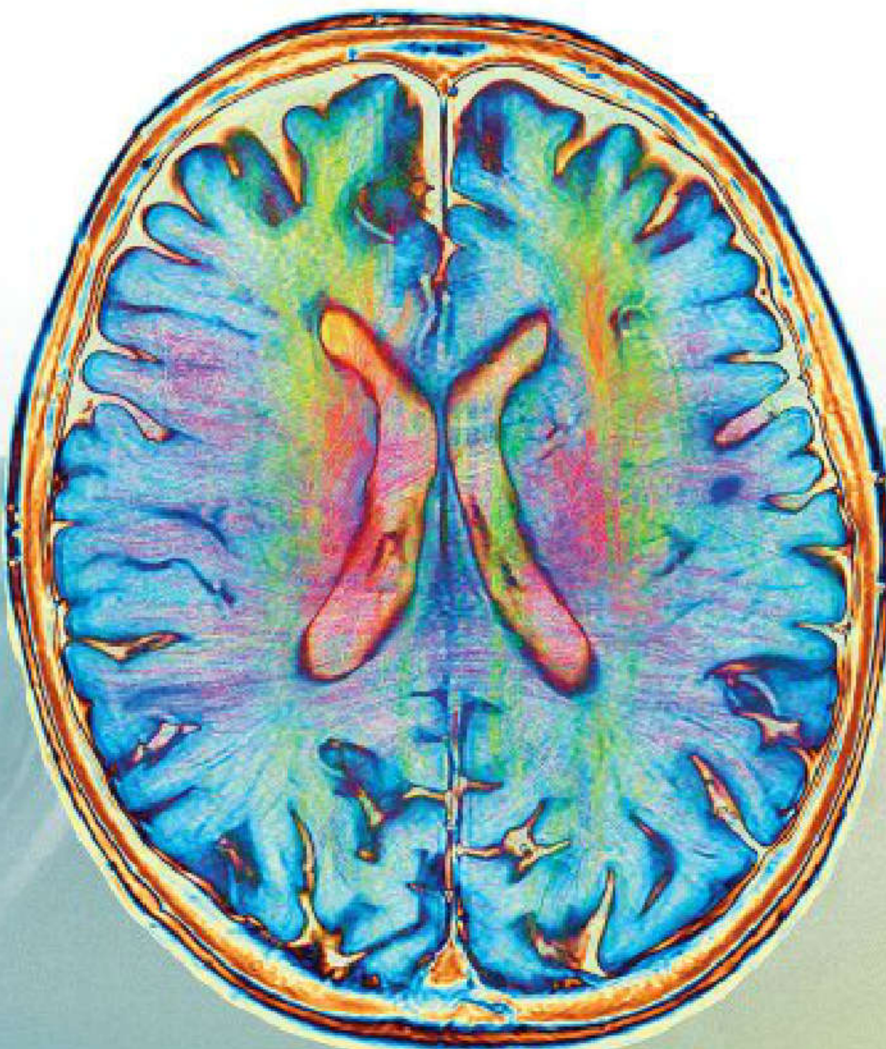
SNELL'S CLINICAL NEUROANATOMY

EIGHTH EDITION



RYAN SPLITTGERBER

Wolters Kluwer

SNELL'S CLINICAL NEUROANATOMY

EIGHTH EDITION

IN MEMORIAM

Richard S. Snell, MRCS, LRCP, MB, MD, PhD

1925–2015

Clinical Anatomy by Regions
Clinical Anatomy by Systems
Clinical Neuroanatomy

SNELL'S CLINICAL NEUROANATOMY

EIGHTH EDITION

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The trip has been long and the cost has been high . . . but no great thing was attained easily. A long tale, like a tall Tower, must be built a stone at a time.

—Stephen King

To my wife, Brienne
For providing more love and support than I deserve.
To my boys, Carter and Caden
For providing inspiration and humor . . . a lot of humor.

To my students
May you find your Tower.

Preface

This book contains the basic neuroanatomical facts necessary for the practice of medicine. It is suitable for medical students, dental students, nurses, and allied health students. Residents find this book useful during their rotations.

The functional organization of the nervous system has been emphasized and indicates how injury and disease can result in neurologic deficits. **The amount of factual information has been strictly limited to that which is clinically important.**

In this edition, authorship has transitioned from the late Dr. Richard Snell, who, with brilliance and dedication, fathered the previous seven editions and provided the framework for the eighth. The content of each chapter has been reviewed and edited to be more straightforward and concise. The traditional artwork has been recolored and updated to enhance the clarity and to provide additional information to each image. High-quality magnetic resonance images and histologic photomicrographs have been updated to provide greater visual details.

Each chapter introduces the relevance of neuroanatomy through a short case report.

- **Clinical Example.** A short case report that serves to dramatize the relevance of neuroanatomy introduces each chapter.
- **Chapter Objectives.** This section details the material that is most important to learn and understand in each chapter.
- **Basic Neuroanatomy.** This section provides basic information on neuroanatomical structures that are of clinical importance. Numerous examples of normal radiographs, CT scans, MRIs, and PET scans are also provided. Many cross-sectional diagrams have been included to stimulate students to think in terms of three-dimensional anatomy, which is so important in the interpretation of CT scans and MR images.
- **Clinical Notes.** This section provides the practical application of neuroanatomical facts that are essential in clinical practice. It emphasizes the structures that the clinician will encounter when making a diagnosis and treating a patient. It also provides the information necessary to understand many procedures and techniques and notes the anatomical "pitfalls" commonly encountered.
- **NEW! Key Concepts.** These quick, bulleted reviews of key topics and information are provided at the end of each chapter.
- **Clinical Problem Solving.** This section provides the student with many examples of clinical situations in which a knowledge of neuroanatomy is necessary to solve clinical problems and to institute treatment; solutions to the problems are provided at the end of the chapter.
- **Review Questions.** The purpose of the questions is threefold: to focus attention on areas of importance, to enable students to assess their areas of weakness, and to provide a form of self-evaluation when questions are answered under examination conditions. Some of the questions are centered around a clinical problem that requires a neuroanatomical answer. Solutions to the problem are provided at the end of each chapter.

An interactive **Review Test**, including over 450 questions, is provided online.

The book is extensively illustrated. The majority of the figures have been kept simple and are in color. As in the previous edition, a concise **Color Atlas** of the dissected brain is included prior to the text. This small but important group of colored plates enables the reader to quickly relate a particular part of the brain to the whole organ.

R.S.
R.S.S.

Acknowledgments

Starting with the first edition of Clinical Neuroanatomy published in 1980, many people have provided their expertise and should be recognized for their contributions. First and foremost, thanks to Richard S. Snell whose shoulders we stand upon to advance our own intellectual progress.

Throughout this text and in previous editions, the following individuals provided valuable contributions and are gratefully acknowledged: N. Cauna, L. Clerk, D. O. Davis, H. Dey, M. Feldman, T. M. J. Fitzgerald, I. Grunther, J. M. Kerns, T. McCarthy, A. Peters, G. Sze, and L. Wener.

EIGHTH EDITION

I am greatly indebted to the staff of Wolters Kluwer, including Crystal Taylor, who brought me in and provided me with this wonderful opportunity, as well as Andrea Vosburgh, development editor, and John Larkin, editorial coordinator. Thanks also to freelance development editor Kelly Horvath, who provided invaluable direction and patience with me throughout the entire process.

SPi Global is gratefully acknowledged for their brilliant art recoloring and enhancing the personality of this textbook.

My special thanks to Stephanie Vas, Program Director of the Magnetic Resonance Imaging Program at the University of Nebraska Medical Center, who produced exceptional MR images for this edition.

I would like to extend my gratitude to my students, colleagues, and mentors for their encouragement and wisdom---especially, Sabra Peetz, Art Dalley, Cathy Pettepher, Lillian Nanney, and Kyle Meyer.

R.S.

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Color Atlas of Brain

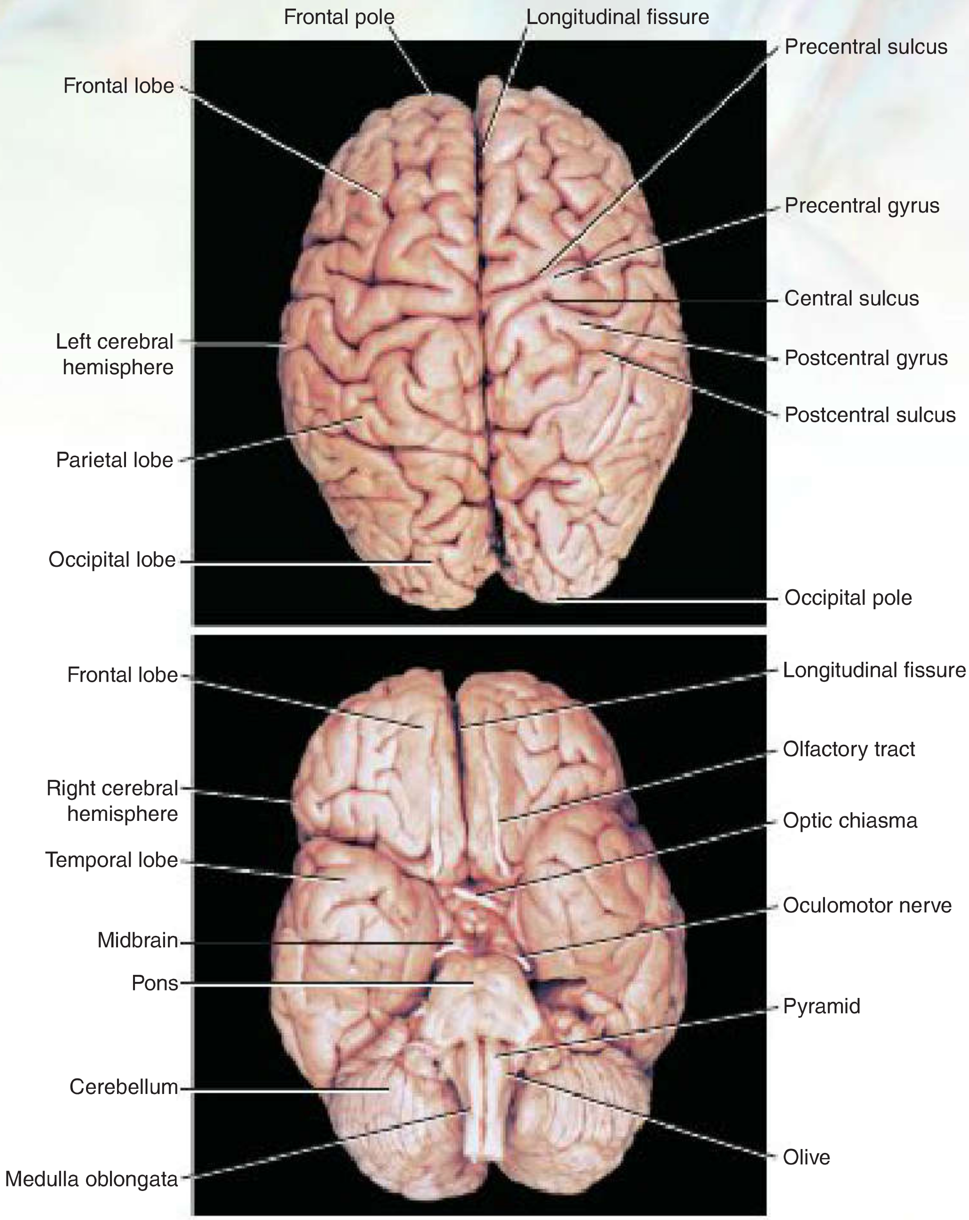

Figure CA-1 **Top:** Superior view of the brain. **Bottom:** Inferior view of the brain.

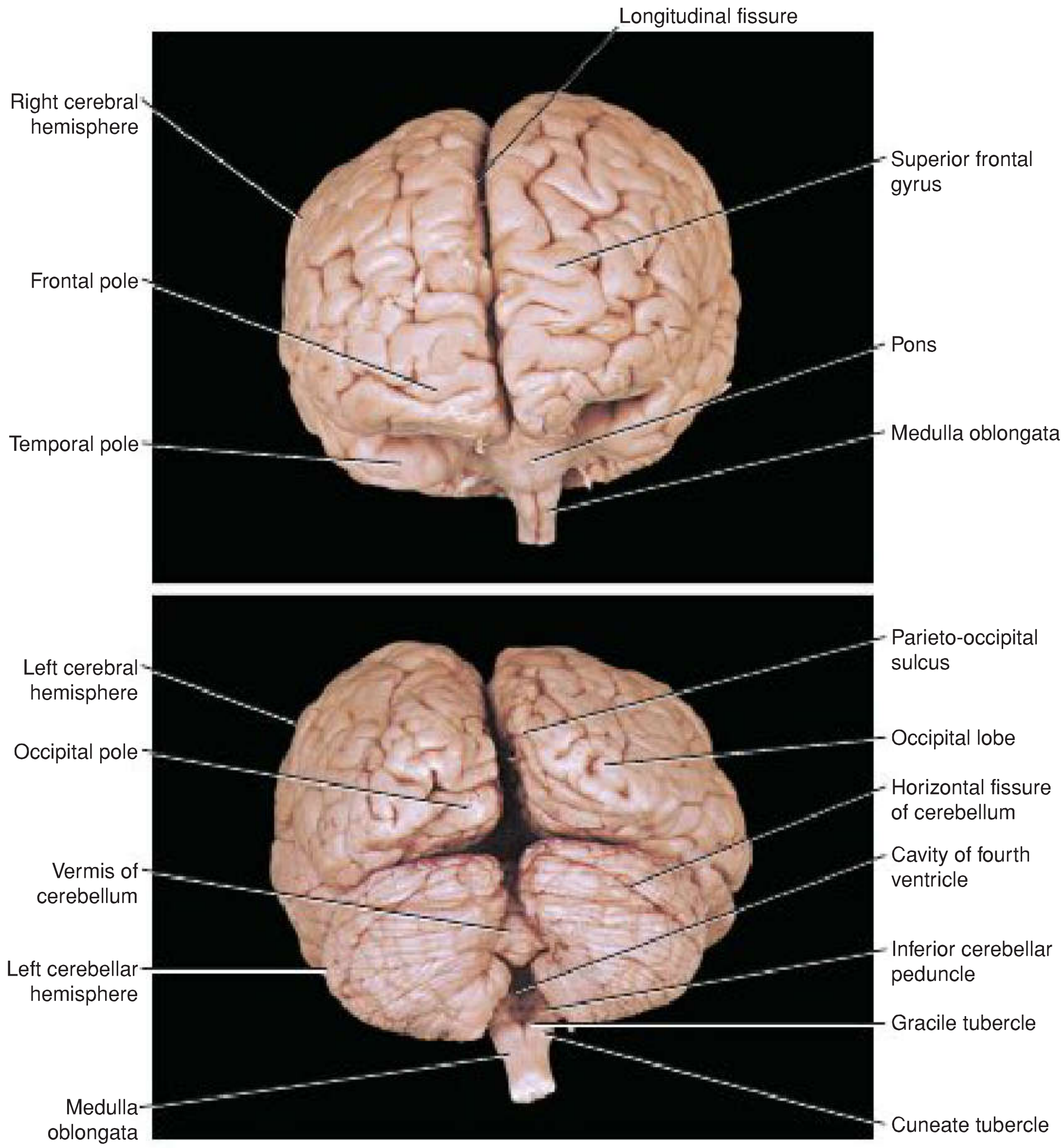

Figure CA-2 **Top:** Anterior view of the brain. **Bottom:** Posterior view of the brain.

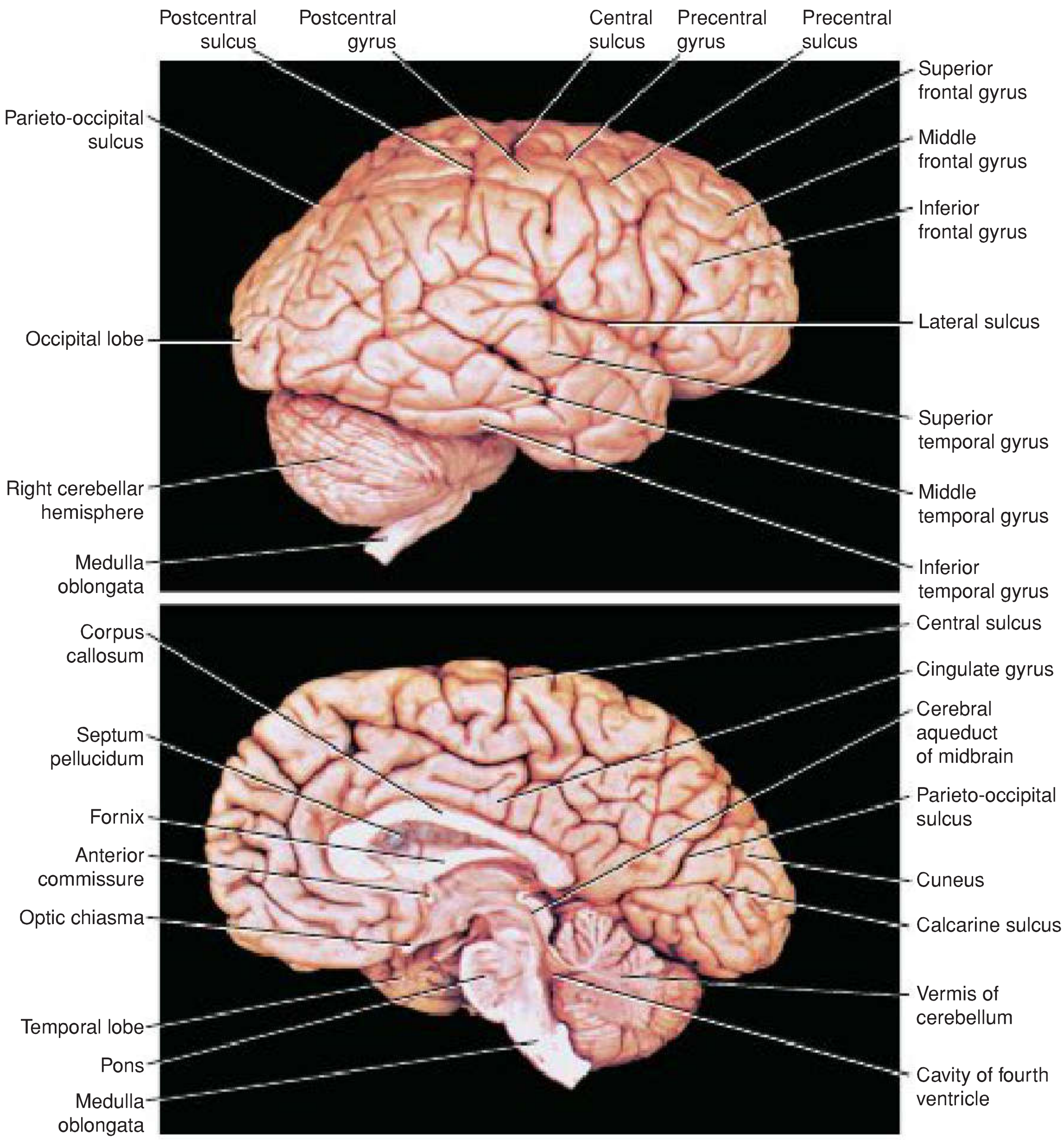

Figure CA-3 **Top:** Right lateral view of the brain. **Bottom:** Medial view of the right side of the brain following median sagittal section.

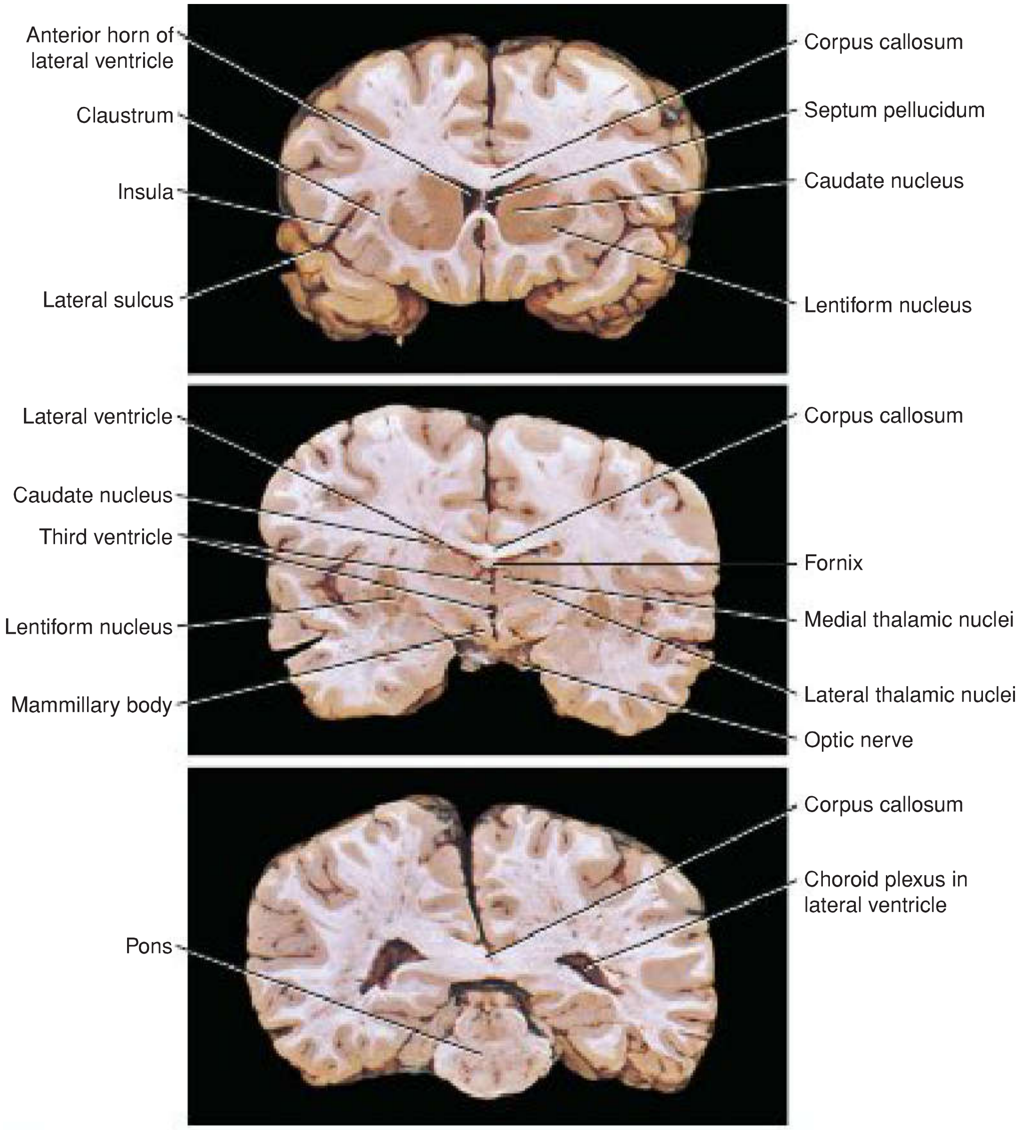

Figure CA-4 Coronal sections of the brain passing through the anterior horn of the lateral ventricle **(top)**, the mammillary bodies **(middle)**, and the pons **(bottom)**.

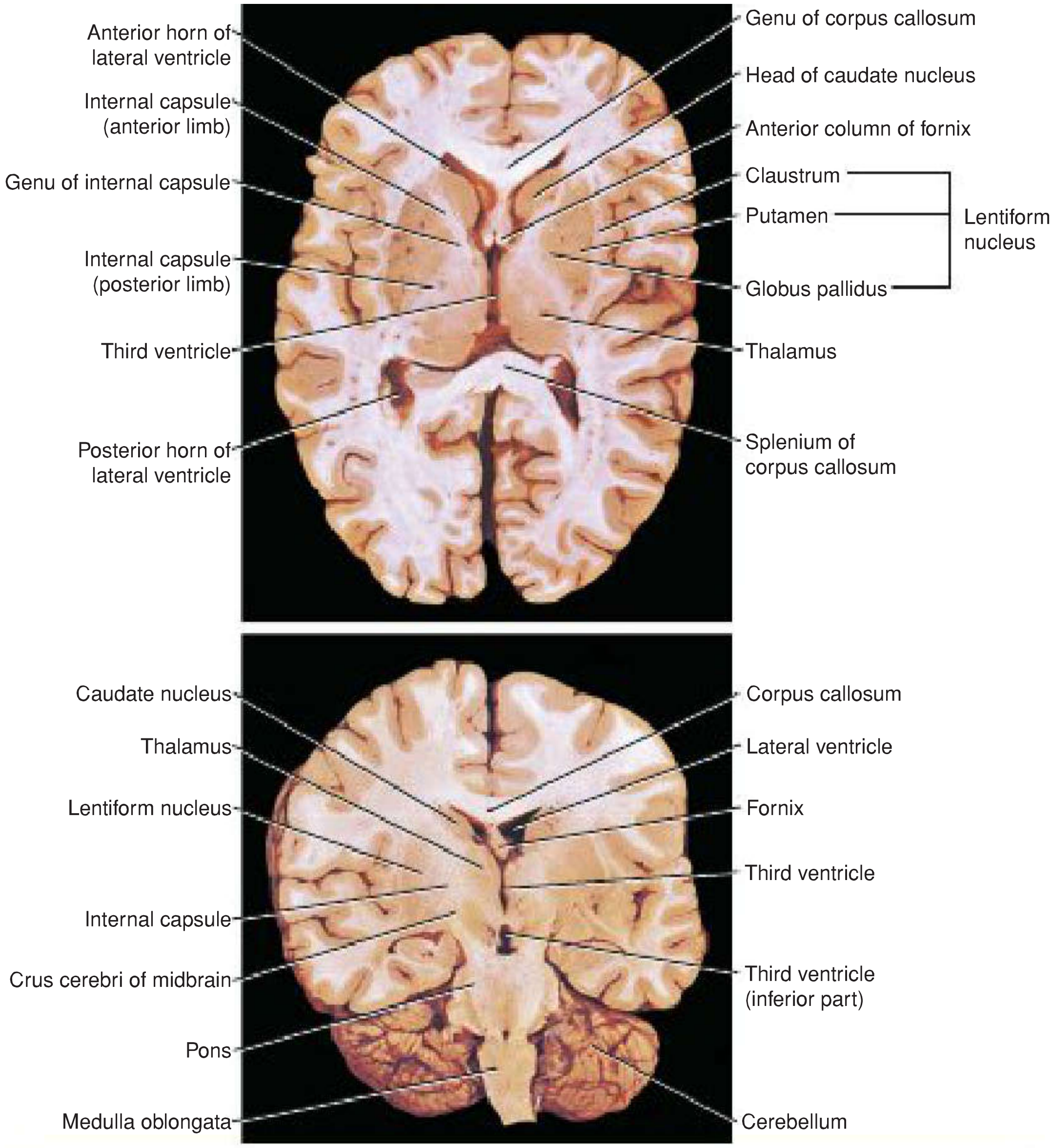

Figure CA-5 **Top:** Horizontal section of the cerebrum showing the lentiform nucleus, the caudate nucleus, the thalamus, and the internal capsule. **Bottom:** Oblique coronal section of the brain.

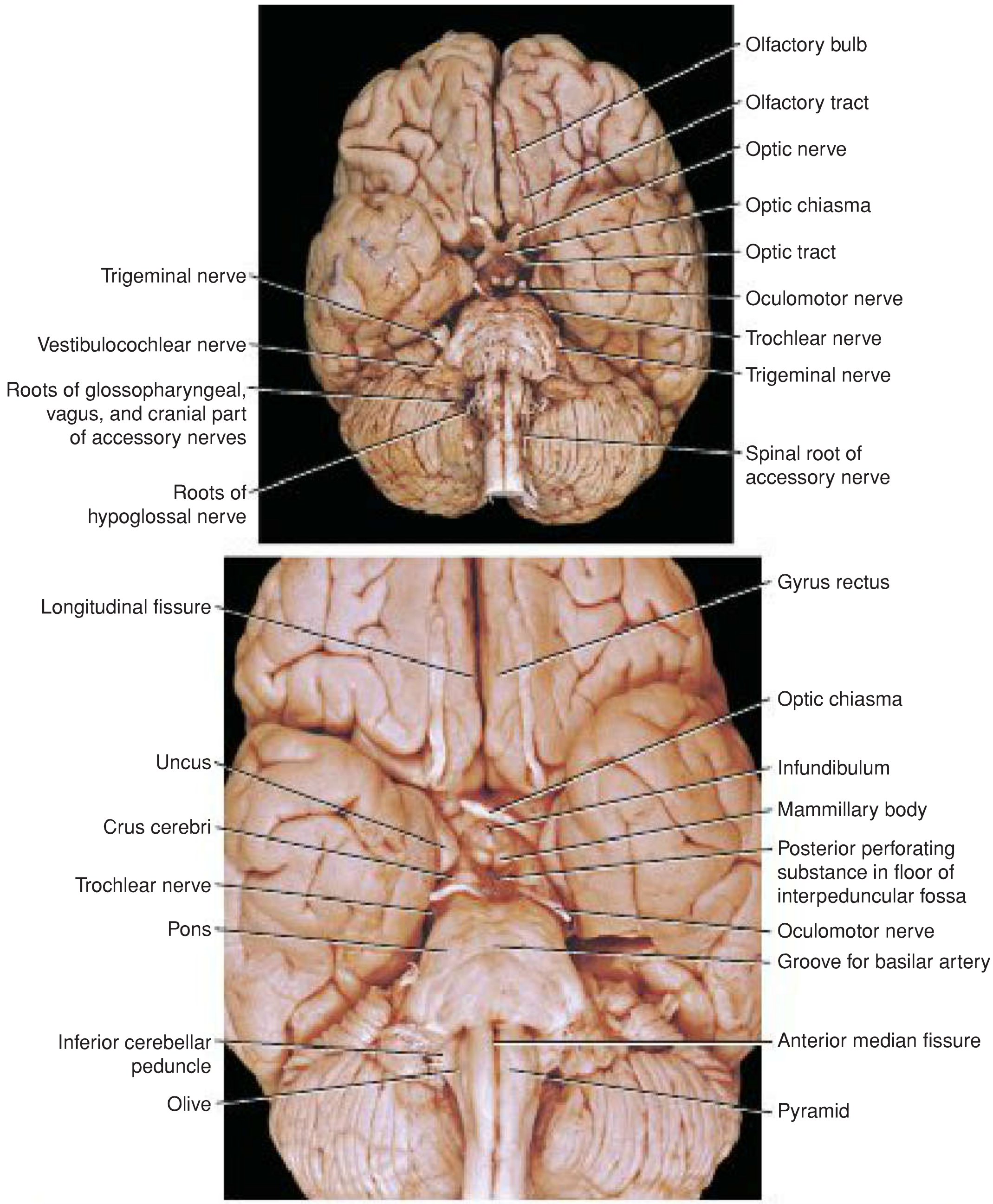

Figure CA-6 **Top:** Inferior view of the brain showing cranial nerves. The abducens and facial nerves cannot be seen. **Bottom:** Enlarged inferior view of the central part of the brain.

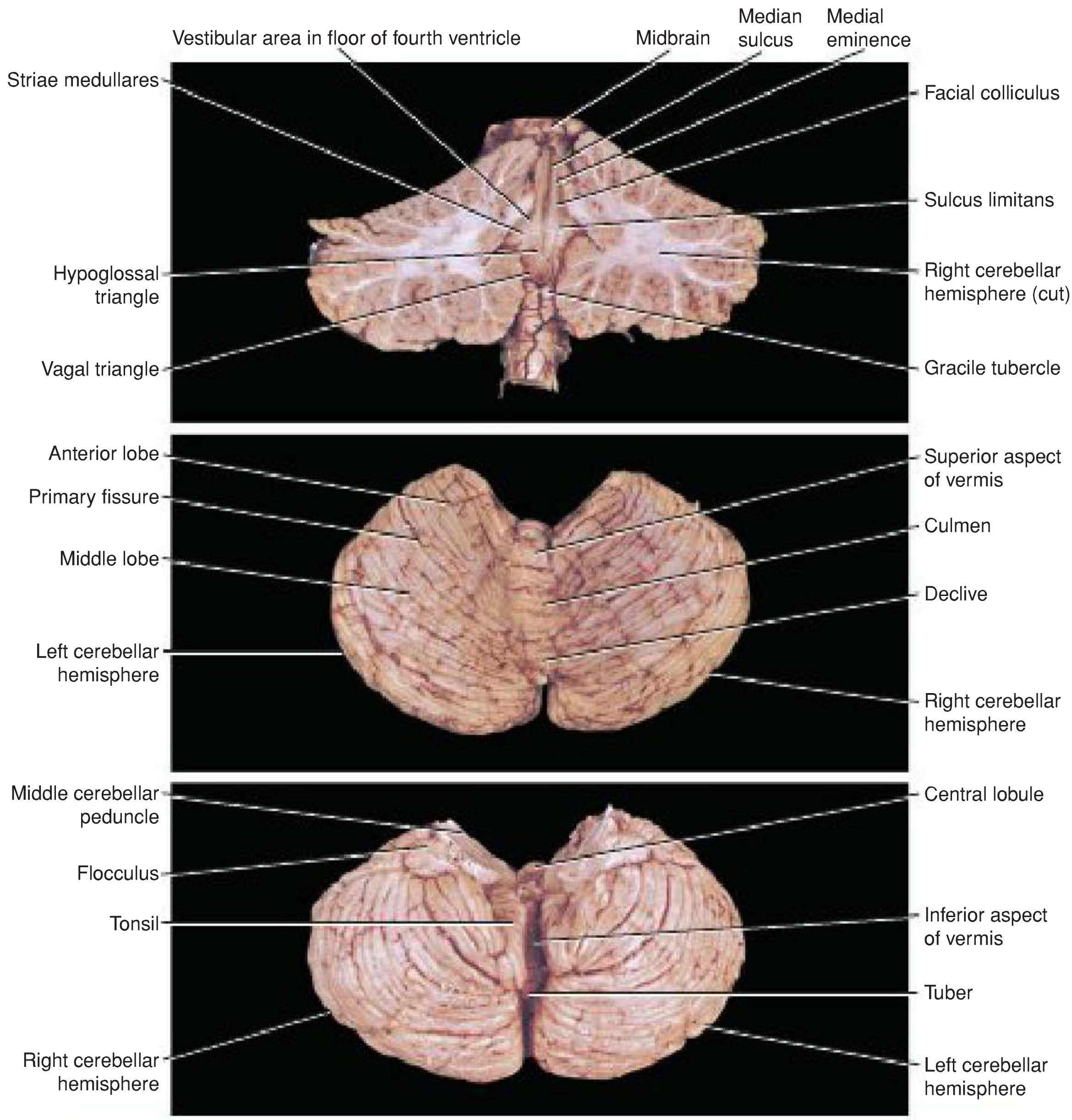

Figure CA-7 **Top:** Posterior view of the brainstem. The greater part of the cerebellum had been removed to expose the floor of the fourth ventricle. **Middle:** Superior view of the cerebellum showing the vermis and right and left cerebellar hemispheres. **Bottom:** Inferior view of the cerebellum showing the vermis and right and left cerebellar hemispheres.

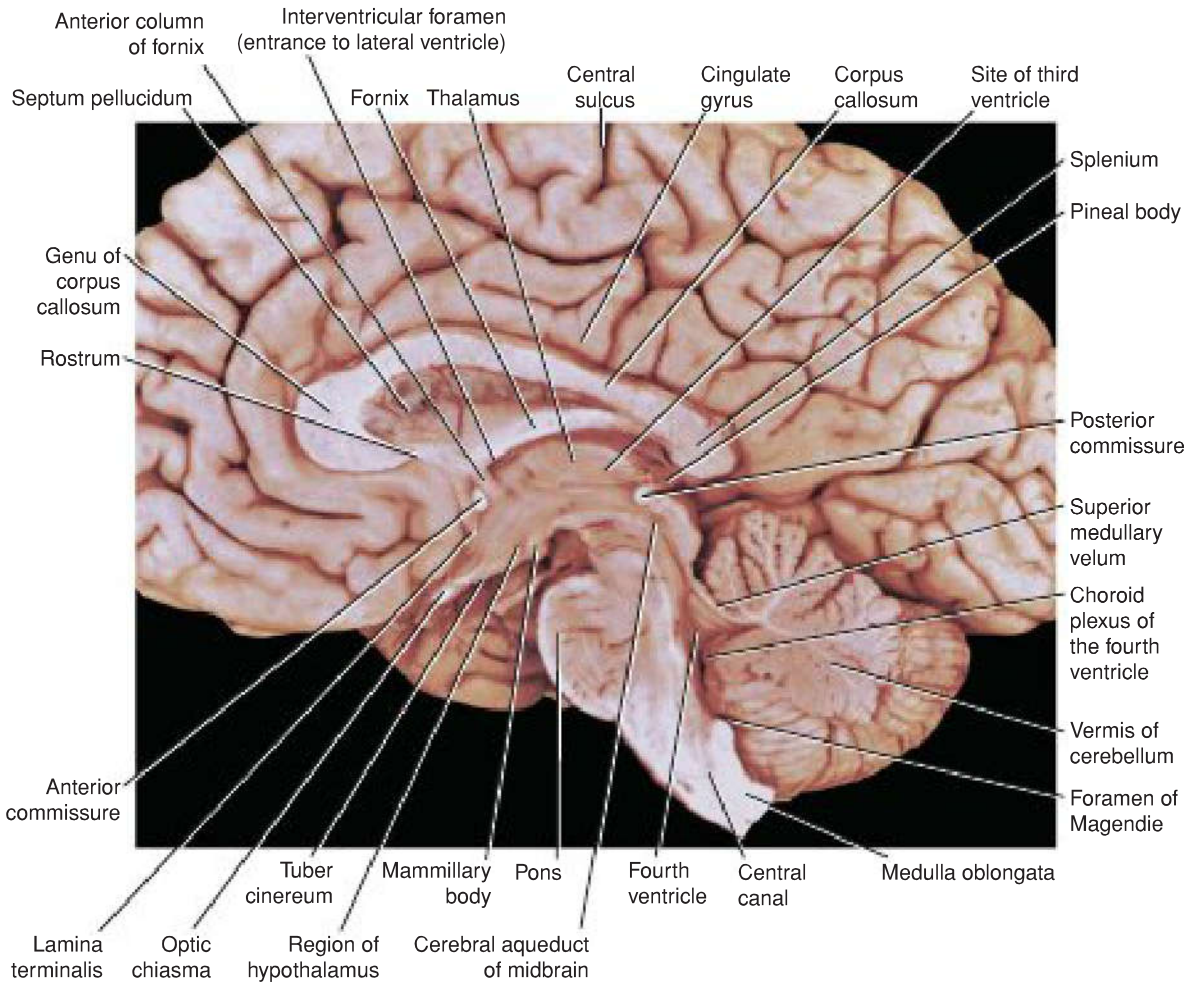

Figure CA-8 Enlarged medial view of the right side of the brain following median sagittal section, showing the continuity of the central canal, fourth ventricle, cerebral aqueduct, and the third ventricle and entrance into the lateral ventricle through the interventricular foramen.

1 Introduction and Organization of the Nervous System

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

A 23-year-old student is driving home from a party and crashes his car head-on into a tree. On examination in the emergency department of the local hospital, he has a fracture dislocation of the 7th thoracic vertebra, with signs and symptoms of severe damage to the spinal cord. Later, he is found to have paralysis of the left leg. Testing of cutaneous sensibility reveals 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 has a narrow band of anesthesia and analgesia. On the right side, he has total analgesia, thermoanesthesia, and partial loss of touch sensation 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 clinician knows that a fracture dislocation of the 7th thoracic vertebra can 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 clinician 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, the relationship between the spinal cord and its surrounding vertebral column must be understood. The various neurologic deficits will be 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. 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

As shown in Figure 1-1, the nervous system is divided into two main parts, for purposes of description: the **central nervous system** (**CNS**), which consists of the brain and spinal cord, and the **peripheral nervous system** (**PNS**), which consists of the cranial and spinal nerves and their associated ganglia.

In the CNS, 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 (**meninges**) and are suspended in **cerebrospinal fluid** (**CSF**). Meninges are further protected by the bones of the skull and the vertebral column (Fig. 1-2).

The CNS is composed of large numbers of **neurons**, which are excitable nerve cells, and their processes,

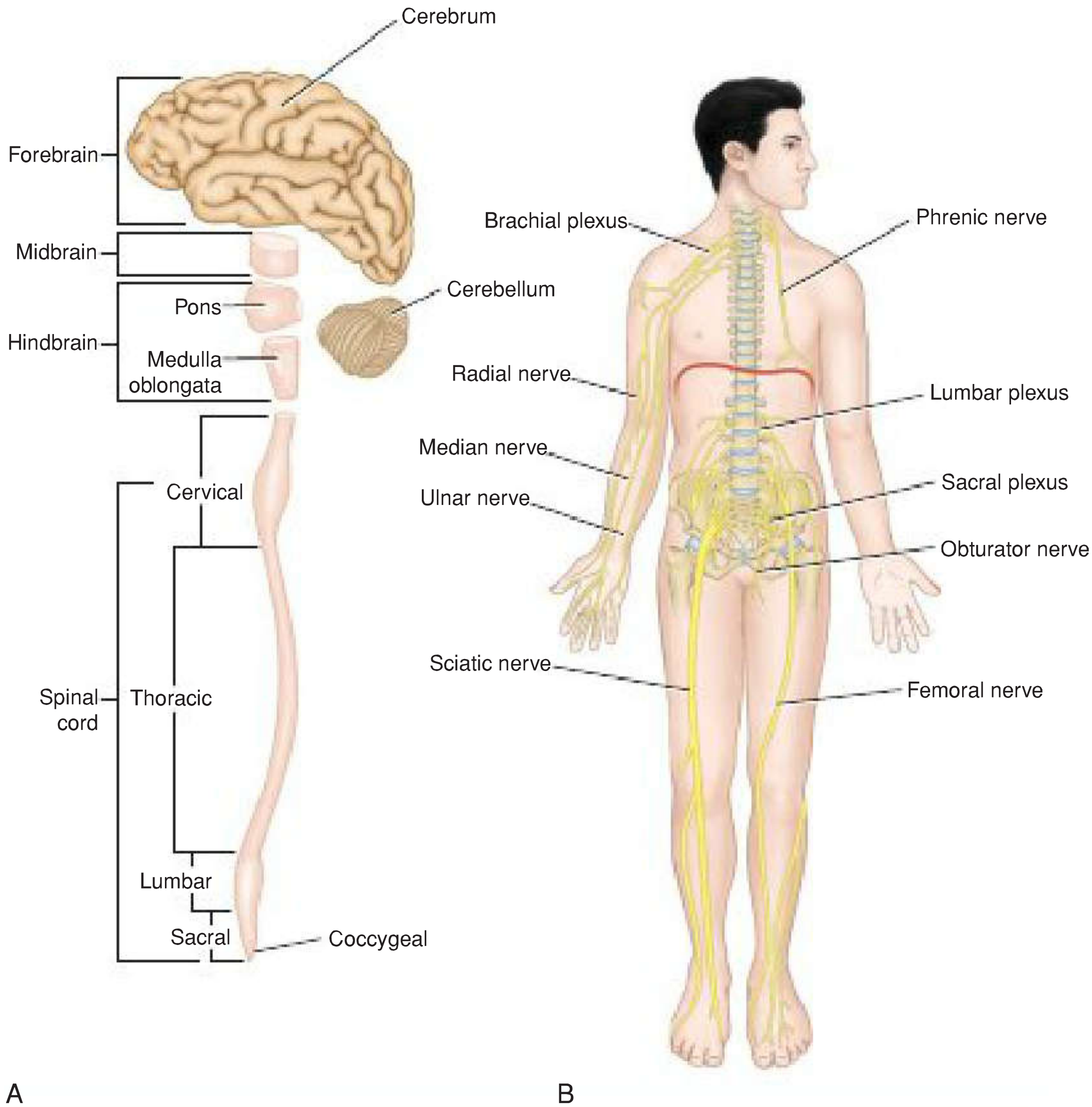

Figure 1-1 **A:** The main divisions of the central nervous system. **B:** The parts of the peripheral nervous system (the cranial nerves have been omitted).

known as **axons** or **nerve fibers**. Neurons are supported by specialized tissue called **neuroglia** (Fig. 1-3).

The CNS interior is organized into gray and white matter. **Gray matter**, which is gray in color, consists of nerve cells embedded in neuroglia. **White matter** consists of nerve fibers embedded in neuroglia and is white in color because of the presence of lipid material in nerve fiber myelin sheaths.

In the PNS, the cranial and spinal nerves, which consist of bundles of nerve fibers (or axons), conduct information to and from the CNS. 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 (ANS) is the part of the nervous system that innervates the body's involuntary structures, such as the heart, smooth muscle, and glands. It is distributed throughout the CNS and PNS and is divided into two parts, the **sympathetic** and the **parasympathetic**, both containing afferent and efferent nerve fibers. The activities of the sympathetic part of the ANS prepare the body for an emergency, whereas those of the parasympathetic part are aimed at conserving and restoring energy.

MAJOR DIVISIONS OF THE CENTRAL NERVOUS SYSTEM

Before proceeding to a detailed description of the spinal cord and brain, understanding the main features of these structures and their general relationship to one another is essential (Table 1-1).

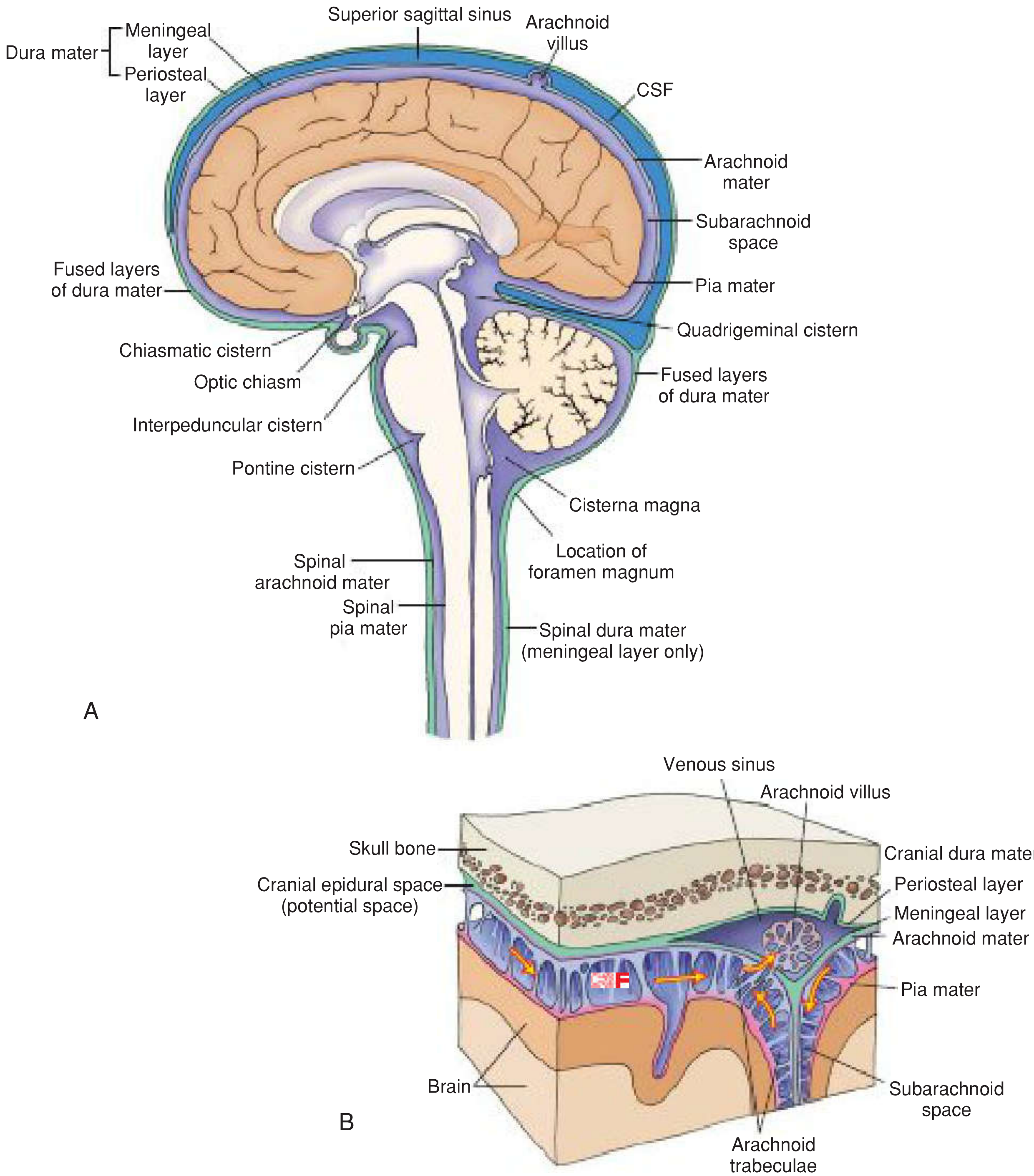

Figure 1-2 **A:** The protective covering of the spinal cord, the meninges, is formed by dura, arachnoid, and pia mater. The space between the arachnoid and pial membranes is called the subarachnoid space and contains cerebrospinal fluid (CSF). The subarachnoid space is enlarged at the cisterna magna and chiasmatic cistern. **B:** In the cranium, the dura consists of fused periosteal and meningeal layers that separate to form dural sinuses. Arachnoid mater projects into the dural venous sinuses to drain CSF from the subarachnoid space. (From Siegel, A., & Sapru, H. N. [2015]. *Essential neuroscience* [3rd ed.]. Baltimore, MD: Wolters Kluwer.)

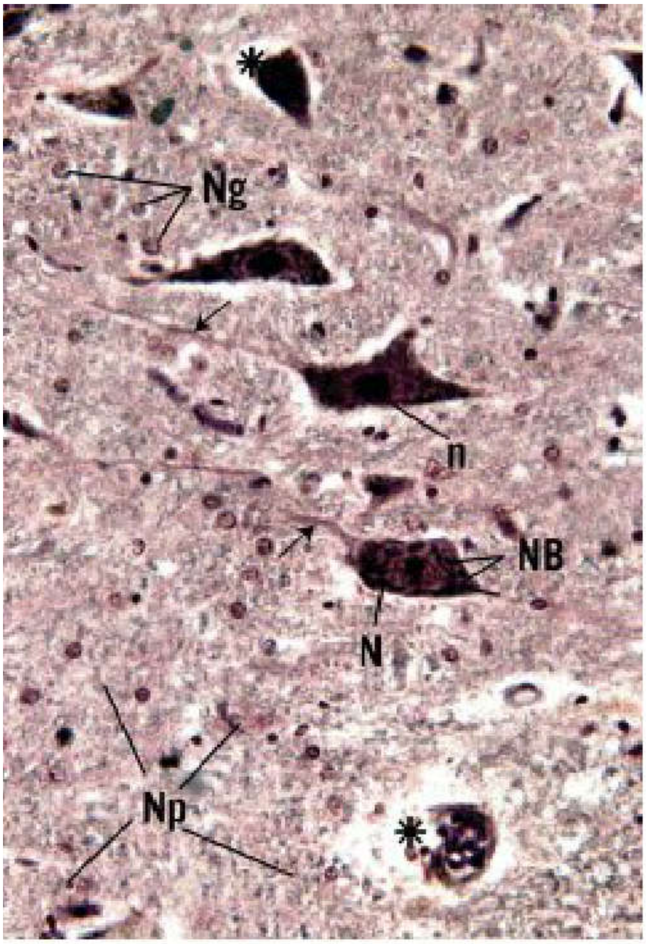

Figure 1-3 Photomicrograph of several large nerve cells with surrounding neuroglia. N, Neuron; n, nucleus; Ng, neuroglia; Np, neuropili; arrows, neurites. (From Gartner, L. P. [2017]. *Color atlas and text of histology* [7th ed.]. Baltimore, MD: Wolters Kluwer.)

Spinal Cord

The spinal cord is situated within the **vertebral canal** of the vertebral column and is surrounded by three meninges (Figs. 1-4 and 1-5): the **dura mater,** the **arachnoid mater,** and the **pia mater.** Further protection is provided by the **CSF**, which surrounds the spinal cord in the **subarachnoid space**.

The spinal cord is roughly cylindrical and begins superiorly at the foramen magnum in the skull, where it is continuous with the **medulla oblongata** of the brain. It terminates inferiorly in the lumbar region. Below, the spinal cord tapers off into the **conus medullaris**, from the apex of which the **filum terminale** (a prolongation of the pia mater) descends to attach to the back of the coccyx (see Fig. 1-4B).

Along the entire length of the spinal cord, 31 pairs of spinal nerves are attached by the **anterior** or **motor roots** and the **posterior** or **sensory roots** (Fig. 1-6; also see Fig. 1-5). Each root is attached to the cord by a series of rootlets, which 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.

[illegible]

Central Nervous System

- Brain
  - Forebrain
    - Cerebrum
    - Diencephalon (between brain)
  - Midbrain
  - Hindbrain
    - Medulla oblongata
    - Pons
    - Cerebellum
- Spinal cord
  - Cervical segments
  - Thoracic segments
  - Lumbar segments
  - Sacral segments
  - Coccygeal segments

Peripheral Nervous System

- Cranial nerves and their ganglia—12 pairs that exit the skull through the foramina
- Spinal nerves and their ganglia—31 pairs that exit the vertebral column through the intervertebral foramina
  - 8 Cervical
  - 12 Thoracic
  - 5 Lumbar
  - 5 Sacral
  - 1 Coccygeal

Spinal Cord Structure

The spinal cord is composed of an inner core of **gray matter**, which is surrounded by an outer covering of **white matter**. 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, is divided into **anterior**, **lateral**, and **posterior white columns** (see Fig. 1-6).

Brain

The brain (Fig. 1-7) lies in the cranial cavity and is continuous with the spinal cord through the foramen magnum (see Fig. 1-5A). As shown in Figure 1-2, it is surrounded by the **dura mater,** the **arachnoid mater**, and the **pia mater**. These three meninges are continuous with the corresponding meninges of the spinal cord. The CSF surrounds the brain in the subarachnoid space.

The brain is conventionally divided into three major divisions: the **hindbrain**, the **midbrain**, and the **forebrain** in ascending order from the spinal cord (see Fig. 1-1A). The **brainstem** (a collective term for the

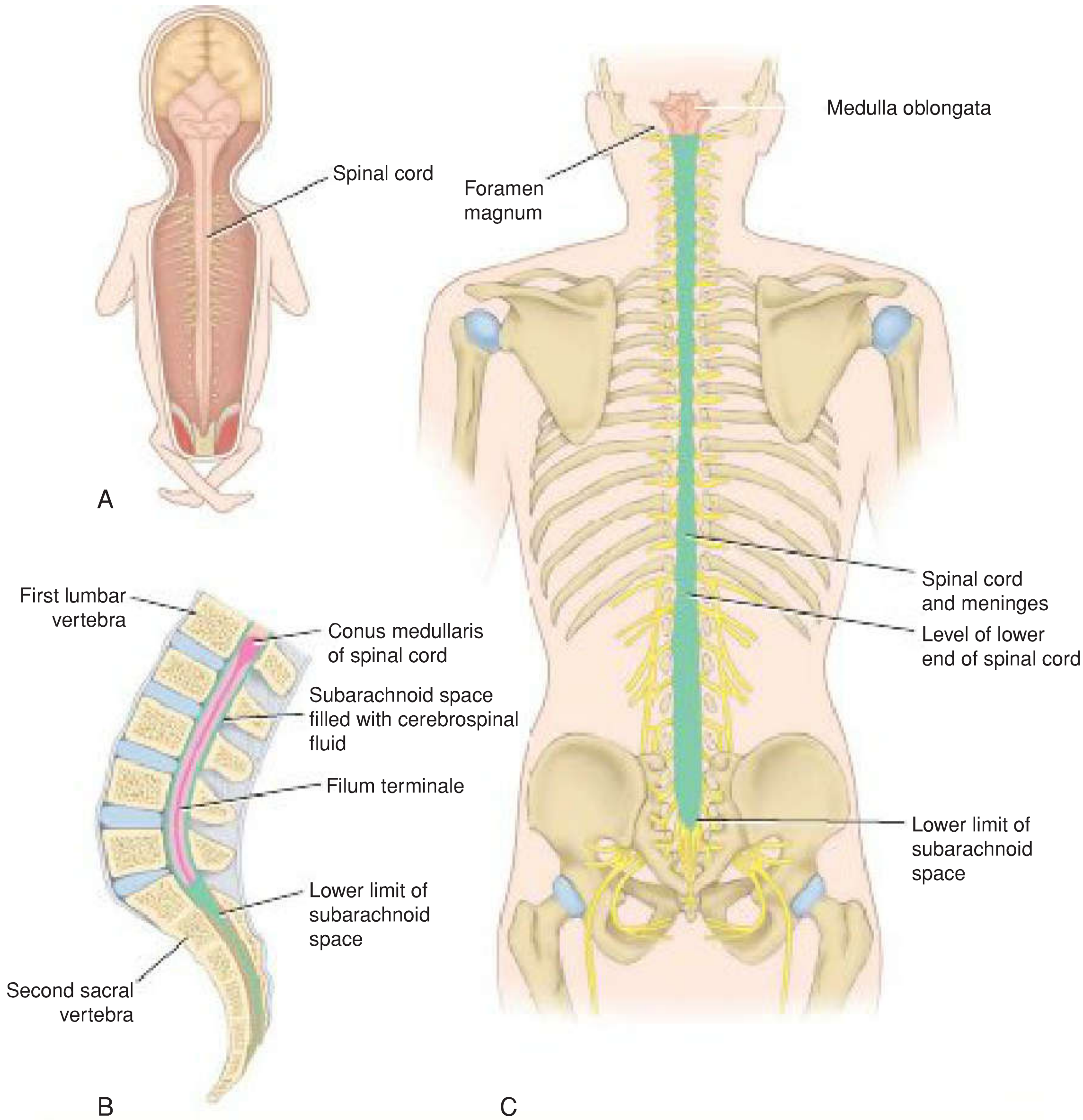

Figure 1-4 **A:** Fetus with the brain and spinal cord exposed on the posterior surface. Note that the spinal cord extends the full length of the vertebral column. **B:** Sagittal section of the vertebral column in an adult showing the spinal cord terminating inferiorly at the level of the lower border of the 1st lumbar vertebra. **C:** Adult spinal cord and covering meninges showing the relationship to surrounding structures.

medulla oblongata, pons, and midbrain) is what remains after the cerebral hemispheres and cerebellum (see below) are removed.

Hindbrain

The hindbrain comprises the **medulla oblongata**, the **pons**, and the **cerebellum**.

Medulla Oblongata

The medulla oblongata is conical in shape and connects the pons superiorly to the spinal cord inferiorly (Fig. 1-8). 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 (Fig. 1-9; also see Fig. 1-8). 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.

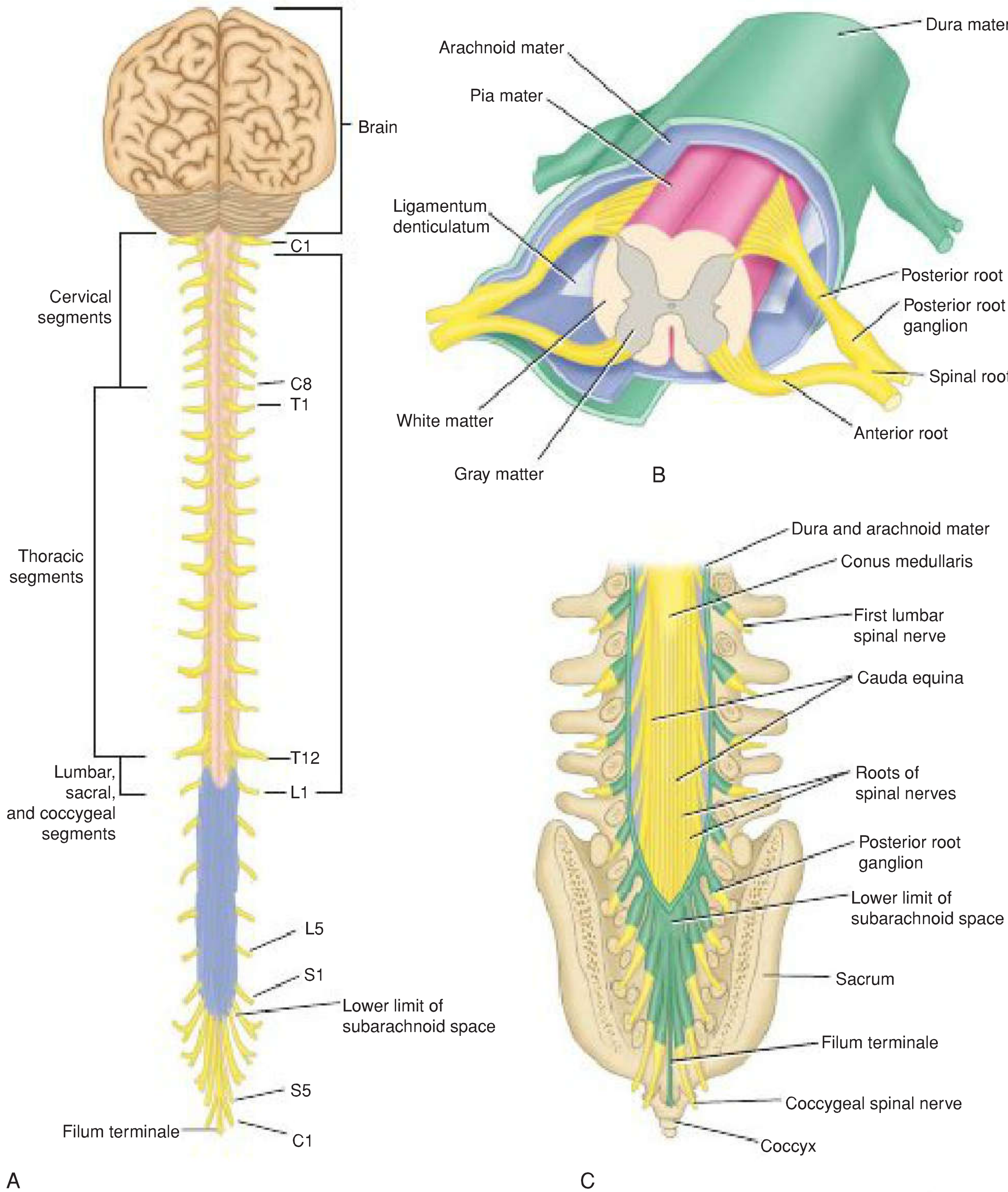

Figure 1-5 **A:** Brain, spinal cord, spinal nerve roots, and spinal nerves as seen on their posterior aspect. **B:** Transverse section through the thoracic region of the spinal cord showing the anterior and posterior roots of a spinal nerve and the meninges. **C:** Posterior view of the lower end of the spinal cord and cauda equina showing their relationship with the lumbar vertebrae, sacrum, and coccyx.

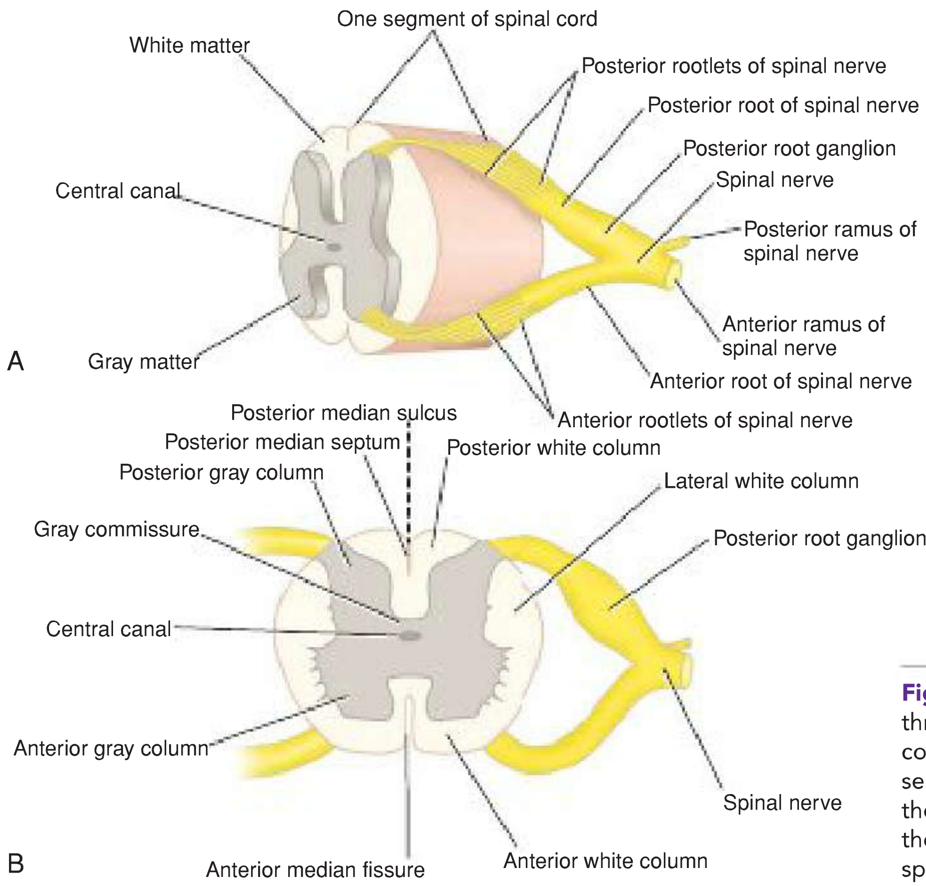

Figure 1-6 **A:** Transverse section through the lumbar part of the spinal cord, oblique view. **B:** Transverse section through the lumbar part of the spinal cord, face view, showing the anterior and posterior roots of a spinal nerve.

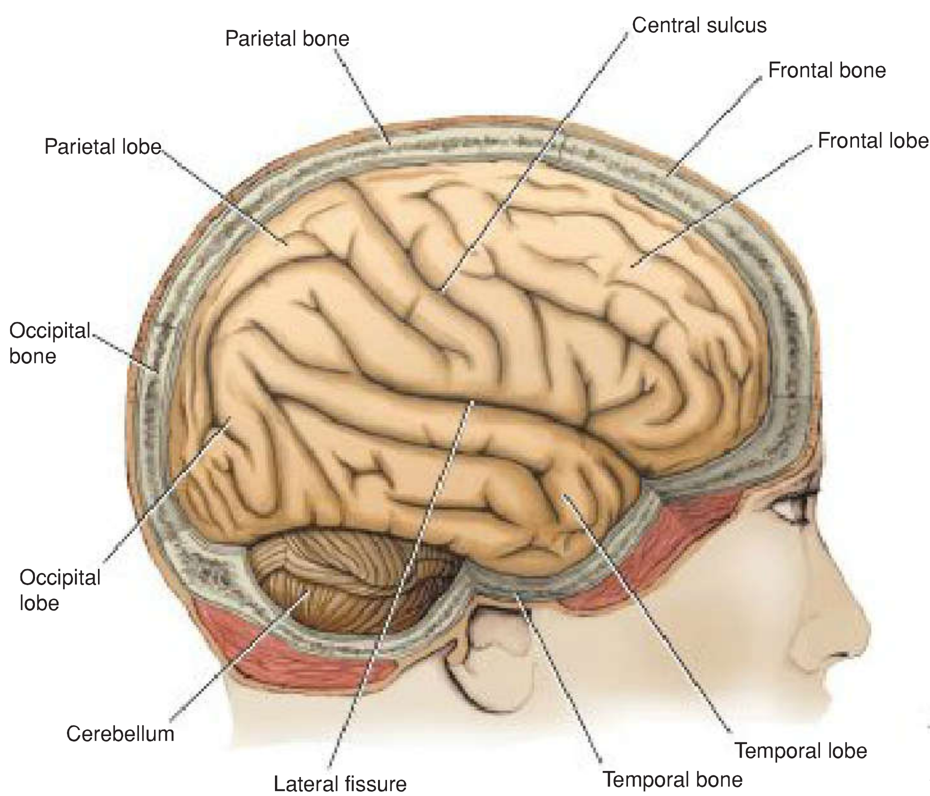

Figure 1-7 Lateral view of the brain within the skull.