Manter & Gatz's

Essentials of Clinical Neuroanatomy and Neurophysiology

edition 6

SID GILMAN, M.D.

SARAH S. WINANS, Ph.D.

Manter & Gatz's

Essentials of Clinical Neuroanatomy and Neurophysiology

edition 6

SID GILMAN, M.D.

Professor and Chairman
Department of Neurology
The University of Michigan Medical School
Ann Arbor, Michigan

SARAH S. WINANS, Ph.D.

Associate Professor
Department of Anatomy and Cell Biology
The University of Michigan Medical School
Ann Arbor, Michigan

F. A. DAVIS COMPANY • Philadelphia

Printed in the United States of America.

Library of Congress Cataloging in Publication Data

Manter, John Tinkham, 1910–1968

Manter & Gatz's essentials of clinical neuroanatomy and neurophysiology.

Rev. ed. of: Manter and Gatz's essentials of neuroanatomy and neurophysiology, 5th ed./Ronald G. Clark. 1975.

Includes index.

1. Neuroanatomy. 2. Neurophysiology. I. Gatz, Arthur John, 1907–1971. II. Gilman, Sid. III. Winans, Sarah. IV. Title. V. Title: Manter and Gatz's essentials of clinical neuroanatomy and neurophysiology. VI. Title: Essentials of clinical neuroanatomy and neurophysiology. [DNLM: 1. Nervous system—Anatomy and histology. 2. Neurophysiology. WL 100 M292e]

QM451.M25 1982 612'.8 81-17437

ISBN 0-8036-4155-9 AACR2

PREFACE TO THE SIXTH EDITION

More than 7 years have elapsed since publication of the 5th edition of this book and in this time a number of advances have occurred in our knowledge of the anatomy and physiology of the nervous system. The present edition has been revised extensively to bring the book up to date. In addition, all of the illustrations have been redrawn to provide greater accuracy and clarity. In revising the text, we have held firmly to Dr. Manter's original objective of providing a short but comprehensive survey of the human nervous system. In the present edition, we have placed greater emphasis upon the physiologic and clinical aspects of the nervous system than in the past. The book has been written chiefly for the beginning student of neuroanatomy and neurophysiology. We hope that it will be useful also to students approaching clinical neurologic problems and for individuals from other branches of medicine interested in refreshing their basic knowledge of the nervous system.

We are indebted to Margaret Brudon for her excellent illustrations and to Christine Young for her support, assistance, and counsel.

Sid Gilman, M.D.
Sarah S. Winans, Ph.D.

PREFACE TO THE FIRST EDITION

This book has been written with the object of providing a short, but comprehensive survey of the human nervous system. It is hoped that it will furnish a unified concept of structure and function which will be of practical value in leading to the understanding of the working mechanisms of the brain and spinal cord. Neither of these two aspects—structure and function—stands apart from the other. Together they furnish the key to the significance of the abnormal changes in function that go hand in hand with structural lesions of the nervous system. The viewpoints of three closely dependent sciences—neuroanatomy, neurophysiology and clinical neurology—are combined and used freely, not with the intent of covering these fields exhaustively, but in the belief that a more discerning approach to the study of the nervous system can be attained by bringing together all three facets of the subject.

To suit the needs of the medical student, or the physician who wishes to review the nervous system efficiently, basic information is presented in concise form. Consequently, it has not been feasible to cite published reports of research from which present concepts of the nervous system have evolved. The planning and arrangement of the chapters are such that whole topics can be covered rapidly. Presenting the subject material to classes in this form allows more time for discussion and review, or, if the teacher desires, for lectures dealing with advanced aspects, than would otherwise be permitted.

For the encouragement and valuable suggestions they have given me, I am indebted to my former colleague, Dr. William H. Waller, Jr., and to Dr. Lester L. Bowles. I am deeply grateful to Mr. A. H. Germagian for executing most of the drawings and diagrams, and to Mr. Richard Meyers for his special assistance with the illustrations.

John T. Manter

CONTENTS

1

INTRODUCTION

NERVE CELLS AND NERVE FIBERS

The *neuron* (nerve cell) is the functional and anatomic unit of the nervous system. Each neuron consists of a *cell body* (perikaryon) containing a nucleus and possessing one to several dozen processes of varying length (Fig. 1A, B). *Dendrites* are branching processes that receive *stimuli* and conduct *impulses* generated by those stimuli *toward* the nerve cell body. Most stimuli affecting nerve cells are chemical messengers or *transmitters* that are secreted from one neuron onto an adjacent neuron. The *axon (axis cylinder)* of a nerve cell is a single fiber extending to other parts of the nervous system or to a muscle or gland. The term *axon,* in a physiologic sense, applies to a fiber that conducts impulses *away* from a nerve cell body. Any long fiber, however, may be referred to as an axon regardless of the direction of conduction.

Many peripheral nerve fibers are encased in a *myelin sheath* and a neurolemma (sheath of Schwann) outside the myelin. The myelin is actually a wrapping of many layers of cell membranes from the same Schwann cell that forms the neurolemma. Each Schwann cell contributes myelin to one segment (or internode) of the axon. Between two adjacent Schwann cell internodes is a small gap called the *node of Ranvier* (Fig. 1E). Some fibers have no myelin sheath but retain a single wrapping of cytoplasm from Schwann cells. These fibers are referred to as unmyelinated fibers.

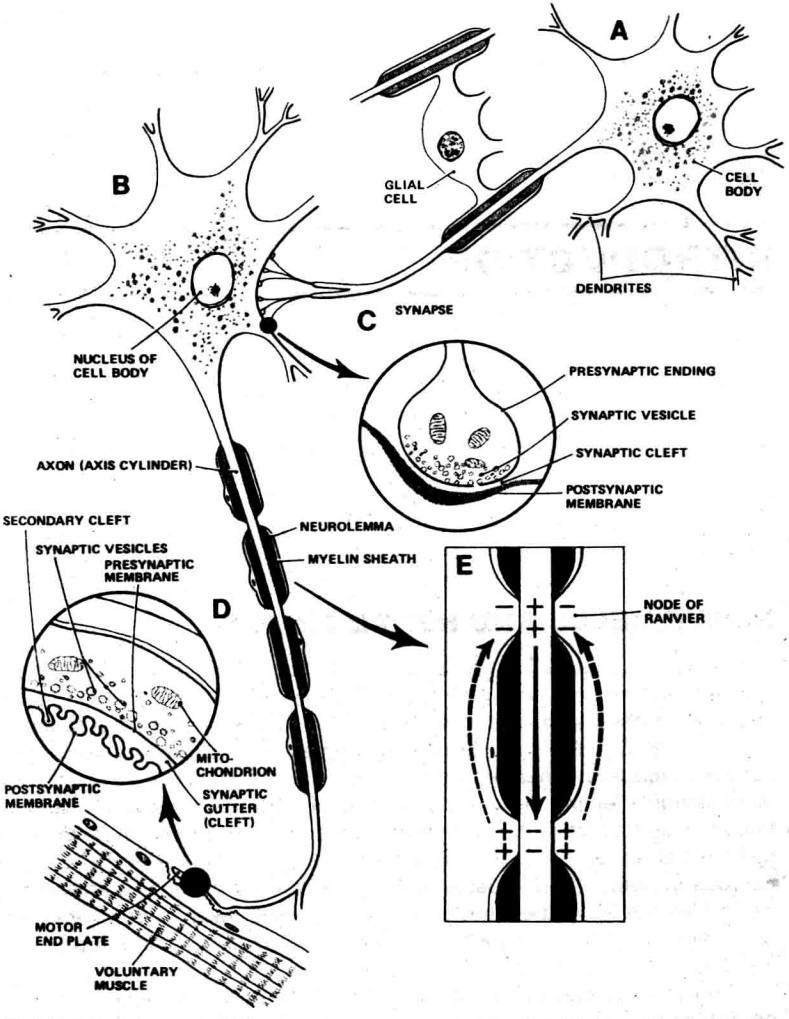

FIGURE 1. Neurons of the central nervous system (CNS). Neuron *A* is confined to the CNS and terminates on neuron *B* at a typical chemical synapse *(C)*. Neuron *B* is a ventral horn cell; its axon extends into a peripheral nerve and innervates a striated (voluntary) muscle at the myoneural junction (motor end plate, *D)*. In *E* the action potential is moving in the direction of the solid arrow inside the axon; the dashed arrows indicate the direction of flow of the action current.

The myelinated fibers that are located in the white matter of the brain and spinal cord possess a myelin sheath but have no neurolemma because their myelin sheaths are formed by cytoplasmic extensions of *glial cells*, rather than by Schwann cells. Each glial cell contributes myelin to several nearby axons (see Fig. 1A).

Like all animal cells, nerve cells are enclosed by membranes consisting of lipoprotein bilayers. The intracellular portions of nerve cells contain high concentrations of potassium (K^+) and low concentrations of sodium (Na^+) and chloride (Cl^-) relative to the extracellular fluid, where concentrations of K^+ are low and those of Na^+ and Cl^- are high. These differences in ionic concentrations across nerve cell membranes are maintained by the expenditure of metabolic energy. The result of the differences in the concentrations of these ions (K^+, Na^+, and Cl^-), as well as organic ions, is a difference in electrical potential across the membrane of the nerve cell, with the *inside of the cell strongly negative compared to the fluids outside the cell.* The difference in potential across the membrane is known as the *resting potential.*

Nerve cells are capable of conducting changes in potential along the membranes of both their cell body and the nerve fibers. During impulse transmission there is an alteration of the resting potential and a flow of electrical current across the membrane. The passage of the impulse results from a potential change that commonly is termed the *action potential.* A flow of current occurs during the action potential and is termed the *action current.* The action potential is characterized by a very rapid depolarization (decrease in negativity of the inside relative to the outside) and a somewhat slower repolarization to the resting potential. During the action potential there is a transient reversal of polarity of the electrical potential such that, at the peak of the action potential, the inside of the cell becomes positive with respect to the outside (see Fig. 1E). The action potential results from an initial inward current due to an in-rush of sodium from the exterior to the interior of the cell and an immediately subsequent outward current from the passage of potassium ions from the interior of the cell to the exterior. The passage of ions across the membrane is referred to as an ionic conductance. The conductance of sodium and potassium is thought to occur through separate channels in the cell membrane.

The action potential has characteristics determined only by the properties of the cell, independent of the characteristics of the exciting stimulus. The action potential can be propagated a very long distance along the nerve fiber without any variation of wave form and at an essentially constant velocity. Information within the nervous system is conveyed by the frequency of action potentials rather than the amplitude.

The ability of a nerve cell to produce an action potential is termed *excitability.* The event that elicits an action potential in excitable cells is called a *stimulus.* The minimal stimulus intensity needed to evoke an action potential is termed a *threshold stimulus.* A stimulus below threshold intensity is called *subthreshold* or *subliminal,* and one above threshold intensity is termed *superthreshold* or *supraliminal.* The expression "all or none" is

used to describe the ability of a nerve fiber to initiate an action potential with consistent characteristics once a superthreshold stimulus has been applied to its surface. Under some circumstances, subthreshold stimuli may combine to cause an action potential to develop. This process is called *summation*. Summation may result from temporal events, as when two subthreshold stimuli are applied in close succession, or from spatial events, as when two subthreshold stimuli occur simultaneously but at different loci on the neuron.

Nerve cells show *refractoriness*, which is the inability to respond to a second stimulus delivered soon after the first stimulus. During the initial portion of the action potential, triggered by the first stimulus, the cell cannot respond to any other stimulus, no matter how intense. This period is called the *absolute refractory period*. Following the absolute refractory period an action potential can be produced, first by a very intense stimulus, and then gradually by stimuli of lesser intensity. The period after the absolute refractory period is called the *relative refractory period*. In unmyelinated fibers, nerve impulses are propagated through the continuous progression of the action potential along the length of the fiber. In myelinated fibers, the process is the same quantitatively, but there is a major difference. During the propagation of the impulse, the transmembrane ionic current does not flow across the myelin sheath, but flows only across the periodic interruptions of the myelin sheath, which are termed the nodes of Ranvier (see Fig. 1E). As a consequence of myelinization, many fibers that conduct impulses at high velocities can be contained in a relatively small-volume nerve trunk.

Transmission of impulses from neuron to neuron occurs at a synapse (Fig. 1C), which is a place where terminals of the axon of one neuron make contact with the cell body or dendrites of another neuron. Action potentials in the presynaptic neuron cause the release of *neurotransmitters* or neuromodulators from *synaptic vesicles*. The transmitter substance traverses the *synaptic cleft* and either prevents or produces electrical potential changes in the *postsynaptic* neuronal membrane. Ramifications of dendrites and terminal branches of axons form a delicate network throughout the gray matter, known as *neuropil*. Nerve cells normally conduct impulses in only one direction—away from the region that receives stimulation. *Afferent* processes (dendrites) conduct the impulse toward the cell body; *efferent* fibers (axons) conduct away from the cell body.

Nerve cell bodies usually are located in groups. Outside of the brain and spinal cord such groups are called *ganglia*. Within the brain and spinal cord neurons form groups of various sizes and shapes, known as *nuclei*. In this instance the term nucleus has a meaning different from that of the nucleus of an individual cell. The laminated sheets of nerve cells on the surface of the cerebrum and cerebellum are referred to as the cerebral cortex and cerebellar cortex. Regions of the brain and spinal cord that contain aggregations of nerve cell bodies comprise the *gray matter* and, in the fresh state, they are grayish in color. The remaining areas consist primarily of myelinated nerve fibers and make up the *white matter*.

Nerve fibers of the brain and spinal cord that have a common origin and a common destination constitute a *tract.* Although a tract occupies a regular position, it does not always form a compact bundle because of some dispersion with intermingling fibers of neighboring tracts. A number of bundles of fibers in the brain are so distinct anatomically that they have been given the names *fasciculus, brachium, peduncle, column,* and *lemniscus.* These may contain only a single tract, or they may consist of several running together in the same bundle. *Nerve, nerve root, nerve trunk, nerve cord,* and *ramus* are appropriate anatomic terms for bundles of nerve fibers outside the brain and spinal cord.

THE PERIPHERAL NERVOUS SYSTEM

The 12 pairs of cranial and 31 pairs of spinal nerves, with their associated ganglia, make up the human *peripheral nervous system* (PNS). Motor (or efferent) fibers of peripheral nerves are of two types: *somatic motor fibers* that terminate in *skeletal muscle,* and autonomic fibers that innervate *cardiac muscle, smooth muscle,* and *glands.* The termination of the somatic motor fiber on a skeletal muscle fiber occurs at the *motor end plate,* which resembles a synapse (Fig. 1D). The sensory (or afferent) fibers of nerves transmit signals from receptors of various types. Each afferent fiber conducts impulses toward the spinal cord and brain from the particular receptor with which it is connected.

THE CENTRAL NERVOUS SYSTEM

The *central nervous system* (CNS) consists of the brain and the spinal cord. The brain of the young adult human male averages 1380 g in weight (generally 100 g less in females). The adult brain is divided into three gross parts: the cerebrum, the cerebellum, and the brain stem.

The Cerebrum

The left and right cerebral hemispheres are incompletely separated by a deep, *medial longitudinal fissure.* The surface of each hemisphere is wrinkled by the presence of eminences, known as *gyri,* and furrows, which are called *sulci* or *fissures.* The *cerebral cortex* consists of a layer of gray matter that varies from 1.3 to 4.5 mm in thickness and covers the expansive surface of the cerebral hemisphere. This cortex is estimated to contain 14 billion nerve cells.

There are two major grooves on the lateral surface of the brain (Fig. 2). The *lateral fissure (of Sylvius)* begins as a deep cleft on the basal surface of the brain and extends laterally, posteriorly, and upward. The *central sulcus (of Rolando)* runs from the dorsal border of the hemisphere near its midpoint obliquely downward and forward until it nearly meets the lateral fissure. For descriptive purposes the lateral surface of the hemisphere is divided into four lobes. The *frontal lobe* (approximately the anterior one-third

of the hemisphere) is the portion which is rostral (anterior) to the central sulcus and above the lateral fissure. The *occipital lobe* is that part lying behind, or caudal to, an arbitrary line drawn from the parieto-occipital fissure to the preoccipital notch. This lobe occupies a small area of the lateral surface but has more extensive territory on the medial aspect of the hemisphere (Fig. 3). The *parietal lobe* extends from the central sulcus to the parieto-occipital fissure and, on the lateral surface, is separated from the *temporal lobe* below by an imaginary line projected from the horizontal portion of the lateral fissure to the middle of the line demarcating the occipital lobe. The gyri within each lobe are subdivided by sulci whose patterns may show considerable individual variation.

Figure 3 depicts the structures that are located on the medial (midsagittal) surface of the brain. This surface is exposed by cutting the brain in half on a plane through the medial longitudinal fissure. This cut severs the corpus callosum, the brain stem, and the cerebellum, and it exposes to view the ventricular system within the brain (Fig. 4). On the medial surface of the cerebral cortex the gyri and sulci of the frontal, parietal, occipital, and temporal lobes are continuous with those seen on the lateral surface. The central sulcus extends a short distance over the dorsal crest of the hemisphere onto the medial side, marking the boundary between the frontal and parietal lobes. The parieto-occipital fissure, as its name implies, separates the parietal and occipital lobes. Only the temporal pole region of the temporal lobe can be seen on this medial section through a whole brain. A part of a fifth lobe can now be seen on the cerebral cortex. This is

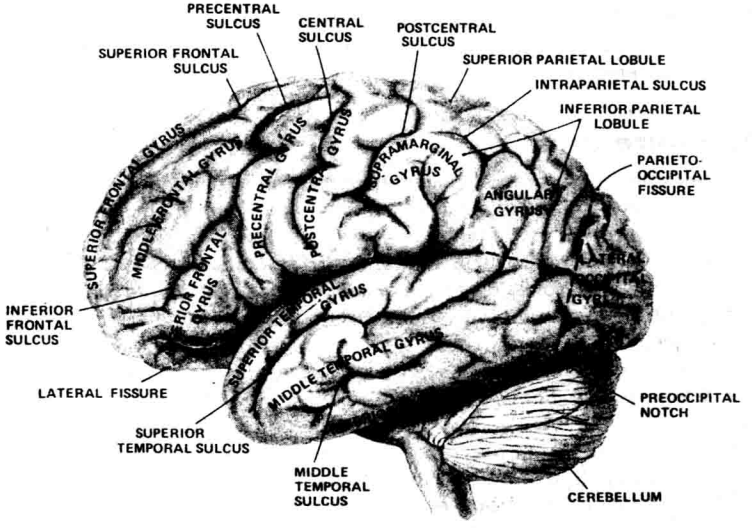

FIGURE 2. Lateral surface of the brain.

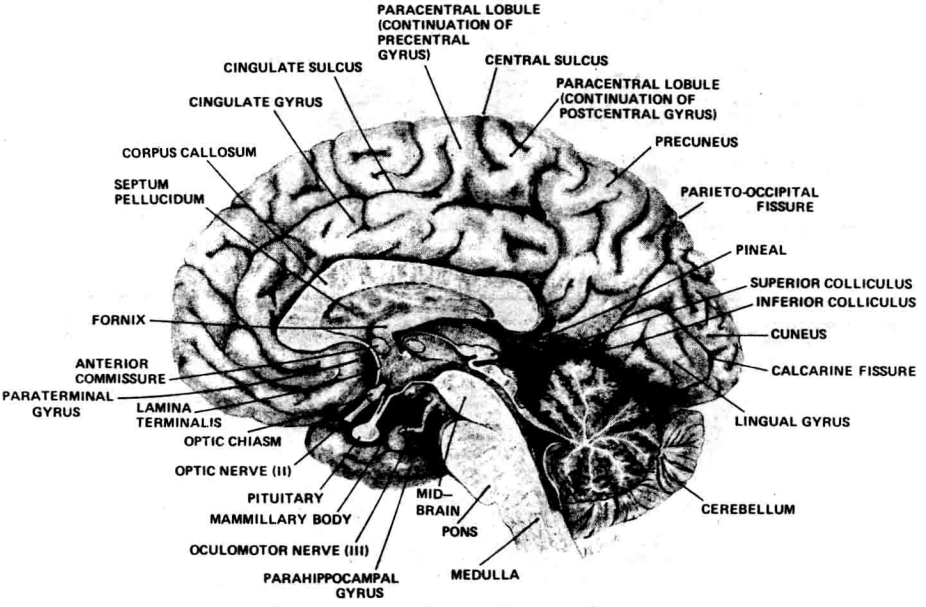

FIGURE 3. Medial (midsagittal) view of a hemisected brain.

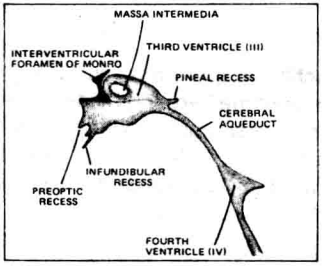

FIGURE 4. Components of the ventricular system as seen on the midsagittal section of the brain (compare Fig. 3).

the *limbic lobe*, a ring (or limbus) of cortical tissue consisting primarily of the paraterminal gyrus, the cingulate gyrus, and the parahippocampal gyrus, which is partially hidden by the brain stem.

A more complete view of the parahippocampal gyrus can be seen on the ventral surface of the brain (Fig. 5). This view also shows the cranial nerves exiting from the brain stem.

A sixth lobe, the *insular lobe*, cannot be seen in any of these figures. It is the cortical tissue that forms the floor of the deep lateral fissure, and can be seen only when the lips (opercula) of this fissure are separated.

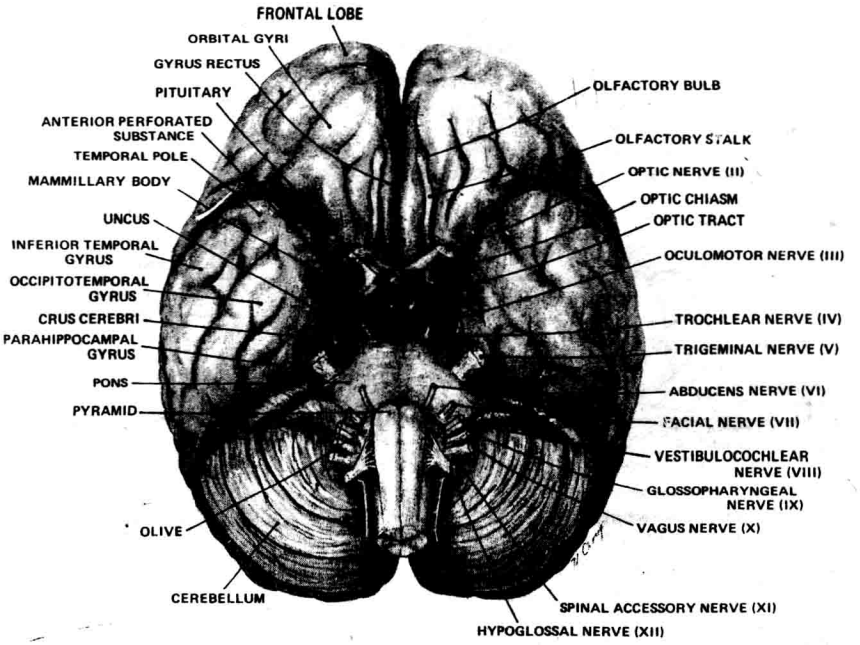

FIGURE 5. Ventral surface of the brain.

The Cerebellum

The cerebellum is attached to the dorsal surface of the brain stem at the level of the pons. Like that of the cerebral hemispheres, its surface is a layer of gray matter, the cerebellar cortex, which is thrown into ridges and grooves. In the cerebellum the eminences of gray matter are called *folia.* On the midsagittally cut brain (see Fig. 3) a core of white matter, the *arbor vitae,* can be seen under the cortex of the folia.

The Brain Stem

The brain stem consists of the following areas of the brain: *medulla, pons, midbrain,* and *diencephalon.* This region is described in Chapter 9.

THE VENTRICLES, MENINGES, AND CEREBROSPINAL FLUID

Cavities within the brain, called the ventricles, are filled with *cerebrospinal fluid* (CSF). CSF is formed by specialized tissue in the ventricles, called the *choroid plexus.* The ventricular system opens to the space outside the

brain at three sites in the brain stem. Through these three openings CSF flows from the ventricles into the *subarachnoid space,* which surrounds the brain and spinal cord. This space exists between the pia mater and the arachnoid, two layers of three connective tissue membranes that enclose the central nervous system. The *pia mater* is intimately attached to the surface of the brain and spinal cord. Fine strands of connective tissue, the trabeculae, stretch across the subarachnoid space between the pia and the *arachnoid.* Outside the arachnoid, the tough *dura mater* lines the bony cranial cavity around the brain and the vertebral canal around the spinal cord. Together, the pia mater, arachnoid, and dura mater constitute the *meninges.* Additional detail on the meninges and CSF can be found in Chapter 25.

THE SPINAL CORD

The human spinal cord is a slender cylinder less than an inch in diameter. It is surrounded by the closely applied *pia mater,* and anchored through the arachnoid to the dura mater by paired lateral septae of pia—the *denticulate ligaments.* From its rostral junction with the medulla to its caudal end, the spinal cord is divided arbitrarily into five regions: cervical, thoracic, lumbar, sacral, and coccygeal. The spinal cord is enlarged in the lower cervical region and in the lower lumbar and sacral regions where nerve fibers supplying the upper and lower extremities are connected. Spinal nerves are attached to the spinal cord in pairs: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal (Fig. 6). The spinal cord does not extend to the lower end of the vertebral canal but ends at the level of the lower border of the first lumbar vertebra in a tapered cone, the *conus medullaris.* The pia mater continues caudally as a connective tissue filament, the *filum terminale,* which passes through the subarachnoid space to the end of the dural sac (level of vertebra L-5, see Fig. 6), where it receives a covering of dura and continues to its attachment to the coccyx bone. Because the cord is some 25 cm shorter than the vertebral column, the segments of the spinal cord are not aligned opposite corresponding vertebrae. Thus the lumbar and sacral spinal nerves have very long roots extending from their respective segments in the cord to the lumbar and sacral intervertebral foramina where dorsal and ventral roots join to form the spinal nerves. These roots descend in a bundle from the conus and, because of its resemblance to the tail of a horse, this formation is known as the *cauda equina.*

In describing the spinal cord the terms *posterior* and *dorsal* are used interchangeably. Similarly, the terms *anterior* and *ventral* are interchangeable. Sections of the spinal cord cut perpendicular to the length of the cord (transverse sections) reveal a butterfly-shaped area of gray matter with surrounding white matter, which is made up mainly of longitudinal nerve fibers (Fig. 7). Midline grooves are present on the dorsal and ventral surfaces: the *dorsal median sulcus* and the *ventral median fissure.* The lateral surface shows a *dorsolateral* and a *ventrolateral sulcus,* which correspond to the

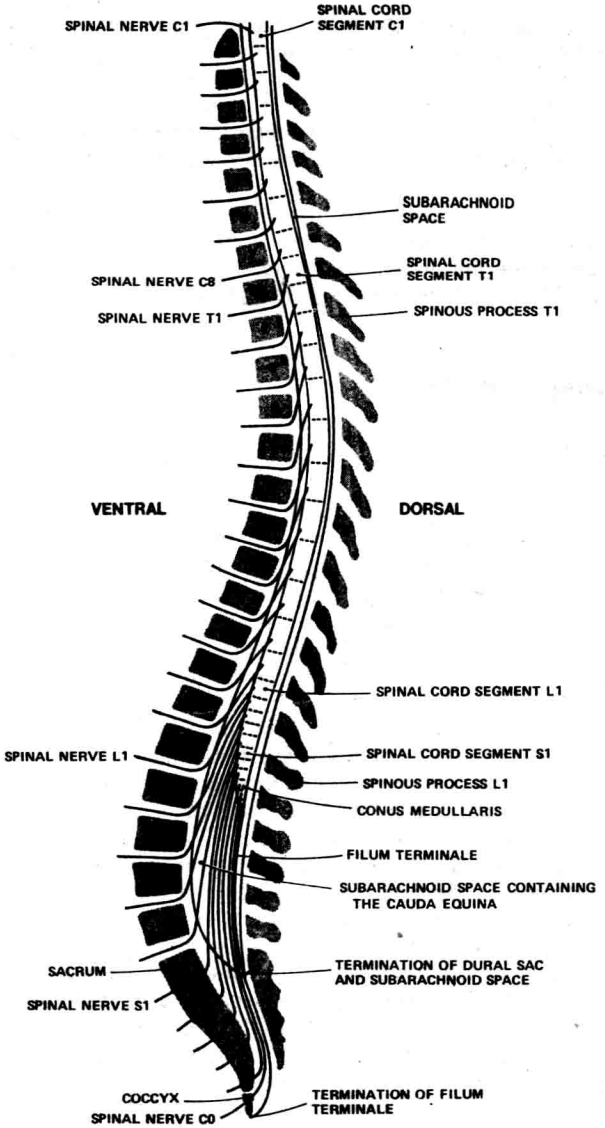

FIGURE 6. Diagram of the relationship of the spinal cord segments and spinal nerve roots to the dural sac and vertebrae of the spinal column. The bodies of the individual vertebrae on the ventral side of the spinal cord are numbered. The spinous processes of the vertebrae are dorsal to the cord. The dural sac and filum terminale are shown in color.