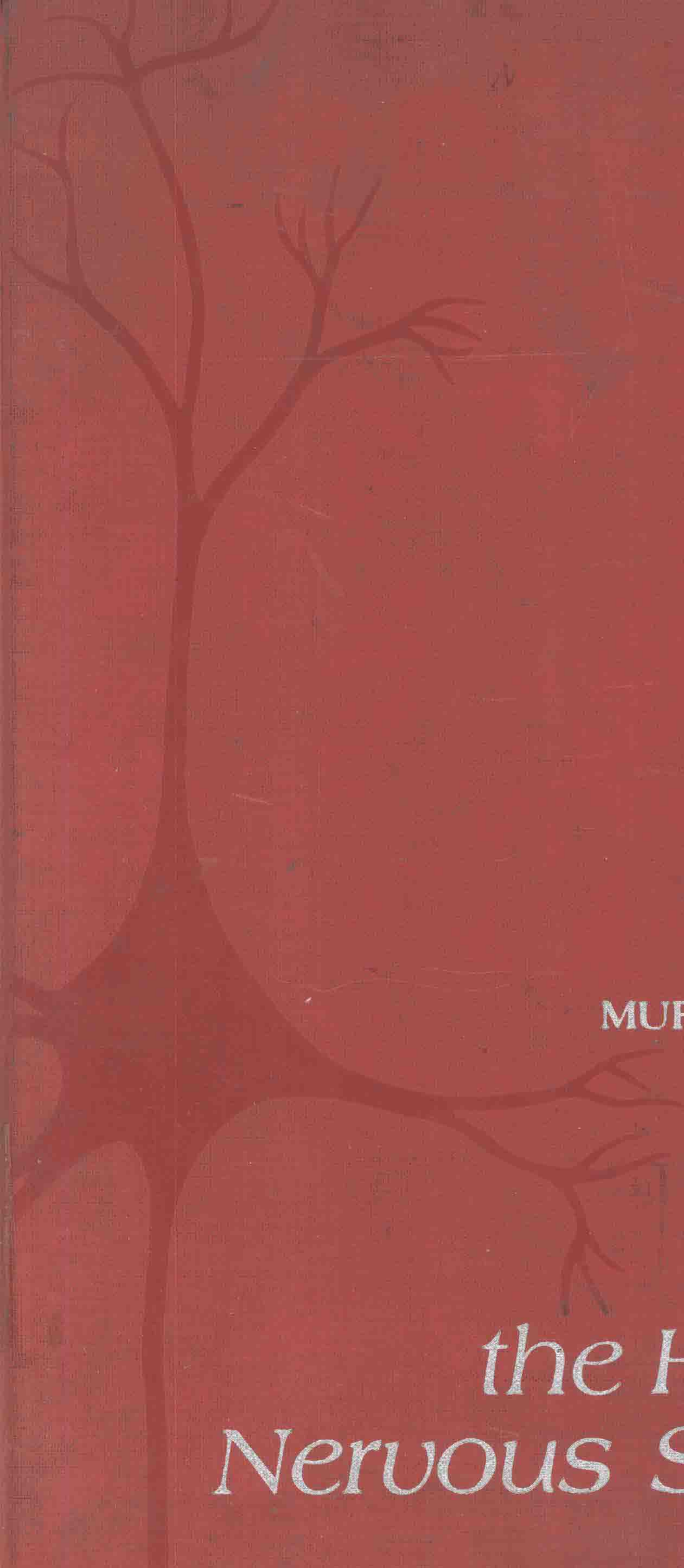

MURRAY L. BARR

the Human Nervous System

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AN ANATOMICAL VIEWPOINT

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THE HUMAN NERVOUS SYSTEM: An Anatomical Viewpoint

Printed in the United States of America. For information address Medical Department, Harper & Row, Publishers, Inc., 2350 Virginia Avenue, Hagerstown, Maryland 21740

First Edition

STANDARD BOOK NUMBER: 06–140314–8

LIBRARY OF CONGRESS CATALOG CARD NUMBER: 78–182561

Preface

Because of the intricacies of neuronal connections and the necessity of being able to visualize structures three-dimensionally, the anatomy of the central nervous system offers a particular challenge to the student. It is only through an adequate understanding of the structure of the brain and spinal cord that concurrent studies along physiological and clinical lines can progress. In particular, the interpretation of neurological signs and symptoms must rest on a sound basis of neurological anatomy. It is hoped that this textbook will provide such a basis for students in the health sciences and others studying the central nervous system of man. The book is written for those approaching the neurosciences for the first time; several excellent larger books on neurological anatomy are available to the advanced student.

The material has been arranged in four sections. The first section deals mainly with neurohistology. The second and largest section is concerned with the regional anatomy of the central nervous system, beginning with the spinal cord and progressing to the highest levels of the brain. Although the sensory and motor systems are discussed regionally, experience in teaching has shown the necessity of reviewing these clinically important systems in their entirety, and this is done in the third section. The fourth section deals with the blood supply of the central nervous system, its meningeal coverings, and the cerebrospinal fluid.

Eponyms are used freely in neurology, in spite of attempts to eliminate them; they frequently offer welcome alternatives to the more formal, and sometimes formidable, anatomical terms. Some facts concerning individuals whose names are attached to structures are provided at the end of the book for students who are curious about the source of eponyms. In addition, since many neurological terms are derived from Greek and Latin, a glossary is included for those students who have not received instruction in the classics.

It is a pleasure to acknowledge the valued assistance of several persons. A special note of appreciation goes to Mrs. Margaret Corrin for the preparation of the drawings, all of which are her own work. Illustrations of this type are of particular importance in a textbook of neurological anatomy. I also wish to thank Mrs. Aileen Densham, who carried out the secretarial work most efficiently. I am greatly indebted to Mr. J. E. Walker for the technical preparation of anatomical specimens for reproduction, to Mr. C. E. Jarvis for the photomicrographs, and to the staff of the Art Service Department of this Health Sciences Centre for their fine photography.

Several colleagues have given of their time to read drafts of all chapters and make valuable suggestions. They are Dr. H. W. K. Barr, of the Department of Clinical Neurological Sciences, and Drs. R. C. Buck, M. J. Hollenberg, and D. G. Montemurro, of the Department of Anatomy. I am also grateful for the many helpful discussions on specific topics with Dr. J. P. Girvin, of the Departments of Clinical Neurological Sciences and Physiology, and with Dr. A. Kertesz, of the Department of Clinical Neurological Sciences. Finally, I wish to express my appreciation to the staff of Harper & Row for their patience, advice, and assistance.

London, Ontario

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Introduction and Neurohistology

1

An Introduction to the Major Regions of the Central Nervous System

It is helpful to refer to embryological development when defining the principal regions or divisions of the central nervous system. The brain and spinal cord have their origin in the neural tube, which forms at the end of the third week of gestation by a midline invagination of the dorsal ectoderm. The nerve cells that eventually constitute the central nervous system, together with most of the interstitial or neuroglial cells, are therefore derivatives of the outer ectodermal layer of the embryo, like the epidermal cells covering the body surface.

Growth and differentiation are greatest in the rostral portion of the neural tube, from which the large and complex brain develops. Three swellings, the *primary brain vesicles,* appear toward the end of the fourth week; they are called the *rhombencephalon, mesencephalon,* and *prosencephalon* (Fig. 1-1*A*). The caudal and rostral primary vesicles each divide into two swellings during the fifth week, so that there are five *secondary brain vesicles;* these are called the *myelencephalon, metencephalon, mesencephalon, diencephalon,* and *telencephalon* (Fig. 1-1*B*). There is a pronounced flexure in the mesencephalic region.

DERIVATIVES OF THE BRAIN VESICLES

The various regions of the brain which develop from the foregoing vesicles acquire a distinctive structure, and some of the formal embryological names are replaced by others for common usage (Table 1-1 and Fig. 1-2). The myelencephalon becomes the medulla oblongata, while the metencephalon develops into the pons and cerebellum. The mesencephalon of the mature brain is usually called the midbrain. The names diencephalon and telencephalon are retained, largely because of the diverse nature of their derivatives. A large mass of gray matter, the thalamus, de-

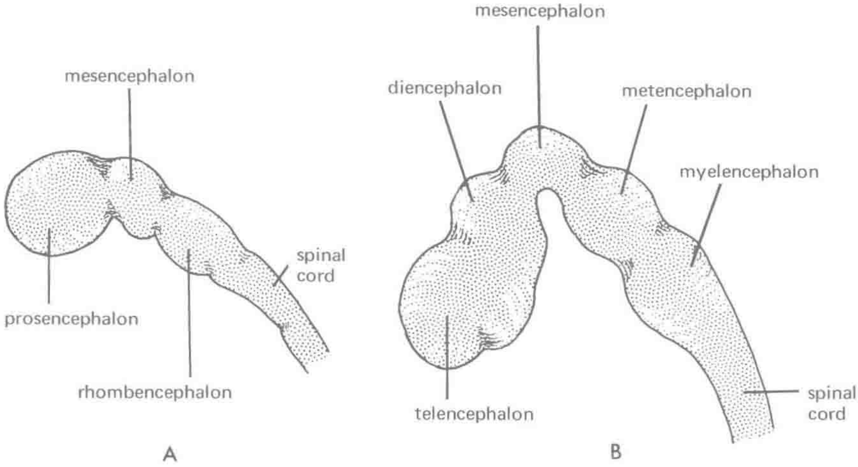

FIG. 1-1. A. Primary brain vesicles, fourth week of gestation. **B.** Secondary brain vesicles, sixth week of gestation.

velops in the diencephalon. Adjacent regions are known as the epithalamus, hypothalamus, and subthalamus, each with distinctive structural and functional characteristics. The telencephalon undergoes the greatest development in the human brain, in respect both to other regions and to the telencephalon of other animals. It includes the olfactory system, the corpus striatum (a mass of gray matter with motor functions), an extensive surface layer of gray matter known as the cortex or pallium, and a medullary center of white matter.

The medulla, pons, and midbrain together make up the brain stem, to which the cerebellum is attached by three pairs of peduncles. The diencephalon and telencephalon constitute the cerebrum, of which the telencephalon is represented by the massive cerebral hemispheres. The lumen

TABLE 1-1. DEVELOPMENT OF THE MATURE BRAIN FROM THE BRAIN VESICLES

Primary brain vesicles	*Secondary brain vesicles*	*Mature Brain*
Rhombencephalon	Myelencephalon	Medulla oblongata
	Metencephalon	Pons and cerebellum
Mesencephalon	Mesencephalon	Midbrain
Prosencephalon	Diencephalon	Thalamus, epithalamus, hypothalamus, and subthalamus
	Telencephalon	Cerebral hemispheres, consisting of the olfactory system, corpus striatum, cortex, and medullary center

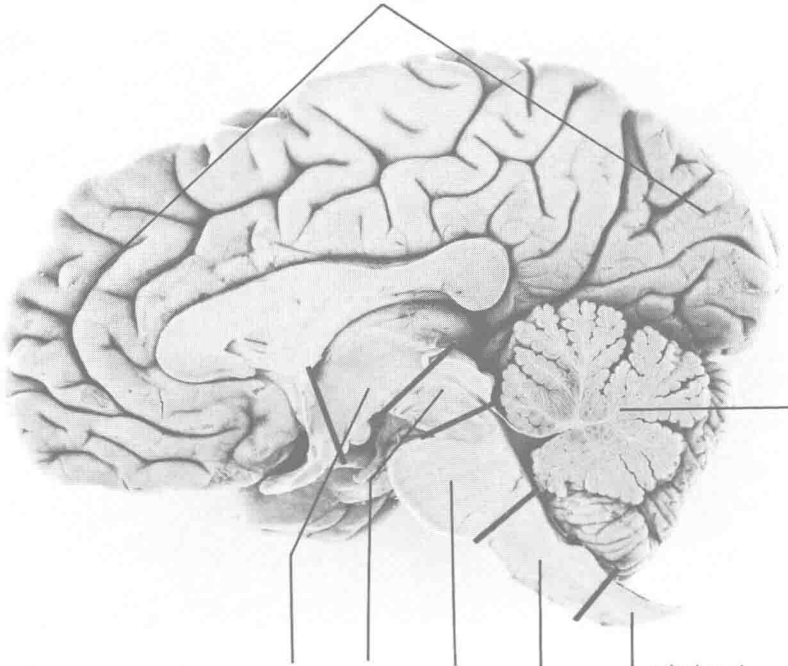

FIG. 1-2. Regions of the mature central nervous system, as seen in sagittal section. ×5/8.

of the neural tube is converted into a lateral ventricle in each cerebral hemisphere, a third ventricle in the diencephalon, and a fourth ventricle bounded by the medulla, pons, and cerebellum. The third and fourth ventricles are connected by a narrow channel or aqueduct that traverses the midbrain.

SUMMARY OF MAIN REGIONS OF THE NERVOUS SYSTEM

Certain features of the main regions are noted in the following summary, by way of introduction and to provide a first acquaintance with some neurological terms.

SPINAL CORD

The *spinal cord* is the least differentiated component of the neuraxis. The segmental nature of the spinal cord is reflected in a series of paired spinal nerves, each of which is attached to the cord by a dorsal sensory root and ventral motor root. The central gray matter, in which nerve cell bodies are located, has a roughly H-shaped outline in transverse section. White matter, which consists of nerve fibers running longitudinally, occupies the periphery of the cord. The spinal cord includes neuronal connections that provide for important spinal reflexes. There are also pathways conveying sensory data to the brain and other pathways conducting impulses from the brain to motor neurons in the spinal cord.

MEDULLA OBLONGATA

The fiber tracts of the spinal cord are continued in the *medulla*, which also contains clusters of nerve cells called nuclei. The most prominent of these, the inferior olivary nuclei, send fibers to the cerebellum through the inferior cerebellar peduncles, which attach the cerebellum to the medulla oblongata. Of the smaller nuclei, some are components of the following cranial nerves: hypoglossal (CN12), accessory (CN11), vagus (CN10), and glossopharyngeal (CN9). Nuclei of the vestibulocochlear nerve (CN8) are partly in the medulla and partly in the pons.

PONS

The *pons* consists of two distinct parts. The dorsal portion has features shared with the rest of the brain stem. It therefore includes sensory and motor tracts, together with nuclei of the facial (CN7), abducens (CN6), and trigeminal (CN5) nerves. (Trigeminal nuclei are also present in the medulla and midbrain.) The basal portion of the pons is special to this part of the brain stem. Its function is to provide for extensive connections between the cortex of a cerebral hemisphere and that of the contralateral cerebellar hemisphere. These connections are important for maximal efficiency of motor activities. A pair of middle cerebellar peduncles attaches the cerebellum to the pons.

MIDBRAIN

Like other parts of the brain stem, the *midbrain* contains sensory and motor pathways, together with nuclei for two cranial nerves, the trochlear (CN4) and the oculomotor (CN3). There is a dorsal region, the roof or tectum, which is concerned principally with the visual and auditory systems. The midbrain also includes two important motor nuclei, the red nucleus and the substantia nigra. The cerebellum is attached to the midbrain by the superior cerebellar peduncles.

CEREBELLUM

The *cerebellum* is especially large in the human brain. Receiving data from most of the sensory systems and the cerebral cortex, the cerebellum eventually influences motor neurons supplying the skeletal musculature. The function of the cerebellum is to influence muscle tonus in relation to equilibrium, locomotion and posture, and nonstereotyped movements based on individual experience. The cerebellum operates behind the scenes at a subconscious level.

DIENCEPHALON

The *diencephalon* forms the central core of the cerebrum. The largest component of the diencephalon, the *thalamus*, receives data from all sensory systems except the olfactory and in turn projects to sensory areas of the cerebral cortex. Part of the thalamus is involved in reverberating circuits with nonspecific cortical areas that are concerned with complex mental processes. Other regions of the thalamus participate in neural circuits related to emotions, and certain thalamic nuclei are incorporated in pathways from the cerebellum and corpus striatum to motor areas of the cerebral cortex. The *epithalamus* includes small tracts and a nucleus, together with the pineal gland, an endocrine organ. The *hypothalamus* is the principal autonomic center of the brain and as such has an important controlling influence over the sympathetic and parasympathetic systems. In addition, neurosecretory cells in the hypothalamus synthesize hormones that reach the blood stream by way of the neural lobe of the pituitary gland or influence the hormonal output of the anterior pituitary through a special portal system of blood vessels. The *subthalamus* includes sensory tracts proceeding to the thalamus, nerve fibers originating in the cerebellum and corpus striatum, and the subthalamic nucleus (a motor nucleus). The retina is a derivative of the diencephalon; the optic nerve (CN2) and visual system are therefore intimately related to this part of the brain.

TELENCEPHALON (Cerebral Hemispheres)

Within the *telencephalon,* the corpus striatum is a large mass of gray matter with motor functions, situated near the base of each hemisphere. The corpus striatum consists of caudate and lenticular nuclei, the latter being subdivided into a putamen and a globus pallidus. The medullary center of the hemisphere consists of (1) fibers connecting cortical areas of the same hemisphere, (2) fibers crossing the midline in a large commissure known as the corpus callosum to connect cortical areas of the two hemispheres, and (3) fibers passing in both directions between cortex and subcortical centers. Fibers of the last category converge to form a compact internal capsule in the region of the thalamus and corpus striatum.

Small areas of cerebral cortex have an ancient lineage (paleocortex); they are olfactory in function, forming part of the rhinencephalon or nosebrain, which dominates the cerebrum of lower vertebrates. Certain areas of cortex were once part of the rhinencephalon but acquired other roles in the evolution of the mammalian brain. These areas are referred to as archicortex; they are included in the limbic system, which is involved with emotions and the influence of emotions on visceral function through the autonomic nervous system. The development of cortex still further removed from olfactory influence (neocortex) was a most significant event in phylogeny. There is very little nonolfactory cortex in the brains of reptiles; the presence of substantial amounts of neocortex is a mammalian characteristic. Its extent and volume have increased during mammalian phylogeny, and the human brain is notable for having much more neocortex than the brain of any other animal. Nine-tenths of the cortex of the human cerebral hemispheres is neocortex, which provides areas for all modalities of sensation, exclusive of smell, and special motor areas. There are also extensive areas of association cortex in which the highest levels of neural function take place, including those inherent in intellectual activity. The unique place of the human species is an endowment conferred by an expanse of neocortex that is possessed by no other animal.

The weight of the mature brain varies according to age and body stature. The normal range in the adult male is 1100–1700 gm (average 1360 gm). The lower figures for the adult female (1050–1550 gm, average 1275 gm) reflect the smaller body stature of females in general, compared with males. There is no evidence of a relation between brain weight, within the normal limits, and a person's level of intelligence.

2
Cells of the Central Nervous System

There are two classes of cells in the central nervous system, aside from the usual cells found in walls of blood vessels. *Nerve cells* or *neurons* are specialized for excitation and nerve impulse conduction, and are therefore responsible for most of the functional characteristics of nervous tissue. The number of neurons in the human central nervous system has been estimated to be of the order of 14 billion. *Neuroglial cells,* also known as interstitial cells, have important ancillary functions. There are four kinds of neuroglia, namely, astrocytes, oligodendrocytes, microglial cells, and ependymal cells.

The central nervous system consists of gray matter and white matter. *Gray matter* contains the cell bodies of neurons, each with a nucleus. In sections prepared by a standard histological stain such as hematoxylin and eosin, the cell bodies are separated by a complicated network of fibers, known as the *neuropil,* which cannot be resolved into its components. With special staining methods and electron microscopy, the neuropil is seen to consist of the processes of neurons in the area and terminal portions of fibers coming from nerve cells elsewhere. *White matter,* on the other hand, consists of relatively long processes of nerve cells, the majority being surrounded by myelin sheaths. Both the gray and the white matter include large numbers of neuroglial cells. In some parts of the brain, notably the brain stem, there are regions that contain both nerve cells and myelinated fibers and are therefore an admixture of gray matter and white matter.

The cytology of the nervous system is described in some detail in standard textbooks of histology. However, a subject so basic to the neurological sciences can hardly be omitted from a students' textbook of neurological anatomy. An account of the cellular components of the brain and spinal cord is therefore introduced at this point.

THE NEURON

The unique feature of neurons is that they are specialized for reception of stimuli and conduction of the nerve impulse. The part of the cell that includes the nucleus is called the *cell body* or *perikaryon*. *Dendrites* are typically short, branching processes which form a major part of the receptor area of the cell. Most neurons of the central nervous system have several dendrites and are therefore multipolar in shape. By reaching out in various directions, these processes improve the capacity of a neuron to receive stimuli from diverse sources. Each cell has a single *axon*. This process, which varies greatly in length from one type of neuron to another, conducts impulses away from the cell body, usually to other neurons. Axons of efferent neurons in the brain stem and spinal cord end on striated muscle fibers, or on nerve cells in peripheral ganglia in the case of autonomic neurons.

Each neuron is a morphological and functional unit. This statement is implicit in the Neuron Theory, which is an extension of the Cell Theory to include nerve cells. The Neuron Theory, as opposed to the view that nerve cells form a continuous reticulum, was advanced by His on the basis of embryological studies, by Forel on the basis of the response of nerve cells to injury, and by Ramón y Cajal from his observations with silver staining methods. The Neuron Theory was given wide distribution in a general review of the whole subject of the individuality of nerve cells by Waldeyer. Because of the special relationship between neurons at synapses (see below), wholly convincing evidence in support of the Neuron Theory had to await the introduction of electron microscopy. It is now clear that the plasma membranes of two neurons are separated at the synapse by an interval about 200 Å wide (Å = one ten-thousandth of a micron). The Neuron Theory is therefore more than a theory; it is a fact or law.

VARIETIES OF NEURONS

Although all nerve cells conform to the general principles outlined above, there is a wide range of structural diversity. The size of the perikaryon varies from 5 μ for the smallest cells in complex circuits to 135 μ for large motor neurons. Dendritic morphology, in particular the pattern of branching, varies greatly and is distinctive for neurons composing a specific cell group or nucleus. The axon of minute neurons is a fraction of a millimeter in length, exceedingly fine, and devoid of a myelin covering. The axon of large neurons, on the other hand, is several feet long in extreme cases, has a substantial diameter, and is typically enclosed in a sheath of myelin. Large and small neurons are known as Golgi type I and Golgi type II neurons, respectively. Intermediate grades, difficult to assign to type I or type II, occur in special locations. The following examples will serve to illustrate the range of variability among neurons of the central nervous system.

Examples of Large Neurons

Pyramidal cells of the cerebral cortex, Purkinje cells of the cerebellar cortex, and motor cells of the spinal cord are familiar examples of Golgi type I neurons. These cells and examples of small neurons are illustrated in Figure 2-1 as they might appear in sections stained by the Golgi silver-bichromate method, in which the outline of the cell body and the dendritic branches stand out clearly.

The *pyramidal cell* derives its name from the shape of the cell body. An apical den-