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# Correlative Neuroanatomy

TWENTIETH EDITION

Jack deGroot

Joseph G. Chusid



1990年7月20日

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TWENTIETH EDITION

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# 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

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## 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.

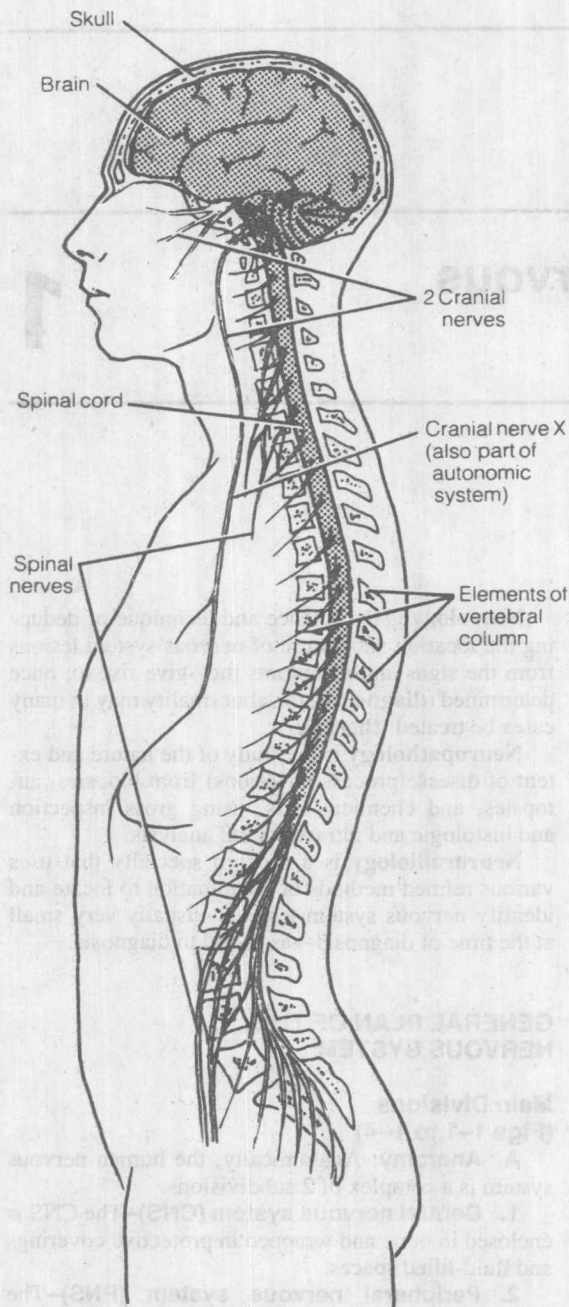
**1. Central nervous system (CNS)**—The CNS is enclosed in bone and wrapped in protective coverings and fluid-filled spaces.

**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**.



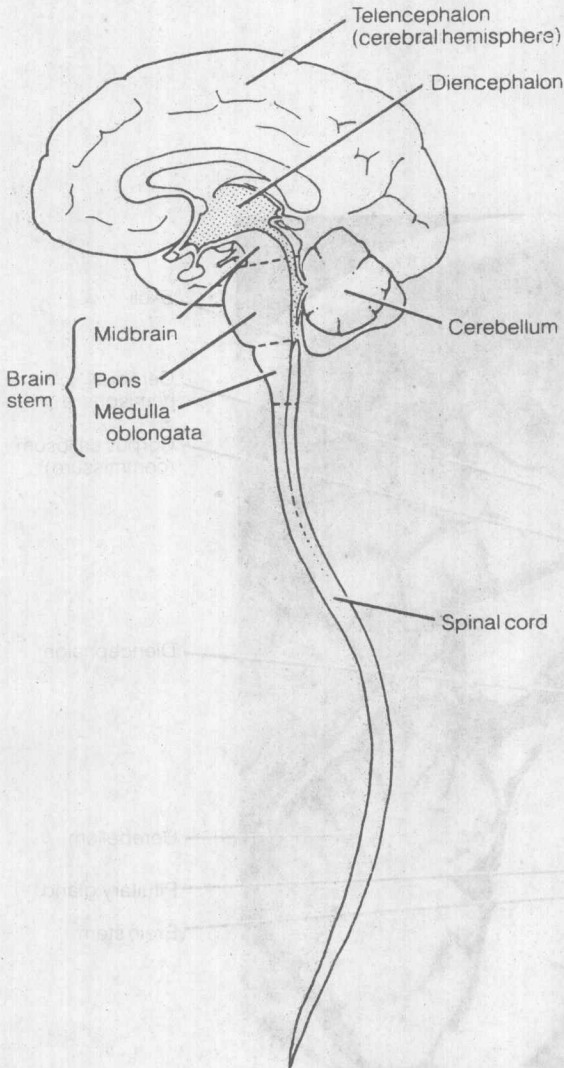
## PERIPHERAL NERVOUS SYSTEM

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.

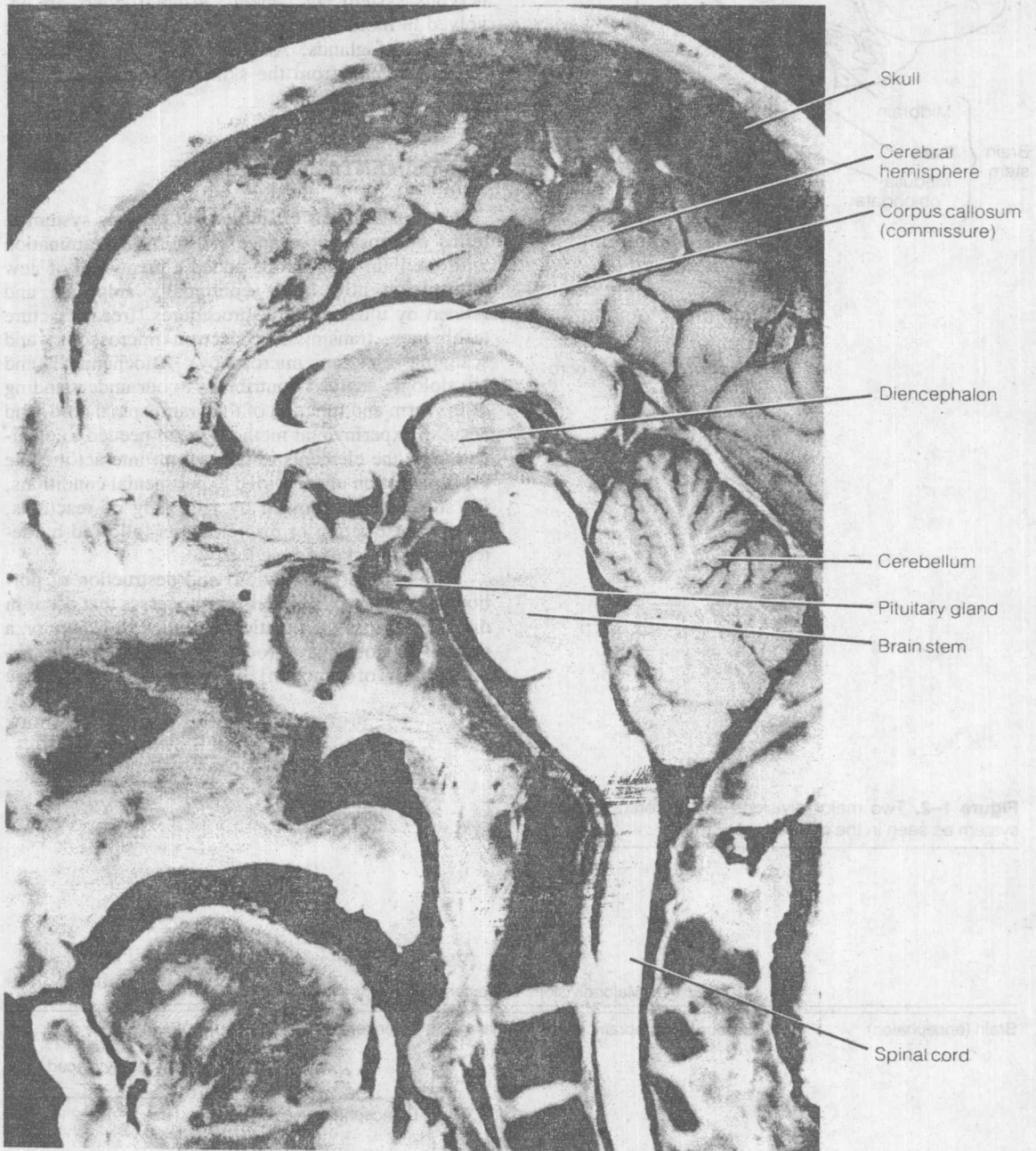
Stimulation (or irritation) and destruction of portions of the nervous system are processes that occur in disease. A loss of function is called a **lesion** or a **deficit**. Lesions may produce **signs** (observable abnormalities of function) or **symptoms** (subjective changes).



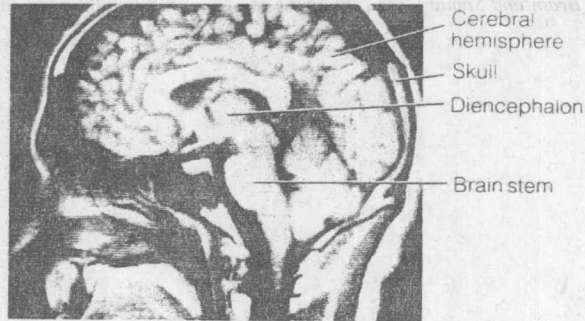
**Figure 1-2.** Two major divisions of the central nervous system as seen in the midsagittal plane.

**Table 1-1.** Major divisions of the central nervous system.

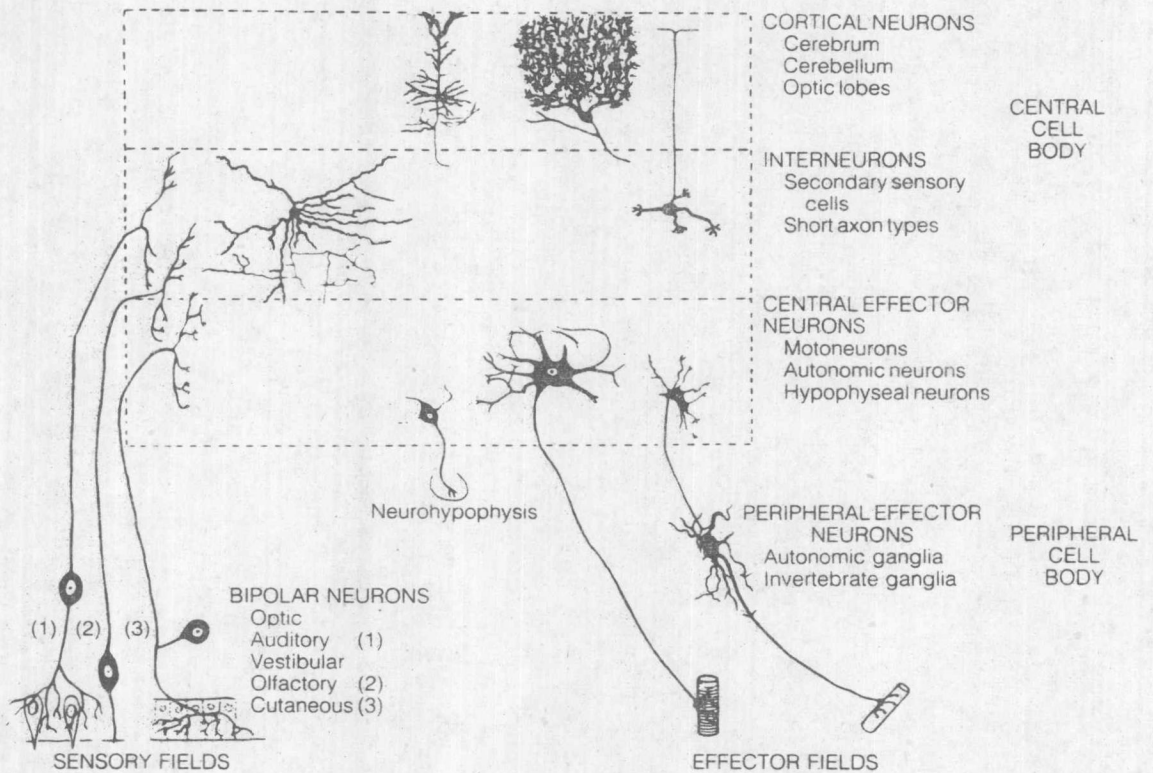
Brain (encephalon)	Cerebrum (forebrain, prosencephalon)	Telencephalon	Cerebral cortex (gray) Subcortical white matter Basal ganglia (deeply placed gray masses)
		Diencephalon	Thalamus Hypothalamus Epithalamus
	Brain stem	Midbrain (mesencephalon) Pons (metencephalon) Medulla oblongata (myelencephalon)	
	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 mid-sagittal 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.)



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Figure 1-4. A schematic diagram of the human brain, showing the major components of the central nervous system. The diagram is a coronal section, illustrating the cerebrum, cerebellum, brainstem, and spinal cord. The cerebrum is the largest part of the brain, responsible for higher-level functions. The cerebellum is located at the back and bottom, coordinating movement. The brainstem connects the cerebrum to the spinal cord. The spinal cord is shown extending downwards from the brainstem.

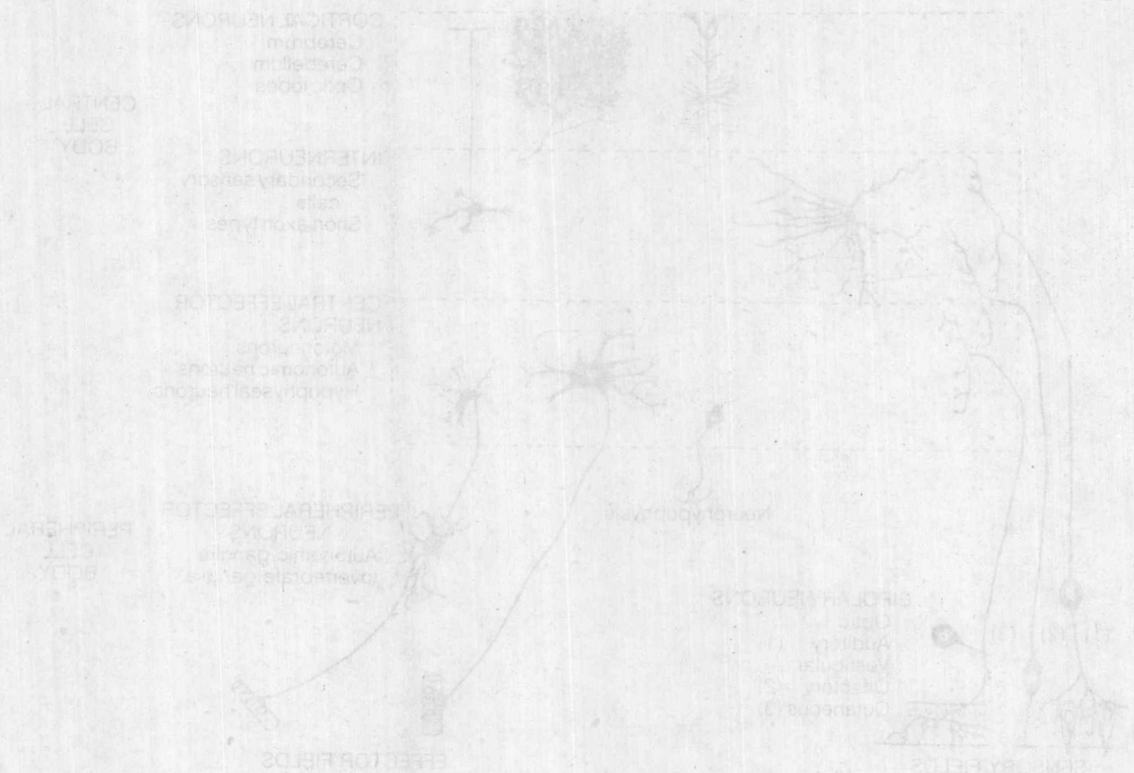


Figure 1-5. Types of neurons in the mammalian nervous system. The diagram shows a schematic representation of the neural pathways and cell types. The sections include: 1. Cortical Neurons (showing pyramidal cells), 2. Interneurons (showing various types of cells in the brain and spinal cord), 3. Central Efferent Neurons (showing axons descending from the brain), 4. Peripheral Efferent Neurons (showing axons in the peripheral nervous system), 5. Sensory Neurons (showing axons ascending from the periphery), and 6. A section labeled 'Efferent Fields' showing the distribution of motor fibers. The diagram is a schematic representation of the neural pathways and cell types.

# 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.

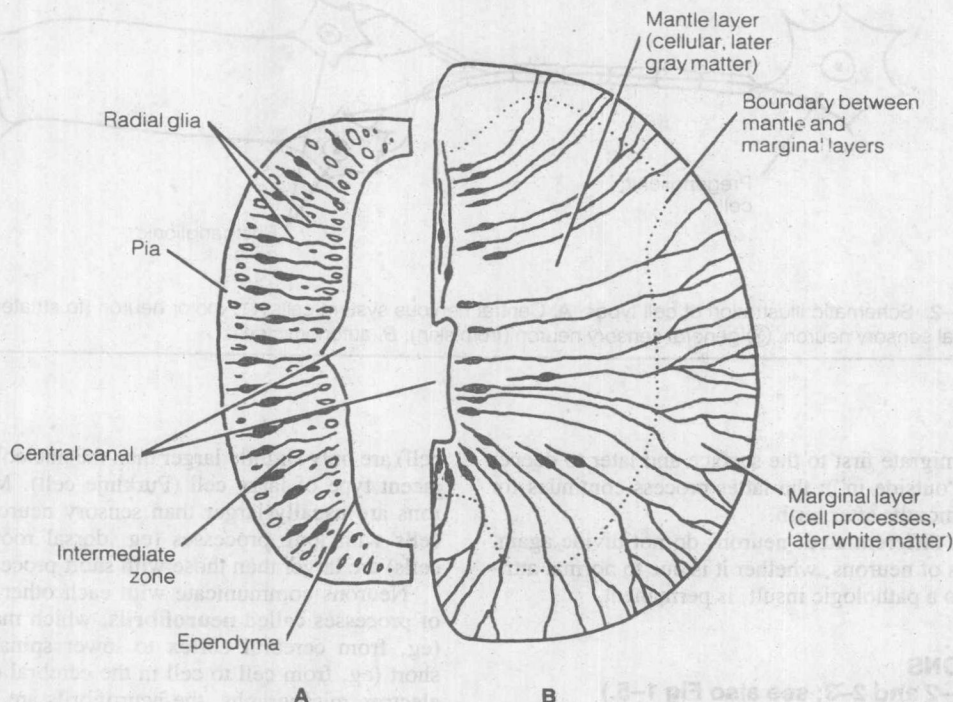
### Layers of the Neural Tube (Fig 2-1)

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—

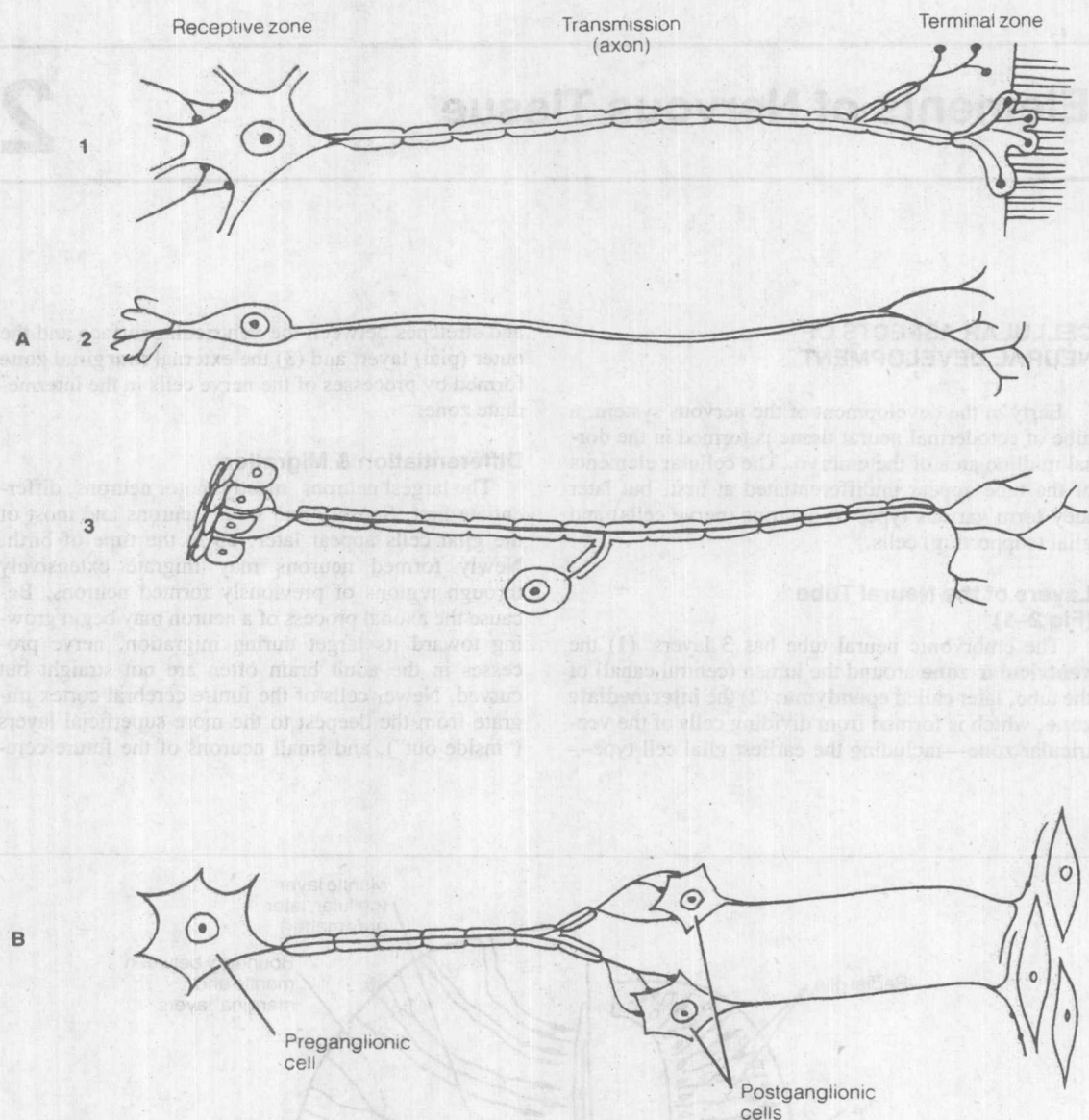
and stretches between the ventricular surface and the outer (pial) layer; and (3) the external **marginal zone** formed by processes of the nerve cells in the intermediate zone.

### 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

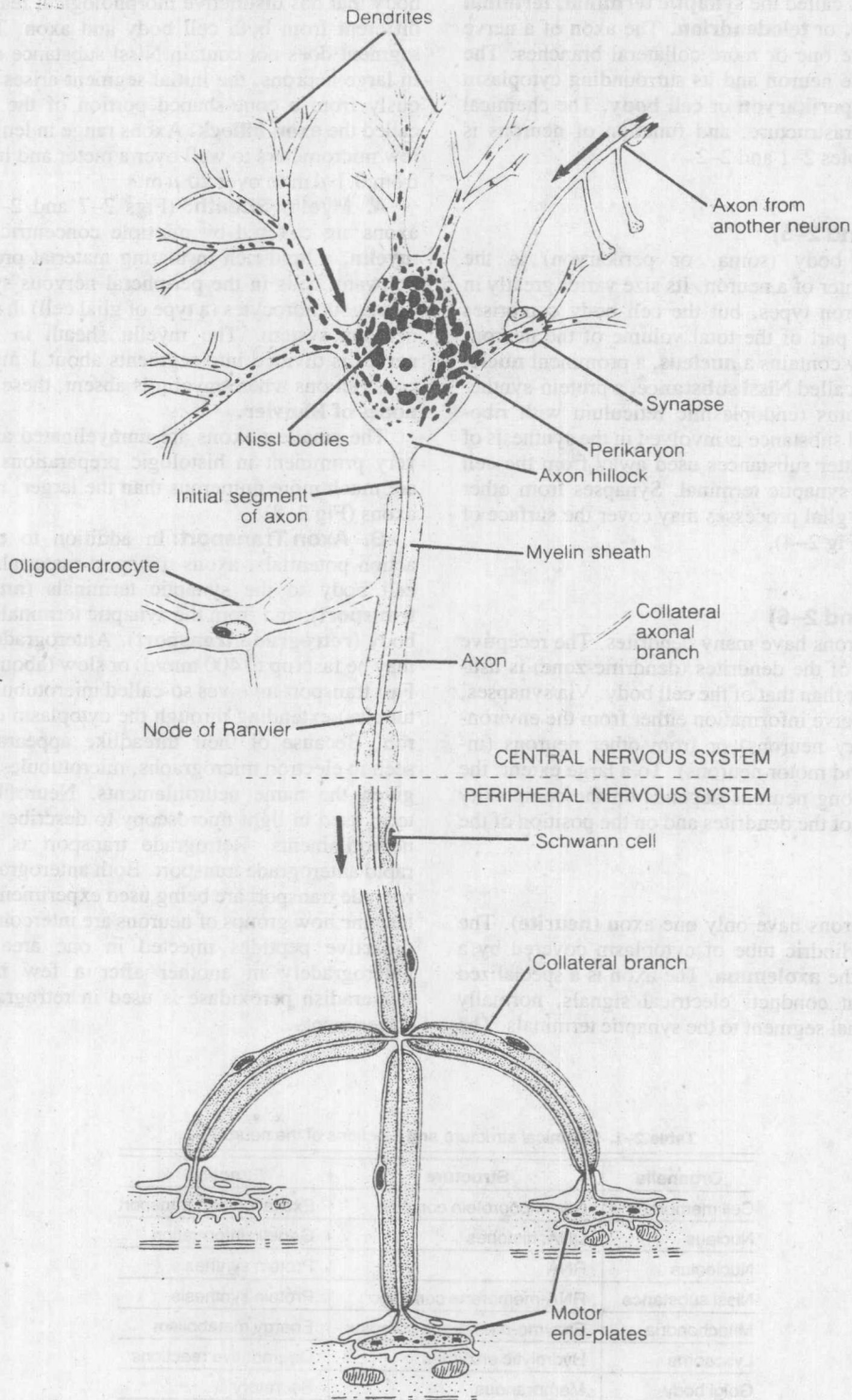
(Figs 2-2 and 2-3; see also Fig 1-5.)

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.)