a LANGE medical book

Correlative Neuroanatomy

TWENTIETH EDITION

Jack deGroot
Joseph G. Chusid

a **LANGE** medical book

Correlative Neuroanatomy

TWENTIETH EDITION

Jack deGroot, MD, PhD
Professor of Anatomy and Radiology
University of California School of Medicine
San Francisco

Joseph G. Chusid, MD
Professor of Neurology Emeritus
New York Medical College
New York City

Director of Department of Neurology Emeritus
St. Vincent's Hospital and Medical Center
New York City

Prentice-Hall International Inc.

ISBN: 0-8385-1341-7

Notice: Our knowledge in clinical sciences is constantly changing. As new information becomes available, changes in treatment and in the use of drugs become necessary. The authors and the publisher of this volume have taken care to make certain that the doses of drugs and schedules of treatment are correct and compatible with the standards generally accepted at the time of publication. The reader is advised to consult carefully the instruction and information material included in the package insert of each drug or therapeutic agent before administration. This advice is especially important when using new or infrequently used drugs.

Italian Edition: *Piccin Nuova Libraria, S.p.A., Via Altinate, 107, 35121 Padua, Italy*
Japanese Edition: *Kinpodo Publishing Co., Ltd., 34 Nishiteranomae-cho, Shishigatani, Sakyo-ku, Kyoto, 606, Japan*
Spanish Edition: *Editoral El Manual Moderno, S.A. de C.V., Av. Sonora 206 - Col. Hipodromo, 06100-Mexico, D.F.*
Portugese Edition: *Editora Guanabara Koogan S.A., Travessado Ouvidor, 11, 20 040 Rio de Janeiro - RJ, Brazil*
Polish Edition: *Panstwowy Zaklad Wydawnictw Lekarskich, P.O. Box 379, 00-950 Warsaw 1, Poland*
German Edition: *Springer-Verlag GmbH & Co. KG, Postfach 10 52 80, 6900 Heidelberg 1, West Germany*
Serbo-Croatian Edition: *Savremena Adminstracija, Crnotravska 7-9, 11000 Belgrade, Yugoslavia*
French Edition: *Masson, Editeur, 120 Boulevard Saint-Germain, F-75280 Paris, Cedex 06, France*
Indonesian Edition: *Yayasan Essentia Medica, P.O. Box 58, Yogyakarta D.I.Y., Indonesia*

88 89 90 91 92 / 10 9 8 7 6 5 4 3 2 1

Prentice-Hall of Australia, Pty. Ltd., Sydney
Prentice-Hall Canada, Inc.
Prentice-Hall Hispanoamericana, S.A., Mexico
Prentice-Hall of India Private Limited, New Delhi
Prentice-Hall International (UK) Limited, London
Prentice-Hall of Japan, Inc., Tokyo
Prentice-Hall of Southeast Asia (Pte.) Ltd., Singapore
Whitehall Books Ltd., Wellington, New Zealand
Editora Prentice-Hall do Brasil Ltda., Rio de Janeiro

ISSN: 0892-1237
ISBN: 0-8385-1341-7

PRINTED IN THE UNITED STATES OF AMERICA

Foreword

Fifty years ago, the first edition of *Correlative Neuroanatomy* appeared at Northwestern University Medical School. At that time a classmate, Dr. Joseph J. McDonald—later to become Dean of American University of Beirut School of Medicine—and I put together a simple book on neuroanatomy that was found to be useful for students taking the course in neuroanatomy.

When the fourth edition appeared in 1947, Joseph G. Chusid—now Professor of Neurology Emeritus of New York Medical College—became a coauthor. From 1970 until 1986, Dr. Chusid was the sole author, maintaining the book as a student's text.

Over the years, the book became popular and has been used in many schools in this country and abroad and translated into nine languages. In the course of its many editions, it has sold over 600,000 copies.

In this new edition, I am pleased to welcome Professor Jack deGroot of the University of California, San Francisco, as the senior author. He retains many of our original concepts of presenting the subject matter and incorporates them into his own extensive experience as a teacher of neuroanatomy, neuroradiology, and neuropathology to medical students. The book still correlates clinical aspects of neuroanatomy with basic information. Dr. deGroot has increased the value of the book by adding new imaging modalities and has enlarged the basic sections considerably. Although *Correlative Neuroanatomy* has been frequently revised, I am pleased to note that parts of the first edition are still to be seen.

Jack D. Lange, MD

Preface

Modern neuroanatomy, the study of the form and function of the nervous system, is part of an exciting array of rapidly developing disciplines comprising the neurosciences. *Correlative Neuroanatomy*, 20th edition, presents the most current knowledge in this evolving field in a practical clinical context and serves as a foundation block in the study of neurosciences.

This book is written as a basic text for students in medicine and other health sciences. It is intended for study in an initial course on the subject and as a review and a reference in a variety of clinical courses.

ORGANIZATION

Correlative Neuroanatomy is divided into six sections. The first section covers the basic divisions, cellular elements, and modes of signaling of the nervous system. The second section described extensively the form and function of the spinal cord, the spine, and spinal nerves. The third section discusses the functional anatomy of the brain and cranial nerves. The fourth section summarizes the functional integration of the entire nervous system. The fifth section presents some diagnostic methods, including modern neuroradiology, and the sixth section discusses in detail the clinical cases presented in earlier chapters.

FEATURES

- *Correlative Neuroanatomy* is a comprehensive overview of the subject, presented in a logical order for study.
- The material is divided into compact units to facilitate comprehension, retention, and ease of access.
- The book is profusely illustrated with drawings and an exceptional number of modern radiologic images, which depict anatomic relationships closely, including numerous CT and MR images of the brain and the spine.
- Clinical aspects of neuroanatomy are consistently emphasized to prepare the student for clinical practice. In particular, numerous clinical correlations and cases are included.
- Brain, spinal, and peripheral lesions, often seen in clinical practice, are presented.
- A unique Section 5 covers diagnostic methods in neuroanatomy.
- Appendices present the Neurologic Examination, Functional Tests of Principal Muscles, and Test Questions and Answers.

I owe thanks to my colleagues who taught me and shared their material with me. Dr. J.G. Chusid has been especially generous, and I am deeply grateful to him. Dr. C.M. Mills kindly provided some of the MR images.

Jack deGroot

San Francisco
July, 1988

Table of Contents

SECTION I. BASIC PRINCIPLES

SECTION II. SPINAL CORD & SPINE

SECTION III. ANATOMY OF THE BRAIN

SECTION IV. FUNCTIONAL SYSTEMS OF THE CENTRAL NERVOUS SYSTEM

SECTION V. DIAGNOSTIC AIDS

SECTION VI. DISCUSSION OF CASES

Section I. Basic Principles

Fundamentals of the Nervous System

1

Modern scientific and technical advances have led to the development of sophisticated machines that might be compared to the human nervous system. The most advanced new mainframe computer is a simple, uncomplicated, clumsy machine compared with the human brain, which has a potentially much larger memory than any computer. The brain has the ability also to make complex decisions, think logically and creatively, draw conclusions, "feel" emotions, and select or preempt responses to stimuli and questions; and "minicomputers" in place at intervals along the spinal cord are capable of initiating or receiving as well as of modifying stimuli. Artificial intelligence using complex computers may some day be able to imitate to a small degree—but no more than that—the complex function of the human brain.

STUDY OF THE NERVOUS SYSTEM

The nervous system can be studied in many ways and in the context of several disciplines collectively called **neurobiology** or **the neurosciences.** Each field of study emphasizes different features, but all are rapidly adding to our understanding of the nervous system.

Neuroanatomy is the study of the form and function of the nervous system. This book sets forth not only normal anatomy but also changes due to selected disorders and defects of the nervous system and modern techniques for depicting normal or abnormal features of the brain, spinal cord and spinal nerves, and their coverings. Many thousands of special terms and identifications (language) are required to describe the processes and connections taking place almost continuously in the various parts of the nervous system (geography); some of these terms are listed in Table 7–1.

Neurology is the science and technique of deducing the location and nature of nervous system lesions from the signs and symptoms they give rise to; once determined (**diagnosis**), the abnormality may in many cases be treated (**therapy**).

Neuropathology is the study of the nature and extent of disease processes (lesions) from biopsies, autopsies, and chemical tests, using gross inspection and histologic and ultrastructural analysis.

Neuroradiology is a modern specialty that uses various refined methods of examination to locate and identify nervous system lesions—usually very small at the time of diagnosis—as an aid to diagnosis.

GENERAL PLAN OF THE NERVOUS SYSTEM

Main Divisions (Figs 1–1 to 1–4)

A. Anatomy: Anatomically, the human nervous system is a complex of 2 subdivisions.

1. Central nervous system (CNS)–The CNS is enclosed in bone and wrapped in protective coverings and fluid-filled spaces.

2. Peripheral nervous system (PNS)–The PNS is formed by the cranial and spinal nerves (Fig 1–1).

B. Physiology: Functionally, the nervous system is divided into 2 systems.

1. Somatic nervous system–This innervates the structures of the body wall (muscles, skin, mucous membranes).

2. Autonomic (visceral) nervous system (ANS)–The ANS contains portions of the central and peripheral systems. It functions to control the activities of the muscles and glands of the internal organs (viscera) and the blood vessels as well as to return sensory information to the brain.

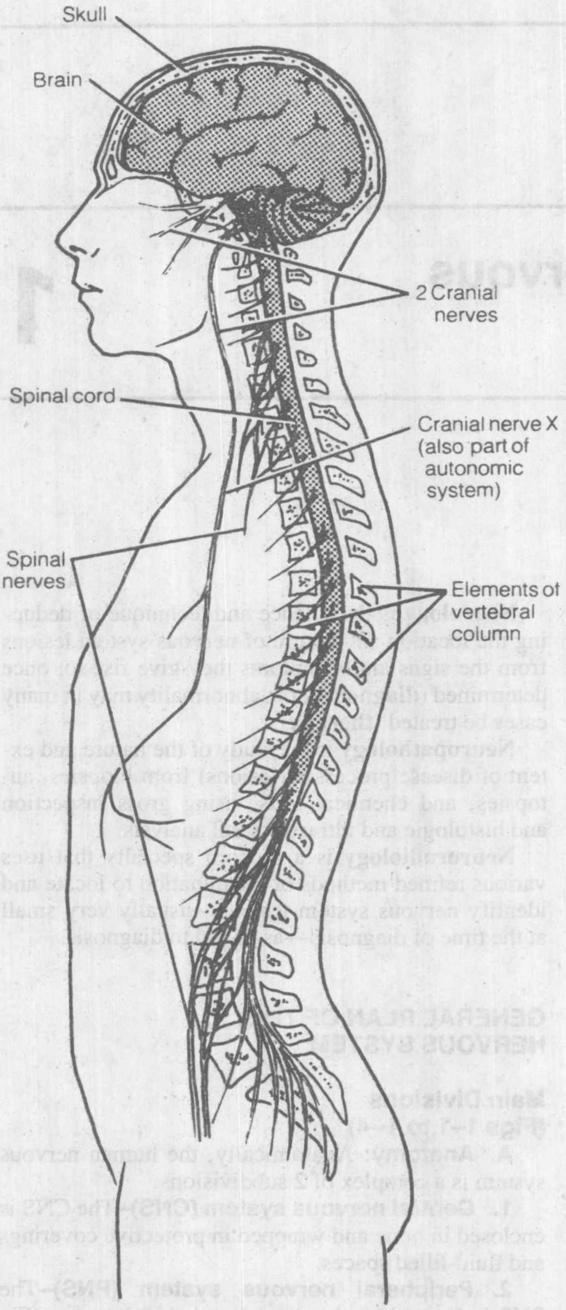

Figure 1–1. The relationships between the central nervous system within bony coverings and the peripheral nervous system.

Structural Units

The central portion of the nervous system consists of a large, complex **brain** (encephalon) and an elongated **spinal cord** (medulla spinalis) (Fig 1–2 and Table 1–1). The brain is further subdivided into the cerebrum, the brain stem, and the cerebellum. The cerebrum (forebrain) consists of the telencephalon and the diencephalon; the telencephalon includes the gray cerebral cortex, subcortical white matter, and the so-called basal ganglia, deep gray masses within the cerebral hemispheres. The major subdivisions of the diencephalon are the thalamus and hypothalamus. The brain stem consists of the midbrain (mesencephalon), pons (metencephalon), and medulla oblongata (myelencephalon). The brain contains a system of ventricles, while the spinal cord has a narrow central canal; these spaces are filled with cerebrospinal fluid (CSF) (Figs 1–3 and 1–4).

Functional Units (Fig 1–5)

The brain, comprising about 2% of the body weight, contains many billions of neurons and glial cells—perhaps even a trillion. Most of the cells are glial cells. The **neurons,** or nerve cells, are specialized cells that by means of their extensions and connections (containing nerve fibers) receive and send signals to other cells. The information is processed and encoded in a sequence of electrical or chemical stimuli. Many neurons have relatively large cell bodies and long extensions that transmit the stimuli quickly over a considerable distance. Most large neurons can be readily identified in histologic sections and have been studied extensively. However, a far greater number of smaller cells (the interneuron pool) play a role in processing information in a way that is still poorly understood. Nerve cells with common form, functions, and connections within the central nervous system often are grouped together into so-called nuclei. These nuclei may originate, relay, modify, or multiply information signals within the nervous system. Nerve cells with common form, function, and connections outside the central nervous system are called ganglia.

Other elements that support and expedite the activity of the neurons are called the **glial cells,** of which there are several types (see Chapter 2). The glial cells outnumber the neurons 10 : 1.

CONNECTIONS

The connections (pathways) between groups of neurons in the central nervous system are in the form of fiber bundles or tracts (**fasciculi**) or are diffusely distributed. Aggregates of tracts, as seen in the spinal cord, are referred to as columns (**funiculi**). Tracts may descend, eg, from the cerebrum to the brain stem or spinal cord—or may ascend in the reverse direction. These pathways are vertical connections that in their course may cross (decussate) from one side of the central nervous system to the other. Horizontal (lateral) connections are called **commissures.**

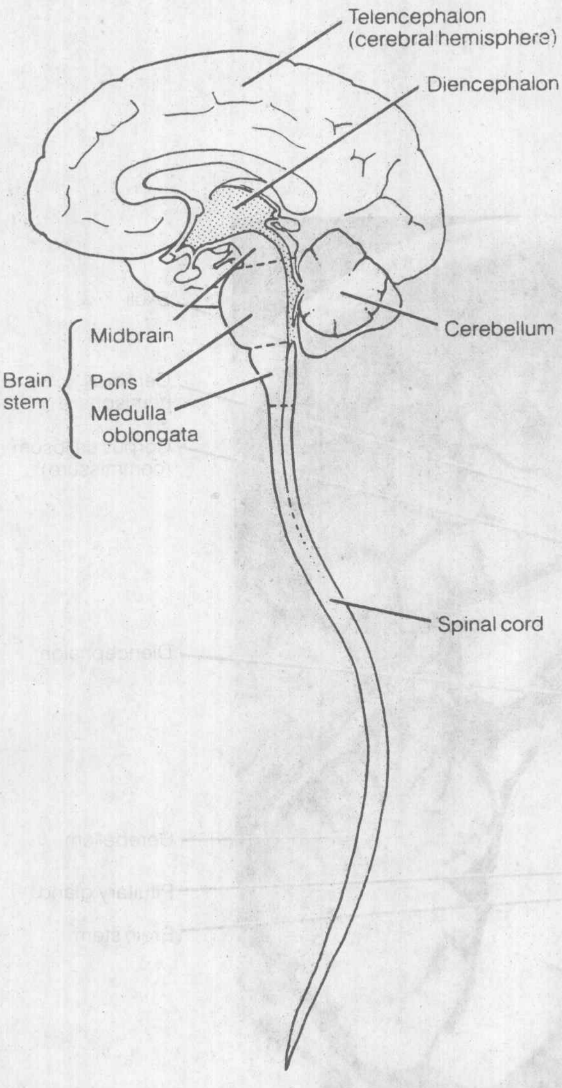

Figure 1–2. Two major divisions of the central nervous system as seen in the midsagittal plane.

PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system consists of spinal nerves, cranial nerves, and their associated ganglia (groups of nerve cells outside the central nervous system). The nerves contain nerve fibers that conduct information to (afferent) or from (efferent) the central nervous system. In general, efferent fibers are involved in motor functions: contraction of muscles or secretion of glands. Afferent fibers usually convey sensory stimuli from the skin, mucous membranes, and deeper structures.

EXPERIMENTAL METHODS

Early anatomists examined the nervous system in terms of gross appearance. Histologic examination with the light microscope added a great deal of new information now being continually amplified and refined by ultrastructural procedures (freeze-fracture techniques, transmission electron microscopy, and scanning electron microscopy). Biochemical and physiologic analysis contributes to our understanding of the form and function of the brain, spinal cord, and nerves. Experimental methods often needed to elucidate how the elements of the system interact include (1) observation under varied experimental conditions, (2) stimulation followed by recording of reactions, and (3) destruction of discrete parts followed by determining deficits of function.

Stimulation (or irritation) and destruction of portions of the nervous system are processes that occur in disease. A loss of function is called a **lesion** or a **deficit.** Lesions may produce **signs** (observable abnormalities of function) or **symptoms** (subjective changes).

Table 1–1. Major divisions of the central nervous system.

Brain (encephalon)	Cerebrum (forebrain, prosencephalon)	Telencephalon	Cerebral cortex (gray) Subcortical white matter Basal ganglia (deeply placed gray masses)
		Diencephalon	Thalamus Hypothalamus Epithalamus
	Brain stem	Midbrain (mesencephalon) Pons (metencephalon) Medulla oblongata (myelencephalon)	
	Cerebellum		
Spinal cord (medulla spinalis)			

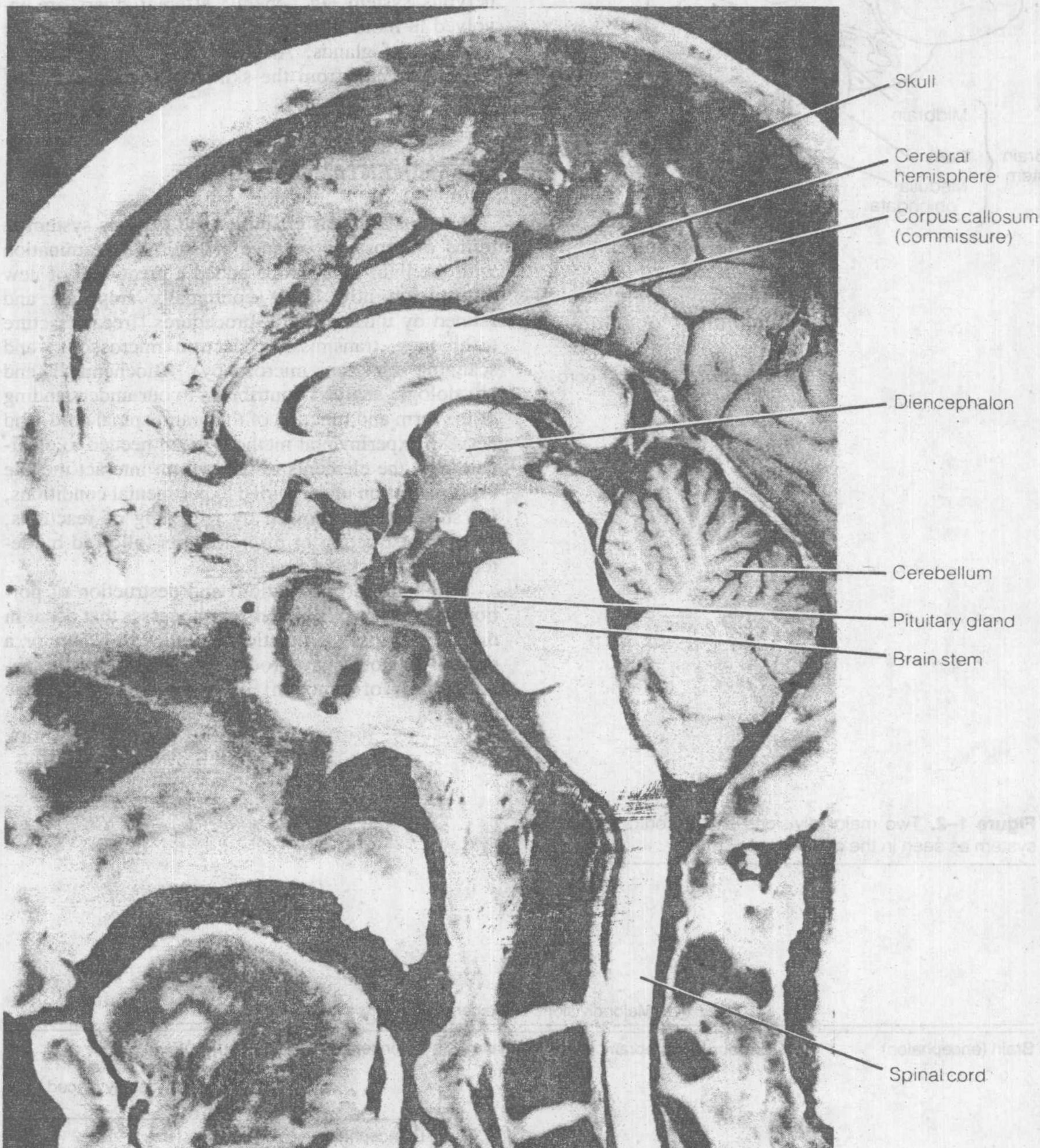

Figure 1–3. Photograph of a midsagittal section through the head and upper neck to show the major divisions of the central nervous system. (Reproduced, with permission, from de Groot J: *Correlative Neuroanatomy of Computed Tomography and Magnetic Resonance Imaging*. Lea & Febiger, 1984.)

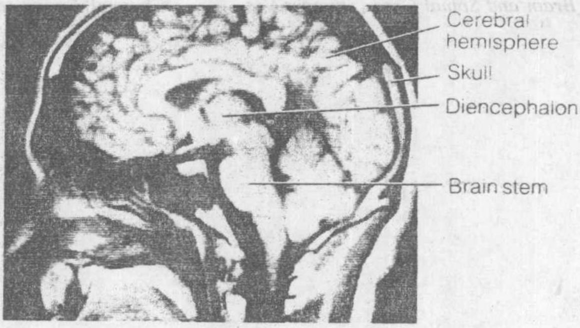

Figure 1–4. Magnetic resonance (MR) image of a midsagittal section through the head. (Compare with Fig 1–3.)

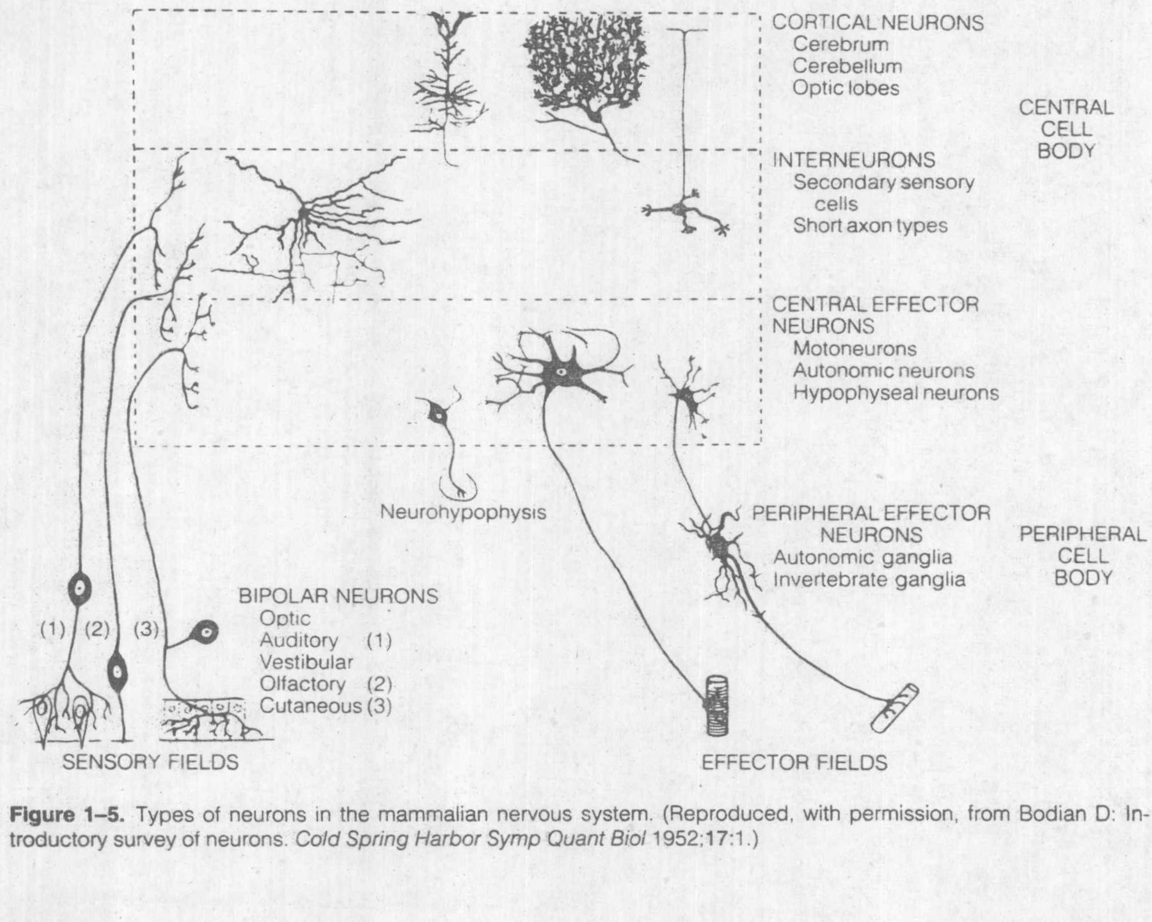

Figure 1–5. Types of neurons in the mammalian nervous system. (Reproduced, with permission, from Bodian D: Introductory survey of neurons. *Cold Spring Harbor Symp Quant Biol* 1952;17:1.)

REFERENCES

Barr ML, Kierman JA: *The Human Nervous System*. 4th ed. Harper & Row, 1983.

Brodal A: *Neurological Anatomy*, 3rd ed. Oxford Univ Press, 1981.

Carpenter MC, Sutin J: *Human Neuroanatomy*, 8th ed. Williams & Wilkins, 1983.

Heimer L: *The Human Brain and Spinal Cord*. Springer-Verlag, 1983.

Kandel ER, Schwartz JH: *Principles of Neural Science*. Elsevier, 1981.

Netter FH: *Nervous System (Atlas and Connotations)*. Vol 1 of *The Ciba Collection of Medical Illustrations*. CIBA Pharmaceutical Company, 1983.

Romero-Sierra C: *Neuroanatomy: A Conceptual Approach*. Churchill Livingstone, 1986.

Elements of Nervous Tissue

2

CELLULAR ASPECTS OF NEURAL DEVELOPMENT

Early in the development of the nervous system, a tube of ectodermal neural tissue is formed in the dorsal midline area of the embryo. The cellular elements of the tube appear undifferentiated at first, but later they form various types of neurons (nerve cells) and glial (supporting) cells.

Layers of the Neural Tube (Fig 2–1)

The embryonic neural tube has 3 layers: (1) the **ventricular zone** around the lumen (central canal) of the tube, later called **ependyma;** (2) the **intermediate zone,** which is formed from dividing cells of the ventricular zone—including the earliest glial cell type—and stretches between the ventricular surface and the outer (pial) layer; and (3) the external **marginal zone** formed by processes of the nerve cells in the intermediate zone.

Differentiation & Migration

The largest neurons, mostly motor neurons, differentiate first. Sensory and small neurons and most of the glial cells appear later, up to the time of birth. Newly formed neurons may migrate extensively through regions of previously formed neurons. Because the axonal process of a neuron may begin growing toward its target during migration, nerve processes in the adult brain often are not straight but curved. Newer cells of the future cerebral cortex migrate from the deepest to the more superficial layers ("inside out"), and small neurons of the future cere-

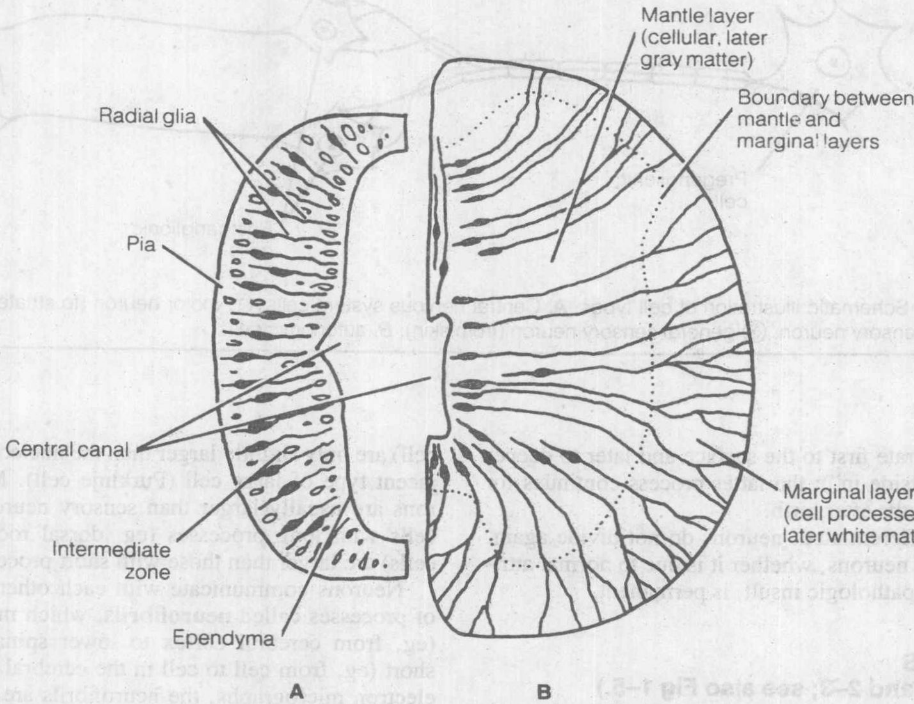

Figure 2–1. Two stages in the development of the neural tube (only half of each cross section is shown). *A,* Early stage with large central canal; *B,* later stage with smaller central canal.

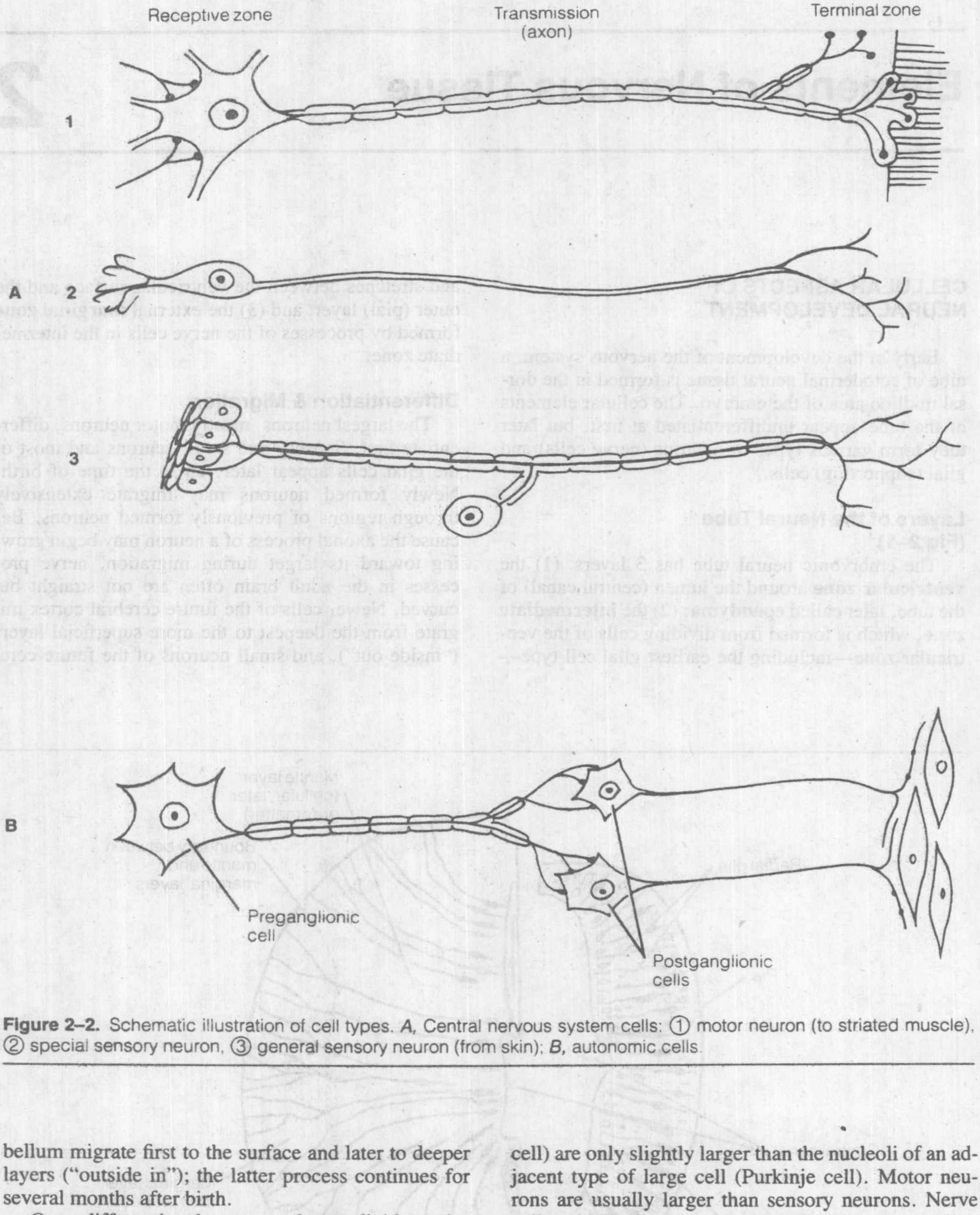

Figure 2–2. Schematic illustration of cell types. *A,* Central nervous system cells: ① motor neuron (to striated muscle), ② special sensory neuron, ③ general sensory neuron (from skin); *B,* autonomic cells.

bellum migrate first to the surface and later to deeper layers ("outside in"); the latter process continues for several months after birth.

Once differentiated, neurons do not divide again. Any loss of neurons, whether it is due to normal attrition or to a pathologic insult, is permanent.

NEURONS (Figs 2–2 and 2–3; see also Fig 1–5.)

Neurons vary in size and complexity. The nuclei of one type of small cerebellar cortical cell (granular cell) are only slightly larger than the nucleoli of an adjacent type of large cell (Purkinje cell). Motor neurons are usually larger than sensory neurons. Nerve cells with long processes (eg, dorsal root ganglion cells) are larger than those with short processes.

Neurons communicate with each other by means of processes called **neurofibrils,** which may be long (eg, from cerebral cortex to lower spinal cord) or short (eg, from cell to cell in the cerebral cortex). In electron micrographs, the neurofibrils are seen to be composed of thin **neurofilaments.** The receptive part of the neuron is the **dendrite** or **dendritic zone;** the

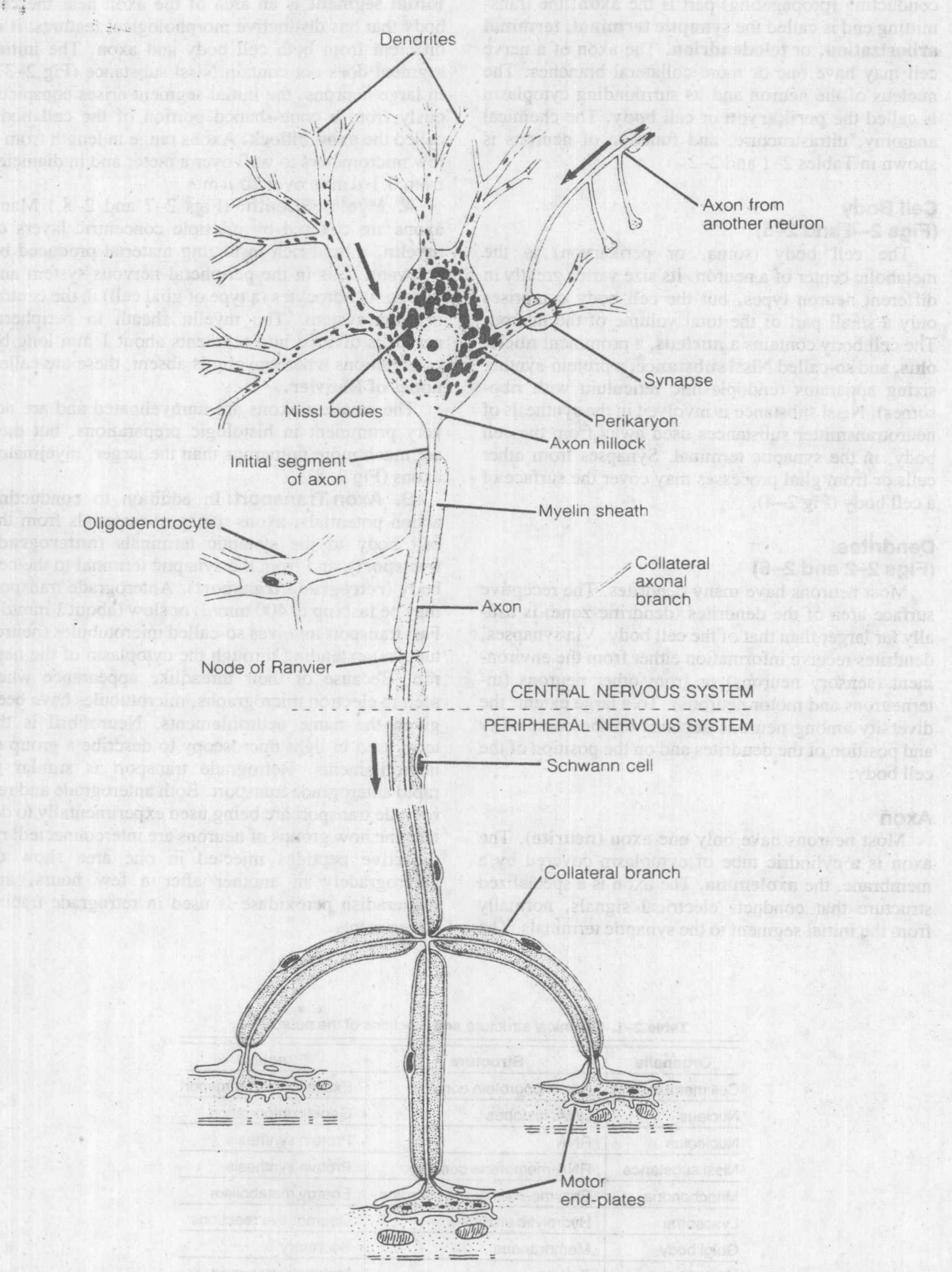

Figure 2–3. Schematic drawing of a Nissl-stained motor neuron. The myelin sheath is produced by oligodendrocytes in the central nervous system and by Schwann cells in the peripheral nervous system. Note the 3 motor end-plates, which transmit the nerve impulse to striated skeletal muscle fibers. Arrows show the direction of the nerve impulse. (Reproduced, with permission, from Junqueira LC, Carneiro J, Long JA: *Basic Histology*, 5th ed. Appleton & Lange, 1986.)