A 23-year-old student was driving home from a party and crashed his car head-on into a tree. On examination in the emergency department of the local hospital, he had a fracture dislocation of the seventh thoracic vertebra, with signs and symptoms of severe damage to the spinal cord. Later, he was found to have paralysis of the left leg. Testing of cutaneous sensibility revealed a band of cutaneous hyperesthesia (increased sensitivity) extending around the abdominal wall on the left side at the level of the umbilicus. Just below this, he had a narrow band of anesthesia and analgesia. On the right side, he had total analgesia, thermoanesthesia, and partial loss of the sensation of touch of the skin of the abdominal wall below the level of the umbilicus and involving the whole of the right leg.

With knowledge of anatomy, a physician knows that a fracture dislocation of the 7th thoracic vertebra would result in severe damage to the 10th thoracic segment of the spinal cord. Because of the small size of the vertebral foramen in the thoracic region, such an injury inevitably results in damage to the spinal cord. Knowledge of the vertebral levels of the various segments of the spinal cord enables the physician to determine the likely neurologic deficits. The unequal sensory and motor losses on the two sides indicate a left hemisection of the cord. The band of anesthesia and analgesia was caused by the destruction of the cord on the left side at the level of the 10th thoracic segment; all afferent nerve fibers entering the cord at that point were interrupted. The loss of pain and thermal sensibilities and the loss of light touch below the level of the umbilicus on the right side were caused by the interruption of the lateral and anterior spinothalamic tracts on the left side of the cord.

To comprehend what has happened to this patient, a knowledge of the relationship between the spinal cord and its surrounding vertebral column must be understood. The various neurologic deficits will become easier to understand after the reader has learned how the nervous pathways pass up and down the spinal cord. This information will be discussed in Chapter 4.
The nervous system and the endocrine system control the functions of the body. The nervous system is composed basically of specialized cells, whose function is to receive sensory stimuli and to transmit them to effector organs, whether muscular or glandular (Fig. 1-1). The sensory stimuli that arise either outside or inside the body are correlated within the nervous system, and the efferent impulses are coordinated so that the effector organs work harmoniously together for the well-being of the individual. In addition, the nervous system of higher species has the ability to store sensory information received during past experiences. This information, when appropriate, is integrated with other nervous impulses and channeled into the common efferent pathway.

Central and Peripheral Nervous Systems

The nervous system is divided into two main parts, for purposes of description: the central nervous system (Fig. 1-2A), which consists of the brain and spinal cord, and the peripheral nervous system (Fig. 1-2B), which consists of the cranial and spinal nerves and their associated ganglia.

In the central nervous system, the brain and spinal cord are the main centers where correlation and integration of nervous information occur. Both the brain and spinal cord are covered with a system of membranes, called meninges, and are suspended in the cerebrospinal fluid; they are further protected by the bones of the skull and the vertebral column (Fig. 1-3).

The central nervous system is composed of large numbers of excitable nerve cells and their processes, called neurons, which are supported by specialized tissue called neuroglia (Fig. 1-4). The long processes of a nerve cell are called axons or nerve fibers.

The interior of the central nervous system is organized into gray and white matter. Gray matter consists of nerve cells embedded in neuroglia; it has a gray color. White matter consists of nerve fibers embedded in neuroglia; it has a white color due to the presence of lipid material in the myelin sheaths of many of the nerve fibers.

In the peripheral nervous system, the cranial and spinal nerves, which consist of bundles of nerve fibers or axons, conduct information to and from the central nervous system. Although the nerves are surrounded by fibrous sheaths as they run to different parts of the body, they are relatively unprotected and are commonly damaged by trauma.

Autonomic Nervous System

The autonomic nervous system is the part of the nervous system concerned with the innervation of involuntary structures, such as the heart, smooth muscle, and glands within the body. It is distributed throughout the central and peripheral nervous systems. The autonomic system may be divided into two parts, the sympathetic and the parasympathetic, and in both parts, there are afferent and efferent nerve fibers. The activities of the sympathetic part of the autonomic system prepare the body for an emergency. The activities of the parasympathetic part of the autonomic system are aimed at conserving and restoring energy.

Spinal Cord

The spinal cord is situated within the vertebral canal of the vertebral column and is surrounded by three meninges (Figs. 1-3A, 1-5, and 1-6): the dura mater, the arachnoid mater, and the pia mater. Further protection is provided by the cerebrospinal fluid, which surrounds the spinal cord in the subarachnoid space.

The spinal cord is roughly cylindrical (Fig. 1-6) and begins superiorly at the foramen magnum in the skull, where it is continuous with the medulla oblongata of the brain (Figs. 1-5 and 1-6). It terminates inferiorly in the lumbar region. Below, the spinal cord tapers off into the conus medullaris, from the apex of which a prolongation of the pia mater, the filum terminale, descends to attach to the back of the coccyx (Fig. 1-5B).

Along the entire length of the spinal cord are attached 31 pairs of spinal nerves by the anterior or motor roots and the posterior or sensory roots (Figs. 1-6 and 1-7). Each root is attached to the cord by a series of rootlets, which

CHAPTER OBJECTIVES

● To understand the basic organization of the main structures that form the nervous system
● To gain a three-dimensional appreciation of the parts of the brain and their relative positions to one another.
Figure 1-1 The relationship of afferent sensory stimuli to memory bank, correlation and coordinating centers, and common efferent pathway.

Figure 1-2 A: The main divisions of the central nervous system. B: The parts of the peripheral nervous system (the cranial nerves have been omitted).
extend the whole length of the corresponding segment of the cord. Each posterior nerve root possesses a posterior root ganglion, the cells of which give rise to peripheral and central nerve fibers.

Structure of the Spinal Cord

The spinal cord is composed of an inner core of gray matter, which is surrounded by an outer covering of white matter (Fig. 1-7). The gray matter is seen on cross section as an H-shaped pillar with anterior and posterior gray columns, or horns, united by a thin gray commissure containing the small central canal. The white matter, for purposes of description, may be divided into anterior, lateral, and posterior white columns (Fig. 1-7).

Brain

The brain (Fig. 1-8) lies in the cranial cavity and is continuous with the spinal cord through the foramen magnum (Fig. 1-6A). It is surrounded by three meninges (Fig. 1-3): the dura mater, the arachnoid mater, and the pia mater; these are continuous with the corresponding meninges of the spinal cord. The cerebrospinal fluid surrounds the brain in the subarachnoid space.

The brain is conventionally divided into three major divisions. These are, in ascending order from the spinal cord, the hindbrain, the midbrain, and the forebrain. The hindbrain may be subdivided into the medulla oblongata, the pons, and the cerebellum. The forebrain may also be subdivided into the diencephalon (between brain), which is the central part of the forebrain, and the cerebrum. The brainstem (a collective term for the medulla oblongata, pons, and midbrain) is that part of the brain that remains after the cerebral hemispheres and cerebellum are removed.

Hindbrain

Medulla Oblongata

The medulla oblongata is conical in shape and connects the pons superiorly to the spinal cord inferiorly (Fig. 1-9). It contains many collections of neurons, called nuclei, and serves as a conduit for ascending and descending nerve fibers.

Pons

The pons is situated on the anterior surface of the cerebellum, inferior to the midbrain and superior to the medulla oblongata (Figs. 1-9 and 1-10). The pons, or bridge, derives its name from the large number of transverse fibers on its anterior aspect connecting the two cerebellar hemispheres. It also contains many nuclei and ascending and descending nerve fibers.

Cerebellum

The cerebellum lies within the posterior cranial fossa of the skull (Figs. 1-8 to 1-10), posterior to the pons and the medulla oblongata. It consists of two laterally placed hemispheres connected by a median portion, the vermis. The cerebellum is connected to the midbrain by the superior cerebellar peduncles, to the pons by the middle cerebellar peduncles, and to the medulla by the inferior cerebellar peduncles (see Fig. 6-9). The peduncles are composed of large bundles of nerve fibers connecting the cerebellum to the remainder of the nervous system.

The surface layer of each cerebellar hemisphere is called the cortex and is composed of gray matter (Fig. 1-12). The cerebellar cortex is thrown into folds, or folia, separated by closely set transverse fissures. Certain masses of gray matter are found in the interior of the cerebellum, embedded in the white matter; the largest of these is known as the dentate nucleus (see Fig. 6-7).

The medulla oblongata, the pons, and the cerebellum surround a cavity filled with cerebrospinal fluid, called the fourth ventricle. This is connected superiorly to the third ventricle by the cerebral aqueduct; inferiorly, it is continuous with the central canal of the spinal cord (Figs. 1-11 and 1-12). It communicates with the subarachnoid space through three openings in the inferior part of the roof. It is through these openings that the cerebrospinal fluid within the central nervous system can enter the subarachnoid space.
Major Divisions of the Central Nervous System

Midbrain
The midbrain is the narrow part of the brain that connects the forebrain to the hindbrain (Figs. 1-2A and 1-11). The narrow cavity of the midbrain is the cerebral aqueduct, which connects the third and fourth ventricles (Fig. 1-11). The midbrain contains many nuclei and bundles of ascending and descending nerve fibers.

Diencephalon
The diencephalon is almost completely hidden from the surface of the brain. It consists of a dorsal thalamus and a ventral hypothalamus (Fig. 1-11). The thalamus is a large, egg-shaped mass of gray matter that lies on either side of the third ventricle. The anterior end of the thalamus forms the posterior boundary of the interventricular foramen, the opening between the third and lateral ventricles (Fig. 1-11). The hypothalamus forms the lower part of the lateral wall and floor of the third ventricle (Fig. 1-11).

Cerebrum
The cerebrum, the largest part of the brain, consists of two cerebral hemispheres, which are connected by a mass of white matter called the corpus callosum (Figs. 1-10 and 1-11). Each hemisphere extends from the frontal to the occipital
Figure 1-5  A: Fetus with the brain and spinal cord exposed on the posterior surface. Note that the spinal cord extends the full length of the vertebral column. B: Sagittal section of the vertebral column in an adult showing the spinal cord terminating inferiorly at the level of the lower border of the first lumbar vertebra. C: Adult spinal cord and covering meninges showing the relationship to surrounding structures.
Figure 1-6  

A: Brain, spinal cord, spinal nerve roots, and spinal nerves as seen on their posterior aspect. 
B: Transverse section through the thoracic region of the spinal cord showing the anterior and posterior roots of a spinal nerve and the meninges. 
C: Posterior view of the lower end of the spinal cord and cauda equina showing their relationship with the lumbar vertebrae, sacrum, and coccyx.
CHAPTER 1 Introduction and Organization of the Nervous System

One segment of spinal cord

Figure 1-7  A: Transverse section through the lumbar part of the spinal cord, oblique view.  B: Transverse section through the lumbar part of the spinal cord, face view, showing the anterior and posterior roots of a spinal nerve.

Figure 1-8  Lateral view of the brain within the skull.
Major Divisions of the Central Nervous System

Figure 1-9 Inferior view of the brain.

Figure 1-10 Brain viewed from its right lateral aspect.
borders in the skull, superior to the anterior and middle cranial fossae; posteriorly, the cerebrum lies above the tentorium cerebelli (see Fig. 15-3). The hemispheres are separated by a deep cleft, the longitudinal fissure, into which projects the falx cerebri (see Fig. 15-1).

The surface layer of each hemisphere, the cortex, is composed of gray matter. The cerebral cortex is thrown into folds, or gyri, separated by fissures, or sulci (Fig. 1-10). The surface area of the cortex is greatly increased by this means. A number of the large sulci are conveniently used to subdivide the surface of each hemisphere into lobes. The lobes are named from the bones of the cranium under which they lie.

Within the hemisphere is a central core of white matter, containing several large masses of gray matter, the basal nuclei or ganglia. A fan-shaped collection of nerve fibers, termed the corona radiata (Fig. 1-13), passes in the white matter to and from the cerebral cortex to the brainstem. The corona radiata converges on the basal nuclei and passes between them as the internal capsule. The tailed nucleus situated on the medial side of the internal capsule is referred to as the caudate nucleus (Fig. 1-14), and the lens-shaped nucleus on the lateral side of the internal capsule is called the lentiform nucleus.

The cavity present within each cerebral hemisphere is called the lateral ventricle (see Figs. 16-2 and 16-3). The lateral ventricles communicate with the third ventricle through the interventricular foramina.

During the process of development, the cerebrum becomes enormously enlarged and overhangs the diencephalon, the midbrain, and the hindbrain.

**Structure of the Brain**

Unlike the spinal cord, the brain is composed of an inner core of white matter, which is surrounded by an outer covering of gray matter. However, as mentioned previously, certain important masses of gray matter are situated deeply within the white matter. For example, within the cerebellum, there are the gray cerebellar nuclei, and within the cerebrum, there are the gray thalamic, caudate, and lentiform nuclei.

**Major Divisions of the Peripheral Nervous System**

The peripheral nervous system consists of the cranial and spinal nerves and their associated ganglia.
Major Divisions of the Peripheral Nervous System

Figure 1-12  Sagittal section through the brainstem and the cerebellum.

Figure 1-13  Right lateral view showing continuity of the corona radiata, the internal capsule, and the crus cerebri of the cerebral peduncles. Note the position of the lentiform nucleus lateral to the internal capsule.
Cranial and Spinal Nerves

The cranial and spinal nerves are made up of bundles of nerve fibers supported by connective tissue.

There are 12 pairs of cranial nerves (Fig. 1-9), which leave the brain and pass through foramina in the skull. There are 31 pairs of spinal nerves (Fig. 1-6), which leave the spinal cord and pass through intervertebral foramina in the vertebral column. The spinal nerves are named according to the regions of the vertebral column with which they are associated: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal. Note that there are 8 cervical nerves and only 7 cervical vertebrae and that there is 1 coccygeal nerve and there are 4 coccygeal vertebrae.

Each spinal nerve is connected to the spinal cord by two roots: the anterior root and the posterior root. The anterior root consists of bundles of nerve fibers carrying nerve impulses away from the central nervous system. Such nerve fibers are called efferent fibers. Those efferent fibers that go to skeletal muscles and cause them to contract are called motor fibers. Their cells of origin lie in the anterior gray horn of the spinal cord.

The posterior root consists of bundles of nerve fibers, called afferent fibers, that carry nervous impulses to the central nervous system. Because these fibers are concerned with conveying information about sensations of touch, pain, temperature, and vibration, they are called sensory fibers. The cell bodies of these nerve fibers are situated in a swelling on the posterior root called the posterior root ganglion (Fig. 1-6).

The spinal nerve roots pass from the spinal cord to the level of their respective intervertebral foramina, where they unite to form a spinal nerve (Fig. 1-15). Here, the motor and sensory fibers become mixed together; thus, a spinal nerve is made up of a mixture of motor and sensory fibers.

Because of the disproportionate growth in length of the vertebral column during development, compared with that of the spinal cord, the length of the roots increases progressively from above downward (Fig. 1-15). In the upper cervical region, the spinal nerve roots are short and run almost horizontally, but the roots of the lumbar and sacral nerves below the level of the termination of the cord (lower border of the first lumbar vertebra in the adult) form a vertical leash of nerves around the filum terminale (Fig. 1-16). Together, these lower nerve roots are called the cauda equina.

Many neuroscientists refer to the anterior and posterior root nerves as ventral and dorsal nerve roots, respectively, even though in the upright human, the roots are anterior and posterior. This is probably due to the fact that the early basic research was performed on animals. In any event, the student must get used to hearing both sets of terms.
After emerging from the intervertebral foramen, each spinal nerve immediately divides into a large \textit{anterior ramus} and a smaller \textit{posterior ramus}, each containing both motor and sensory fibers. The posterior ramus passes posteriorly around the vertebral column to supply the muscles and skin of the back. The anterior ramus continues anteriorly to supply the muscles and skin over the anterolateral body wall and all the muscles and skin of the limbs.

The anterior rami join one another at the root of the limbs to form complicated nerve plexuses (Fig. 1-2B). The \textit{cervical and brachial plexuses} are found at the root of the upper limbs, and the \textit{lumbar and sacral plexuses} are found at the root of the lower limbs.

\section*{Ganglia}

Ganglia may be divided into sensory ganglia of spinal nerves (posterior root ganglia) and cranial nerves and autonomic ganglia.

\subsection*{Sensory Ganglia}

Sensory ganglia are fusiform swellings (Fig. 1-6) situated on the posterior root of each spinal nerve just proximal to the root's junction with a corresponding anterior root. They are referred to as \textit{posterior root ganglia}. Similar ganglia that are also found along the course of cranial nerves V, VII, VIII, IX, and X are called \textit{sensory ganglia} of these nerves.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure_1-15.png}
\caption{Posterior view of the spinal cord showing the origins of the roots of the spinal nerves and their relationship to the different vertebrae. On the right, the laminae have been removed to expose the right half of the spinal cord and the nerve roots.}
\end{figure}
Autonomic Ganglia

Autonomic ganglia, which are often irregular in shape, are situated along the course of effector nerve fibers of the autonomic nervous system. They are found in the paravertebral sympathetic chains (see Figs. 14-1 and 14-2) around the roots of the great visceral arteries in the abdomen and close to, or embedded within, the walls of various viscera.

**EARLY DEVELOPMENT OF THE NERVOUS SYSTEM**

Before the formation of the nervous system in the embryo, three main cell layers become differentiated. The innermost layer, the **ectoderm**, gives rise to the gastrointestinal tract, the lungs, and the liver. The **mesoderm** gives rise to the muscle, connective tissues, and the vascular system. The third and outermost layer, the **ectoderm**, formed of columnar epithelium, gives rise to the entire nervous system.

During the third week of development, the ectoderm on the dorsal surface of the embryo between the primitive knot and the buccopharyngeal membrane becomes thickened to form the **neural plate**. The plate, which is pear shaped and wider cranially, develops a longitudinal **neural groove**. The groove now deepens so that it is bounded on either side by **neural folds** (Fig. 1-17).

With further development, the neural folds fuse, converting the neural groove into a **neural tube**. Fusion starts at about the midpoint along the groove and extends cranially and caudally so that in the earliest stage, the cavity of the tube remains in communication with the amniotic cavity through the **anterior and posterior neuropores** (Fig. 1-17).
The anterior neuropore closes first, and 2 days later, the posterior neuropore closes. Thus, normally, the neural tube closure is complete within 28 days. Meanwhile, the neural tube has sunk beneath the surface ectoderm.

During the invagination of the neural plate to form the neural groove, the cells forming the lateral margin of the plate do not become incorporated in the neural tube but instead form a strip of ectodermal cells that lie between the neural folds.

**Table 1-2**  
*The Primary Divisions of the Developing Brain*

<table>
<thead>
<tr>
<th>Primary Vesicle</th>
<th>Primary Division</th>
<th>Subdivision</th>
<th>Adult Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forebrain</td>
<td>Prosencephalon</td>
<td>Telencephalon</td>
<td>Cerebral hemisphere, basal ganglia, hippocampus</td>
</tr>
<tr>
<td></td>
<td>(forebrain)</td>
<td>Diencephalon</td>
<td>Thalamus, hypothalamus, pineal body, infundibulum</td>
</tr>
<tr>
<td>Midbrain</td>
<td>Mesencephalon</td>
<td>Mesencephalon</td>
<td>Tectum, tegmentum, crus cerebri</td>
</tr>
<tr>
<td></td>
<td>(midbrain)</td>
<td>(midbrain)</td>
<td></td>
</tr>
<tr>
<td>Hindbrain</td>
<td>Rhombencephalon</td>
<td>Metencephalon</td>
<td>Pons, cerebellum</td>
</tr>
<tr>
<td></td>
<td>(hindbrain)</td>
<td>Myelencephalon</td>
<td>Medulla oblongata</td>
</tr>
</tbody>
</table>
tube and the covering ectoderm. This strip of ectoderm is called the neural crest (Fig. 1-17); subsequently, this group of cells will migrate ventrolaterally on each side around the neural tube. Ultimately, the neural crest cells will differentiate into the cells of the posterior root ganglia, the sensory ganglia of the cranial nerves, autonomic ganglia, the cells of the suprarenal medulla, and the melanocytes. It is also believed that these cells give rise to mesenchymal cells in the head and neck.

Meanwhile, the proliferation of cells at the cephalic end of the neural tube causes it to dilate and form three primary brain vesicles: the forebrain vesicle, the midbrain vesicle, and the hindbrain vesicle (Fig. 1-18 and Table 1-2). The rest of the tube elongates and remains smaller in diameter; it will form the spinal cord.

The subsequent differentiation of cells in the neural tube is brought about by the inductive interactions of one group of cells with another. The inducing factors influence the control of the gene expression in the target cells. Ultimately, the simplest progenitor cell will differentiate into neurons and neuroglial cells. It is interesting to note that excessive numbers of neurons and neuroglial cells are developed, and many (nearly half of the developing neurons) will be programmed to die by a process known as programmed cell death. Research into the identification of neurotrophic factors that promote the development and survival of neurons is of great importance, as the results could possibly be applied to the problem of regeneration of the spinal cord neurons following trauma or the inhibition of degenerative diseases, such as Alzheimer disease.

The further development of the nervous system will be fully described in Chapter 18 following the description of the different parts of the nervous system and their neuronal connections.
Clinical Notes

Relationship of Spinal Cord Segments to Vertebral Numbers
Because the spinal cord is shorter than the vertebral column, the spinal cord segments do not correspond numerically with the vertebrae that lie at the same level (Fig. 1-15). The following table will help a physician determine which spinal segment is related to a given vertebral body (Table 1-3).

On examination of a patient’s back, one can see that the spinous processes lie approximately at the same level as the vertebral bodies. In the lower thoracic region, however, because of the length and extreme obliquity of the spines, the tips of the spines lie at the level of the vertebral body below.

Injuries to the Spinal Cord and Brain
The spinal cord and brain are well protected. Both are suspended in fluid, the cerebrospinal fluid, and are surrounded by the bones of the vertebral column and skull (see Chapters 4 and 5). Unfortunately, if the forces of violence are sufficiently great, these protective structures can be overcome, with consequent damage to the delicate underlying nervous tissue. Moreover, the cranial and spinal nerves and blood vessels are also likely to be injured.

Spinal Cord Injuries
The degree of spinal cord injury at different vertebral levels is governed largely by anatomical factors. In the cervical region, dislocation or fracture dislocation is common, but the large size of the vertebral canal often prevents severe injury to the spinal cord. However, when there is considerable displacement of the bones or bone fragments, the cord is sectioned. Respiration ceases if the cord is completely severed above the segmental origin of the phrenic nerves (C3-5), since the intercostal muscles and the diaphragm are paralyzed, and death occurs.

In fracture dislocations of the thoracic region, displacement is often considerable, and because of the small size of the vertebral canal, severe injury to this region of the spinal cord results.

In fracture dislocations of the lumbar region, two anatomical facts aid the patient. First, the spinal cord in the adult extends down only as far as the level of the lower border of the first lumbar vertebra (Fig. 1-16). Second, the large size of the vertebral foramen in this region gives the roots of the cauda equina ample room. Nerve injury may therefore, be minimal in this region.

Injury to the spinal cord may produce partial or complete loss of function at the level of the lesion and partial or complete loss of function of afferent and efferent nerve tracts below the level of the lesion. The symptoms and signs of such injuries are considered after the detailed structure of the spinal cord is discussed, and the ascending and descending tracts are considered in Chapter 4.

Spinal Nerve Injuries
Disease and the Intervertebral Foramina
The intervertebral foramina (Fig. 1-19) transmit the spinal nerves and the small segmental arteries and veins, all of which are embedded in areolar tissue. Each foramen is bounded superiorly and inferiorly by the pedicles of adjacent vertebrae, anteriorly by the lower part of the vertebral body and by the intervertebral disc, and posteriorly by the articulare processes and the joint between them. In this situation, the spinal nerve is very vulnerable and may be pressed on or irritated by disease of the surrounding structures. Herniation of the intervertebral disc, fractures of the vertebral bodies, and osteoarthritis involving the joints of the articulare processes or the joints between the vertebral bodies may all result in pressure, stretching, or edema of the emerging spinal nerve. Such pressure would give rise to dermatomal pain, muscle weakness, and diminished or absent reflexes.

Herniated Intervertebral Discs
Herniation of the intervertebral discs occurs most commonly in those areas of the vertebral column where a mobile part joins a relatively immobile part—for example, the cervicothoracic junction and the lumbosacral junction. In these areas, the posterior part of the anulus fibrosus of the disc ruptures, and the central nucleus pulposus is forced posteriorly like toothpaste out of a tube. This herniation of the nucleus pulposus may result either in a central protrusion in the midline under the posterior longitudinal ligament of the vertebrae or in a lateral protrusion at the side of the posterior ligament close to the intervertebral foramen (Fig. 1-20).

Cervical disc herniations are less common than in the lumbar region. The discs most susceptible to this condition are those between the fifth and sixth and the sixth and seventh cervical vertebrae. Lateral protrusions cause pressure on a spinal nerve or its roots. Each spinal nerve emerges above the corresponding vertebra; thus, the protrusion of the disc between the fifth and sixth cervical vertebrae may compress the C6 spinal nerve or its roots. Pain is felt near the lower part of the back of the neck and shoulder and along the area in the distribution of the spinal nerve involved. Central protrusions may press on the spinal cord and the anterior spinal artery and involve the various spinal tracts.

Lumbar disc herniations are more common than cervical disc herniations (Fig. 1-20). The discs usually affected are those between the fourth and fifth lumbar vertebrae and between the fifth lumbar vertebra and the sacrum. In the lumbar region, the roots of the cauda equina run posteriorly over a number of intervertebral discs (Fig. 1-20). A lateral herniation may press on one or two roots and often involves the nerve root going to the intervertebral foramen just below. The nucleus pulposus occasionally herniates directly backward, and if it is a large herniation, the whole cauda equina may be compressed, producing paraplegia. In lumbar disc herniations, pain is referred down the leg and foot in the distribution of the affected nerve. Because the sensory posterior roots most commonly pressed on are the fifth lumbar and first sacral, pain is usually felt down the back and lateral side of the leg, radiating to the sole of the foot. This condition is often called sciatica. In severe cases, paresis or actual sensory loss may occur.

Pressure on the anterior motor roots causes muscle weakness. Involvement of the fifth lumbar motor root weakens dorsiflexion of the ankle, whereas pressure on the first sacral motor root causes weakness of plantar flexion. The ankle jerk reflex may be diminished or absent (Fig. 1-20).

A large, centrally placed protrusion may give rise to bilateral pain and muscle weakness in both legs. Acute retention of urine may also occur.
Figure 1-19  A: Joints in the cervical, thoracic, and lumbar regions of the vertebral column. B: Third lumbar vertebra seen from above showing the relationship between the intervertebral disc and the cauda equina. C: Sagittal section through three lumbar vertebrae showing the ligaments and the intervertebral discs. Note the relationship between the emerging spinal nerve in an intervertebral foramen and the intervertebral disc.
Spinal Tap

Spinal tap (lumbar puncture) may be performed to withdraw a sample of cerebrospinal fluid for microscopic or bacteriologic examination or to inject drugs to combat infection or induce anesthesia. Fortunately, the spinal cord terminates inferiorly at the level of the lower border of the first lumbar vertebra in the adult. (In the infant, it may reach inferiorly to the third lumbar vertebra.) The subarachnoid space extends inferiorly as far as the lower border of the second sacral vertebra. The lower lumbar part of the vertebral canal is thus occupied by the subarachnoid space, which contains the lumbar and sacral nerve roots and the filum terminale (the cauda equina). A needle introduced into the subarachnoid space in this region usually pushes the nerve roots to one side without causing damage.

With the patient lying on his or her side or in the upright sitting position, with the vertebral column well flexed, the space between adjoining laminae in the lumbar region is opened to a maximum (Fig. 1-21). An imaginary line joining the highest points on the iliac crests passes over the fourth lumbar spine. Using a careful aseptic technique and local anesthesia, the physician passes the lumbar puncture needle, fitted with a stylet, into the vertebral canal above or below the fourth lumbar spine. The needle will pass through the following anatomical structures before it enters the subarachnoid space: (a) skin, (b) superficial fascia, (c) supraspinous ligament, (d) interspinous

Figure 1-20  A, B: Posterior views of the vertebral bodies in the cervical and lumbar regions showing the relationship that might exist between a herniated nucleus pulposus and spinal nerve roots. Note there are eight cervical spinal nerves and only seven cervical vertebrae. In the lumbar region, for example, the emerging L4 nerve roots pass out laterally close to the pedicle of the fourth lumbar vertebra and are not related to the intervertebral disc between the fourth and fifth lumbar vertebrae. C: Posterolateral herniation of the nucleus pulposus of the intervertebral disc between the fifth lumbar vertebra and the first sacral vertebra showing pressure on the S1 nerve root. D: An intervertebral disc that has herniated its nucleus pulposus posteriorly. E: Pressure on the L5 motor nerve root produces weakness of dorsiflexion of the ankle; pressure on the S1 motor nerve root produces weakness of plantar flexion of the ankle joint.
ligament, (e) ligamentum flavum, (f) areolar tissue containing the internal vertebral venous plexus, (g) dura mater, and (h) arachnoid mater. The depth to which the needle will have to pass will vary from 1 inch (2.5 cm) or less in a child to as much as 4 inches (10 cm) in an obese adult.

As the stylet is withdrawn, a few drops of blood commonly escape. This usually indicates that the point of the needle is situated in one of the veins of the internal vertebral plexus and has not yet reached the subarachnoid space. If the entering needle should stimulate one of the nerve roots of the cauda equina, the patient will experience a fleeting discomfort in one of the dermatomes or a muscle will twitch, depending on whether a sensory or a motor root was impaled.

The cerebrospinal fluid pressure may be measured by attaching a manometer to the needle. When the patient is in the recumbent position, the normal pressure is about 60 to 150 mm of water. The pressure shows oscillations corresponding to the movements of respiration and the arterial pulse.

A block of the subarachnoid space in the vertebral canal, which may be caused by a tumor of the spinal cord or the meninges, may be detected by compressing the internal jugular veins in the neck. This raises the cerebral venous pressure and inhibits the absorption of cerebrospinal fluid in the arachnoid granulations, thus producing an increase in the manometer reading of the cerebrospinal fluid pressure. If this rise fails to occur, the subarachnoid space is blocked, and the patient is said to exhibit a positive Queckenstedt sign.

**Caudal Anesthesia**

Anesthetic solutions may be injected into the sacral canal through the sacral hiatus. The solutions pass upward in the loose connective tissue and bathe the spinal nerves as they emerge from the dural sheath (Fig. 1-22). Obstetricians use this method of nerve block to relieve the pains of the first and second stages of labor. The advantage is that when anesthetic is administered by this method, the infant is not affected. Caudal anesthesia may also be used in operations in the sacral region, including anorectal surgery.

**Head Injuries**

A blow to the head may cause the scalp to be merely bruised; severe blows may cause the scalp to be torn or split. Even if the head is protected by a crash helmet, the brain may be severely damaged without clinical evidence of scalp injury.
Clinical Notes

Fractures of the Skull

Severe blows to the head often result in the skull changing shape at the point of impact. Small objects may penetrate the skull and produce local laceration of the brain. Larger objects applied with great force may shatter the skull, and fragments of bone are driven into the brain at the site of impact.

In the adult, fractures of the skull are common, but in the young child, they are less common. In the infant, the skull bones are more resilient than in the adult, and they are separated by fibrous sutural ligaments. In the adult, the inner table of the skull is particularly brittle. Moreover, the sutural ligaments begin to ossify during middle age.

The type of fracture that occurs in the skull will depend on the age of the patient, the severity of the blow, and the area of the skull receiving the trauma. The adult skull may be likened to an eggshell, because it possesses a certain limited resilience beyond which it splinters. A severe, localized blow will produce a local indentation, often accompanied by splintering of the bone. Blows to the vault often result in a series of linear fractures, which radiate out through the thin areas of the bone. The petrous parts of the temporal bones and the occipital crests (see p. 00) strongly reinforce the base of the skull and tend to deflect linear fractures.

The young child’s skull may be likened to a table tennis ball, because a localized blow produces a depression without splintering. This common type of circumscribed lesion is referred to as a “pond” fracture.

Brain Injuries

Brain injuries are produced by displacement and distortion of the neuronal tissues at the moment of impact (Fig. 1-22). The brain, which is incompressible, may be likened to a water-soaked log suspended in water. The brain is floating in the cerebrospinal fluid in the subarachnoid space and is capable of a certain amount of anteroposterior and lateral gliding movement. The anteroposterior movement is limited by the attachment of the superior cerebral veins to the superior sagittal sinus. Lateral displacement of the brain is limited by the falx cerebri. The tentorium cerebelli and the falx cerebelli also restrict displacement of the brain.

From these anatomical facts, it follows that blows on the front or back of the head lead to displacement of the brain, which may produce severe cerebral damage, stretching and distortion of the brainstem, and stretching and even tearing of the commissures of the brain. Blows to the side of the head produce less cerebral displacement, and the injuries to the brain consequently tend to be less severe. It should be noted, however, that the falx cerebri is a tough structure and may cause considerable damage to the softer brain tissue in cases where there has been a severe blow to the side of the head (Fig. 1-23). Furthermore, it is important to remember that glancing blows to the head may cause considerable rotation of the brain, with shearing strains and distortion of the brain, particularly in areas where further rotation is prevented by bony prominences in the anterior and middle cranial fossae. Brain lacerations are very likely to occur when the brain is forcibly thrown against the
sharp edges of bone within the skull (see p. 00)—the lesser wings of the sphenoid, for example.

When the brain is suddenly given momentum within the skull, the part of the brain that moves away from the skull wall is subjected to diminished pressure because the cerebrospinal fluid has not had time to accommodate to the brain movement. This results in a suction effect on the brain surface, with rupture of surface blood vessels.

A sudden severe blow to the head, as in an automobile accident, may result in damage to the brain at two sites: at the point of impact and at the pole of the brain opposite the point of impact, where the brain is thrown against the skull wall. This is referred to as **contrecoup injury**.

The movement of the brain within the skull at the time of head injuries not only is likely to cause avulsion of cranial nerves but commonly leads to rupture of tethering blood vessels. Fortunately, the large arteries found at the base of the brain are tortuous, and this, coupled with their strength, explains why they are rarely torn. The thin-walled cortical veins, which drain into the large dural venous sinuses, are very vulnerable and can produce severe subdural or subarachnoid hemorrhage (Fig. 1-23).

**Traumatic Brain Injury following an Explosion or Blast**

Soldiers deployed to Afghanistan and Iraq are frequently exposed to explosive devices, which may result in extensive injuries to the limbs, eyes, and ears. Open injuries to the skull,
Intracranial Hemorrhage

Although the brain is cushioned by the surrounding cerebrospinal fluid in the subarachnoid space, any severe hemorrhage within the relatively rigid skull will ultimately exert pressure on the brain.

Intracranial hemorrhage may result from trauma or cerebral vascular lesions (Fig. 1-21). Four varieties are considered here: (1) epidural, (2) subdural, (3) subarachnoid, and (4) cerebral.

Epidural (extradural) hemorrhage results from injuries to the meningeal arteries or veins (see p. 000). The anterior division of the middle meningeal artery is the common artery to be damaged. A comparatively minor blow to the side of the head, resulting in fracture of the skull in the region of the anterior inferior portion of the parietal bone, may sever the artery (Fig. 1-23). Arterial or venous injury is especially likely to occur if the vessels enter a bony canal in this region. Bleeding occurs and strips the meningeal layer of dura from the internal surface of the skull. The intracranial pressure rises, and the enlarging blood clot exerts local pressure on the underlying precentral gyrus (motor area). Blood may also pass laterally through the fracture line to form a soft swelling on the side of the head. To stop the hemorrhage, the torn artery must be ligated or plugged. The burr hole through the skull wall should be placed about 1-1/2 inches (4 cm) above the midpoint of the zygomatic arch.

Subdural hemorrhage results from tearing of the superior cerebral veins where they enter the superior sagittal sinus (see Figs. 15-1 and 17-5). The cause is usually a blow to the forehead or back of the head, resulting in excessive anteroposterior displacement of the brain within the skull. This condition, which is much more common than middle meningeal hemorrhage, can be produced by a sudden minor blow. Once the vein is torn, blood under low pressure begins to accumulate in the potential space between the dura and the arachnoid. In a few patients, the condition is bilateral.

Acute and chronic forms of the clinical condition occur, depending on the speed of accumulation of fluid in the subdural space. For example, if the patient starts to vomit, the venous pressure will rise as the result of a rise in the intrathoracic pressure. Under these circumstances, the subdural blood clot will rapidly increase in size and produce acute symptoms. In the chronic form, over a course of several months, the small blood clot will attract fluid by osmosis, in which case a hemorrhagic cyst forms and gradually expands and produces pressure symptoms. In both forms, the blood clot must be removed through burr holes in the skull.

Subarachnoid hemorrhage results from nontraumatic leakage or rupture of a congenital aneurysm on the cerebral arterial circle (circle of Willis) or less commonly from an arteriovenous malformation. The symptoms, which are sudden in onset, will include severe headache, stiffness of the neck, and loss of consciousness. The diagnosis is established by performing CT or MRI or by withdrawing heavily blood-stained cerebrospinal fluid through a lumbar puncture.

With regard to cerebral hemorrhage, spontaneous intracerebral hemorrhage (Fig. 1-23) is most common in patients with hypertension. It is generally due to rupture of the thin-walled lenticulostriate artery (see Fig. 17-11), a branch of the middle cerebral artery (Fig. 17-4). The hemorrhage involves important descending nerve fibers in the internal capsule and produces hemiplegia on the opposite side of the body. The patient immediately loses consciousness, and the paralysis is evident when consciousness is regained. The diagnosis is established by performing brain CT or MRI.

The Shaken-Baby Syndrome

Inflicted head injury is the most common cause of traumatic death in infancy. It is believed that sudden deceleration, which occurs when an infant is held by the arms or trunk and shaken or the head is forcefully struck against a hard surface, is responsible for the brain injuries. Biomechanical studies have shown that the rotation of the floating brain about its center of gravity causes diffuse brain injuries, including diffuse axonal injury and subdural hematoma. In shaken-baby syndrome, major rotational forces have to occur that clearly exceed those encountered in normal child play activities.

Most cases of shaken-baby syndrome take place during the first year of life, and they are usually restricted to infants under 3 years of age. Common symptoms include lethargy, irritability, seizures, altered muscle tone, and symptoms indicating raised intracranial pressure, such as impaired consciousness, vomiting, breathing abnormalities, and apnea. In severe cases, the baby may be unresponsive, the fontanelles are bulging, and the child may have retinal hemorrhages. Spinal tap may reveal blood in the cerebrospinal fluid. Subdural or subarachnoid hemorrhages can be readily detected on CT or MRI scans. Autopsy findings commonly include localized subdural hemorrhage in the parieto-occipital region and subarachnoid blood, associated with massive cerebral swelling and widespread neuronal loss.

Space-Occupying Lesions within the Skull

Space-occupying or expanding lesions within the skull include tumor, hematoma, and abscess. Since the skull is a rigid container of fixed volume, these lesions will add to the normal bulk of the intracranial contents.

An expanding lesion is first accommodated by the expulsion of cerebrospinal fluid from the cranial cavity. Later, the veins become compressed, interference with the circulation of blood and cerebrospinal fluid begins, and the intracranial pressure starts to rise. The venous congestion results in increased production and diminished absorption of cerebrospinal fluid, the volume of the cerebrospinal fluid begins to rise, and thus, a vicious circle is established.

The position of the tumor within the brain may have a dramatic effect on the signs and symptoms. For example, a tumor that obstructs the outflow of cerebrospinal fluid or directly presses on the great veins will cause a rapid increase in intracranial pressure. The signs and symptoms that enable the physician to localize the lesion will depend on the interference with the brain function and the degree of destruction of the nervous tissue produced by the lesion. Severe headache, possibly due to...
the stretching of the dura mater and vomiting, due to pressure on the brainstem, are common complaints. A spinal tap should not be performed in patients with suspected intracranial tumor. The withdrawal of cerebrospinal fluid may lead to a sudden displacement of the cerebral hemisphere through the notch in the tentorium cerebelli into the posterior cranial fossa (Fig. 1-24) or herniation of the medulla oblongata and cerebellum through the foramen magnum. CT scans or MRIs are used in making the diagnosis.

Computed Tomography
CT is used for the detection of intracranial lesions. The procedure is quick, safe, and accurate. The total dose of irradiation is no greater than for a conventional skull radiograph. CT relies on the same physics as conventional x-rays, in that structures are distinguished from one another by their ability to absorb energy from x-rays. The x-ray tube emits a narrow beam of radiation as it passes in a series of scanning movements through an arc of 180 degrees around the patient’s head. The x-rays having passed through the head are collected by a special x-ray detector. The information is fed to a computer that processes the information, which is then displayed as a reconstructed picture on a televisionlike screen. Essentially, the observer sees an image of a thin slice through the head, which may then be photographed for later examination (Fig. 1-25).

The sensitivity is such that small differences in x-ray absorption can be easily displayed. The gray matter of the cerebral cortex, white matter, internal capsule, corpus callosum, ventricles, and subarachnoid spaces can all be recognized. An iodine-containing medium can be injected intravascularly, which enhances greatly the contrast between tissues having a different blood flow.

Since a CT scan can be performed in 5 to 10 minutes, it is the method of choice in an emergency situation with patients with head trauma or suspected intracranial hemorrhage.

Magnetic Resonance Imaging
The technique of MRI uses the magnetic properties of the hydrogen nucleus excited by radiofrequency radiation transmitted by a coil surrounding the head. The excited hydrogen nuclei emit a signal that is detected as induced electric currents in a receiver coil. MRI is absolutely safe to the patient, and because it provides better differentiation between gray and white matter, MRI can be more revealing than CT. The reason for this is that gray matter contains more hydrogen in the form of water than does white matter, and the hydrogen atoms are less bound in fat (Fig. 1-26). MRI is the best imaging method for detecting low-contrast lesions such as brain tumors or small multiple sclerosis plaques. It is also capable of showing clear images of the brain stem, cerebellum, and the pituitary fossa, which in the case of a CT scan are overshadowed by the dense bones of the base of the skull. The spinal cord structure is much more clearly visualized with MRI.

Unfortunately, an MRI takes longer and costs two-thirds more than a CT scan.

Positron Emission Tomography
Positron emission tomography (PET) uses radioactive isotopes that decay with the emission of positively charged electrons (positrons) to map the biochemical, physiologic, and pharmacologic processes taking place in the brain.

The appropriate isotope is incorporated into molecules of known biochemical behavior in the brain and then is injected into the patient. The metabolic activity of the compound can
Figure 1-25  CT scan showing the structure of the brain. A, B: Horizontal cuts (axial sections).
then be studied by making cross-sectional tomographic images of the brain using the same principles as in CT (Fig. 1-27). By making a series of time-lapse images at different anatomical sites, it is possible to study the variations in brain metabolism at these sites. This technique has been used to study the distribution and activity of neurotransmitters, the variations in oxygen utilization, and cerebral blood flow.

PET has been successfully used in the evaluation of patients with brain tumors (Figs. 1-28 and 1-29), movement disorders, seizures, and schizophrenia.

Figure 1-26  MRI showing the structure of the brain. A: Sagittal. B: Coronal. Compare with Figure 1-25. Note the better differentiation between gray and white matter.
**Figure 1-27** Axial (horizontal) PET scan of a normal brain following the injection of 18-fluorodeoxyglucose. Regions of active metabolism (yellow areas) are seen in the cerebral cortex. The lateral ventricles are also demonstrated. (Courtesy Dr. Holley Dey.)

**Figure 1-28** Axial (horizontal) PET scan of a 62-year-old male patient with a malignant glioma in the left parietal lobe, following the injection of 18-fluorodeoxyglucose. A high concentration of the compound (circular yellow area) is seen in the region of the tumor. (Courtesy Dr. Holley Dey.)

**Figure 1-29** Coronal PET scan of a 62-year-old male patient with a malignant glioma in the left parietal lobe, following the injection of 18-fluorodeoxyglucose (same patient as in Fig.1-26). A high concentration of the compound (circular yellow area) is seen in the region of the tumor. (Courtesy Dr. Holley Dey.)
CLINICAL PROBLEM SOLVING

1. A 45-year-old woman was examined by her physician and found to have carcinoma of the thyroid gland. Apart from the swelling in the neck, the patient also complained of back pain in the lower thoracic region, with a burning soreness radiating around the right side of her thorax over the 10th intercostal space. Although the back pain was often relieved by changing posture, it was worsened by coughing and sneezing. A lateral radiograph of the thoracic part of the vertebral column revealed a secondary carcinomatous deposit in the 10th thoracic vertebral body. Further physical examination revealed muscular weakness of both legs. Using your knowledge of neuroanatomy, explain the following: (a) the pain in the back, (b) the soreness over the right 10th intercostal space, (c) the muscular weakness of both legs, and (d) which segments of the spinal cord lie at the level of the 10th thoracic vertebral body.

2. A 35-year-old coal miner was crouching down at the end of the bumper while his friend stood on the other end. Suddenly, he felt an acute pain in the back that extended down the back and outer side of his right leg. Later, he was examined by an orthopedic surgeon, who found that the pain was accentuated by coughing. A lateral radiograph of the lumbar vertebral column revealed nothing abnormal. An MRI, taken in the sagittal plane, showed a small posterior prolapse of the nucleus pulposus in the disc between the fifth lumbar and the first sacral vertebrae. A diagnosis of herniation of the intervertebral disc between the fifth lumbar and first sacral vertebrae was made. Using your knowledge of neuroanatomy, explain the symptoms of this disease. Which spinal nerve roots were pressed on?

3. A 20-year-old man with a long history of tuberculosis of the lungs was examined by an orthopedic surgeon because of the sudden development of a humpback (kyphosis). He also had symptoms of a stabbing pain radiating around both sides of his thorax intensified by coughing or sneezing. A diagnosis of tuberculous osteitis of the fifth thoracic vertebra was made, with the collapse of the vertebral body responsible for the kyphosis. Using your knowledge of neuroanatomy, explain why the collapse of the fifth thoracic vertebral body should produce pain in the distribution of the fifth thoracic segmental nerve on both sides.

4. A 50-year-old man woke up one morning with a severe pain near the lower part of the back of the neck and left shoulder. The pain was also referred along the outer side of the left upper arm. Movement of the neck caused an increase in the intensity of the pain, which was also accentuated by coughing. A lateral radiograph of the neck showed a slight narrowing of the space between the fifth and sixth cervical vertebral bodies. An MRI showed disruption of the intervertebral disc between the fifth and sixth cervical vertebrae. Using your knowledge of anatomy, state which nerve root was involved. Also, state the nature of the disease.

5. A medical student offered to help a fellow student straighten out the bumper of his foreign sports car. He had just finished his course in neuroanatomy and was in poor physical shape. Undaunted, he attempted to lift the end of the bumper while his friend stood on the other end. Suddenly, he felt an acute pain in the back that extended down the back and outer side of his right leg. Later, he was examined by an orthopedic surgeon, who found that the pain was accentuated by coughing. A lateral radiograph of the lumbar vertebral column revealed nothing abnormal. An MRI, taken in the sagittal plane, showed a small posterior prolapse of the nucleus pulposus in the disc between the fifth lumbar and the first sacral vertebrae. A diagnosis of herniation of the intervertebral disc between the fifth lumbar and first sacral vertebrae was made. Using your knowledge of neuroanatomy, explain the symptoms of this disease. Which spinal nerve roots were pressed on?

6. A 5-year-old child was seen in the emergency department, and a diagnosis of acute meningitis was made. The resident decided to perform a lumbar puncture in order to confirm the diagnosis. Using your knowledge of neuroanatomy, where would you perform a lumbar puncture needle is introduced into the subarachnoid space.

7. A pregnant young woman told her friends that she hated the idea of going through the pain of childbirth but that she equally detested the thought of having a general anesthetic. Is there a specialized local analgesic technique that will provide painless childbirth but that equally detested the thought of having a general anesthetic?

8. While crossing the road, a pedestrian was struck on the right side of his head by a passing car. He fell to the ground but did not lose consciousness. After resting for an hour and then getting up, he appeared to be confused and irritable. Later, he staggered and fell to the floor. On questioning, he was seen to be drowsy and twitching of the lower left half of his face and left arm. On questioning, he was seen to be drowsy and twitching of the lower left half of his face and left arm.

9. A 45-year-old woman was examined by a neurologist and found to have an intracranial tumor. She complained of severe headaches, which occurred during the night and early morning. She described the pain as “bursting” in nature, and although at first, 6 months ago, the headaches were intermittent, they were now more or less continuous. Coughing, stooping, and straining at stool made the pain worse. The pain was accompanied by vomiting on three recent occasions. What is the sequence of events that occurs within the skull as the intracranial pressure rises? Would you perform a routine lumbar puncture on every patient you suspected of having an intracranial tumor?

10. While examining an unconscious 18-year-old man admitted to the emergency room following a motorcycle accident, the neurosurgeon asked the attending medical student what happens to the brain in an accident in which it is suddenly decelerated within the skull. What is the value of wearing a crash helmet?
1. Carcinoma of the thyroid, breast, kidney, lung, and prostate commonly gives rise to metastases in bone. (a) The pain in the back was caused by the carcinoma invading and destroying the 10th thoracic vertebral body. (b) Compression of the posterior nerve root of the 10th thoracic spinal nerve by the carcinoma of the vertebral column produced the hyperesthesia and hyperalgesia over the right 10th intercostal space. (c) Muscular weakness of the legs was caused by pressure on the descending motor nerve fibers in the spinal cord by the carcinoma’s invasion of the vertebral canal. (d) Although there is disproportionate growth in length of the vertebral column during development compared with that of the spinal cord, the upper cervical segments of the spinal cord still lie posterior to the vertebral bodies of the same number; however, the spinal cord in the adult terminates inferiorly at the level of the lower border of the first lumbar vertebra, and therefore, the first and second lumbar segments of the spinal cord lie at the level of the 10th thoracic vertebral body.

2. This patient had a severe fracture dislocation between the seventh and eighth thoracic vertebrae. The vertical arrangement of the articular processes and the low mobility of this region because of the thoracic cage mean that a dislocation can occur in this region only if the articular processes are fractured by a great force. The small circular vertebral canal leaves little space around the spinal cord; thus, severe cord injuries are certain.

3. Each spinal nerve is formed by the union of a posterior sensory root and an anterior motor root and leaves the vertebral canal by traveling through an intervertebral foramen. Each foramen is bounded superiorly and inferiorly by the pedicles of adjacent vertebrae, anteriorly by the lower part of the vertebral body and by the intervertebral disc, and posteriorly by the articular processes and the joint between them. In this patient, the fifth thoracic vertebral body had collapsed, and the intervertebral foramina on both sides had been considerably reduced in size, causing compression of the posterior sensory roots and the spinal nerves. The consequent irritation of the sensory fibers was responsible for the pain.

4. This patient had symptoms suggestive of irritation of the left sixth cervical posterior nerve root. The radiograph revealed narrowing of the space between the fifth and sixth cervical vertebral bodies, suggesting a herniation of the nucleus pulposus of the intervertebral disc at this level. MRI showed the nucleus pulposus extending posteriorly beyond the anulus fibrosus, thus confirming the diagnosis.

5. The herniation occurred on the right side and was relatively small. The pain occurred in the distribution of the fifth lumbar and first sacral segments of the spinal cord, and the posterior sensory roots of these segments of the cord were pressed on the right side.

6. In a 5-year-old child, the spinal cord terminates inferiorly at about the level of the second lumbar vertebra (certainly no lower than the third lumbar vertebra). With the child lying on his side and comforted by a nurse and with the operator using an aseptic technique, the skin is anesthetized in the midline just below the fourth lumbar spine. The fourth lumbar spine lies on an imaginary line joining the highest points on the iliac crests. The lumbar puncture needle, fitted with a stylet, is then passed carefully into the vertebral canal. The needle will pass through the following anatomical structures before it enters the subarachnoid space: (a) skin, (b) superficial fascia, (c) supraspinous ligament, (d) interspinous ligament, (e) ligamentum flavum, (f) areolar tissue containing the internal vertebral venous plexus, (g) dura mater, and (h) arachnoid mater.

7. Caudal analgesia (anesthesia) is very effective in producing a painless labor if it is performed skillfully. The anesthetic solutions are introduced into the sacral canal through the sacral hiatus. Sufficient solution is given so that the nerve roots up as far as T11-12 and L1 are blocked. This will make the uterine contractions painless during the first stage of labor. If the nerve fibers of S2-4 are also blocked, the perineum will be anesthetized.

8. A blow on the side of the head may easily fracture the thin anterior part of the parietal bone. The anterior branch of the middle meningeal artery commonly enters a bony canal in this region and is sectioned at the time of the fracture. The resulting hemorrhage causes gradual accumulation of blood under high pressure outside the meningeal layer of the dura mater. The pressure is exerted on the underlying brain as the blood clot enlarges, and the symptoms of confusion and irritability become apparent. This is followed later by drowsiness. Pressure on the lower end of the motor area of the cerebral cortex (the right precentral gyrus) causes twitching of the facial muscles and, later, twitching of the left arm muscles. As the blood clot progressively enlarges, the intracranial pressure rises and the patient’s condition deteriorates.

9. A detailed account of the various changes that occur in the skull in patients with an intracranial tumor is given on page 23. A patient suspected of having an intracranial tumor should not undergo a spinal tap. The withdrawal of cerebrospinal fluid may lead to a sudden displacement of the cerebral hemisphere through the opening in the tentorium cerebelli into the posterior cranial fossa or herniation of the medulla oblongata and cerebellum through the foramen magnum. CT scans or MRIs are now used in making the diagnosis.

10. The brain is floating in the cerebrospinal fluid within the skull, so a blow to the head or sudden deceleration leads to displacement of the brain. This may produce severe cerebral damage: stretching or distortion of the brainstem; avulsion of cranial nerves; and commonly, rupture of tethering cerebral veins. (For further details, see p. 21.) A crash helmet helps to protect the brain by cushioning the blow and thus slowing up the brain’s rate of deceleration.
CHAPTER 1 Introduction and Organization of the Nervous System

REVIEW QUESTIONS

Directions: Each of the incomplete statements in this section is followed by completions of the statement. Select the ONE lettered completion that is BEST in each case.

1. The spinal cord has
   (a) an outer covering of gray matter and an inner core of white matter.
   (b) an enlargement below that forms the conus medullaris.
   (c) anterior and posterior roots of a single spinal nerve attached to a single segment.
   (d) cells in the posterior gray horn that give rise to efferent fibers that supply skeletal muscles.
   (e) a central canal that is situated in the white commissure.

2. The medulla oblongata has
   (a) a tubular shape.
   (b) the fourth ventricle lying posterior to its lower part.
   (c) the midbrain directly continuous with its upper border.
   (d) no central canal in its lower part.
   (e) the spinal cord directly continuous with its lower end in the foramen magnum.

3. The midbrain has
   (a) a cavity called the cerebral aqueduct.
   (b) a large size.
   (c) no cerebrospinal fluid around it.
   (d) a cavity that opens above into the lateral ventricle.
   (e) a location in the middle cranial fossa of the skull.

Directions: Each of the numbered items in this section is followed by answers. Select the ONE lettered answer that is CORRECT.

4. The following statements concern the cerebellum:
   (a) It lies within the middle cranial fossa.
   (b) The cerebellar cortex is composed of white matter.
   (c) The vermis is the name given to that part joining the cerebellar hemispheres together.
   (d) The cerebellum lies anterior to the fourth ventricle.
   (e) The dentate nucleus is a mass of white matter found in each cerebellar hemisphere.

5. The following statements concern the cerebrum:
   (a) The cerebral hemispheres are separated by a fibrous septum called the tentorium cerebelli.
   (b) The bones of the vault of the skull are named for the lobes of the cerebral hemisphere over which they lie.
   (c) The corpus callosum is a mass of gray matter lying within each cerebral hemisphere.
   (d) The internal capsule is an important collection of nerve fibers, which has the caudate nucleus and the thalamus on its medial side and the lentiform nucleus on its lateral side.
   (e) The cavity present within each cerebral hemisphere is called the cerebral ventricle.

6. The following statements concern the peripheral nervous system:
   (a) There are ten pairs of cranial nerves.
   (b) There are eight pairs of cervical spinal nerves.
   (c) The posterior root of a spinal nerve contains many efferent motor nerve fibers.
   (d) A spinal nerve is formed by the union of an anterior and a posterior ramus in an intervertebral foramen.
   (e) A posterior root ganglion contains the cell bodies of autonomic nerve fibers leaving the spinal cord.

7. The following statements concern the central nervous system:
   (a) A CT brain scan cannot distinguish between white matter and gray matter.
   (b) The lateral ventricles are in direct communication with the fourth ventricle.
   (c) An MRI of the brain uses the magnetic properties of the hydrogen nucleus excited by radiofrequency radiation transmitted by a coil surrounding the patient's head.
   (d) Following trauma and sudden movement of the brain within the skull, the large arteries at the base of the brain are commonly torn.
   (e) The movement of the brain at the time of head injuries is unlikely to damage the small sixth cranial nerve.

8. The following statements concern the cerebrospinal fluid:
   (a) The cerebrospinal fluid in the central canal of the spinal cord is unable to enter the fourth ventricle.
   (b) With the patient in the recumbent position, the normal pressure is about 60 to 150 mm of water.
   (c) It plays only a minor role in the protection of the brain and spinal cord from traumatic injury.
   (d) Compression of the internal jugular veins in the neck lowers the cerebrospinal fluid pressure.
   (e) The subdural space is filled with cerebrospinal fluid.

9. The following statements concern the vertebral levels and the spinal cord segmental levels:
   (a) The first lumbar vertebra lies opposite the L3-4 segments of the cord.
   (b) The third thoracic vertebra lies opposite the third thoracic spinal cord segment.
   (c) The fifth cervical vertebra lies opposite the seventh cervical spinal cord segment.
   (d) The eighth thoracic vertebra lies opposite the ninth thoracic spinal cord segment.
   (e) The third cervical vertebra lies opposite the fourth cervical spinal cord segment.

Directions: Each case history is followed by questions. Select the ONE BEST lettered answer.

A 23-year-old woman was unconscious when admitted to the emergency department. While crossing the road, she had been hit on the side of the head by a bus. Within an hour, she was found to have a large doughlike swelling over the right temporal region. She also had signs of muscular paralysis on the left side of the body. A lateral radiograph of the skull showed a fracture line running downward and forward
across the anterior inferior angle of the right parietal bone. Her coma deepened, and she died 5 hours after the accident.

10. Select the most likely cause of the swelling over the right temporal region in this patient.
   (a) Superficial bruising of the skin
   (b) Hemorrhage from a blood vessel in the temporalis muscle
   (c) Rupture of the right middle meningeal vessels
   (d) Edema of the skin
   (e) Hemorrhage from a blood vessel in the superficial fascia

11. Select the most likely cause of the muscular paralysis of the left side of the body in this patient.
   (a) Laceration of the right side of the cerebral hemisphere
   (b) Right-sided epidural hemorrhage
   (c) Left-sided epidural hemorrhage
   (d) Injury to the cerebral cortex on the left side of the brain
   (e) Injury to the right cerebellar hemisphere

A 69-year-old man was admitted to the neurology unit complaining of severe discomfort of the lower back. Radiologic examination showed significant narrowing of the spinal canal caused by advanced osteoarthritis.

12. Explain the discomfort in the lower back experienced by this patient.
   (a) Muscle fatigue
   (b) Prolapsed intervertebral disc
   (c) Torn ligament in the joints of the lumbar region of the spine
   (d) Compression of the cauda equina
   (e) Bad posture

Later, in this same patient, the back pain became more severe and now radiated down the back of the left leg; the patient was also experiencing difficulty walking. Examination of the patient revealed weakness and some wasting of the muscles of the left leg. Radiologic examination showed that the osteoarthritic changes had spread to involve the boundaries of many of the lumbar intervertebral foramina.

13. Explain the change in the symptoms and signs found in this patient.
   (a) The sciatic nerve was compressed in the pelvis by a spreading rectal cancer.
   (b) The patient had developed advanced atherosclerosis of the arteries of the right lower limb.
   (c) The osteoarthritic process had produced osteophytes that encroached on the intervertebral foramina, compressing the segmental spinal nerve roots.
   (d) Neuritis had developed in the sciatic nerve trunk.
   (e) The patient was experiencing psychiatric problems.

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**ANSWERS AND EXPLANATIONS TO REVIEW QUESTIONS**

1. C is correct. Anterior and posterior roots of a single spinal nerve are attached to a single spinal cord segment. A. The spinal cord has an outer covering of white matter and an inner core of gray matter (see Fig. 1-6). B. The spinal cord tapers off below to form the conus medullaris. D. The cells in the posterior gray horn of the spinal cord are associated with sensory function (see p. 0). E. The central canal of the spinal cord is situated in the gray commissure (see Fig. 1-7).

2. E is correct. The lower end of the medulla oblongata is directly continuous with the spinal cord in the foramen magnum (see Fig. 1-5). A. The medulla oblongata is conical in shape (see p. 4). B. The medulla oblongata has the fourth ventricle lying posterior to its upper part. C. The medulla oblongata has the pons directly continuous with its upper border. D. The medulla oblongata has a canal in its lower part that is continuous with that of the spinal cord.

3. A is correct. The midbrain has a cavity called the cerebral aqueduct. B. The midbrain is of small size (see Fig. 1-2). C. The midbrain is completely surrounded with cerebrospinal fluid in the subarachnoid space (see p. 0). D. The midbrain has a cavity called the cerebral aqueduct, which opens above into the third ventricle (see Fig. 1-11). E. The midbrain is located in the posterior cranial fossa.

4. C is correct. The vermis is the name given to that part of the cerebellum joining the cerebellar hemispheres together (see p. 0). A. The cerebellum lies in the posterior cranial fossa (see Fig. 1-8). B. The cerebellar cortex is composed of gray matter (see p. 0). D. The cerebellum lies posterior to the fourth ventricle (see Fig. 1-11). E. The dentate nucleus is a mass of gray matter found in each cerebellar hemisphere (see p. 0).

5. D is correct. The internal capsule is an important collection of ascending and descending nerve fibers, which has the caudate nucleus and the thalamus on its medial side and the lentiform nucleus on its lateral side (see Fig. 1-14). A. The cerebral hemispheres are separated by a vertical, sagittally placed fibrous septum called the falx cerebri (see p. 0). The tentorium cerebelli is horizontally placed and roofs over the posterior cranial fossa and separates the cerebellum from the occipital lobes of the cerebrum (see p. 0). B. The lobes of the cerebral hemisphere are named for the skull bones under which they lie. C. The corpus callosum is a mass of white matter lying within each cerebral hemisphere (see p. 0). E. The cavity present within each cerebral hemisphere is called the lateral ventricle.

6. B is correct. There are 8 pairs of spinal cervical nerves (only 7 cervical vertebrae). A. There are 12 pairs of cranial nerves. C. The posterior root of a spinal nerve contains afferent nerve fibers (see p. 0). D. A spinal nerve is formed by the union of an anterior and a posterior root in an intervertebral foramen. E. A posterior root...
ganglion contains the cell bodies of sensory nerve fibers entering the spinal cord.

7. C is correct. An MRI of the brain uses the magnetic properties of the hydrogen nucleus excited by radiofrequency radiation transmitted by a coil surrounding the patient's head (see p. 24). A. A CT brain scan can distinguish between white and gray matter (see Fig. 1-23). B. The lateral ventricles communicate indirectly with the fourth ventricle through the interventricular foramen, the third ventricle, and the cerebral aqueduct of the midbrain (see Fig. 1-11). D. Following trauma and sudden movement of the brain within the skull, the large arteries at the base of the brain are rarely torn. E. The movement of the brain at the time of head injuries may stretch and damage the small delicate sixth cranial nerve (the small fourth cranial nerve may also be injured).

8. B is correct. With the patient in the recumbent position, the normal pressure of cerebrospinal fluid is 60 to 150 mm of water. A. The cerebrospinal fluid in the central canal of the spinal cord is able to enter the fourth ventricle through the central canal of the lower part of the medulla oblongata (see p. 00). C. The cerebrospinal fluid is important in protecting the brain and spinal cord from traumatic injury by dissipating the force. (Compare with the role of the liquor amnii in protecting the fetus in the pregnant uterus.) D. Compression of the internal jugular vein in the neck raises the cerebrospinal fluid pressure by inhibiting its absorption into the venous system (see p. 00). E. The subarachnoid space is filled with cerebrospinal fluid; the potential subdural space contains only tissue fluid.

9. E is correct. The third cervical vertebra lies opposite the fourth cervical spinal cord segment (see Table 1-3, Page 16). A. The first lumbar vertebra lies opposite the sacral and coccygeal spinal cord segments. B. The third thoracic vertebra lies opposite the fifth thoracic spinal cord segment. C. The fifth cervical vertebra lies opposite the sixth cervical spinal cord segment. D. The eighth thoracic vertebra lies opposite the 11th thoracic spinal cord segment.

10. C is correct. The swelling over the right temporal region and the radiologic finding of a linear fracture over the anterior inferior angle of the right parietal bone would strongly suggest that the right middle meningeal artery had been damaged and an epidural (extradural) hemorrhage had occurred. Blood had spread through the fracture line into the overlying temporalis muscle and soft tissue.

11. B is correct. The left-sided paralysis (left hemiplegia) was due to pressure exerted by the right-sided epidural hemorrhage on the precentral gyrus of the right cerebral hemisphere.

12. D is correct. In persons in whom the spinal canal was originally small, significant narrowing of the canal in the lumbar region can lead to neurologic compression of the cauda equina with pain radiating to the back, as in this patient.

13. C is correct. One of the complications of osteoarthritis of the vertebral column is the growth of osteophytes, which commonly encroach on the intervertebral foramina, causing pain along the distribution of the segmental nerve. In this patient, the segmental nerves L4-5 and S1-3, which form the important sciatic nerve, were involved. This would explain the pain radiating down the left leg and the atrophy of the leg muscles.

Additional Reading


Snell, R. S. Clinical Anatomy by Regions (8th ed.). Philadelphia: Lippincott Williams & Wilkins, 2008.