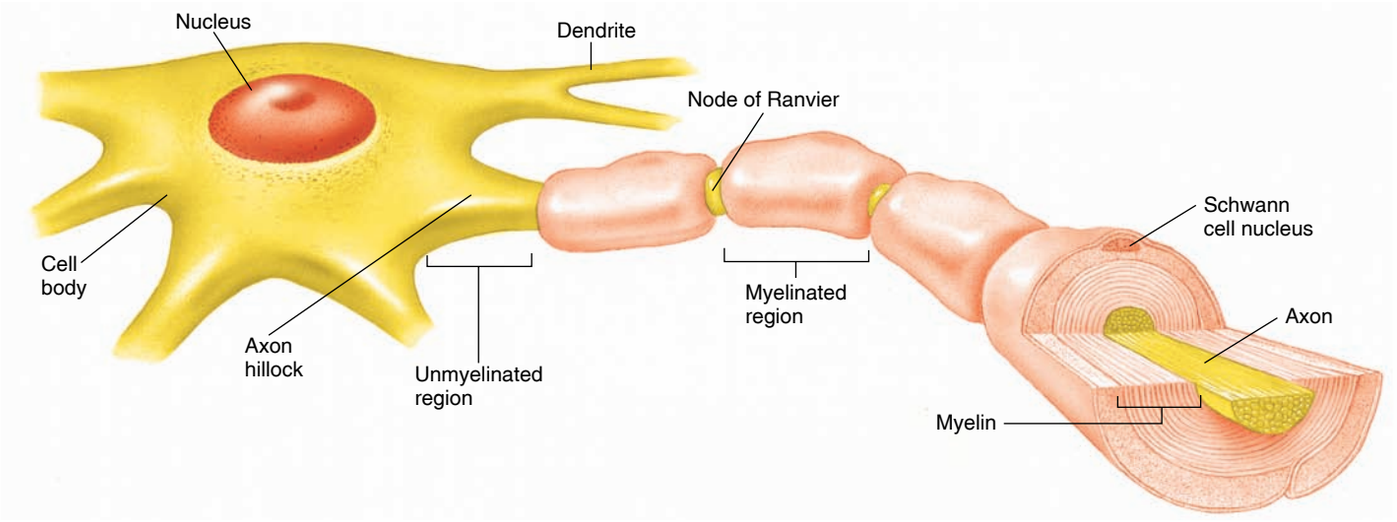

Figure 7.2 **Parts of a neuron.** The axon of this neuron is wrapped by Schwann cells, which form a myelin sheath.

Table 7.1 | Terminology Pertaining to the Nervous System

Term	Definition
Central nervous system (CNS)	Brain and spinal cord
Peripheral nervous system (PNS)	Nerves, ganglia, and nerve plexuses (outside of the CNS)
Association neuron (interneuron)	Multipolar neuron located entirely within the CNS
Sensory neuron (afferent neuron)	Neuron that transmits impulses from a sensory receptor into the CNS
Motor neuron (efferent neuron)	Neuron that transmits impulses from the CNS to an effector organ; for example, a muscle
Nerve	Cablelike collection of many axons in the PNS; may be "mixed" (contain both sensory and motor fibers)
Somatic motor nerve	Nerve that stimulates contraction of skeletal muscles
Autonomic motor nerve	Nerve that stimulates contraction (or inhibits contraction) of smooth muscle and cardiac muscle and that stimulates glandular secretion
Ganglion	Grouping of neuron cell bodies located outside the CNS
Nucleus	Grouping of neuron cell bodies within the CNS
Tract	Grouping of axons that interconnect regions of the CNS

Dendrites (from the Greek *dendron* = tree branch) are thin, branched processes that extend from the cytoplasm of the cell body. Dendrites provide a receptive area that transmits graded electrochemical impulses to the cell body. The **axon** is a longer process that conducts impulses, called *action potentials* (section 7.2), away from the cell body. Axons vary in length from only a millimeter long to up to a meter or more (for those that extend from the CNS to the foot). The origin of the axon near the cell body is an expanded region called the *axon hillock;* it is here that action potentials originate. Side branches called *axon collaterals* may extend from the axon.

Because axons can be quite long, special mechanisms are required to transport organelles and proteins from the cell body to the axon terminals. This **axonal transport** is energy-dependent and is often divided into a *fast component* and two *slow components*. The fast component (at 200 to 400 mm/day) mainly transports membranous vesicles (important for synaptic transmission, as discussed in section 7.3). One slow component (at 0.2 to 1 mm/day) transports microfilaments and microtubules of the cytoskeleton, while the other slow component (at 2 to 8 mm/day) transports over 200 different proteins, including those critical for synaptic function. The slow components appear to transport their cargo in fast bursts with frequent pauses, so that the overall rate of transport is much slower than that occurring in the fast component.

Axonal transport may occur from the cell body to the axon and dendrites. This direction is called **anterograde transport,** and involves molecular motors of *kinesin* proteins that move cargo along the microtubules of the cytoskeleton (chapter 3, section 3.2). For example, kinesin motors move synaptic vesicles, mitochondria, and ion channels from the cell body through the axon. Similar anterograde transport

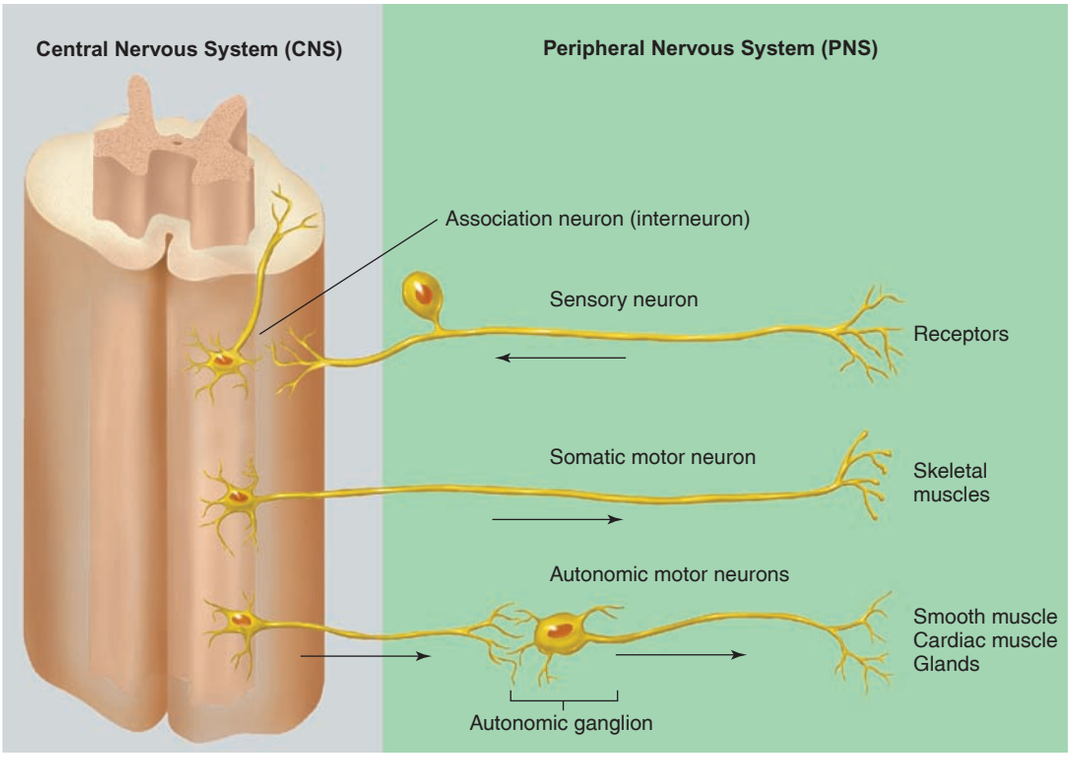

Figure 7.3 **The relationship between CNS and PNS.** Sensory and motor neurons of the peripheral nervous system carry information into and out of, respectively, the central nervous system (brain and spinal cord).

occurs in the dendrites, as kinesin moves postsynaptic receptors for neurotransmitters and ion channels along the microtubules in the dendrites.

By contrast, axonal transport in the opposite direction—that is, along the axon and dendrites toward the cell body—is known as **retrograde transport** and involves molecular motor proteins of *dyneins.* The dyneins move membranes, vesicles, and various molecules along microtubules of the cytoskeleton toward the cell body of the neuron. Retrograde transport can also be responsible for movement of herpes virus, rabies virus, and tetanus toxin from the nerve terminals into cell bodies.

Classification of Neurons and Nerves

Neurons may be classified according to their function or structure. The functional classification is based on the direction in which they conduct impulses, as indicated in figure 7.3. **Sensory,** or **afferent, neurons** conduct impulses from sensory receptors *into* the CNS. **Motor,** or **efferent, neurons** conduct impulses *out* of the CNS to effector organs (muscles and glands). **Association neurons,** or **interneurons,** are located entirely within the CNS and serve the associative, or integrative, functions of the nervous system.

There are two types of motor neurons: somatic and autonomic. **Somatic motor neurons** are responsible for both reflex and voluntary control of skeletal muscles. **Autonomic motor neurons** innervate (send axons to) the involuntary effectors—smooth muscle, cardiac muscle, and glands. The cell bodies of the autonomic neurons that innervate these organs are located outside the CNS in autonomic ganglia (fig. 7.3). There are two subdivisions of autonomic neurons: *sympathetic* and *parasympathetic.* Autonomic motor neurons, together with their central control centers, constitute the *autonomic nervous system,* the focus of chapter 9.

The structural classification of neurons is based on the number of processes that extend from the cell body of the neuron (fig. 7.4). **Pseudounipolar neurons** have a single short process that branches like a T to form a pair of longer processes. They are called pseudounipolar (from the Late Latin *pseudo* = false) because, although they originate with two processes, during early embryonic development their two processes converge and partially fuse. Sensory neurons are pseudounipolar—one of the branched processes receives sensory stimuli and produces nerve impulses; the other delivers these impulses to synapses within the brain or spinal cord. Anatomically, the part of the process that conducts impulses toward the cell body can be considered a dendrite, and the part that conducts impulses away from the cell body can be considered an axon. Functionally, however, the branched process behaves as a single, long axon that continuously conducts action potentials (nerve impulses). Only the small projections at the receptive end of the process function as typical dendrites, conducting graded electrochemical impulses rather than action potentials. **Bipolar neurons** have two processes, one at either end; this type is found in the retina of the eye. **Multipolar neurons,** the most

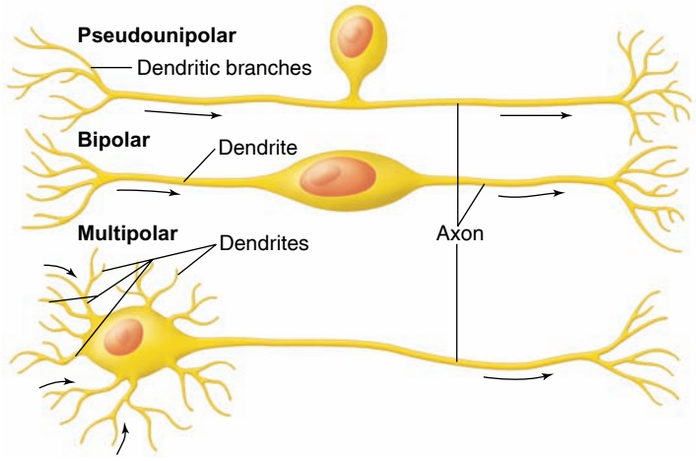

Figure 7.4 **Three different types of neurons.** Pseudounipolar neurons, which are sensory, have one process that splits. Bipolar neurons, found in the retina and cochlea, have two processes. Multipolar neurons, which are motor and association neurons, have many dendrites and one axon.

common type, have several dendrites and one axon extending from the cell body; motor neurons are good examples of this type.

A **nerve** is a bundle of axons located outside the CNS. Most nerves are composed of both motor and sensory fibers and are thus called *mixed nerves.* Some of the cranial nerves, however, contain sensory fibers only. These are the nerves that serve the special senses of sight, hearing, taste, and smell. A bundle of axons in the CNS is called a **tract.**

Supporting Cells

Unlike other organs that are "packaged" in connective tissue derived from mesoderm (the middle layer of embryonic tissue), most of the supporting cells of the nervous system are derived from the same embryonic tissue layer (ectoderm) that produces neurons. The term **neuroglia** (or **glia**) traditionally refers to the supporting cells of the CNS, but in current usage the supporting cells of the PNS are often also called glial cells.

There are two types of supporting cells in the peripheral nervous system:

1. **Schwann cells** (also called *neurolemmocytes*), which form myelin sheaths around peripheral axons; and
2. **satellite cells,** or **ganglionic gliocytes,** which support neuron cell bodies within the ganglia of the PNS.

There are four types of supporting cells in the central nervous system (fig. 7.5):

1. **oligodendrocytes,** which form myelin sheaths around axons of the CNS;
2. **microglia,** which migrate through the CNS and phagocytose foreign and degenerated material;
3. **astrocytes,** which help to regulate the external environment of neurons in the CNS; and
4. **ependymal cells,** which line the ventricles (cavities) of the brain and the central canal of the spinal cord.

Microglia are of hematopoietic (bone marrow) origin, and indeed can be replenished by monocytes (a type of leukocyte)

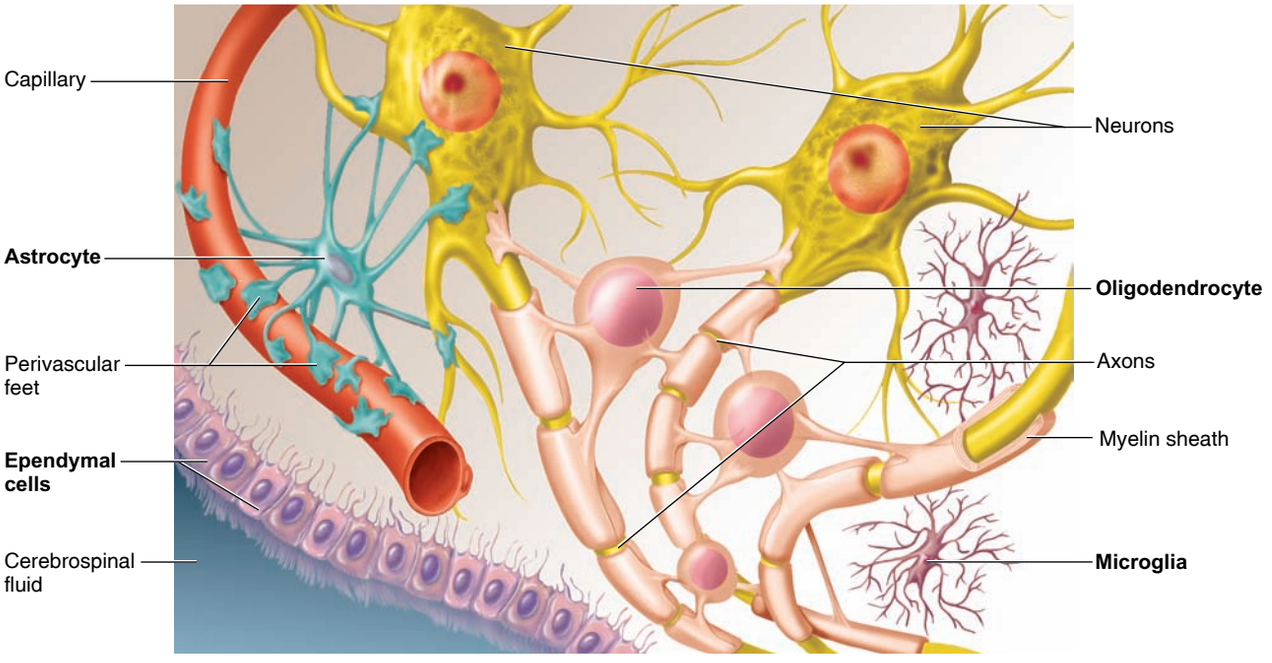

Figure 7.5 **The different types of neuroglial cells.** Myelin sheaths around axons are formed in the CNS by oligodendrocytes. Astrocytes have extensions that surround both blood capillaries and neurons. Microglia are phagocytic, and ependymal cells line the brain ventricles and central canal of the spinal cord.

Table 7.2 | Neuroglial Cells and Their Functions

Cell Type	Location	Functions
Schwann cells	PNS	Also called neurolemmocytes, produce the myelin sheaths around the myelinated axons of the peripheral nervous system; surround all PNS axons (myelinated and nonmyelinated) to form a neurilemmal sheath, or sheath of Schwann
Satellite cells	PNS	Support functions of neurons within sensory and autonomic ganglia; also called ganglionic gliocytes
Oligodendrocytes	CNS	Form myelin sheaths around central axons, producing "white matter" of the CNS
Microglia	CNS	Phagocytose pathogens and cellular debris in the CNS
Astrocytes	CNS	Cover capillaries of the CNS and induce the blood-brain barrier; interact metabolically with neurons and modify the extracellular environment of neurons
Ependymal cells	CNS	Form the epithelial lining of brain cavities (ventricles) and the central canal of the spinal cord; cover tufts of capillaries to form choroid plexuses—structures that produce cerebrospinal fluid

from the blood. They remove toxic debris within the brain and secrete anti-inflammatory factors, functions that are essential for the health of neurons. Yet their actions have a negative side; overactive microglial cells can release free radicals that promote oxidative stress (chapter 19, section 19.1) and thereby contribute to neurodegenerative diseases. The functions of the other supporting cells are described in detail in the next sections and are summarized in table 7.2.

Neurilemma and Myelin Sheath

All axons in the PNS (myelinated and unmyelinated) are surrounded by a continuous living sheath of Schwann cells, known as the **neurilemma,** or **sheath of Schwann.** The axons of the CNS, by contrast, lack a neurilemma (Schwann cells are found only in the PNS). This is significant in terms of regeneration of damaged axons, as will be described shortly.

Some axons in the PNS and CNS are surrounded by a **myelin sheath.** In the PNS, this insulating covering is formed by successive wrappings of the cell membrane of Schwann cells; in the CNS, it is formed by oligodendrocytes. Those axons smaller than 2 micrometers (2 μm) in diameter are usually *unmyelinated* (have no myelin sheath), whereas those that are larger are likely to be *myelinated.* Myelinated axons conduct impulses more rapidly than those that are unmyelinated.

Myelin Sheath in PNS

In the process of myelin formation in the PNS, Schwann cells roll around the axon, much like a roll of electrician's tape is wrapped around a wire. Unlike electrician's tape, however, the Schwann cell wrappings are made in the same spot, so that each wrapping overlaps the previous layers. The number of times the Schwann cells wrap themselves around the axon, and thus the number of layers in the myelin sheath, is greater for thicker than for thinner axons.

The cytoplasm, meanwhile, is forced into the outer region of the Schwann cell, much as toothpaste is squeezed to the top of the tube as the bottom is rolled up (fig. 7.6). Each Schwann cell wraps only about a millimeter of axon, leaving gaps of exposed axon between the adjacent Schwann cells. These gaps in the myelin sheath are known as the **nodes of Ranvier.** The successive wrappings of Schwann cell membrane provide insulation around the axon, leaving only the nodes of Ranvier exposed to produce nerve impulses.

The Schwann cells remain alive as their cytoplasm is forced to the outside of the myelin sheath. As a result, myelinated axons of the PNS are surrounded by a living sheath of Schwann

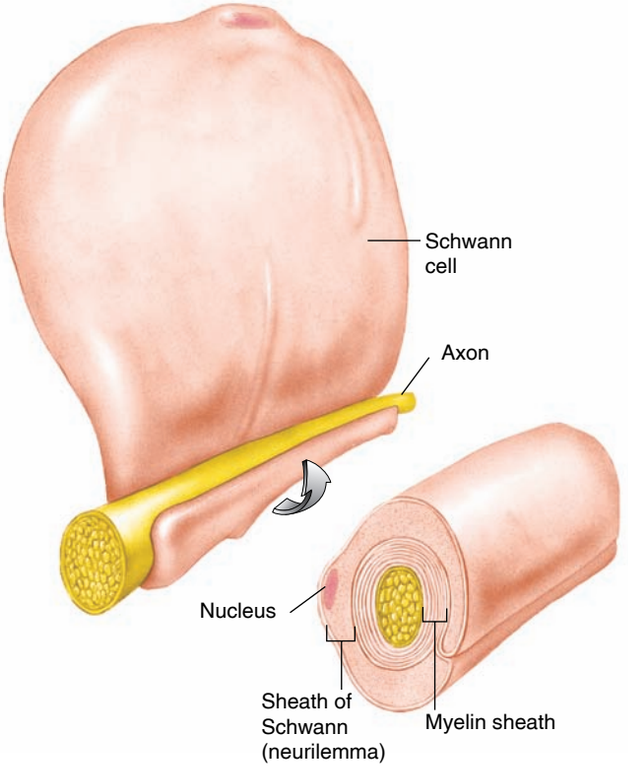

Figure 7.6 The formation of a myelin sheath around a peripheral axon. The myelin sheath is formed by successive wrappings of the Schwann cell membranes, leaving most of the Schwann cell cytoplasm outside the myelin. The sheath of Schwann is thus external to the myelin sheath.

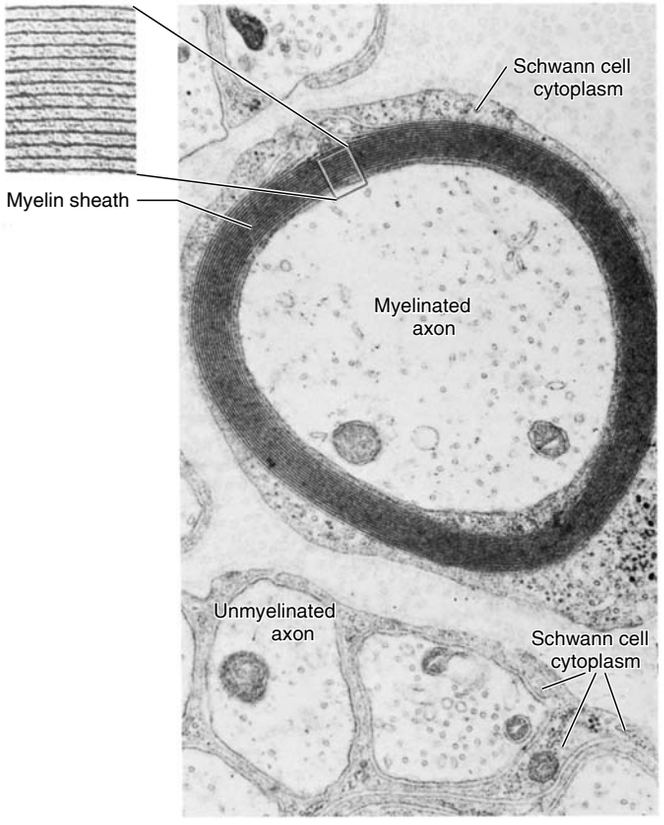

Figure 7.7 **An electron micrograph of unmyelinated and myelinated axons.** Notice that myelinated axons have Schwann cell cytoplasm to the outside of their myelin sheath, and that Schwann cell cytoplasm also surrounds unmyelinated axons.

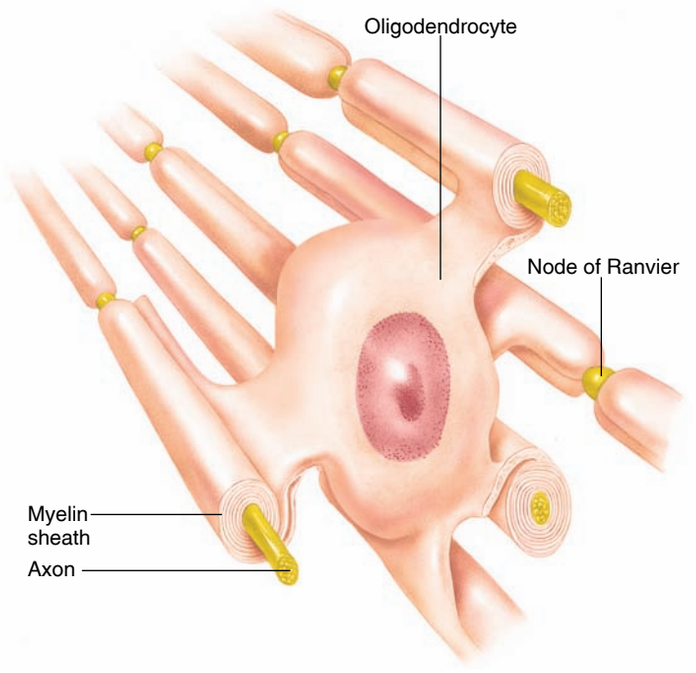

Figure 7.8 **The formation of myelin sheaths in the CNS by an oligodendrocyte.** One oligodendrocyte forms myelin sheaths around several axons.

cells, or neurilemma (fig. 7.7). Unmyelinated axons are also surrounded by a neurilemma, but they differ from myelinated axons in that they lack the multiple wrappings of Schwann cell plasma membrane that compose the myelin sheath.

Myelin Sheath in CNS

As mentioned earlier, the myelin sheaths of the CNS are formed by oligodendrocytes. This process occurs mostly postnatally (after birth). Unlike a Schwann cell, which forms a myelin sheath around only one axon, each oligodendrocyte has extensions, like the tentacles of an octopus, that form myelin sheaths around several axons (fig. 7.8). The myelin sheaths around axons of the CNS give this tissue a white color; areas of the CNS that contain a high concentration of axons thus form the **white matter.** The **gray matter** of the CNS is composed of high concentrations of cell bodies and dendrites, which lack myelin sheaths.

Regeneration of a Cut Axon

When an axon in a peripheral nerve is cut, the distal portion of the axon that was severed from the cell body degenerates and is phagocytosed by Schwann cells. The Schwann cells, surrounded by the basement membrane, then form a *regeneration tube* (fig. 7.9) as the part of the axon that is connected to the cell body begins to grow and exhibit amoeboid movement. The Schwann cells of the regeneration tube are believed to secrete chemicals that attract the growing axon

CLINICAL APPLICATION

Multiple sclerosis (MS) is a common neurological disease, usually diagnosed in people (most often women) between the ages of 20 and 40. It is a chronic disease, remitting and relapsing with progressively advancing symptoms that are highly variable; these include sensory impairments, motor dysfunction and spasticity, bladder and intestinal problems, fatigue, and others. Infiltration of the CNS with lymphocytes (particularly T cells; chapter 15) and immune attack of self-antigens leads to degeneration of oligodendrocytes and myelin sheaths, which can develop hardened *scleroses,* or scars (from the Greek *sklerosis* = hardened) followed by axonal degeneration. Thus, MS is believed to be an autoimmune disease (chapter 15, section 15.6). Because this degeneration is widespread and affects different areas of the nervous system in different people, MS has a wider variety of symptoms than any other neurological disease. The causes of MS are not fully understood, but are believed to involve a number of genes that affect a person's susceptibility to environmental agents (such as viruses) that may trigger an immune attack on self-antigens in the CNS.

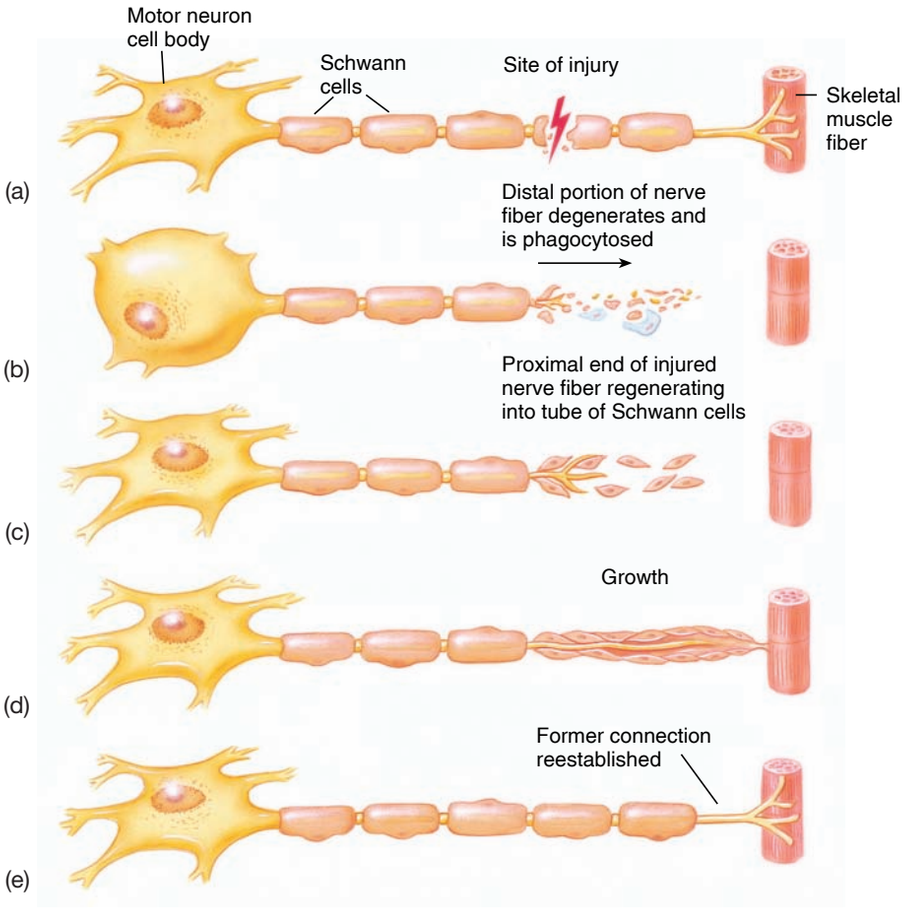

Figure 7.9 **The process of peripheral neuron regeneration.** (*a*) If a neuron is severed through a myelinated axon, the proximal portion may survive, but (*b*) the distal portion will degenerate through phagocytosis. The myelin sheath provides a pathway (*c*) and (*d*) for the regeneration of an axon, and (*e*) innervation is restored.

tip, and the regeneration tube helps guide the regenerating axon to its proper destination. Even a severed major nerve may be surgically reconnected—and the function of the nerve largely reestablished—if the surgery is performed before tissue death occurs.

After spinal cord injury, some neurons die as a direct result of the trauma. However, other neurons and oligodendrocytes in the region die later because they produce "death receptors" that promote apoptosis (cell suicide; chapter 3, section 3.5). Injury in the CNS stimulates growth of axon collaterals, but central axons have a much more limited ability to regenerate than peripheral axons. Regeneration of CNS axons is prevented, in part, by inhibitory proteins in the membranes of the myelin sheaths. Also, regeneration of CNS axons is prevented by a glial scar that eventually forms from astrocytes. This glial scar physically blocks axon regeneration and induces the production of inhibitory proteins.

Three growth-inhibiting proteins, produced by oligodendrocytes, have been identified to date. These include glycoproteins that are associated with the myelin sheaths of CNS axons. These molecules inhibit the growth of a severed axon by binding to a receptor (called the *Nogo* receptor) on the axon.

Surprisingly, Schwann cells in the PNS also produce myelin proteins that can inhibit axon regeneration. However, after axon injury in the PNS, the fragments of old myelin are rapidly removed (through phagocytosis) by Schwann cells and macrophages. Also, quickly after injury the Schwann cells stop producing the inhibitory proteins. The rapid changes in Schwann cell function following injury (fig. 7.9) create an environment conducive to axon regeneration in the PNS.

Neurotrophins

In a developing fetal brain, chemicals called **neurotrophins** promote neuron growth. *Nerve growth factor (NGF)* was the first neurotrophin to be identified; others include *brain-derived neurotrophic factor (BDNF); glial-derived neurotrophic factor (GDNF); neurotrophin-3;* and *neurotrophin-4/5*

(the number depends on the animal species). NGF and neurotrophin-3 are known to be particularly important in the embryonic development of sensory neurons and sympathetic ganglia.

Neurotrophins also have important functions in the adult nervous system. NGF is required for the maintenance of sympathetic ganglia, and there is evidence that neurotrophins are required for mature sensory neurons to regenerate after injury. In addition, GDNF may be needed in the adult to maintain spinal motor neurons and to sustain neurons in the brain that use the chemical dopamine as a neurotransmitter.

Functions of Astrocytes

Astrocytes (from the Greek *aster* = star) are large stellate cells with numerous cytoplasmic processes that radiate outward. They are the most abundant of the glial cells in the CNS, constituting up to 90% of the nervous tissue in some areas of the brain.

Astrocytes (fig. 7.10) have processes that terminate in *end-feet* surrounding the capillaries of the CNS; indeed, the entire surface of these capillaries is covered by the astrocyte end-feet. In addition, astrocytes have other extensions adjacent to the synapses between the axon terminal of one neuron and the dendrite or cell body of another neuron. The astrocytes are thus ideally situated to influence the interactions between neurons and between neurons and the blood.

Here are some of the proposed functions of astrocytes:

1. **Astrocytes take up K^+ from the extracellular fluid.** Because K^+ diffuses out of neurons during the production of nerve impulses (described in section 7.2), this function may be important in maintaining the proper ionic environment for neurons.
2. **Astrocytes take up some neurotransmitters released from the axon terminals of neurons.** For example, the neurotransmitter glutamate (the major neurotransmitter of the cerebral cortex) is taken into astrocytes and transformed into glutamine (fig. 7.10). The glutamine is then released back to the neurons, which can use it to reform the neurotransmitter glutamate.
3. **The astrocyte end-feet surrounding blood capillaries take up glucose from the blood.** The glucose is metabolized into lactic acid, or lactate (fig. 7.10). The lactate is then released and used as an energy source by neurons, which metabolize it aerobically into CO_2 and H_2O for the production of ATP. Thus, PET scans and fMRI (chapter 8, section 8.2), which visualize brain locations by their metabolic activities, are based on the functions of astrocytes as well as neurons.
4. **Astrocytes appear to be needed for the formation of synapses in the CNS.** Few synapses form in the absence of astrocytes, and those that do are defective. Normal synapses in the CNS are ensheathed by astrocytes (fig. 7.10).
5. **Astrocytes regulate neurogenesis in the adult brain.** They appear to be needed for stem cells in the

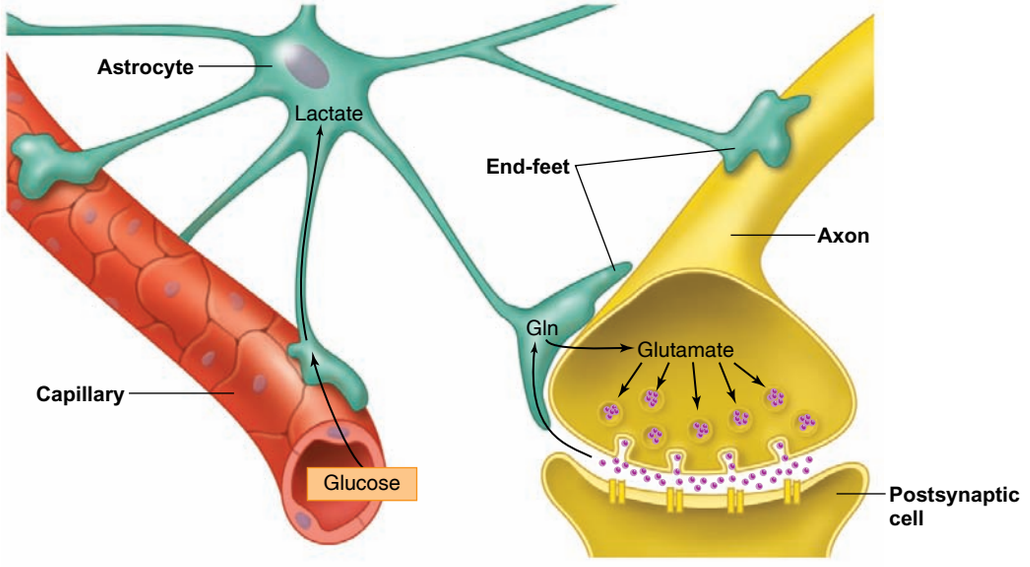

Figure 7.10 **Astrocytes have processes that end on capillaries and neurons.** Astrocyte end-feet take up glucose from blood capillaries and use this to help supply energy substrates for neurons. Astrocytes also take up the neurotransmitter glutamate from synapses and convert it to glutamine (Gln), which is then recycled to the neurons.

hippocampus and subventricular zone (chapter 8) to differentiate into both glial cells and neurons.

6. **Astrocytes induce the formation of the blood-brain barrier.** The nature of the blood-brain barrier is described in the next section.
7. **Astrocytes release transmitter chemicals that can stimulate or inhibit neurons.** Such transmitters—including glutamate, ATP, adenosine, D-serine, and others—have been shown to stimulate (in response to glutamate) and inhibit (in response to ATP) the activity of particular neurons.

Astrocyte physiology is also influenced by neural activity. Although astrocytes do not produce action potentials (impulses), they can be classified as excitable because they respond to stimulation by transient changes in their intracellular Ca^{2+} concentration. For example, scientists have found that when certain neurons are active, they release ATP, which produces (directly or by conversion to adenosine) a rise in the Ca^{2+} concentrations within nearby astrocytes. These astrocytes then also release ATP, which causes a rise in the Ca^{2+} concentrations within other astrocytes. This has been described as a *Ca^{2+} wave* that spreads among astrocytes away from the active neuron. A rise in the Ca^{2+} concentration can promote the production of prostaglandin E_2, which is released from the astrocyte end-feet surrounding cerebral blood vessels and stimulates vasodilation. Because this chain of events is triggered by the release of ATP from active neurons, an increase in neural activity within a brain region is accompanied by an increased blood flow to that region.

Blood-Brain Barrier

Capillaries in the brain, unlike those of most other organs, do not have pores between adjacent endothelial cells (the cells that compose the walls of capillaries). Instead, the endothelial cells of brain capillaries are joined together by tight junctions. Unlike other organs, therefore, the brain cannot obtain molecules from the blood plasma by a nonspecific filtering process. Instead, molecules within brain capillaries must be moved through the endothelial cells by diffusion and active transport, as well as by endocytosis and exocytosis. This feature of brain capillaries imposes a very selective **blood-brain barrier.**

The structural components of the blood-brain barrier—the tight junctions between endothelial cells of brain capillaries—restricts the paracellular movement of molecules between epithelial cells (chapter 6), requiring the molecules to instead take the transcellular route and pass through the epithelial cells. Nonpolar O_2 and CO_2, as well as some organic molecules such as alcohol and barbiturates, can pass through the phospholipid components of the plasma membranes on each side of the capillary endothelial cells. Ions and polar molecules require ion channels and carrier proteins in the plasma membrane to move between the blood and brain. For example, plasma glucose can pass into the brain using specialized carrier proteins known as GLUT1. The GLUT1 glucose carriers, found in most brain regions, are always present; they do not require insulin stimulation like the GLUT4 carriers in skeletal muscles (chapter 11) or the hypothalamus (the brain region that contains hunger centers; chapters 8 and 19). There is also a metabolic component to the blood-brain barrier, including a variety of enzymes that can metabolize and inactivate potentially toxic molecules.

There is evidence that astrocytes can induce many of the characteristics of the blood-brain barrier, including the tight junctions between endothelial cells, the production of carrier proteins and ion channels, and the enzymes that destroy potentially toxic molecules. Astrocytes influence the capillary endothelial cells by secreting neurotrophins, such as glial-derived neurotrophic factor (GDNF, previously discussed). The endothelial cells, in turn, appear to secrete regulators that promote the growth and differentiation of astrocytes. This two-way communication leads to a view of the blood-brain barrier as a dynamic structure, and indeed scientists currently believe that the degree of its "tightness" and selectivity can be adjusted by a variety of regulators.

The blood-brain barrier presents difficulties in the chemotherapy of brain diseases because drugs that could enter other organs may not be able to enter the brain. In the treatment of *Parkinson's disease,* for example, patients who need a chemical called dopamine in the brain are often given a precursor molecule called levodopa (L-dopa) because L-dopa can cross the blood-brain barrier but dopamine cannot. Some antibiotics also cannot cross the blood-brain barrier; therefore, in treating infections such as meningitis, only those antibiotics that can cross the blood-brain barrier are used.

CHECKPOINT

1. Draw a neuron, label its parts, and describe the functions of these parts.
2. Distinguish between sensory neurons, motor neurons, and association neurons in terms of structure, location, and function.
3. Describe the structure of the sheath of Schwann, or neurilemma, and explain how it promotes nerve regeneration. Explain how a myelin sheath is formed in the PNS.
4. Explain how myelin sheaths are formed in the CNS. How does the presence or absence of myelin sheaths in the CNS determine the color of this tissue?
5. Explain what is meant by the blood-brain barrier. Describe its structure and discuss its clinical significance.