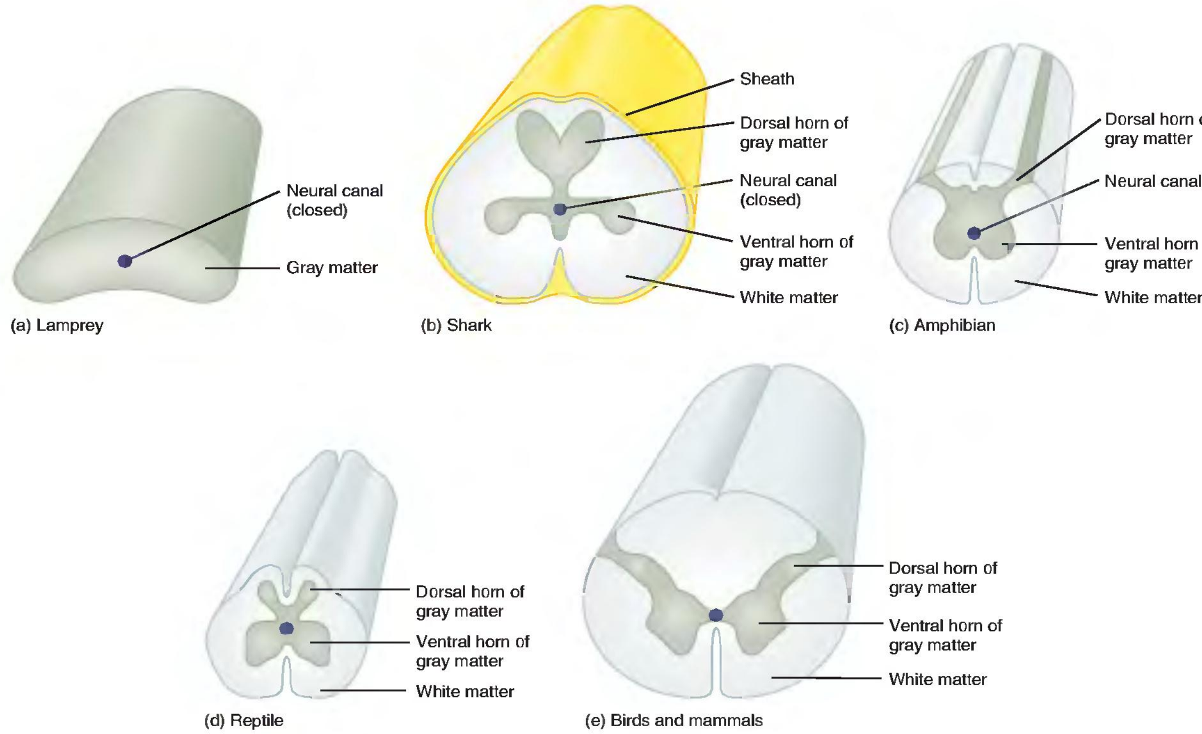

FIGURE 24.9

Spinal Cords of Vertebrates. *(a)* The spinal cord of a typical agnathan (lamprey) is flattened and possesses no myelinated axons. Its shape facilitates the diffusion of gases, nutrients, and other products. *(b,c)* In fishes and amphibians, the spinal cord is larger, well vascularized, and rounded. With more white matter, the spinal cord bulges outward. The gray matter in the spinal cord of *(d)* a reptile and *(e)* birds and mammals has a characteristic butterfly shape.

THE SPINAL CORD

The spinal cord serves two important functions in an animal; it is the connecting link between the brain and most of the body, and it is involved in spinal reflex actions. A reflex is a predictable, involuntary response to a stimulus. Thus, both voluntary and involuntary limb movements, as well as certain organ functions, depend on this link.

The spinal cord is the part of the central nervous system that extends from the brain to near or into the tail (figure 24.9). A cross section shows a neural canal that contains cerebrospinal fluid. The gray matter consists of cell bodies and dendrites, and is concerned mainly with reflex connections at various levels of the spinal cord. Extending from the spinal cord are the ventral and dorsal roots of the spinal nerves. These roots contain the main motor and sensory fibers (axons and/or dendrites), respectively, that contribute to the major spinal nerves. The white matter of the spinal cord gets its name from the whitish myelin that covers the axons.

Three layers of protective membranes called **meninges** (pl. of meninx, membrane) surround the spinal cord. They are continuous with similar layers that cover the brain. The outer layer, the **dura mater,** is a tough, fibrous membrane. The middle layer, the **arachnoid,** is delicate and connects to the innermost layer, the **pia mater.** The pia mater contains small blood vessels that nourish the spinal cord.

SPINAL NERVES

Generally, the number of spinal nerves is directly related to the number of segments in the trunk and tail of a vertebrate. For example, a frog has evolved strong hind legs for swimming or jumping, a reduced trunk, and no tail in the adult. It has only 10 pairs of spinal nerves. By contrast, a snake, which moves by lateral undulations of its long trunk and tail, has several hundred pairs of spinal nerves.

THE BRAIN

Anatomically, the vertebrate brain develops at the anterior end of the spinal cord. During embryonic development, the brain undergoes regional expansion as a hollow tube of nervous tissue forms and develops into the hindbrain, midbrain, and forebrain (figure 24.10). The central canal of the spinal cord extends up

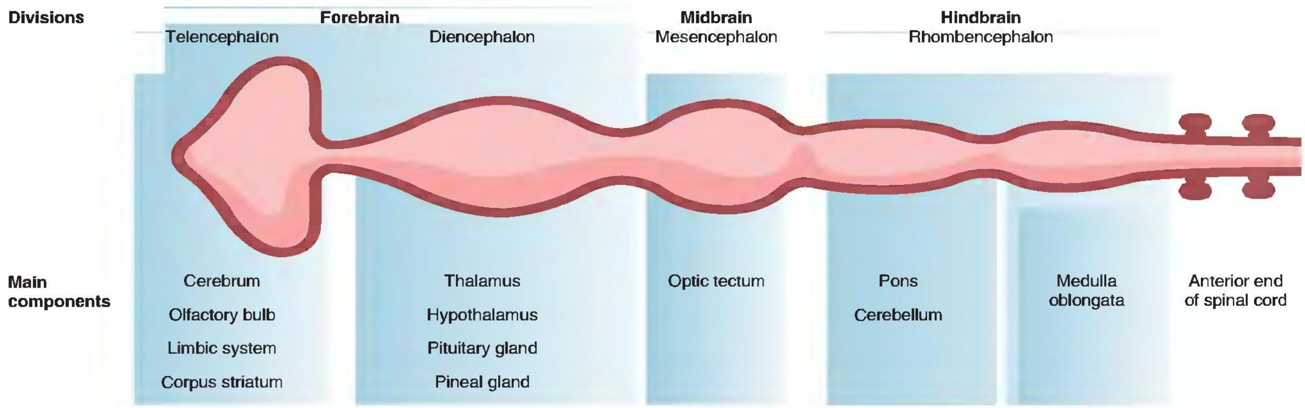

FIGURE 24.10

Development of the Vertebrate Brain. Summary of the three major subdivisions and some of the structures they contain. This drawing is highly simplified and flattened.

into the brain and expands into chambers called ventricles. The ventricles are filled with cerebrospinal fluid.

Hindbrain

The **hindbrain** is continuous with the spinal cord and includes the medulla oblongata, cerebellum, and pons. The **medulla oblongata** is the enlargement where the spinal cord enters the brain. It contains reflex centers for breathing, swallowing, cardiovascular function, and gastric secretion. The medulla oblongata is well developed in all jawed vertebrates, reflecting its ability to control visceral functions and to serve as a screen for information that leaves or enters the brain.

The **cerebellum** is an outgrowth of the medulla oblongata. It coordinates motor activity associated with limb movement, maintaining posture, and spatial orientation. The cerebellum in cartilaginous fishes has distinct anterior and posterior lobes. In teleosts, the cerebellum is large in active swimmers and small in relatively inactive fishes. Amphibians often have a rudimentary cerebellum, reflecting their relatively simple locomotor patterns (figure 24.11). In tetrapods, the cerebellum is laterally expanded. These expanded lateral lobes provide locomotor control of muscles of the appendages. *The cerebellum is much larger in birds and mammals—a reflection of complex locomotor patterns and a common evolutionary history of limb development and phylogeny as terrestrial vertebrates.*

The **pons** is a bridge of transverse nerve tracts from the cerebrum of the forebrain to both sides of the cerebellum. It also contains tracts that connect the forebrain and spinal cord in all vertebrates.

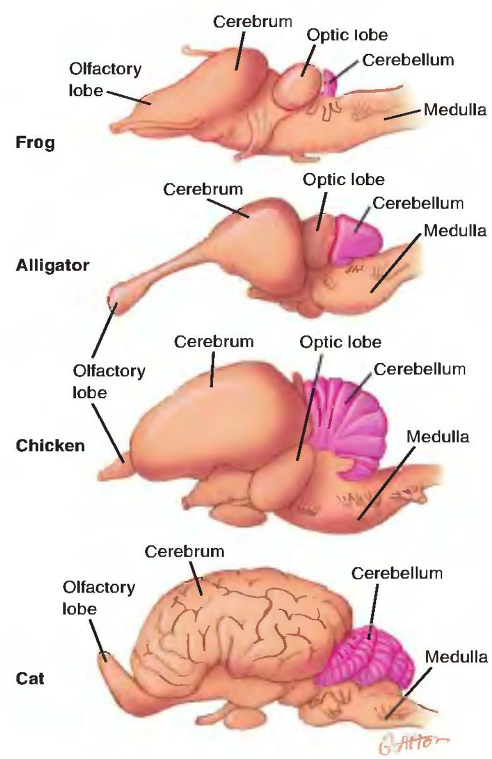

FIGURE 24.11

Vertebrate Brains. Comparison of several vertebrate brains, as viewed from the side. The drawings are not drawn to the same scale. Notice the increase in relative size of the cerebrum from amphibian (frog) to mammal (cat).

Midbrain

The **midbrain** was originally a center for coordinating reflex responses to visual input. As the brain evolved, it took on added functions relating to tactile (touch) and auditory (hearing) input, but it did not change in size. The roof of the midbrain, called the optic tectum, is a thickened region of gray matter that integrates visual and auditory signals.

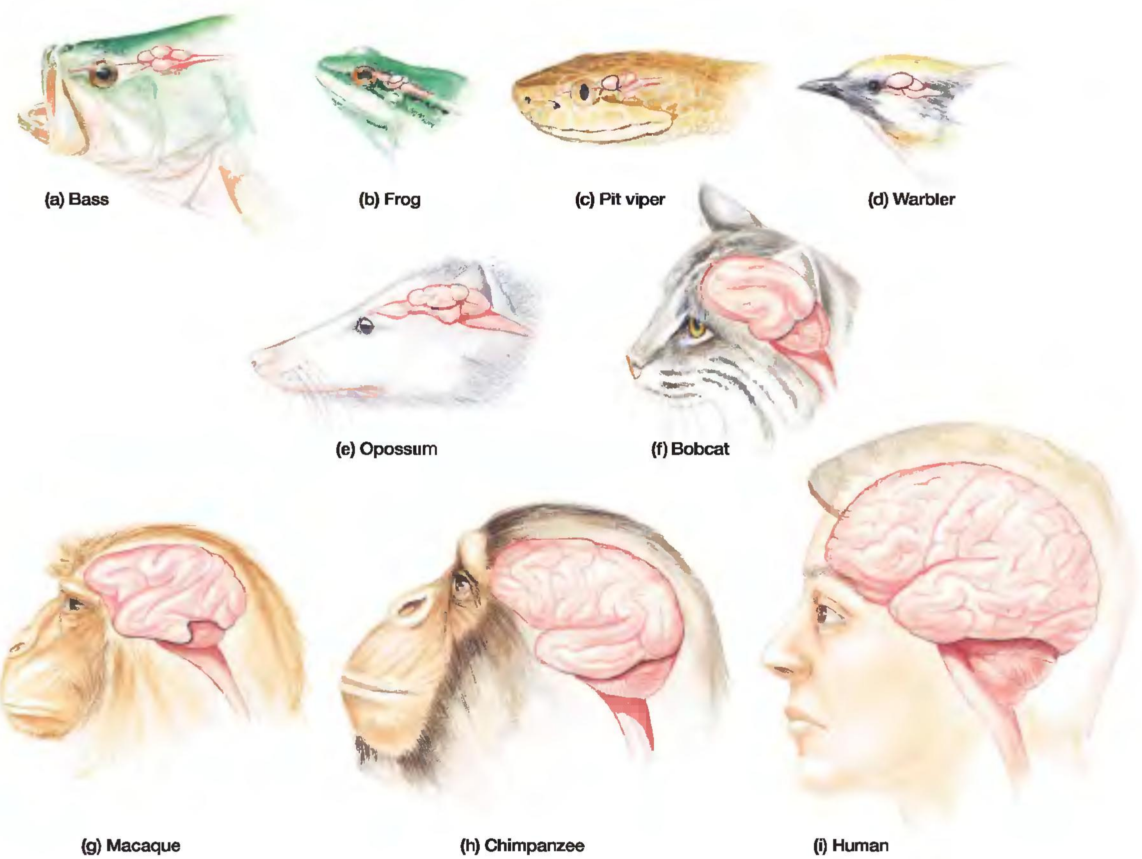

FIGURE 24.12

Cerebrum in Different Vertebrate Species. The cerebrum increases in both size and complexity of its neural connections in more advanced groups. *(a)* Fishes and *(b)* amphibians lack cerebral cortices, whereas *(c)* reptiles and *(d)* birds have a small amount of gray matter covering their cerebrums. Most primitive mammals, such as *(e)* the opossum, have smooth cortices. Carnivores, such as *(f)* the bobcat, have larger cerebrums, and the cortex has a few convolutions, *(g,h)* In the primates, the cerebrum is much increased relative to other brain structures, and the cortex is highly convoluted. *(i)* The human cerebrum dominates in brain evolution and is highly convoluted.

Forebrain

The vertebrate forebrain has changed a great deal during vertebrate evolution. The **forebrain** has two main parts: the diencephalon and telencephalon (*see figure 24.10*). The diencephalon lies just in front of the midbrain and contains the pineal gland, pituitary gland, hypothalamus, and thalamus. The **thalamus** relays all sensory information to higher brain centers. The **hypothalamus** lies below the thalamus and regulates many functions, such as body temperature, sexual drive, carbohydrate metabolism, hunger, and thirst. The pineal gland controls some body rhythms. The pituitary is a major endocrine gland, and chapter 25 discusses it in detail.

In fishes and amphibians, the diencephalon processes sensory information. In reptiles and birds, the most important part of the brain is the corpus striatum, which plays a role in their complex behavior patterns (*see chapter 21*).

As the diencephalon slowly expanded during evolution and handled more and more sensory functions, the telencephalon (the front part of the forebrain) expanded rapidly in both size and complexity.

External to the corpus striatum is the **cerebrum,** which a large groove divides into right and left cerebral hemispheres. The parts of the brain related to sensory and motor integration changed greatly as vertebrates became more agile and inquisitive (figure 24.12). Many functions shifted from the optic tectum to the expanding cerebral hemispheres. The increasing importance of the cerebrum affected many other brain regions, especially the thalamus and cerebellum. *In mammals, the outermost part of the cerebrum, called the cerebral cortex, progressively increased in size and complexity. This layer folds back on itself to a remarkable extent, suggesting that the evolution of the mammalian cerebrum outpaced the enlargement of the skull-bones housing it.*

Different parts of the cerebrum have specific functions. For example, the cerebral cortex contains primary sensory areas and primary motor areas. Other areas of the cortex are involved in the perception of visual or auditory signals from the environment. In humans, this includes the ability to use language—both written and spoken.

TABLE 24.1
FUNCTIONS OF THE CRANIAL NERVES OF REPTILES, BIRDS, AND MAMMALS

NERVE		TYPE	INNERVATION AND FUNCTION
I	Olfactory	Sensory	Smell
II	Optic	Sensory	Vision
III	Oculomotor	Primarily motor	Eyelids, eyes, adjustments of light entering eyes, lens focusing (motor)
IV	Trochlear	Primarily motor	Condition of muscles (sensory) Eye muscles (motor)
V	Trigeminal	Mixed	Condition of muscles (sensory)
	Ophthalmic division		Eyes, tear glands, scalp, forehead, and upper eyelids (sensory)
	Maxillary division		Upper teeth, upper gum, upper lip, lining of the palate, and skin of the face (sensory)
	Mandibular division		Scalp, skin of the jaw, lower teeth, lower gum, and lower lip (sensory)
VI	Abducens	Primarily motor	Jaws, floor of the mouth (motor) Eye muscles (motor)
VII	Facial	Mixed	Condition of muscles (sensory) Taste receptors of the anterior tongue (sensory) Facial expression, tear glands, and salivary glands (motor)
VIII	Vestibulocochlear	Sensory	
	Vestibular branch		Equilibrium; vestibule
	Cochlear branch		Hearing; cochlea
IX	Glossopharyngeal	Mixed	Pharynx, tonsils, posterior tongue, and carotid arteries (sensory) Pharynx and salivary glands (motor)
X	Vagus	Mixed	Speech and swallowing, heart, and visceral organs in the thorax and abdomen (motor) Pharynx, larynx, esophagus, and visceral organs of the thorax and abdomen (sensory)
XI	Accessory	Motor	
	Cranial branch		Soft palate, pharynx, and larynx
	Spinal branch		Neck and back
XII	Hypoglossal	Motor	Tongue muscles

CRANIAL NERVES

In addition to the paired spinal nerves, the peripheral nervous system of vertebrates includes paired cranial nerves (table 24.1). Reptiles, birds, and mammals have 12 pairs of cranial nerves. Fishes and amphibians have only the first 10 pairs. Some of the nerves (e.g., optic nerve) contain only sensory axons, which carry signals to the brain. Others contain sensory and motor axons, and are termed mixed nerves. For example, the vagus nerve has sensory axons leading to the brain as well as motor axons leading to the heart and smooth muscles of the visceral organs in the thorax and abdomen.

THE AUTONOMIC NERVOUS SYSTEM

The vertebrate autonomic nervous system is composed of two divisions that act antagonistically (in opposition to each other) to control the body's involuntary muscles (smooth and cardiac) and glands. The **parasympathetic nervous system** functions during relaxation. It contains nerves that arise from the brain and sacral region of the spinal cord. It consists of a network of long efferent nerve fibers that synapse at ganglia in the immediate vicinity of organs, and short efferent neurons that extend from the ganglia to the organs. The **sympathetic nervous system** is responsible for the "fight-or-flight" response. It contains nerves that arise from the thoracic and lumbar regions of the spinal cord. It is a network of short efferent central nervous system fibers that extend to ganglia near the spine, and long efferent neurons extending from the ganglia directly to each organ.

Many organs receive input from both the parasympathetic and sympathetic systems. For example, parasympathetic input stimulates salivary gland secretions and intestinal movements, contracts pupillary muscles in the eyes, and relaxes sphincter muscles. Sympathetic input controls antagonistic actions: the inhibition of salivary gland secretions and intestinal movements, the relaxation of pupillary muscles, and the contraction of sphincters.