## LEARNING OBJECTIVES — *continued*

14. Describe the pathophysiology of hydrocephalus, differentiating the communicating from the noncommunicating types.
15. Describe the signs of increasing intracranial pressure in the neonate.
16. Describe the major types of spina bifida and the effect on a child who has the defect.
17. Describe the types of cerebral palsy and signs of each.
18. Differentiate the types of seizures.
19. Describe the pathophysiology, course, and effects of multiple sclerosis.
20. Relate the pathophysiology to the signs of Parkinson's disease.
21. Explain how amyotrophic lateral sclerosis affects motor function and how this relates to the signs of progression.
22. Describe the pathophysiology of myasthenia gravis and its effects on the body.
23. Describe the inheritance of Huntington's disease and the onset and early signs.
24. Describe the changes in the brain as Alzheimer's disease develops and the effects on function.
25. Compare the disorders of schizophrenia, depression, and panic disorder with regard to the pathophysiology and effects on behavior.

## KEY TERMS

afferent
amnesia
anencephaly
anomalies
aphasia
athetoid
atresia
aura
bifurcation
choreiform
clonic
cognitive
coma
contralateral
disorientation
efferent
fissure
flaccid
flaccid
foramina
fulminant
ganglion
gyri
hyperreflexia
hyperreflexia
infratentorial
ipsilateral
labile
nuchal rigidity
paralysis
paresis
paresthesia
photophobia
postictal
precursor
pressoreceptors
prodromal
ptosis
retina
scotoma
spastic
stupor
sulcus, sulci
supratentorial
sutures
tetraplegia
tonic
transillumination

## Review of Nervous System Anatomy and Physiology

The nervous system consists of the central and peripheral nervous system.

- Central nervous system—brain and spinal cord
- Peripheral nervous system—cranial and spinal nerves; ganglia; sensory neurons, neuromuscular junctions

### Brain

The brain is the communication and control center of the body. It receives, processes, and evaluates many kinds of input; decides on the response or action to be taken; and then initiates the response. Responses include both involuntary activity that is required to maintain homeostasis in the body (regulated by the autonomic nervous system) and voluntary actions (controlled by the somatic nervous system). With both reflex and voluntary activities, the individual is often not aware of the amount and diversity of input received or the integration or assessment of that input, but knows only of the response (Fig. 14-1).

### Protection for the Brain

The brain is protected by the rigid bone of the skull, the three membranes or meninges, and the cerebrospinal fluid (CSF). The cranial and facial bones are connected by **sutures**, which are relatively immovable joints consisting of fibrous tissue. If pressure inside the skull increases in infants before the sutures fuse or ossify, the cranial bones may separate, causing the head to enlarge. The skull contains a number of cavities, or fossae, as well as **foramina** (openings) and canals through which nerves and blood vessels pass. The largest opening, the foramen magnum, is located in the occipital bone at the base of the skull, where the spinal cord emerges.

#### *Meninges*

The meninges consist of three continuous connective tissue membranes covering the brain and spinal cord.



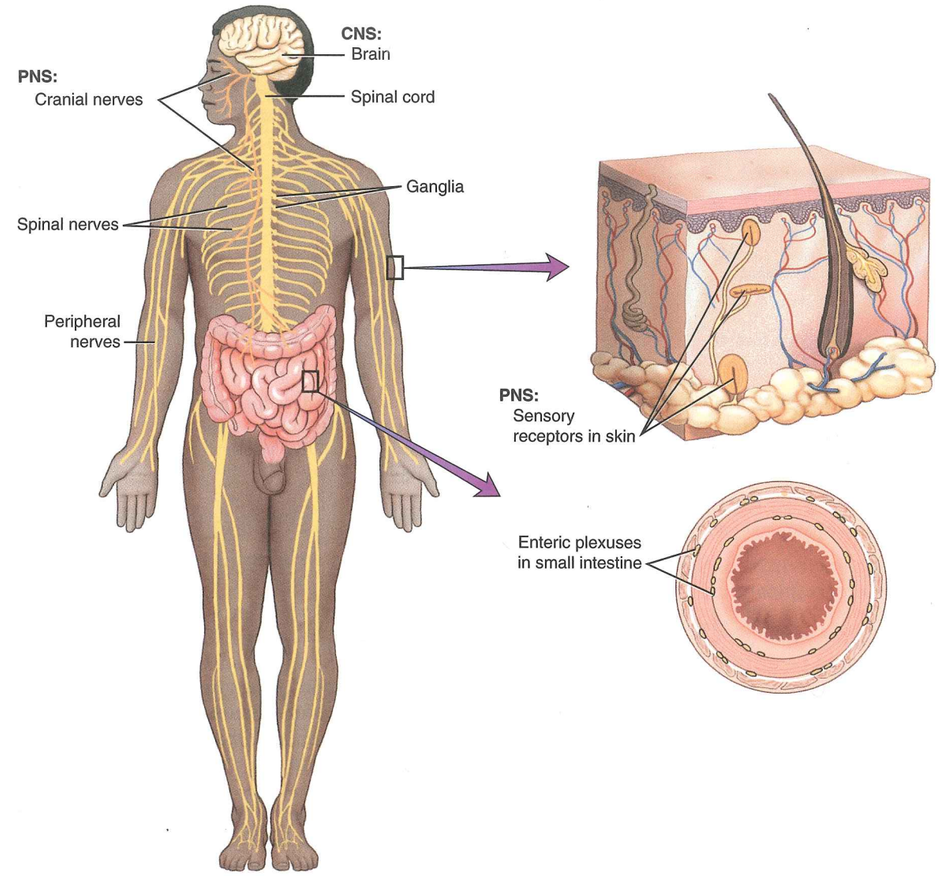


FIGURE 14-1 **Overview of the Nervous System** The nervous system is divided into two components: the central nervous system composed of the brain and the spinal cord, and the peripheral nervous system containing the cranial and spinal nerves, ganglia, and sensory receptors. *(From VanMeter K, Hubert R:* Microbiology for the Healthcare Professional, *St. Louis, 2010, Elsevier.)*

The meninges and the contents of the spaces between the layers are as follows:

- The *dura mater*, the outer layer, is a tough, fibrous, double-layered membrane that separates at specific points to form the dural sinuses, which collect *venous* blood and CSF for return to the general circulation
- The *subdural space*, lying beneath the dura, is a *potential space* (i.e., normally empty, this space could fill with blood after an injury).
- The *arachnoid (arachnoid mater)*, a loose, weblike covering, is the middle layer.
- The *subarachnoid space*, which contains the *CSF* and the cerebral arteries and veins, lies beneath the arachnoid.
- *Arachnoid villi* are projections of arachnoid into the dural sinuses at several places around the brain, through which CSF can be absorbed into the venous blood.
- The *pia mater*, a delicate connective tissue that adheres closely to all convolutions on the surface of the brain, is the inner layer. Many small blood vessels are found in the pia mater (Fig. 14-2).

#### *Cerebrospinal Fluid*

The cerebrospinal fluid (CSF) provides a cushion for the brain and spinal cord. Similar to plasma in appearance, it is a clear, almost colorless liquid, but it differs from plasma in the concentrations of electrolytes,

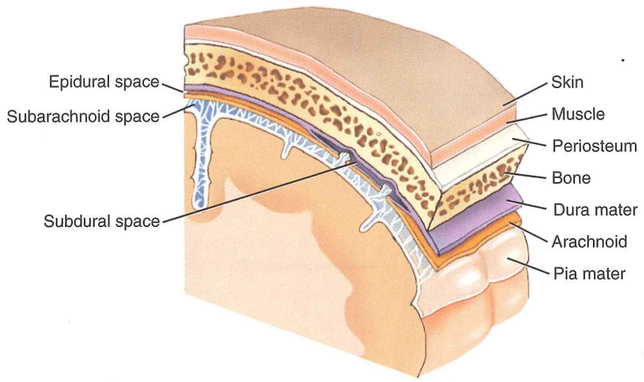


FIGURE 14-2 **The Meninges** The brain and the spinal cord are covered by three protective membranes, collectively called *meninges*. The outermost membrane is the dura mater, the middle layer is the arachnoid, and the innermost membrane is the pia mater. *(From VanMeter K, Hubert R:* Microbiology for the Healthcare Professional, *St. Louis, 2010, Elsevier.)*

**TABLE 14-1 Characteristics of Normal Cerebrospinal Fluid**

| | |
|---|---|
| Appearance | Clear and colorless |
| Pressure | 9-14 mmHg or 150 mm $H_2O$ |
| Red blood cells | None |
| White blood cells | Occasional |
| Protein | 15-45 mg/dL |
| Glucose | 45-75 mg/dL |
| Sodium | 140 mEq/L |
| Potassium | 3 mEq/L |
| Specific gravity | 1.007 |
| pH | 7.32-7.35 |
| Volume in the system at one time | 125-150 mL |
| Volume formed in 24 hours | 500-800 mL |

glucose, and protein (Table 14-1), which remain relatively *constant*. A change in the characteristics of the CSF is a useful diagnostic tool (see Fig. 14-11). For example, the presence of significant numbers of erythrocytes in CSF indicates bleeding in the central nervous system.

Cerebrospinal fluid is formed constantly in the choroid plexuses in the ventricles and then flows into the subarachnoid space, where it circulates around the brain and spinal cord and eventually passes through the arachnoid villi, returning into the venous blood. To maintain a relatively constant pressure within the skull (intracranial pressure), it is important for equal amounts of CSF to be produced and reabsorbed at the same rate.

### *Blood-Brain Barrier and Blood-Cerebrospinal Fluid Barrier*

The blood-brain barrier is a protective mechanism provided primarily by relatively impermeable capillaries in the brain. The endothelial cells of the capillaries are tightly joined together by tight junctions rather than possessing pores. This barrier limits the passage of potentially damaging materials into the brain and controls the delicate but essential balance of electrolytes, glucose, and proteins in the brain. There is a similar blood-CSF barrier at the choroid plexus to control the constituents of CSF. The blood-brain barrier is poorly developed in neonates, and therefore substances such as bilirubin (see Chapter 22) or other toxic materials can pass easily into the infant's brain, causing damage. When fully developed, the blood-brain barrier can be a disadvantage, because it does not allow the passage of many essential drugs into the brain (i.e., certain antibiotics and anticancer drugs). Lipid-soluble substances, including alcohol, pass freely into the brain.

**THINK ABOUT 14-1**

a. List, in order, the brain coverings and spaces with their contents, from the brain tissue outward.
b. Explain the effect of the production of more CSF than can be reabsorbed.

## Functional Areas

### *Cerebral Hemispheres*

The cerebral hemispheres make up the largest and most obvious portions of the brain. The outer surface is covered by elevations, or **gyri** (sing., gyrus), that are separated by grooves, or **sulci** (sing., sulcus). The longitudinal fissure separates the left and right hemispheres. The corpus callosum consists of nerve fibers connecting the left and right hemisphere for the purpose of communication between the two hemispheres.

Each hemisphere is divided into four major lobes, each of which has specific functions (Fig. 14-3). Complex functions, such as language and memory, involve many areas of the brain. Each hemisphere is concerned with voluntary movement and sensory function in the opposite (**contralateral**) side of the body, and these areas of the cortex have been well mapped. In Figure 14-3, note the large number of nerve cells required to innervate the face compared with the amount of cortex allocated to the trunk. The cells of the motor cortex of the frontal lobe initiate specific voluntary movements, and these cells are often referred to as upper motor neurons (UMNs). Their axons form the corticospinal tracts in the spinal cord. Because the crossover of most of these tracts occurs in the medulla, damage to the motor cortex in the left frontal lobe adjacent to the longitudinal fissure (on top of the head) results in **paralysis** or **paresis** of the muscles of the right leg.

Each special sensory area of the cortex has an *association area* surrounding the primary cortex, in which the sensory input is recognized and interpreted. For example, the occipital lobe contains the primary visual cortex, which receives the stimuli from the eye, and the surrounding association cortex identifies the object seen. If the primary cortex is damaged, the person is blind, but if the association area is damaged, the person can see an object but cannot comprehend its significance.



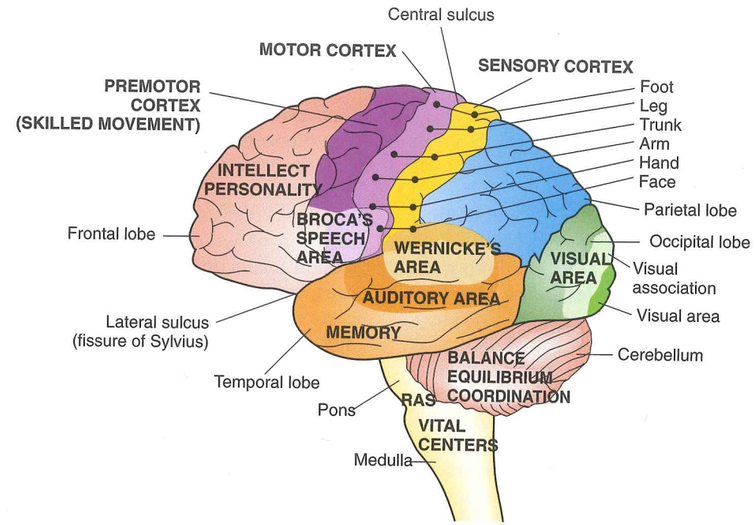


FIGURE 14-3 Functional areas of the brain showing the *left* side of the cerebral hemispheres.

The right and left hemispheres are generally similar in structure but not necessarily in function (Table 14-2). The term *dominant hemisphere* refers to the side of the brain that controls *language*, which in most people is the left hemisphere. There are two special areas involved in language skills. *Broca's area* is considered the motor or expressive speech area, in which the output of words, both verbal and written, is coordinated in an appropriate and understandable way. This area is located at the base of the premotor area of the left frontal lobe. *Wernicke's area* is the integration center that comprehends language received, both spoken and written. This area is located in the posterior temporal lobe and has connecting fibers to the prefrontal, visual, and auditory areas. The left hemisphere also appears to be responsible for mathematical, problem-solving, and logical reasoning abilities. The right hemisphere has greater influence on artistic abilities, creativity, spatial relationships, and emotional and behavioral characteristics.

The *prefrontal cortex* lies anterior to the motor and premotor cortex and recent research indicates that it functions in coordinating complex cognitive behavior as well as providing components for expression of personality. It plays a very significant role in social relationships and impulse control.

The *basal nuclei* (previously called the basal ganglia) are clusters of cell bodies or gray matter located deep among the tracts of the cerebral hemispheres. These are part of the *extrapyramidal system* (EPS) of motor control, which controls and coordinates skeletal muscle activity, preventing excessive movements and initiating accessory and often involuntary actions, such

**TABLE 14-2 Major Functional Areas of the Brain**

| Area | Function |
|---|---|
| Frontal lobe | |
| Prefrontal area (left cortex) | Intellectual function and personality |
| Premotor cortex | Skilled movements |
| Motor cortex | Voluntary movements |
| Broca's area (left cortex) | Speech (expression) |
| Parietal lobe | |
| Somatosensory area | Sensation (e.g., touch, pain) |
| Occipital lobe | |
| Visual cortex | Vision |
| Temporal lobe | |
| Auditory cortex | Hearing |
| Olfactory cortex | Smell |
| Wernicke's area (left cortex) | Comprehension of speech |
| | Memory |
| Cerebellum | Body balance and position, coordinated movement |
| Medulla oblongata | Control and coordination centers for respiration and cardiovascular activity |
| | Swallow reflex center, vomiting reflex, cough reflex |
| | Nuclei of five cranial nerves |
| Hypothalamus | Autonomic nervous system |
| | Link with endocrine system |
| | Control of body temperature, fluid balance |
| | Centers for thirst, hunger |
| Thalamus | Sensory sorting and relay center |
| Basal nuclei | Coordination and control of body movement |
| Reticular activating System | Arousal or awareness |
| Limbic system | Emotional responses |

as arm-swinging when walking. Two additional nuclei located in the midbrain, the substantia nigra and the red nucleus, are also connected to the basal nuclei and the EPS.

The *limbic system* consists of many nuclei and connecting fibers in the cerebral hemispheres that encircle the superior part of the brain stem. The limbic system is responsible for emotional reactions or feelings, and for this purpose, it has many connections to all areas of the brain. Part of the hypothalamus is involved with the limbic system. The hypothalamus provides the link for the autonomic responses, such as altered blood pressure or nausea, which occur when one experiences fear, excitement, or an unpleasant sight or odor. Any cognitive (intellectual) decision arising from the higher cortical centers may be accompanied by an emotional aspect mediated through the limbic system.

### *Diencephalon*

The diencephalon is the central portion of the brain. It is surrounded by the hemispheres and contains the thalamus, the hypothalamus, and the epithalamus. The *thalamus* consists of many nerve cell bodies, the major function of which is to serve as a sorting and relay station for incoming sensory impulses. From the thalamus, connecting fibers transmit impulses to the cerebral cortex and other appropriate areas of the brain. The *hypothalamus* has a key role in maintaining homeostasis in the body, controlling the autonomic nervous system and much of the endocrine system through the hypophysis, or pituitary gland. It is responsible for the regulation of body temperature, intake of food and fluid, and the regulation of sleep cycles. The hypothalamus is also the key to the stress response and plays major roles in emotional responses through the limbic system and in biologic behaviors, such as the sex drive (libido).

### *Brain Stem*

The inferior portion of the brain, called the brain stem, is the connecting link to the spinal cord. The *pons* is composed of bundles of afferent (incoming) and efferent (outgoing) fibers. Several nuclei of cranial nerves are also located in the pons. The *medulla oblongata* contains the vital control centers that regulate respiratory and cardiovascular function and the coordinating centers that govern the cough reflex, swallowing, and vomiting. The medulla is the location of the nuclei of several cranial nerves. It is distinguished by two longitudinal ridges on the ventral surface, termed the pyramids, marking the site of crossover (decussation) of the majority of fibers of the corticospinal (pyramidal) tracts, which results in the contralateral control of muscle function.

The *reticular formation* is a network of nuclei and neurons scattered throughout the brain stem that has connections to many parts of the brain. The *reticular-activating system (RAS)* is part of this formation and determines the degree of arousal or awareness of the cerebral cortex. In other words, these neurons decide which of the incoming sensory impulses the brain ignores and which it notices. Many drugs can affect the activity of the RAS, thus increasing or decreasing the input to the brain.

### *Cerebellum*

The cerebellum is located dorsal to the pons and medulla, below the occipital lobe. It functions to coordinate movement and maintain posture and equilibrium by continuously assessing and adjusting to input from the pyramidal system, the proprioceptors in joints and muscles, the visual pathways, and the vestibular pathways from the inner ear.



**THINK ABOUT 14-2**

a. Describe the specific location and function of each of the following: the prefrontal cortex, somatosensory area, the RAS, Wernicke's area, the basal nuclei, and the visual association area.
b. Describe white matter—what it is and what its function is—and give an example.
c. Predict the effects of brain damage in the prefrontal cortex, left frontal lobe, the cerebellum, or the hypothalamus.

## Blood Supply to the Brain

Blood is supplied to the brain by the internal carotid arteries and the vertebral arteries. Each *internal carotid* artery is a branch of a common carotid artery (right or left) and includes the carotid sinus, which is the location of the pressoreceptors, or baroreceptors, that signal changes in blood pressure and the chemoreceptors that monitor variations in blood pH and oxygen levels.

At the base of the brain, each internal carotid artery divides into an anterior and middle cerebral artery (see Fig. 14-14).

- The *anterior cerebral artery* supplies the frontal lobe.
- The *middle cerebral artery* supplies the lateral part of the cerebral hemispheres, primarily the temporal and parietal lobes, which comprise a high proportion of the brain tissue.

Posteriorly, the *vertebral arteries* join to form:

- The *basilar artery,* which supplies branches to the brain stem and cerebellum as it ascends.

At the base of the brain, the basilar artery divides into:

- The right and left *posterior cerebral arteries,* which supply blood to the occipital lobes.
- The anterior, middle, and posterior cerebral arteries follow a course over the surface of each hemisphere, with many branches penetrating into the brain substance (see Fig. 14-13*A*).

*Anastomoses* between these major arteries at the base of the brain are provided by the:

- *Anterior communicating artery* between the anterior cerebral arteries
- *Posterior communicating arteries* between the middle cerebral and posterior cerebral arteries
- This arrangement forms the *circle of Willis* and provides an alternative source of blood when the internal carotid or vertebral artery is obstructed. This circle of arteries surrounds the pituitary gland and optic chiasm.

Blood flow in the cerebral arteries is relatively constant because the brain cells constantly use oxygen and glucose (essential nutrients for neurons) and have little storage capacity. *Autoregulation* is a mechanism by which increased carbon dioxide levels or decreased pH in the blood, or decreased blood pressure, in an area of the brain results in immediate local vasodilation. The pressoreceptors (baroreceptors) and chemoreceptors protect the brain from damage related to abnormal blood pressure or pH levels in the systemic flow.

As mentioned, venous blood from the brain collects in the dural sinuses and then drains into the right and left internal jugular veins, to be returned to the heart.

## Cranial Nerves

There are 12 pairs of cranial nerves. They originate from the brain stem and pass through the foramina in the skull to serve structures in the head and neck, including the eyes and ears. The vagus nerve (cranial nerve X) serves a more extensive area, branching to innervate many of the viscera. A cranial nerve may consist of motor fibers only (with associated sensory fibers from proprioceptors in the skeletal muscles) or of sensory fibers only, or it may be a mixed nerve, containing both motor and sensory fibers (Table 14-3). Four cranial nerves (III, VII, IX, X) include parasympathetic fibers.

**THINK ABOUT 14-3**

a. Explain the function of the circle of Willis.
b. Describe the effect of an obstruction in the right anterior cerebral artery.
c. Explain how a lack of glucose or oxygen will affect brain function.
d. What are the different types of fibers and the functions of cranial nerves II, III, and IX? Describe the effects of damage to each.

# Spinal Cord

## Spinal Cord

The spinal cord is protected by the bony vertebral column, the meninges, and the CSF. The cord is continuous with the medulla oblongata and ends at the level of the first lumbar vertebra. Beyond this extends a bundle of nerve roots known as the cauda equina. This arrangement is significant because there is little risk of damaging the cord when a needle is inserted into the subarachnoid space below the first lumbar level (usually in the space between L3 and L4) to obtain a sample of CSF (see Fig. 14-11).

The spinal cord consists of the white matter (outer region) containing the spinal cord tracts, composed of myelinated fibers, and the gray matter (inner region) containing the nerve cell bodies, dendrites, and nonmyelinated axons. Within the gray matter three distinct areas can be identified:

- Ventral horn
  - Contain motor neurons and their axons leave via the ventral root

**TABLE 14-3 Major Components of Cranial Nerves**

| Number | Name | Type of Fibers | Function |
|---|---|---|---|
| I | Olfactory | Sensory | Special sensory—smell |
| II | Optic | Sensory | Special sensory—vision |
| III | Oculomotor | Motor | Eye movements |
| | | | Four extrinsic eye muscles |
| | | | Upper eyelid—levator palpebrae muscle |
| | | PNS | Iris—pupillary constrictor muscle |
| | | | Ciliary muscle—accommodation |
| IV | Trochlear | Motor | Eye movements—superior oblique eye muscle |
| V | Trigeminal | Sensory | General sensory—eye, nose, face and oral cavity, teeth |
| | | Motor | Muscles of mastication with sensory proprioceptive fibers; speech |
| VI | Abducens | Motor | Eye movements—lateral rectus eye muscle |
| VII | Facial | Sensory | Special sensory—taste, anterior two-thirds of tongue |
| | | Motor | Muscles of facial expression |
| | | | Scalp muscles |
| | | PNS | Lacrimal gland, nasal mucosa, salivary glands (sublingual and submandibular) |
| VIII | Vestibulocochlear | Sensory | Special sensory—hearing and balance (inner ear) |
| IX | Glossopharyngeal | Sensory | Special sensory—taste, posterior one-third of tongue |
| | | | General sensory—pharynx and soft palate (gag reflex) |
| | | | Sensory—carotid sinus for baroreceptors and chemoreceptors |
| | | Motor | Pharyngeal muscles—swallowing |
| | | PNS | Salivary gland (parotid) |
| X | Vagus | Sensory | Special sensory—taste, pharynx, posterior tongue |
| | | | General sensory—external ear and diaphragm |
| | | | Visceral sensory—viscera in thoracic and abdominal cavities |
| | | Motor | Pharynx and soft palate—swallowing and speech |
| | | PNS | Heart and lungs; smooth muscle and glands of digestive system |
| XI | Spinal accessory | Motor | Voluntary muscles of palate, pharynx, and larynx |
| | | | Head movements—sternocleidomastoid and trapezius muscles |
| XII | Hypoglossal | Motor | Muscles of tongue |

PNS, parasympathetic nervous system.

- Dorsal horn
  - Contain interneurons receiving information from sensory neurons of the dorsal root ganglia
- Lateral horns
  - Contain visceral motor neurons

The white matter is composed of afferent (sensory) and efferent (motor) fibers that are organized into tracts and communicating fibers that run between the two sides of the spinal cord. Each tract is assigned a unique position in the white matter; a cross-section of the cord would illustrate the "map" of tracts (Fig. 14-4*B*). The name of the tract is based on its source and destination, and the fibers in it transmit one type of impulse. For example, the lateral spinothalamic tract is made up of *ascending* fibers that conduct pain or temperature *sensations*, which are relayed from spinal nerves and receptors on the opposite side of the body, to the thalamus.

The *descending* tracts are of two types. The *pyramidal*, or corticospinal, tracts conduct impulses concerned with voluntary movement from the motor cortex (*upper motor neurons*) to the *lower motor neurons* in the anterior horn at the appropriate level of the spinal cord. Most of these tracts cross in the medulla. The *extrapyramidal* tracts carry impulses that modify and coordinate voluntary movement and maintain posture. Lower motor neurons may receive both stimulatory and inhibitory input from upper motor neurons and from interneurons in the spinal cord. The sum of the input determines what activity occurs in the spinal nerves and skeletal muscles.

## Spinal Nerves

Thirty-one pairs of spinal nerves emerge from the spinal cord, carrying motor and sensory fibers to and from the



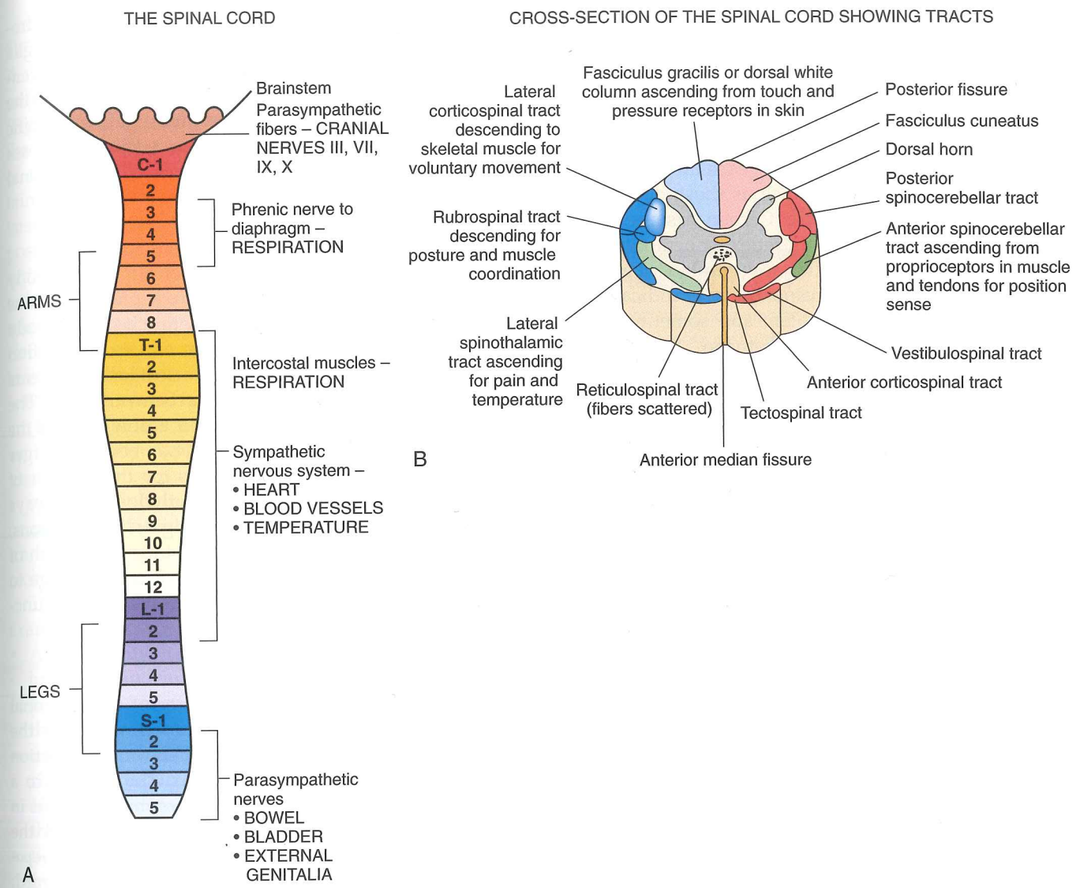


FIGURE 14-4 Functional areas of the spinal cord.

organs and tissues of the body. They are named by the location in the vertebral column where they emerge (see Fig. 14-4) and are numbered within each section. For example, there are eight pairs of *cervical nerves*, numbered *C1 to C8*. Each spinal nerve is connected to the spinal cord by two short roots. The ventral, or anterior, root is made up of efferent or motor fibers from the lower motor neurons in the anterior horn. The dorsal, or posterior, root consists of afferent or sensory fibers from the dorsal root ganglion (a collection of nerve cell bodies in the peripheral nervous system), where sensory fibers from peripheral receptors have already synapsed.

The area of sensory innervation of the skin by a specific spinal nerve is called a *dermatome*, and these can be drawn on a "map" of the body surface (see Fig. 14-22). Assessment of sensory awareness using the dermatome map can be a useful tool in determining the level of damage to the spinal cord.

Four *plexuses* are located where fibers from several spinal nerves branch and then reform in different combinations to become specific peripheral nerves: the cervical, brachial, lumbar, and sacral. This networking means that the phrenic nerve, for example, consists of fibers from spinal nerves C3 to C5, and the sciatic nerve contains fibers from spinal nerves L4 to L5 and S1 to S3. Also, the fibers in each spinal nerve can be distributed in several peripheral nerves. This dispersal pattern can minimize the effects on a muscle's contraction of damage to one spinal cord segment.

## Reflexes

Reflexes are automatic, rapid, involuntary responses to a stimulus. A simple reflex involves a sensory stimulus from a receptor that is conducted along an afferent nerve fiber, a synapse in the spinal cord, and an efferent impulse that is conducted along a peripheral nerve to elicit the response. Touching a hot object with the hand

thus results in an immediate movement of the hand away from the object. At the same time, connecting neurons or interneurons transmit the sensory information up to the brain to initiate an assessment and further action if required. Many reflexes that control visceral activities or posture take place continuously, *without* the individual's awareness. In addition, each individual has *acquired*, or learned, reflexes, such as those developed when learning to ride a bicycle. Certain basic reflexes, such as the patellar, or knee-jerk reflex, or oculocephalic (doll's head eye response) reflex are useful in diagnosis. Absent, weak, or abnormal responses may indicate the presence of a neurologic problem and sometimes can show the location of spinal cord damage.

**THINK ABOUT 14-4**

a. At which level of the spine would a lumbar puncture occur, and why?
b. Describe the general location of the cervical spinal nerves.
c. Describe a dermatome and its purpose.
d. Describe the path of nerve impulses involved in the withdrawal reflex that occurs when one pricks a finger on a sharp pin. Name each element in the reflex arc and state its function.

## Neurons and Conduction of Impulses

### Neurons

Neurons, or nerve cells, are highly specialized, nonmitotic cells that conduct impulses throughout the central nervous system (CNS) and the peripheral nervous system. They require glucose and oxygen for metabolism. There are many variations in the specific structural characteristics of each neuron, depending on its function. The cell body has a variable number of processes, or extensions, depending on the type of neuron involved. These processes make up nerves and tracts. The dendrite is the receptor site, which conducts impulses toward the cell body. The cell body contains the nucleus. The axon conducts impulses away from the cell body toward an effector site or connecting neuron, where it can release neurotransmitter chemicals at its terminal point.

Many nerve fibers are covered by a myelin sheath, which insulates the fiber and speeds up the rate of conduction. The myelin sheath, which wraps many layers of its plasma membrane around the axon, is formed by Schwann cells in the peripheral nervous system and by oligodendrocytes in the central nervous system. The interruptions in the myelin sheath are called the nodes of Ranvier.

The neurons are supported and protected by large numbers of *glial (neuroglial) cells*. Astroglia or astrocytes provide a link between neurons and capillaries for physical and probably metabolic support, as well as contributing to the blood-brain barrier. Oligodendrocytes provide myelin for axons in the CNS. Microglia have phagocytic activity. Ependymal cells line the ventricles and neural tube cavity and form part of the choroid plexus. Researchers are investigating specific roles that glial cells may play in areas such as synapses and intercellular communication, as well as neuronal metabolism.

#### *Regeneration of Neurons*

Neurons cannot undergo cell division. If the cell body is damaged, the neuron dies. In the peripheral nervous system, axons may be able to regenerate if the cell body is viable. After damage to the axon occurs, the section distal to the injury degenerates because it lacks nutrients and is removed by macrophages and Schwann cells. The Schwann cells then attempt to form a new tube at the end of the remaining axon. The cell body becomes larger and synthesizes additional proteins for the growth of the replacement axon. The new growth does not always occur appropriately or make its original connections, because the surrounding tissue may interfere. Much of spinal cord research is focused on reducing damage to neurons immediately after injury and facilitating functional reconnections.

### Conduction of Impulses

A stimulus increases the permeability of the neuronal membrane, allowing sodium ions to flow inside the cell, thus *depolarizing* it and generating an action potential when threshold is reached. The change to a positive electrical charge inside the membrane results in increased permeability of the adjacent area, and the impulse moves along the membrane. Recovery, or *repolarization*, occurs as potassium ions move outward; the normal permeability of the membrane is restored, and the sodium-potassium pump returns the sodium and potassium ions to their normal locations (see Fig. 2-5). In myelinated fibers, this action potential is generated only at the nodes of Ranvier, and therefore the impulse can "skip" along rapidly (saltatory conduction). Generally the larger axons conduct impulses more rapidly than smaller ones. The synapse provides the connection between two or more neurons or a neuron and an effector site. Complex "electrical circuits" exist in the nervous system, with multiple synapses on each neuron. The electrical activity of the brain can be monitored by attaching electrodes to the scalp and measuring the brain waves by means of an electroencephalogram (EEG).

**APPLY YOUR KNOWLEDGE 14-1**

Predict five possible points of dysfunction and explain how each might occur and the effects to be expected.



### Synapses and Chemical Neurotransmitters

A chemical synapse involves the release of neurotransmitters from vesicles in the synaptic buds of the axons (Fig. 14-5). These transmitters may stimulate or inhibit the postsynaptic neuron. A typical synapse consists of the terminal axon of the presynaptic neuron, containing the vesicles with neurotransmitter (synaptic vesicles), and the receptor site on the membrane of the postsynaptic neuron. The axon and the receptor site are separated by the synaptic cleft. When the action potential reaches the axon terminal, the neurotransmitter is released from the vesicles and diffuses across the cleft to act on the receptor in the postsynaptic membrane, creating a postsynaptic potential. Receptors are specific for each neurotransmitter. Neurotransmitters are then either inactivated by specific enzymes or taken up by the presynaptic axon to prevent continued stimulation. Because there are usually many impulses from a variety of neurons arriving at one postsynaptic neuron, that neuron can process the input and then transmit the net result of the information to the next receptor site.

There are many neurotransmitters in the body; a few examples follow:

- Acetylcholine (ACh) is present at neuromuscular junctions and in the autonomic nervous system, the peripheral nervous system, and, less commonly, the CNS.
- Catecholamines, including norepinephrine, epinephrine, and dopamine, are present in the brain.
- Norepinephrine is a neurotransmitter in the sympathetic nervous system (SNS).
- Both norepinephrine and epinephrine, when released from the adrenal medulla in response to SNS stimulation, circulate in the blood and interstitial fluid, ultimately diffusing into the synaptic cleft and stimulating the appropriate receptors in the SNS.
  - Serotonin involved in mood, emotions, and sleep
  - Histamine involved in emotions, regulation of body temperature, and water balance
  - Gamma-aminobutyric acid (GABA), most common inhibitory neurotransmitter in the brain
  - Glycine, most common inhibitory neurotransmitter in the spinal cord

The roles of many neurotransmitters in mental illness and other pathologies are being studied intensively. For example, norepinephrine and dopamine are excitatory, and thus low levels may be linked to depression. The enkephalins and beta-endorphins are of interest because they can block the conduction of pain impulses in the spinal cord and brain (see Chapter 4). Many drugs have been developed that can mimic the effects of natural chemical neurotransmitters by stimulating specific receptors and promoting similar effects (see Chapter 3). Other drugs are designed to bind to certain receptors but not stimulate them. These drugs block the action of normal neurotransmitters, inhibiting the activity initiated by them. Drugs can also affect neurotransmission, by either inhibiting the enzymes that normally inactivate transmitters or interfering with the uptake of neurotransmitters into the axons for recycling.

**THINK ABOUT 14-5**

a. If postsynaptic membrane permeability is increased, is the neuron more easily stimulated or less excitable?
b. Explain the effect of the myelin sheath and the nodes of Ranvier on the conduction of impulses.
c. Briefly describe, in the correct sequence, the events that occur in synaptic transmission.
d. Explain how and why surface receptors on neurons are specific for certain neurotransmitters?

## Autonomic Nervous System

The autonomic nervous system (ANS) incorporates the sympathetic and parasympathetic nervous systems. These systems generally have antagonistic effects, thereby providing a fine balance that aids in maintaining homeostasis in the body (Table 14-4).

The autonomic system provides motor and sensory innervation to smooth muscle, cardiac muscle, and glands. Although the individual is largely unaware of this involuntary activity, it is integrated with somatic activity by the higher brain centers. The neural pathways in the motor fibers of the autonomic system differ from somatic nerves because each involves two neurons and a ganglion. The *preganglionic* fiber is located in the brain or spinal cord (see Fig. 14-5). This axon then synapses with the second neuron in the *ganglion* outside the CNS, and the *postganglionic* fiber continues to the effector organ or tissue.

### Sympathetic Nervous System

The sympathetic nervous system (SNS), or thoracolumbar nervous system, increases the general level of activity in the body, increasing cardiovascular, respiratory, and neurologic functions. The SNS is necessary for the fight-or-flight, or stress, response and is augmented by the increased secretions of the adrenal medulla in response to SNS stimuli.

The preganglionic fibers of the sympathetic nerves arise from the thoracic and the first two lumbar segments of the spinal cord. The ganglia are located in two *chains* or trunks, one on either side of the spinal cord. In the ganglia, preganglionic fibers synapse with postganglionic fibers or connecting fibers to other ganglia in the chain.

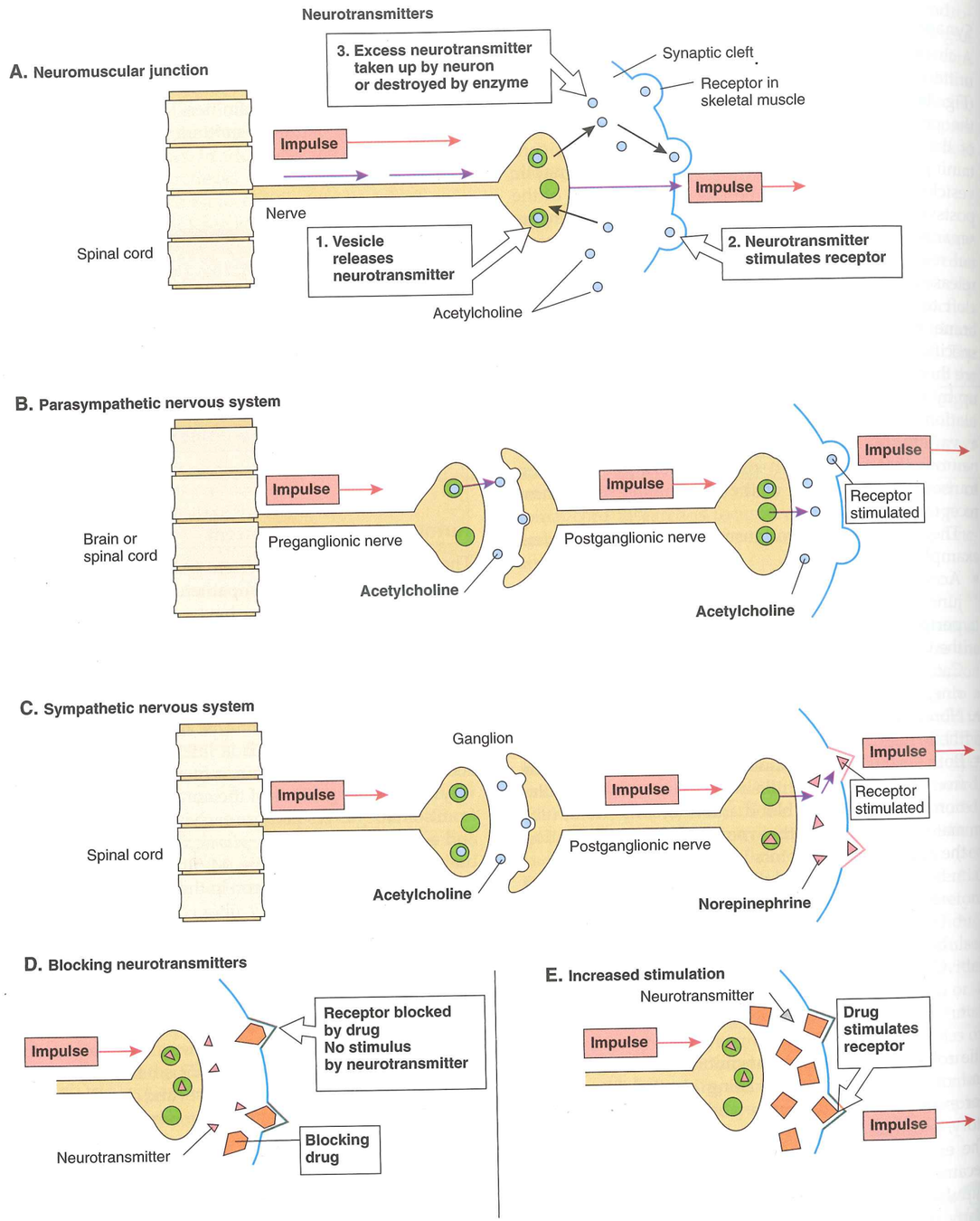


FIGURE 14-5 Neurotransmitters at the synapse.



**TABLE 14-4 Effect of Stimulation of the Autonomic Nervous System**

| Area | SNS Receptor | Sympathetic | Parasympathetic |
|---|---|---|---|
| Cardiovascular System | | | |
| Heart blood vessels | β-1 (beta-1) | Increases rate and force of contractions | Decreases rate and contractility |
| Skin, mucosa, viscera | α-1 (alpha-1) | Vasoconstriction | No innervation |
| Skeletal muscle | β-2 | Vasodilation | No innervation |
| Adrenal medulla | | Secretion of epinephrine and norepinephrine | No innervation |
| Respiratory system | β-2 | Bronchodilation (smooth muscle) | Bronchoconstriction |
| Eye | α-1 | Pupil dilation (radial muscle) | Pupil constriction (sphincter or circular muscle) |
| Sweat glands | α-1 | Increased secretion | |
| Digestive system | α-2 | | |
| Secretions | | Decreased | Increased |
| Peristalsis | | Decreased | Increased |
| Sphincters | α-1 | Constricts | Relaxes |
| Urinary system | | | |
| Sphincters of bladder | α-1 | Constricts | Relaxes |
| Renin | β-1 | Increased secretion | |
| Male genitalia | α-1 | Ejaculation | Erection |

SNS, sympathetic nervous system.

The neurotransmitters and receptors are important in the autonomic nervous system because they are closely linked to drug actions. The neurotransmitter released by preganglionic fibers at the ganglion is acetylcholine; hence these fibers are termed *cholinergic* fibers. Most SNS postganglionic fibers release *norepinephrine*, also called *adrenaline* (*adrenergic* fibers). The postganglionic fibers to sweat glands and blood vessels in skeletal muscle are cholinergic.

Several types of *adrenergic receptors* in the tissues respond to norepinephrine and epinephrine. Norepinephrine acts primarily on *alpha* (α) receptors, and epinephrine acts on both alpha and *beta* (β) receptors. (See Table 14-4 for a summary of the major sites of the receptors and the effects of stimulation.) An organ or tissue may have more than one type of receptor, but one type is usually present in greater numbers and exerts the dominant effect. It is possible that other specific types of receptors will be discovered in the future.

Drugs may be used to stimulate these receptors or to prevent stimulation (see Fig. 14-5*D,E*). For example, $beta_1$-adrenergic receptors (sympathetic receptors) are located in the cardiac muscle. With SNS stimulation, epinephrine stimulates these receptors, resulting in an increased heart rate and force of contraction. In a patient with a damaged heart, drugs such as beta-adrenergic blocking agents (commonly called beta-blockers) may be used to block these receptors, thus preventing the stimulation and the resulting excessive heart activity. A patient may, in contrast, require a drug that can stimulate the beta receptors to improve heart function (a beta-adrenergic drug). The best drugs are specific for one type of receptor in one organ or tissue and do not alter function in other areas of the body; that is, the more specific the drug action is, the milder the adverse effects of the drug.

## Parasympathetic Nervous System

The parasympathetic nervous system (PNS), or craniosacral nervous system, dominates the digestive system and aids in the recovery of the body after sympathetic activity. There are two locations of PNS preganglionic fibers—cranial nerves III, VII, IX, and X at the brain stem level and the sacral spinal nerves. The vagus nerve (cranial nerve X) provides extensive innervation to the heart and digestive tract. In the PNS, the ganglia are scattered and located close to the target organ, and the neurotransmitter at both preganglionic and postganglionic synapses is ACh.

There are two types of cholinergic receptors: nicotinic and muscarinic. Nicotinic receptors are always stimulated by ACh and are located in all postganglionic cholinergic neurons in the PNS and SNS. Muscarinic receptors are located in all effector cells and may be stimulated or inhibited by ACh, depending on the organ. Similar to the pharmacologic effects of drugs in the SNS, cholinergic blocking agents reduce PNS activity, whereas cholinergic or anticholinesterase agents (which prevent the enzyme cholinesterase from breaking down ACh) increase PNS activity.

**THINK ABOUT 14-6**

a. Compare the location of the ganglia and the junction of PNS and SNS peripheral nerve fibers with those in the CNS.
b. Explain how the PNS and SNS affect cardiovascular activity and blood pressure.
c. List the synapses in which ACh is the neurotransmitter.
d. Which part of the autonomic nervous system promotes digestion and absorption? How does this occur?
e. Briefly describe the action and effect of a drug classified as an alpha-1 adrenergic blocking agent.
f. Briefly describe where a cholinergic drug acts and how it affects the postsynaptic receptors. Give two examples of its possible effects on function.

## General Effects of Neurologic Dysfunction

The effects of neurologic damage from different causes have many similarities, because specific areas of the brain and spinal cord have established functions. Therefore damage to a certain area from a tumor or head injury, for example, can result in the same neurologic loss and signs. Also, the effects of increased pressure within the CNS are basically similar, regardless of the cause. To facilitate study and prevent repetition, these common effects are discussed in this section and are then referred to in the subsequent sections on specific disorders. Some unique variations in the effects of damage to the nervous system do occur, given the diversity of pathologic conditions and the possible combinations of effects.

### Local (Focal) Effects

Local effects are signs related to the specific area of the brain or spinal cord in which the lesion is located (see Fig. 14-3). Examples include paresis or paralysis of the right arm that results from damage to a section of the left frontal lobe and loss of vision that results from damage to the occipital lobe. With an expanding lesion, such as a growing tumor or hemorrhage, additional impairment is noted as the adjacent areas become involved.

### Supratentorial and Infratentorial Lesions

**Supratentorial** lesions occur in the cerebral hemispheres above the tentorium cerebelli. A lesion in this location leads to a specific dysfunction in a discrete area, perhaps numbness in a hand. The lesion must become very large before it affects consciousness. An **infratentorial** lesion is located in the brain stem, or below the tentorium. A relatively small lesion in this location may affect many motor and sensory fibers, resulting in widespread impairment, because the nerves are bundled together when passing through the brain stem. Also, respiratory and circulatory function and the level of consciousness may be impaired by a small lesion in this area.

### Left and Right Hemispheres

Certain effects of brain damage are unique to the left or right hemisphere. These occur in addition to focal effects. In most individuals, damage to the left hemisphere leads to loss of logical thinking ability, analytical skills, other intellectual abilities, and communication skills. Right-sided brain damage impairs appreciation of music and art and causes behavioral problems. Spatial orientation and recognition of relationships may be deficient, resulting in interference with mobility and "neglect" of the contralateral side of the body (which is not recognized as "self"). For a further explanation of the role of the right and left hemisphere, please consult your physiology text.

### Level of Consciousness

Normally a person is totally aware of surrounding activities and incoming stimuli and oriented to time, place, and people; the person can respond quickly and appropriately to questions, commands, or events. An individual may exert various levels of attention on different aspects of the immediate environment. The cerebral cortex and the RAS in the brain stem determine the level of consciousness. Information must be processed in the association areas of the cortex before one is conscious of the information.

One of the early changes noted in those with acute brain disorders is a decreasing level of consciousness or responsiveness. Usually extensive supratentorial lesions must be present in the cerebral hemispheres to cause loss of consciousness, whereas relatively small lesions in the brain stem (infratentorial lesions) can affect the reticular activating system (RAS). Space-occupying masses in the cerebellum can also compress the brain stem and RAS. In addition to CNS lesions, many systemic disorders, such as acidosis or hypoglycemia, can depress the CNS, reducing the level of consciousness.

Various levels of reduced consciousness may present as lethargy, confusion, **disorientation**, memory loss, unresponsiveness to verbal stimuli, or difficulty in arousal. Standard categories, in tools such as the *Glasgow Coma Scale*, provide consistency in the medical assessment (Table 14-5). The most serious level is loss of consciousness or **coma**, in which the affected person does not respond to painful or verbal stimuli and the body is motionless, although some reflexes are present. The terminal stage, deep coma, is marked by a loss of all reflexes, fixed and dilated pupils, and slow and irregular pulse and respirations.

A *vegetative state* is a loss of awareness and mental capabilities, resulting from diffuse brain damage, although brain stem function continues, supporting respiratory, cardiovascular, and autonomic functions. There appears to be a sleep-wake cycle (eyes are open or closed), but the person is unresponsive to external stimuli. Some individuals may in time recover consciousness but often survive with significant neurologic impairment.

*Locked-in syndrome* refers to a condition in which an individual with brain damage is aware and capable of thinking but is paralyzed and cannot communicate. Some individuals can move their eyes in a "yes" or "no" response.

A diagnosis of *brain death* is often required to terminate medical intervention, because individuals can be maintained artificially on cardiopulmonary support systems. The criteria for brain death include:

- Cessation of brain function, including function of the cortex and the brain stem (e.g., a flat or inactive EEG)
- Absence of brain stem reflexes or responses
- Absence of spontaneous respirations when ventilator assistance is withdrawn
- Establishment of the certainty of irreversible brain damage by confirmation of the cause of the dysfunction

Drug overdose or hypothermia can cause loss of brain activity temporarily; thus, a longer time period and additional testing are required before brain death can be confirmed in these cases.



**TABLE 14-5 Glasgow Coma Scale and Use in Assessment**

| Criteria | Maximum | Example—0700Hours | Example—0900Hours | Example—1100Hours |
|---|---|---|---|---|
| Eye opening | | | | |
| Spontaneous | 4 | | | |
| Response to speech | 3 | × | × | |
| Response to pain | 2 | | | |
| None | 1 | | | × |
| Motor response | | | | |
| Obeys commands | 6 | × | | |
| Localizes pain | 5 | | × | |
| Normal flexion (to pain) | 4 | | | |
| Abnormal flexion (decorticate) | 3 | | | |
| Abnormal extension (decerebrate) | 2 | | | |
| None (flaccid) | 2 | | | × |
| Verbal response | | | | |
| Oriented to time and place | 5 | | | |
| Confused | 4 | × | | |
| Inappropriate words | 3 | | × | |
| Incomprehensible | 2 | | | |
| None | 1 | | | × |
| Score | 15 (good, normal) | 13 | 11 | 4 |

### Motor Dysfunction

Damage to the upper motor neurons in the posterior zone of the frontal lobe of cerebral cortex or to the corticospinal tracts in the brain interferes with voluntary movements, causing weakness or paralysis on the opposite (contralateral) side of the body. This contralateral effect is determined by the crossover of the corticospinal tracts in the medulla. The area affected, such as a leg or arm, depends on the specific site of damage. Muscle tone and reflexes may be increased (**hyperreflexia**) because the intact spinal cord continues to conduct impulses with no moderating or inhibiting influences sent from the brain (**spastic** paralysis). This frequently leads to immobility resulting in contractures in the affected limbs.

Damage to the lower motor neurons in the anterior horns of the spinal cord causes weakness or paralysis on the same side of the body, at and below the level of damage. In the area of damage, the muscles are usually **flaccid** (absence of tone), and reflexes are absent (flaccid paralysis). If the cord distal to the damage is intact, some reflexes in that area may be present and hyperactive (hyperreflexia). Lower motor neurons are also located in the nuclei of *cranial nerves* in the brain stem, and similarly, **ipsilateral** weakness or flaccid paralysis may result from damage to any cranial nerves containing motor fibers (see Table 14-3).

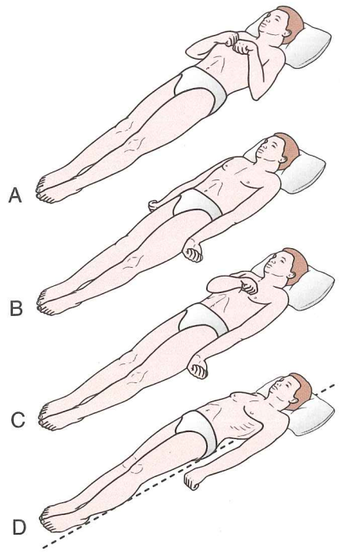


FIGURE 14-6 **Decorticate and Decerebrate Posturing A,** Decorticate response. Flexion of arms, wrists, and fingers with adduction in upper extremities. Extension, internal rotation, and plantar flexion in lower extremities. **B,** Decerebrate response. All four extremities in rigid extension, with hyperpronation of forearms and plantar flexion of feet. **C,** Decorticate response on right side of body and decerebrate response on left side of body. **D,** Opisthotonic posturing. *(From Lewis SM, Heitkemper MM, Dirksen SR: Medical-Surgical Nursing, ed 6, St. Louis, 2004, Mosby).*

Two involuntary motor responses that occur in persons with severe brain trauma include *decorticate* and *decerebrate* posturing (Fig. 14-6). Decorticate responses include rigid flexion in the upper limbs, with adducted arms and internal rotation of the hands; the lower limbs are extended. This response may occur in persons with severe damage in the cerebral hemispheres. Decerebrate responses occur in persons with brain stem lesions and CNS depression caused by systemic effects. Both the upper and lower limbs are extended, as is the head, and the body is arched.

## Sensory Deficits

Sensory loss may involve touch, pain, temperature, and position and the special senses of vision, hearing, taste, and smell. The somatosensory cortex in the parietal lobe (see Fig. 14-3), which receives and localizes basic sensory input from the body, is mapped to correspond to receptors in the skin and skeletal muscles of various body regions. The specific site of damage determines the deficit. Mapping of the dermatomes (see Fig. 14-22) assists in the evaluation of spinal cord lesions. Damage to the cranial nerves or their nuclei or to the assigned area of the brain may interfere with vision or other special senses.

## Visual Loss: Hemianopia

Because of the unique anatomy of the visual pathway, loss of the visual field depends on the site of damage in the visual pathway (Fig. 14-7). (See Chapter 15 for review of the structure of the eye.) At the optic chiasm, the fibers in each optic nerve come together and then divide. If the optic chiasm is totally destroyed, vision is lost in both eyes. Partial loss can result in a variety of effects, depending on the particular fibers damaged. Fibers from the medial (inner) half of each **retina** (cells receive visual stimuli) cross over to the other hemisphere, whereas fibers from the lateral or outer half of the retina remain on the same side. Thus, the optic tract coursing from the optic chiasm to the occipital lobe on one side includes fibers from half of each eye. If the optic tract or occipital lobe is damaged, vision is lost from the medial half of one eye and the lateral half of the other eye; this is called *homonymous hemianopia.* The overall effect is loss of the visual field on the side opposite to that of the damage. In other words, damage to the left occipital lobe means loss of the right visual field because the left half of both retinas receives light waves from the right side of the visual field. If you were caring for this patient, it would be best to stand on the patient's left side.

Other types of visual loss may occur depending on the point of damage in the visual pathway. Partial loss of vision may lead to inability to coordinate input from right and left visual fields. This may lead to **diplopia** or double vision as well as loss of depth perception and hand to eye coordination.

## Language Disorders

**Aphasia** refers to an inability to comprehend or to express language. There are many types of aphasia; the main types are expressive, receptive, and global (Table 14-6). Variations and combinations may occur in individual cases. Dysphasia refers to partial impairment, which is more common, but the term *aphasia* is frequently used to refer to both partial and total loss of communicating ability.

- *Expressive*, or *motor*, *aphasia* results in an impaired ability to speak or write fluently or appropriately. Such a person may be unable to find any intelligible words or construct a meaningful sentence. This type of aphasia occurs when Broca's area in the dominant (usually the left lobe) frontal lobe, inferior motor cortex, is damaged (see Fig. 14-3).
- *Receptive*, or *sensory*, *aphasia* is an inability to read or understand the spoken word. This category does not include hearing or visual impairment. The source of the problem is the inability to process information in the brain. The individual may be capable of fluent speech, but frequently it is meaningless. Damage to Wernicke's area in the left temporal lobe results in receptive aphasia.
- *Global aphasia* commonly describes a combination of expressive and receptive aphasia that results from major damage to the brain, including Broca's area, Wernicke's area, and many communicating fibers throughout the brain.

Aphasia may also be described as *fluent* or *nonfluent*; in fluent aphasia the pace of speech is relatively normal but contains made-up words and sentences that do not make sense. Fluent aphasia is associated with damage to Wernicke's area. Nonfluent aphasia is slow and labored speech with short phrases; often small words are omitted. It is associated with damage to Broca's area.



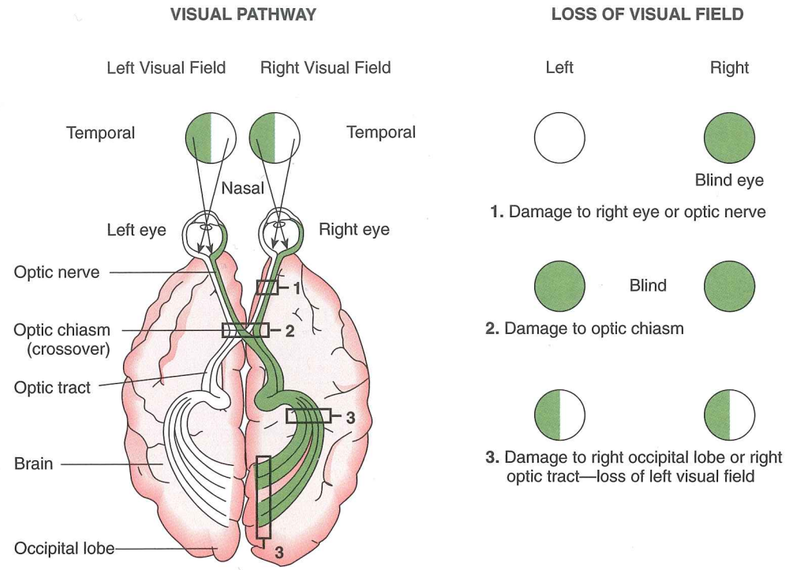


FIGURE 14-7 The visual pathway.

**TABLE 14-6 Aphasia**

| Type | Site of Damage | Effect |
|---|---|---|
| Expressive (motor) | Broca's area<br>Left frontal lobe | Cannot speak or write fluently or appropriately |
| Receptive (sensory) | Wernicke's area<br>Left temporal lobe, prefrontal | Unable to understand written or spoken language |
| Global | Broca's and Wernicke's areas and connecting fibers | Cannot express self or comprehend others' language |

Other types of language disorders include the following:

- *Dysarthria*, in which words cannot be articulated clearly, is a motor dysfunction that usually results from cranial nerve damage or muscle impairment.
- *Agraphia* is impaired writing ability.
- *Alexia* is impaired reading ability.
- *Agnosia* is loss of recognition or association. For example, visual agnosia indicates an inability to recognize objects.

Thorough testing is required before a specific diagnosis can be made of any of these disorders.

**THINK ABOUT 14-7**

a. Compare normal function and coma, using two characteristics of these levels of consciousness.
b. Describe two possible areas of CNS damage that might cause flaccid paralysis.
c. Describe the effects on motor function of damage to the lateral surface of the frontal lobe.
d. Describe the characteristics of expressive aphasia, and state the usual location of the damage.

## Seizures

Seizures or convulsions are caused by spontaneous excessive discharge of neurons in the brain. This state may be precipitated by inflammation, hypoxia, or bleeding in the brain. Often the seizure is focal or is

related to the particular site of the irritation, but it may become generalized. Frequently the seizure is manifested by involuntary repetitive movements or abnormal sensations.

## Increased Intracranial Pressure

The skull contains brain tissue, blood, and CSF. The volume of each of these normally remains relatively constant, thus maintaining a normal pressure inside the cranial cavity. Temporary fluctuations in blood flow and blood pressure may occur with activities such as coughing or bending over. The fluids, blood and CSF, are not compressible. Because the brain is encased in the rigid, nonexpandable skull, any increase in fluid, such as blood or inflammatory exudate, or any additional mass, such as a tumor, causes an increase in pressure in the brain. The result is that less arterial blood can enter the "high pressure" area in the brain, and eventually the brain tissue itself is compressed. Both of these effects decrease the function of the neurons, both locally and generally. Eventually brain tissue dies. The pressure increases at the site of the problem initially but gradually is dispersed throughout the CNS by means of the continuous flow of CSF and blood, leading to widespread loss of function. Changes in intracranial pressure (ICP) can be monitored directly by instruments placed in the ventricles (an invasive procedure) or indirectly by methods such as radiologic examinations or assessment of the level of consciousness and vital signs.

Increased ICP is common in many neurologic problems, including brain hemorrhage, trauma, cerebral edema, infection, tumors, or accumulation of excessive amounts of CSF (Fig. 14-8). All of these problems create the same general set of manifestations, which are summarized in Table 14-7.

### Early Signs

When ICP increases, the body initially attempts to compensate for it by shifting more CSF to the spinal cavity, for example, and increasing venous return from the brain. These compensation mechanisms are effective for only a short time. The resulting hypoxia triggers arterial vasodilation in the brain through local autoregulatory reflexes, in an attempt to improve the blood supply to the brain. However, this adds to the fluid volume inside the skull and is also effective for only a short time. Because of these compensatory mechanisms, ICP is often significantly elevated before signs become apparent.

If the cause of the increased pressure has not been removed, the *first* indication of increased ICP is usually a *decreasing level of consciousness* or decreased responsiveness (lethargy). Additional early indications of increased ICP include the following:

- *Severe headache* occurs from stretching of the dura and walls of large blood vessels.

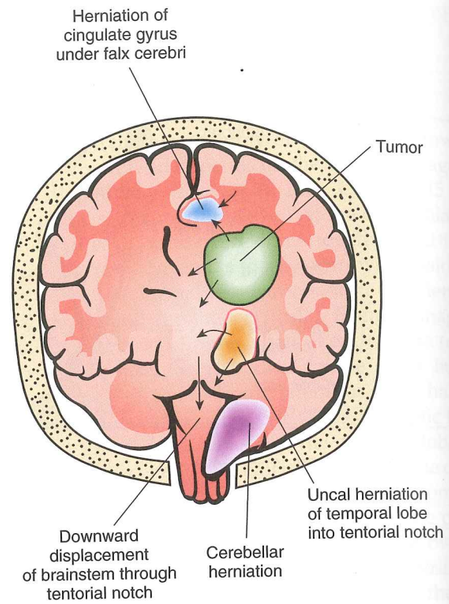


FIGURE 14-8 Increased intracranial pressure and possible herniations.

**TABLE 14-7 Effects of Increased Intracranial Pressure**

| General Signs | Rationale |
|---|---|
| Decreasing level of consciousness | Pressure on RAS (brain stem) or cerebral cortex |
| Headache | Stretching or distortion of meninges or walls of large blood vessels |
| Vomiting | Pressure on emetic center in medulla |
| **Vital Signs** | |
| Increasing blood pressure with increasing pulse pressure | Cushing's reflex; response to cerebral ischemia causes systemic vasoconstriction |
| Slow heart rate | Response to increasing blood pressure |
| **Signs Affecting Vision** | |
| Papilledema | Increased pressure of CSF causes swelling around the optic disc |
| Pupil, fixed and dilated | Pressure on cranial nerve III (oculomotor) |

CSF, cerebrospinal fluid; RAS, reticular activating system.

- *Vomiting*—often projectile vomiting that is not associated with food intake—is the result of pressure stimulating the emetic center in the medulla.
- *Papilledema* may be present, caused by increased ICP and swelling of the optic disc (Fig. 14-9).



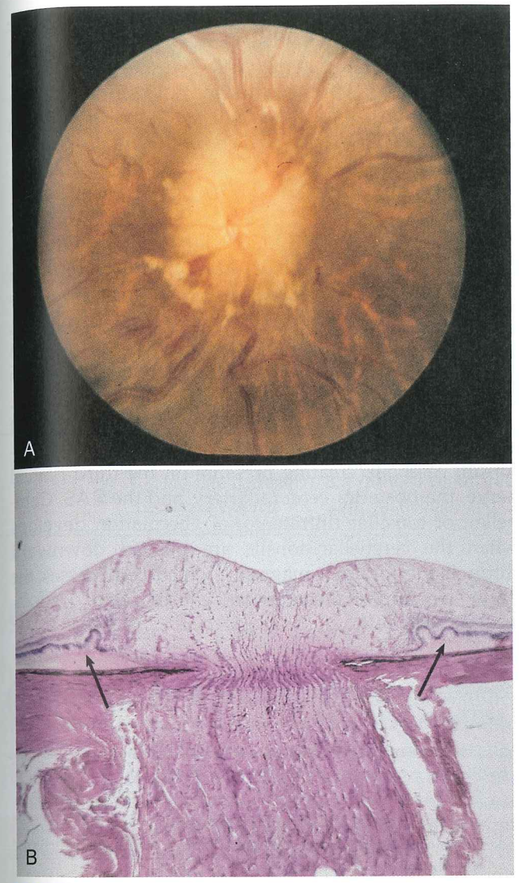


FIGURE 14-9 **A**, Papilledema. **B**, Papilledema showing displacement and folding of the retina (*arrows*) as well as edema and congestion of the optic nerve head. *(A, Courtesy John W. Payne, MD, The Wilmer Ophthalmological Institute, The Johns Hopkins University and Hospital, Baltimore, MD, from Seidel HM, Ball JW, Dains JE, et al:* Mosby's Guide to Physical Examination, *ed 5, St. Louis, 2003, Mosby; B, From Cotran RS, Kumar V, Collins T:* Robbins Pathologic Basis of Disease, *ed 6, Philadelphia, 1999, Saunders.)*

Papilledema can be observed by looking through the pupil of the eye at the retina, where the optic disc provides a "window" into the brain (see Fig. 15-1). The optic nerve (cranial nerve II) is essentially a projection of brain tissue that is surrounded by CSF and meninges and enters the eye at the optic disc, where it reflects the effects of increased ICP in the brain. These early manifestations continue to increase in severity as long as ICP continues to rise.

### Vital Signs

If ICP continues to build, a sequence of events occurs in an effort to supply critical oxygen to the brain, as follows:

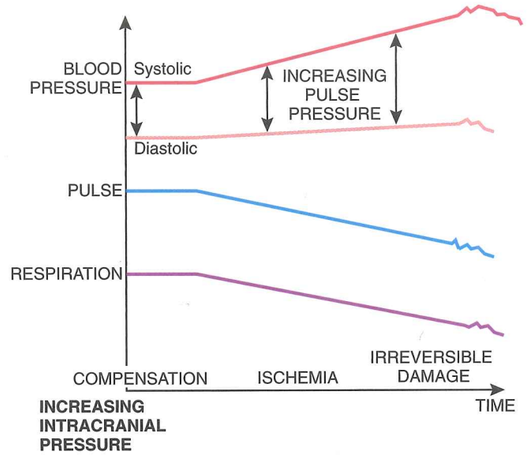


FIGURE 14-10 Vital signs with increased intracranial pressure.

1. Cerebral ischemia develops, which stimulates a powerful response (Cushing's reflex) from the vasomotor centers in an attempt to increase the arterial blood supply to the brain.
2. Systemic vasoconstriction occurs to increase systemic blood pressure and force more blood into the brain to relieve the ischemia.
3. Baroreceptors in the carotid arteries respond to the increased blood pressure by slowing the heart rate.
4. Chemoreceptors respond to the low carbon dioxide levels that accompany the accelerated systemic circulation by reducing the respiratory rate.
5. As improved cerebral circulation relieves ischemia, the reflex vasoconstriction momentarily ceases. However, the increasing ICP causes ischemia to recur in a very short time, and the cycle is repeated.

In other words, the brain responds to ischemia by one mechanism, whereas feedback control for blood pressure uses other mechanisms to protect the rest of the body, resulting in a conflict of interests.

As ICP continues to rise, so does systemic blood pressure (Fig. 14-10). An increasing *pulse pressure* (the difference between systolic and diastolic pressures) is significant in people with ICP. The widening gap in pulse pressure results from the slow heart rate and the intermittent but rapid on-off cycle of Cushing's reflex controlling systemic vasoconstriction.

Eventually severe ischemia and neuronal death prevent any circulatory control, and the blood pressure drops. Pressure and ischemia also destroy respiratory controls. Various abnormal respiratory patterns develop, such as Cheyne-Stokes respirations, with alternating apnea and periods of increasing and decreasing respirations, depending on the site of the lesion (see Fig. 13-7).

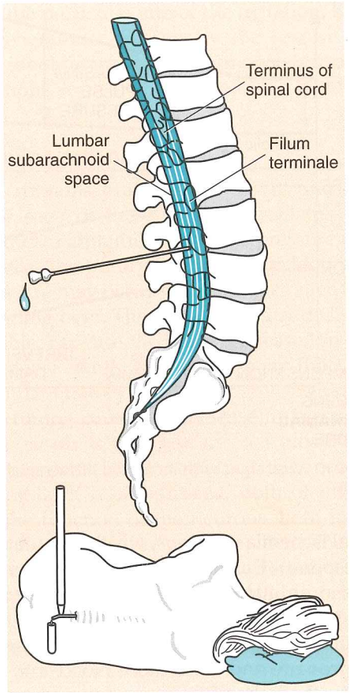


FIGURE 14-11 **Lumbar Puncture** Cerebrospinal fluid is obtained by inserting a needle into the subarachnoid space in the lumbar region. *(From Mahon CR, Manuselis G:* Textbook of Diagnostic Microbiology, *ed 2, Philadelphia, 2000, Saunders.)*

### Visual Signs

In addition to papilledema and specific reflex changes, several other significant indicators of increasing ICP are seen in the eyes. Pressure on the oculomotor nerve (cranial nerve III) affects the size and response of the pupils. Usually one pupil ipsilateral to the lesion becomes fixed (unresponsive to light) and dilated as the PNS fibers in the affected oculomotor nerve become nonfunctional. With an additional pressure increase, both pupils become fixed and dilated ("blown").

Other signs of increased ICP may include **ptosis**, or "droopy eyelid," which is another effect of pressure on cranial nerve III because innervation to the muscle of the upper eyelid is impaired, and abnormal or excessive eye movements, such as nystagmus.

### Changes in Cerebrospinal Fluid

A specimen may be procured with a lumbar puncture by inserting a fine needle between the vertebrae at L3-4, into the subarachnoid space, and withdrawing a small sample of CSF (Fig. 14-11). A manometer may be attached to the syringe to measure pressure. The pressure of CSF is elevated (above 20 mmHg) in patients with increased ICP.

The composition of the fluid may vary with the cause of the problem (see Table 14-1). The CSF may be pinkish in color and contain erythrocytes, suggesting hemorrhage. A cloudy, yellowish fluid that contains numerous WBCs may indicate infection, whereas abnormal protein levels in the CSF may indicate a neoplasm.

## Herniation

When a mass, such as a blood clot or tumor, becomes large enough, it may displace brain tissue, leading to herniation. There are several different types of herniation (see Fig. 14-8). In transtentorial (central) herniation, the cerebral hemispheres, diencephalon, and midbrain are displaced downward. The resulting pressure affects the flow of blood and CSF, the RAS, and respiration. Uncal (uncinate) herniation occurs when the uncus of the temporal lobe is displaced downward past the tentorium cerebelli, creating pressure on the third cranial nerve, the posterior cerebral artery, and the RAS. Cerebellar, or tonsillar (infratentorial), herniation develops when the cerebellar tonsils are pushed downward through the foramen magnum, which compresses the brain stem and vital centers and causes death.

**THINK ABOUT 14-8**

a. List the early signs of increased ICP.
b. Explain why headache occurs with an increase in ICP.
c. Describe the usual changes in vital signs that result from increased ICP in early and later stages.
d. Explain why a lesion in the brain stem is more critical than one in the cerebral hemisphere.

## Diagnostic Tests

Computed tomographic (CT) scans, magnetic resonance imaging (MRI), cerebral angiography, Doppler ultrasound (for assessing patency of the carotid and intracerebral vessels), and EEG provide useful information. A radionuclide such as technetium may be added to track perfusion in CNS. Lumbar puncture is used to check pressure and analyze the CSF for altered components.

Clinical assessment routinely includes tools such as the assessment of normal reflexes and the Glasgow coma scale to assess the level of consciousness.

# Acute Neurologic Problems

Neurologic disorders have been divided into acute problems and chronic problems. Although some overlap occurs, there are major differences in onset, course, and management of the two groups.



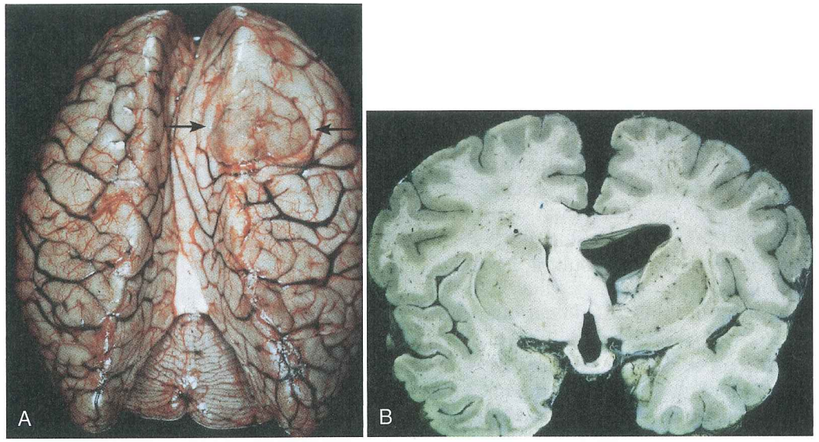


FIGURE 14-12 **Brain Tumor A,** Astrocytoma in right frontal lobe has expanded the gyri (arrows indicate flattening). **B,** Expanded white area in left hemisphere distorts brain structures. *(From Kumar V, Abbas AK, Fausto M:* Robbins and Cotran Pathologic Basis of Disease, *ed 7, Philadelphia, 2005, Saunders.)*

## Brain Tumors

Tumors serve as a good example of space-occupying lesions that cause increased ICP because of space constraints within the rigid skull, and localized dysfunction related to their location. Therefore benign tumors as well as malignant tumors can be life threatening, unless they are in an accessible superficial location where they can be removed. Gliomas form the largest category of primary malignant tumors. They arise from one of the glial cells, the parenchymal cells in the CNS (see Fig. 20-13 for CT scan of a brain tumor). This group of tumors is further classified according to the cell of derivation (e.g., astrocytomas are the most common) and the location of the tumor. In addition, tumors may develop in the meninges (meningioma) or pituitary gland (adenoma, see Chapter 16), causing similar neurologic effects that result from pressure on the brain. Primary malignant tumors rarely metastasize outside the CNS, but multiple tumors may be present within the CNS. Secondary brain tumors are quite common, usually metastasizing from breast or lung tumors, and they cause effects similar to those of primary brain tumors.

The combined incidence rate for brain cancer in children and adults is 22,000 in 2008 with 13,000 deaths. Case fatality rates with this cancer are relatively high. Brain cancer is responsible for greater than 2% of cancer deaths. Diagnosis is made by MRI, with a stereotactic biopsy providing confirmation.

### *Pathophysiology*

Primary malignant brain tumors, particularly astrocytomas, do not usually have well-defined margins but are invasive and have irregular projections into adjacent tissue that are difficult to totally remove (see Fig. 14-12). There is usually an area of inflammation around the tumor, adding to the pressure. In some cases, obstruction of the flow of CSF or of the venous sinuses increases ICP. As the mass expands, it compresses and distorts the tissue around it, eventually resulting in herniation. A relatively small tumor in the brain stem or cerebellum can compress the medulla within a short time. However, tumors in the cerebral hemispheres, particularly in "silent" areas (without obvious function), may grow quite large before their effects are noticeable.

### *Etiology*

Brain stem and cerebellar tumors are common in young children, and research into the cause of these tumors continues, particularly with regard to prenatal parental exposure to carcinogens and embryonic development. Tumors occur in adults most often in mid-life. Adults are affected more frequently by tumors in the cerebral hemispheres; predisposing factors have not been established.

### *Signs and Symptoms*

The specific site of the tumor determines the focal signs. If the tumor grows rapidly, signs of increased ICP develop quickly, often beginning with morning headaches. Over time, these headaches increase in severity and frequency. Vomiting occurs. Lethargy and irritability may develop, along with personality and behavioral changes. In some cases, focal or generalized seizures are the first sign, as the tumor irritates the surrounding tissue. Brain stem or cerebellar tumors may affect several