Basic Clinical Neuroscience

Paul A. Young
Paul H. Young
Daniel L. Tolbert

THIRD EDITION

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Basic Clinical Neuroscience

Third Edition

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Third edition

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To our parents

Preface to the Third Edition

This third edition of *Basic Clinical Neuroscience* continues the fundamental objective of the first edition "to provide the anatomical basis for neurologic abnormalities …" so as to be able to answer the question "Where is the lesion located?" The second edition, in addition to the emphasis of "... to correlate neuroanatomic structures with clinically relevant function," included fundamental physiologic concepts underlying normal nervous system function and the pathophysiologic basis for abnormal nervous system activity. In this new edition, our goal continues to be to describe the subject in a succinct and simple manner so that it will facilitate learning in students of all health science fields.

Substantial changes have been made in the third edition to facilitate student learning of clinical neurosciences. First and foremost, most of the figures have been colorized, thereby greatly enhancing the most important features of neural structure and connections. Secondly, revision to the text has brought up-to-date current knowledge of brain structure and function. Additional Clinical Connections have been added to augment student awareness of clinical correlates of brain structure and connectivity. Finally, additional questions, most in USMLE format, have been added at the end of each chapter with the answers explained in Appendix A.

The authors are most grateful to Ms. Patricia Anderson and especially Ms. Kris Sherman for their assistance in preparing the manuscript. Mr. Larry Clifford prepared the illustrations used in the first edition, many of which have been modified in the third edition by adding multiple colors to highlight significant structures and connections. The authors are very grateful and much indebted to the staff of Lippincott Williams & Wilkins for their interest and support, particularly Crystal Taylor, Lauren Pecarich, and Jennifer Clements. All Williams & Wilkins staff were extremely gracious and patient in aiding the authors to bring the third edition to print.

Preface to the First Edition

The main objective of this monograph is to provide the anatomical basis for neurologic abnormalities. Knowledge of basic clinical neuroanatomy will enable medical students to answer the first question asked when examining a patient with an injured or a diseased nervous system: "Where is the lesion located?" Knowledge of basic clinical neuroanatomy will enable students in health-related fields, such as nursing, physical therapy, occupational therapy, and physician assistants, to understand the anatomical basis of the neurologic abnormalities in their patients. To accomplish these objectives, the anatomical relationships and functions of the clinically important structures are emphasized. Effort is exerted to simplify as much as possible the anatomical features of the brain and spinal cord.

This monograph is neither a reference book nor a textbook of neuroanatomy. Most neuroanatomy textbooks include much information about anatomical structures that aids in the understanding of a particular system or mechanism, but when these structures are damaged, clinical signs or symptoms do not result. Such superfluous information is kept to a minimum in this book.

This basic clinical anatomy book is presented in three main sections: (1) the basic plan, (2) the functional systems, and (3) the associated structures. The basic plan includes the organization of the nervous system, its histologic features and supporting structures, distinguishing anatomical characteristics of the subdivisions of the brain and spinal cord, and an introduction to clinically important brain and spinal cord functional levels. Only those structures needed to identify the subdivisions and their levels are included in this part.

The second section deals with the functional systems and their clinically relevant features. This section is arranged so that the motor and somatosensory systems, of paramount importance because they include structures located in every subdivision of the brain and spinal cord, are described first. The remainder of this section includes the pathways associated with the special senses, higher mental functions, and the behavioral and visceral systems.

In the third section, the vascular supply and the ventricular cerebrospinal fluid system are presented.

The visualization of three-dimensional anatomical relationships plays a key role in localizing lesions and understanding the anatomical basis of neurologic disorders. Every effort has been made to include illustrations that enhance this visualization of three-dimensional images of the clinically important structures. In addition to the three-dimensional illustrations, schematic diagrams of the functional systems and drawings of myelin-stained sections from selected functional levels of the brain and spinal cord are used to provide the anatomical relationships that enhance the understanding of the anatomical basis for neurologic disorders and their syndromes. Clinical relevance is emphasized throughout this book and illustrations of some neurologic abnormalities are included.

Review questions are found at the end of each chapter, and an entire chapter is devoted to the principles of locating lesions and clinical illustrations. Answers to the chapter questions are found in the appendixes. Also in the appendixes are a section devoted to cranial nerve components and their clinical correlations, a glossary of terms, a list of suggested readings, and an atlas of the myelin-stained sections used throughout the book.

The authors are most grateful to Mr. Larry Clifford for his artistic skills in creating the illustrations, all of which are an invaluable part of this book. Our deep appreciation is expressed to Ms. Susan Quinn for her superb assistance in preparing the manuscript and to Ms. Susan McClain for her computer expertise in preparing the charts and tables. Finally, the authors are much indebted to the publisher, Williams & Wilkins, and its editorial and marketing staff for their interest, support, and patience throughout the project.

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Part I

Organization, Cellular Components, and Topography of the CNS

1 Introduction, Organization, and Cellular Components

Two fundamental properties of animals, irritability and conductivity, reach their greatest development in the human nervous system. Irritability, the capability of responding to a stimulus, and conductivity, the capability of conveying signals, are specialized properties of the basic functional units of the nervous system: the nerve cells or neurons. Neurons respond to stimuli, convey signals, and process information that enables the awareness of self and surroundings; mental functions such as memory, learning, and speech; and the regulation of muscular contraction and glandular secretion.

ORGANIZATION OF THE NERVOUS SYSTEM

The basic functional unit of the nervous system is the neuron. Each neuron has a cell body that receives nerve impulses and an **axon** that conveys the nerve impulse away from the cell body. The nervous system comprises neurons arranged in longitudinal series. The serial arrangement forms two types of circuits: reflex and relay. A reflex circuit conveys the impulses that result in an involuntary response such as muscle contraction or gland secretion (Fig. 1-1A). A relay circuit conveys impulses from one part of the nervous system to another. For example, relay circuits convey impulses from sensory organs in the skin, eyes, ears, and so forth that become perceived by the brain as sensations (Fig. 1-1B). Relay circuits are categorized according to their functions and are called functional paths, for example, pain path, visual path, or motor or voluntary movement path. A functional path may consist of a series of only two or three neurons or as many as hundreds of neurons. Reflex circuits may overlap with parts of relay circuits (Fig. 1-1C).

A functional path may contain thousands or even millions of nerve cell bodies and axons. The nerve cell bodies may form pools or clumps, in which cases they are called nuclei or ganglia, or the nerve cell bodies may be arranged in the form of layers or laminae. The axons in a functional path usually form bundles called tracts, fasciculi, or nerves. Therefore, the entire nervous system is composed of functional paths whose neuronal cell bodies are located in the nuclei, ganglia, or laminae and whose axons are located in the tracts or nerves.

The human nervous system is divided into central and peripheral parts. The brain and spinal cord form the central nervous system (CNS), and the cranial, spinal, and autonomic nerves and their ganglia form the peripheral nervous system (PNS). The CNS integrates and controls the entire nervous system, receiving information (input) about changes in the internal and external environments, interpreting and integrating this information, and providing signals (output)

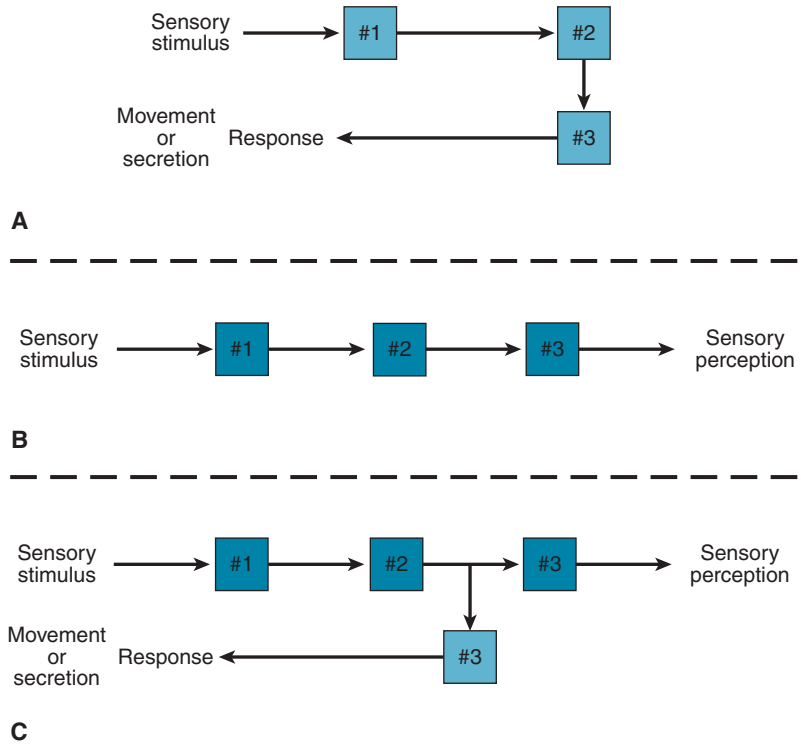

Figure 1-1 Simple reflex and relay circuits. **A.** Three-neuron reflex circuit. **B.** Three-neuron sensory relay circuit. **C.** Combined three-neuron relay and reflex circuits.

for the execution of activities, such as movement or secretion. The PNS connects the CNS to the tissues and organs of the body. Hence, the PNS is responsible for conveying input and output signals to and from the CNS. Signals passing to the CNS are called **afferent,** whereas those passing away from the CNS are called **efferent.**

NERVOUS SYSTEM SUPPORT AND PROTECTION

Nerve cells are extremely fragile and cannot survive without the protection of supporting cells. The brain and spinal cord, also very fragile, are protected from the surrounding bones of the cranial cavity and vertebral or spinal canal by three coverings or membranes, called the meninges.

The Meninges

The CNS is supported and protected by the meninges, three connective tissue membranes located between the brain and the cranial bones and between the spinal cord and the vertebral column. The meninges are, from external to internal, the **dura mater,** the **arachnoid,** and the **pia mater.** The meninges around the brain and spinal cord are continuous at the foramen magnum, the large opening in the base of the skull where the brain and spinal cord are continuous.

Dura Mater

The dura mater is a strong, fibrous membrane that consists of two layers. In the cranial dura, which surrounds the brain, the two layers are fused and adhere to the inner surfaces of the cranial bones except in those regions where the layers split (Fig. 1-2) to form the venous sinuses that carry blood from the brain to the veins in the neck. The inner layer of the dura forms four folds that extend internally to partially partition various parts of the brain (Fig. 1-3). The sickle-shaped **falx cerebri** lies in the longitudinal groove between the upper parts of the brain, the cerebral hemispheres. The **falx cerebelli,** also oriented longitudinally, separates the upper parts of the

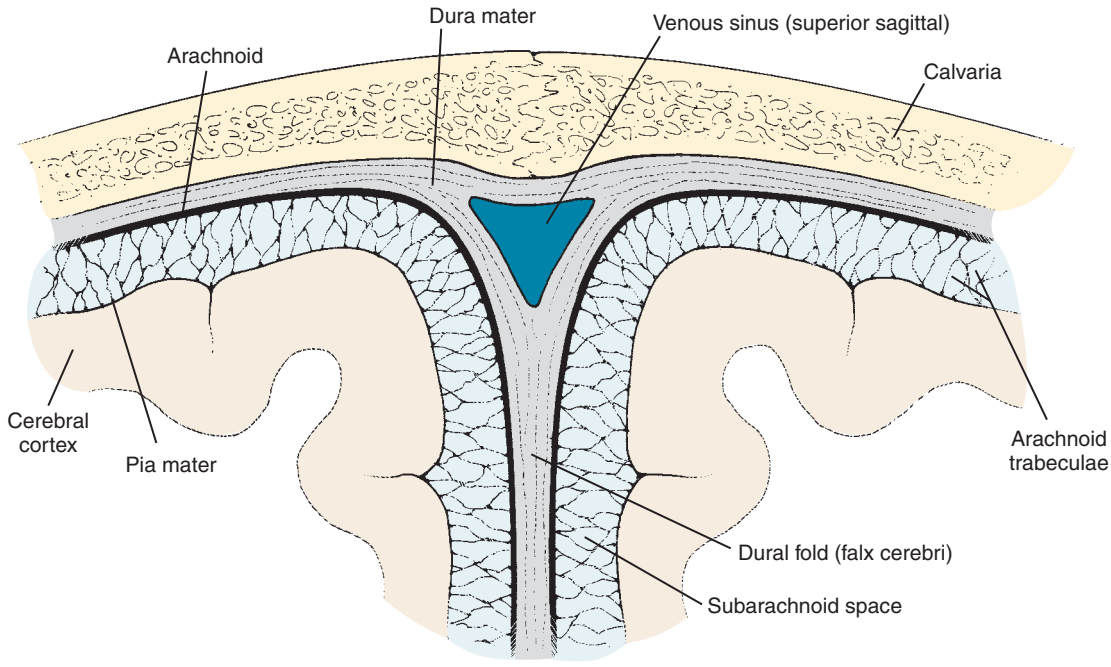

Figure 1-2 Coronal section of cranial meninges showing a venous sinus and dural fold.

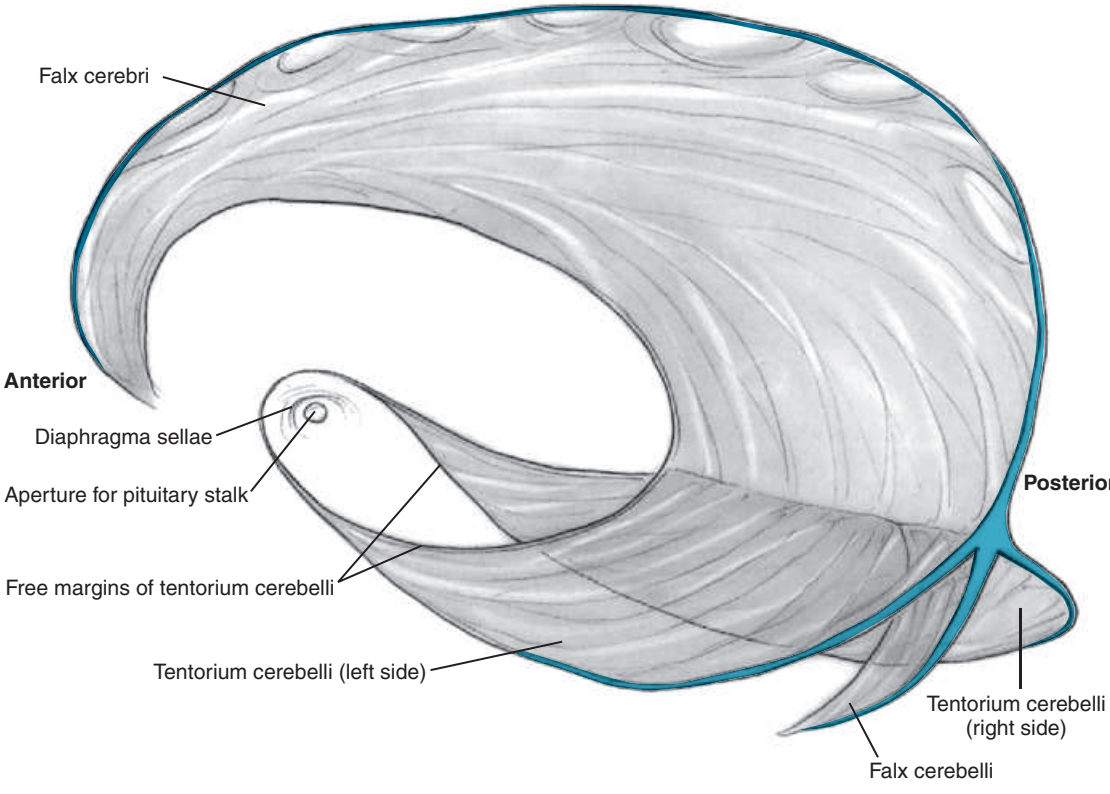

Figure 1-3 The dural folds as viewed from the left side.

hemispheres of the cerebellum, or "little brain." The tentorium cerebelli is a flat dural fold that separates the posterior parts of the cerebral hemispheres above from the cerebellum below. The **diaphragma sellae** is a circular, horizontal fold beneath the brain that covers the sella turcica, in which the pituitary gland is located. The stalk of the pituitary gland pierces the diaphragma sellae and attaches to the undersurface of the brain.

The spinal dura consists of two layers: the outer layer forms the periosteal lining of the vertebral foramina that form the vertebral or spinal canal; the inner layer loosely invests the spinal cord and forms a cuff around the spinal nerves as they emerge from the vertebral canal.

Arachnoid

The arachnoid is a thin, delicate membrane that loosely surrounds the brain and spinal cord. The outer part of the arachnoid adheres to the dura (Fig. 1-4). Extending internally from this outer part are numerous cobweb-like projections or trabeculae that attach to the pia mater.

Pia Mater

The pia mater is the thin membrane that closely invests the brain and spinal cord. The pia is highly vascular and contains the small blood vessels that supply the brain and spinal cord.

Meningeal Spaces

Several clinically important spaces are associated with the meninges (Fig. 1-4). The **epidural space** is located between the bone and the dura mater, and the **subdural space** is located between the dura and arachnoid. Normally, both the epidural and subdural spaces are potential spaces in the cranial cavity. Both may become actual spaces if blood accumulates because of epidural or subdural hemorrhages caused by traumatic tearing of blood vessels that pass through the spaces. In the spinal cord, the subdural space is also potential, but the

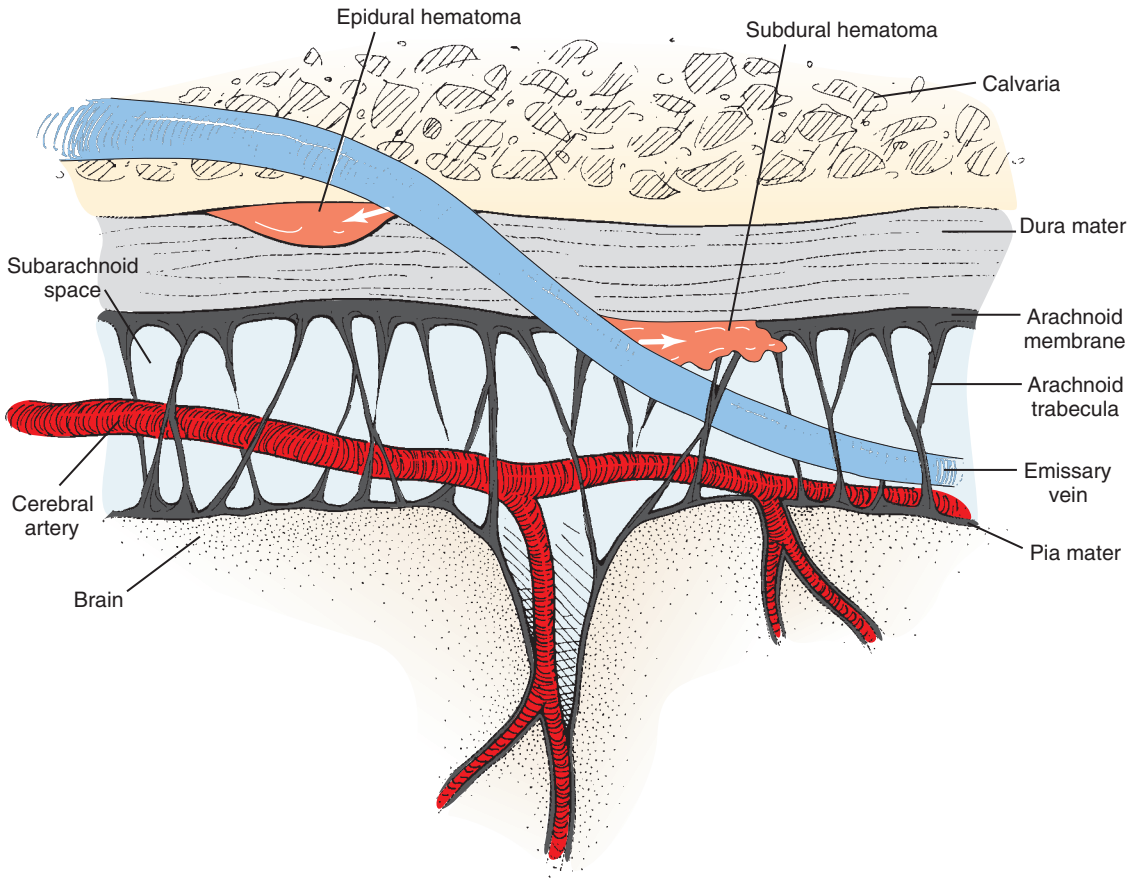

Figure 1-4 Relation of meningeal spaces to blood vessels and hemorrhages.

epidural space is actual and contains semifluid fat and thin-walled veins.

The **subarachnoid space** is located in the area between the arachnoid and pia mater and contains **cerebrospinal fluid.** The subarachnoid space communicates with the cavities or ventricles of the brain where cerebrospinal fluid is formed. Also located within the subarachnoid space are the initial parts of the cranial and spinal nerves and numerous blood vessels on the surfaces of the brain and spinal cord. Vascular accidents involving the vessels here result in subarachnoid hemorrhage.

Clinical Connection

Inflammation of the meningeal membranes surrounding the brain and spinal cord, due primarily to either a viral or bacterial infection of the meninges, may result in a life-threatening condition of meningitis. Less common causes include fungal, parasitic, and drug-mediated meningitis. In adults, neck stiffness and headache with fever, altered consciousness, vomiting, and aversion to bright light or loud noises are the primary symptoms of meningitis. In children, symptoms may be less apparent than in adults and consist of only irritability and drowsiness. Pathogen access to the meninges may be blood borne or as the result of direct entry from the nasal cavities. Diagnosis most commonly is by lumbar puncture if there is no indication of elevated intracranial pressure in the patient. Bacterial meningitis is treated by antibiotics.

Supporting Cells

Three basic types of supporting or glial cells exist: ependymal, microglial, and macroglial cells. The ependymal cells line the fluid-filled cavities or ventricles of the brain and the central canal of the spinal cord. The microglial cells are mesodermal in origin being derived from bone marrow, are formed in all parts of the brain and spinal cord, and play roles in immunological activities. They also become macrophages, phagocytizing the debris resulting from injury, infections, or diseases in the CNS. The macroglia are derived from neuroectoderm and consist of four cell types: **astrocytes** and **oligodendrocytes** in the CNS and **Schwann cells** and **capsular cells** in the PNS.

Astrocytes

Astrocytes are the most numerous cells in the CNS (Fig. 1-5). Each astrocyte has a star-shaped cell body and numerous irregularly shaped processes, some of which may be extremely long. Processes of some astrocytes have end-feet on the surface of the brain or spinal cord. These end-feet form a protective covering called the external limiting membrane or glial membrane. Many astrocytic processes have vascular end-feet, which surround capillaries. The endothelial cells of CNS capillaries are interconnected by tight junctions and form the **blood-brain barrier,** which selectively governs the passage of materials, including many drugs, from the circulating blood into the CNS.

Astrocytes have other functions as well. They play a major role in the electrolyte balance of the CNS, produce neurotrophic factors necessary for neuronal survival, and remove certain neurotransmitters from synaptic clefts. Astrocytes are the first cells to undergo alterations in response to CNS insults such as ischemia, trauma, or radiation. Also, astrocytes form scars resulting from CNS injury. Astrocytes are highly susceptible to the formation of neoplasms.

Oligodendrocytes

The formation and maintenance of CNS myelin are the primary functions of the oligodendrocytes, small glial cells with relatively few processes (Fig. 1-5). The myelin sheath is formed by oligodendrocyte processes, which wrap around the axon to form a tight spiral. The myelin itself is located within the processes. Each oligodendrocyte envelops a variable number of axons depending on the thickness of the myelin sheaths. In the case of thin myelin sheaths, one oligodendrocyte may be related to 40 or 50 axons. Oligodendrocytes may also surround the cell bodies of neurons, but in this location, they do not contain myelin. Recent research suggests that oligodendrocytes also produce neurotrophic factors, the most important of which is a nerve growth factor that may promote the growth of damaged CNS axons. Autoimmune reactions to CNS myelin may be associated with multiple sclerosis.

Schwann Cells

The PNS counterpart of the oligodendrocyte is the Schwann cell. Unlike the oligodendrocyte, which envelops many myelinated axons,

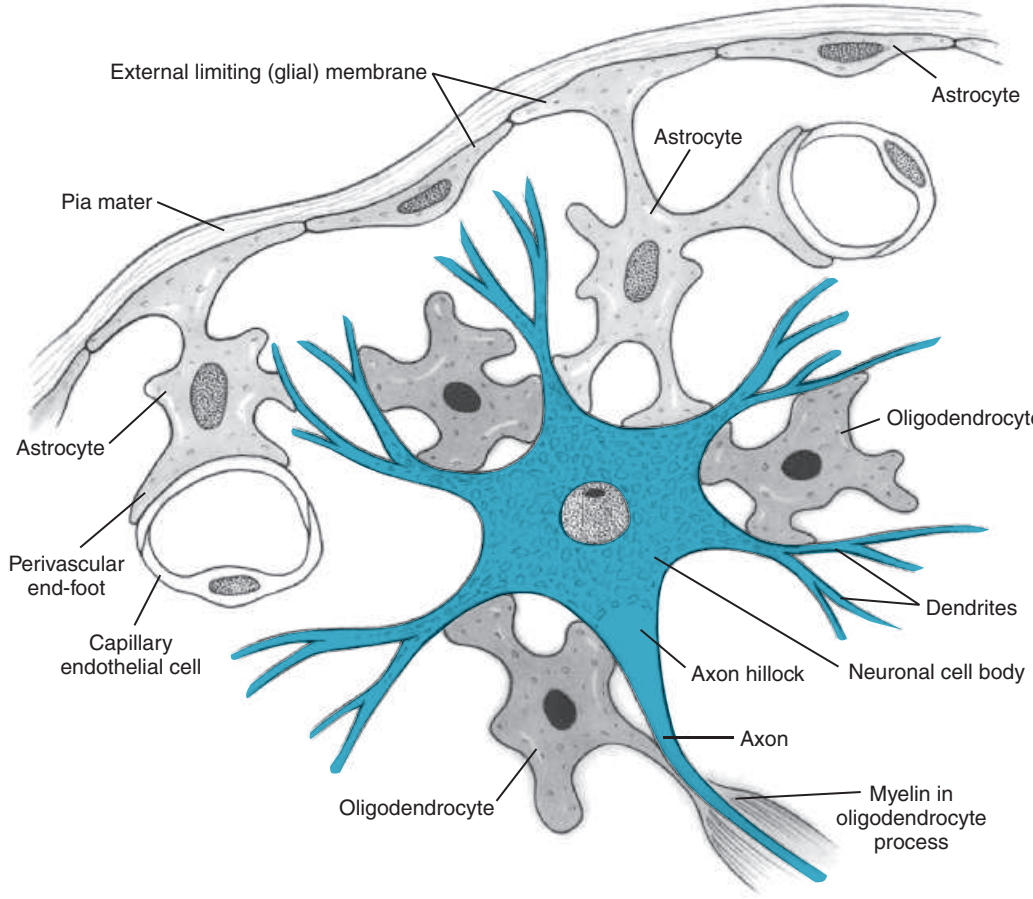

Figure 1-5 Relation of neurons, glia, and capillaries.

the Schwann cell envelops only part of one myelinated axon. During development of the myelin sheath, the Schwann cell first encircles and then spirals around the axon many times, forming multiple layers or lamellae. The myelin is actually located within the Schwann cell lamellae (Fig. 1-6). The outermost layer of the Schwann cell lamellae is called the **neurolemma**

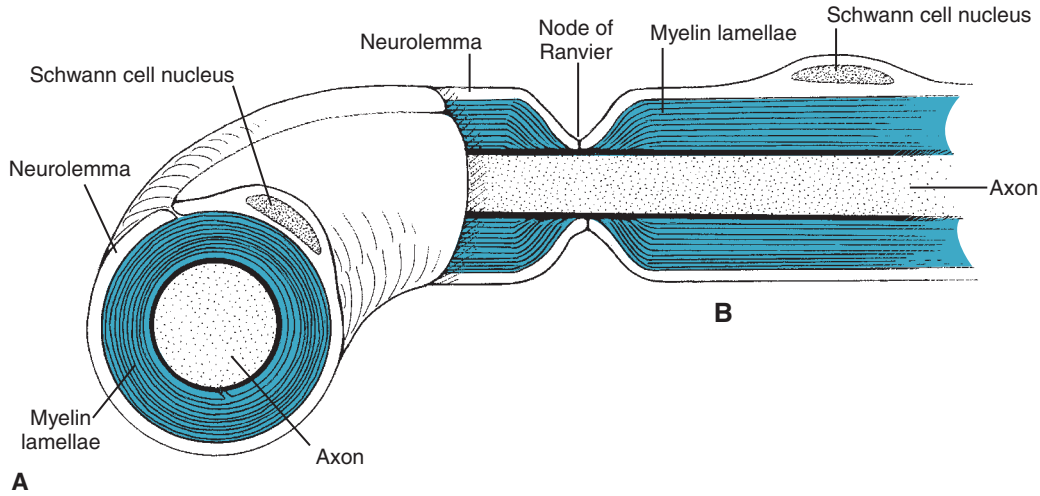

Figure 1-6 Myelinated axon in the peripheral nervous system. **A.** Transverse view. **B.** Longitudinal view.

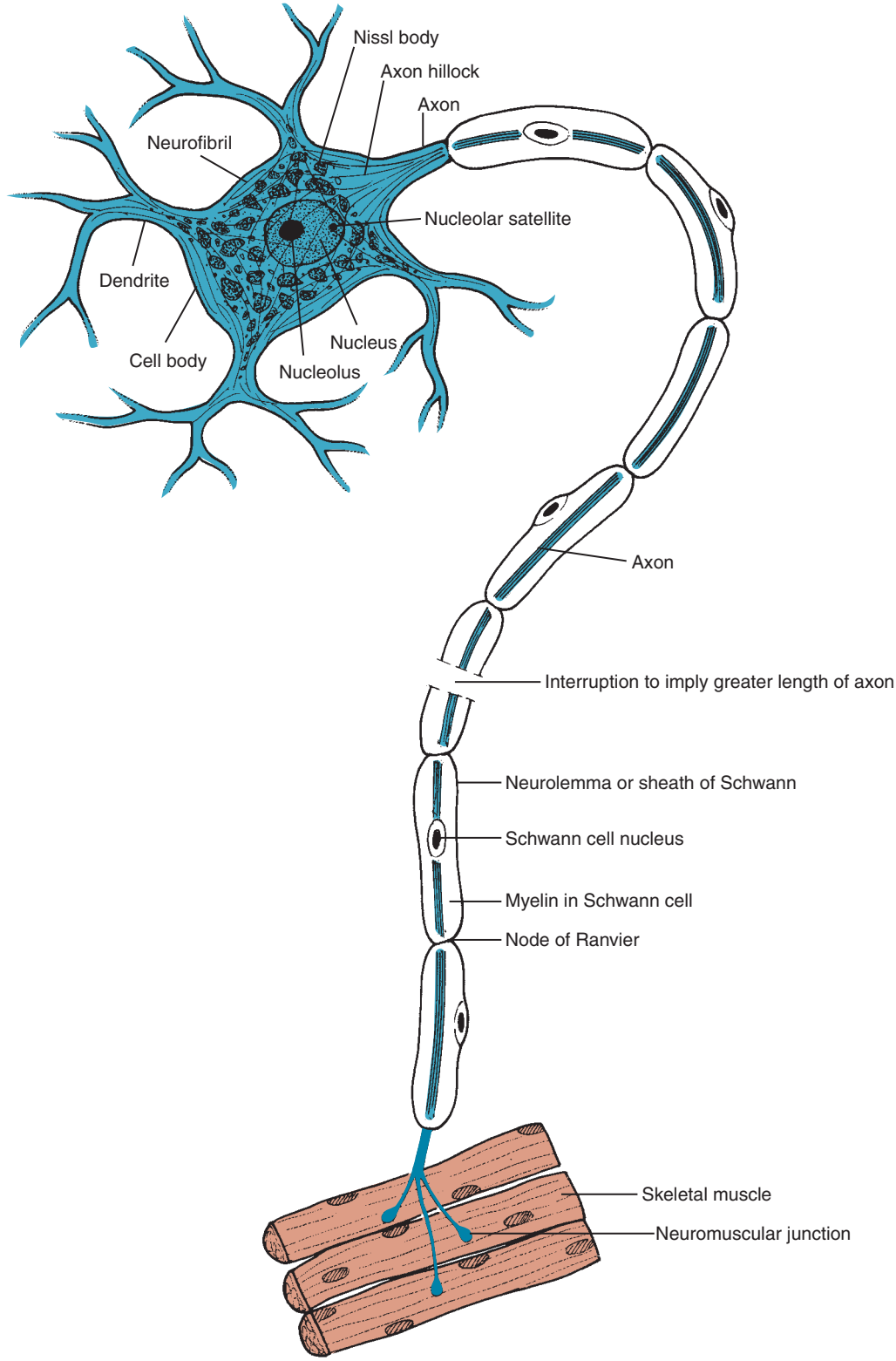

Figure 1-7 Neuron whose myelinated axon supplies skeletal muscle fibers.

or **sheath of Schwann.** Because each Schwann cell myelinates only a small extent of the axon, myelination of the entire axon requires a long string of Schwann cells. Between each Schwann cell, the myelin is interrupted. These areas of myelin sheath interruption are called **nodes of Ranvier** (Figs. 1-6, 1-7). Similar interruptions of myelin sheaths occur in the CNS. In unmyelinated fibers, one Schwann cell envelops many axons. Autoimmune reactions to PNS myelin may be associated with Guillain-Barré syndrome.

Schwann cells not only form and maintain the myelin sheath but also are extremely important in the regeneration of damaged axons. When an axon is cut, the part of the axon separated from the cell body degenerates; however, the string of Schwann cells distal to the injury proliferates and forms a tube. Growth sprouts arising from the proximal end of the transected axon enter this tube and travel to the structures supplied by the axon before its injury. Such functional axonal regeneration is common in the PNS. Axonal regeneration has not occurred in the human CNS, and this lack of regeneration may be related, in part, to the absence of Schwann cells.

Capsular Cells

Capsular cells are the glial elements that surround the neuronal cell bodies in sensory and autonomic ganglia. The sensory ganglia of the spinal nerves and some cranial nerves contain large, round neurons whose cell bodies are surrounded by a nearly complete layer of flattened capsular or satellite cells, thereby separating the ganglion cell from the nonneural connective tissue and vascular structures. Although capsular cells are present in autonomic ganglia, because of the irregular shapes of these ganglion cells the capsules are less uniform and, hence, incomplete.

NEURONS

Morphologic Properties

A neuron consists of a cell body or soma and of protoplasmic processes called **dendrites** and **axons** (Fig. 1-7). The cell body is the metabolic center of a neuron and contains the nucleus and the cytoplasm. The nucleus contains nucleoplasm, chromatin, a prominent nucleolus, and, in the female only, a nucleolar satellite. The cytoplasm contains the usual cellular organelles such as mitochondria, Golgi apparatus, and lysosomes. In addition, various-sized clumps of rough endoplasmic reticulum, called **Nissl bodies,** are prominent in the cytoplasm of neurons. However, the neuronal cytoplasm where the axon emerges is devoid of Nissl bodies; this area is called the axon hillock. Another cytoplasmic characteristic of neurons are neurofibrils, which are arranged longitudinally in the cell body, the axons, and the dendrites.

Neurons are classified morphologically as unipolar, bipolar, or multipolar according to their number of protoplasmic processes (Fig. 1-8). The single process of a unipolar neuron is the axon. Unipolar neurons are located almost exclusively in the ganglia of spinal nerves and some cranial nerves. Bipolar neurons have an axon and one dendrite and are limited to the visual, auditory, and vestibular pathways. All the remaining nerve cells are multipolar neurons and have an axon and between 2 and 12 or more dendrites.

Dendrites and Axons

Dendrites, cytologically similar to the neuronal cell body, are short and convey impulses toward the cell body (Table 1-1). Axons do not contain Nissl bodies, vary in length from microns to meters, and convey impulses away from the cell body.

The integrity of the axon, regardless of its length, is maintained by the cell body via two types of axoplasmic flow or axonal transport. In **anterograde axonal transport,** the cell body nutrients are carried in a forward direction from the cell body to the distal end or termination of the axon. Anterograde axonal transport is vital for axonal growth during development, for maintenance of axonal structure, and for the synthesis and release of **neurotransmitters,** the chemicals that assist in the transfer of nerve impulses from one cell to another.

Besides anterograde transport, **retrograde axonal transport** occurs from the distal end of the axon back to the cell body. The function