FUNCTIONAL NEURO-ANATOMY

Including an Atlas of the Brain Stem

BY

A. R. BUCHANAN, M.D.

Professor of Anatomy, University of Colorado School of Medicine, Denver, Colorado

Second Edition, Thoroughly Revised,
With 273 Illustrations, 19 in Color

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PREFACE TO THE SECOND EDITION

THE reception accorded the first edition of *Functional Neuro-anatomy* by medical students, both in and out of medical schools, has made the preparation of the second edition, two years after publication of the first, a relatively simple task. Additions to, deletions from, and rearrangement of the textual material have been carried out where indicated in order to conform to recent research contributions to the field of Neurology where such contributions tend to clarify certain areas of the subject. A real effort has been made to retain the relative brevity of the text because the letters received from medical students have uniformly indicated approval of this feature.

The most frequent criticism of the first edition, as was anticipated, has been directed at its lack of an atlas of the brain stem. The second edition includes an atlas prepared from a series of Weil-stained sections of a human brain stem. The left half of each of the figures comprising the atlas, is an actual photograph of one-half of such a brain-stem section and the right half represents the structural details in a more or less diagrammatic line drawing prepared by tracing the outlines of the important structures in a photograph. Labelling of structures on that half of the figure presented as a line drawing facilitates orientation and identification of them as they appear in the other half which is an accurate photographic reproduction of a section stained in the same manner as is ordinarily characteristic of brain-stem sections provided for laboratory study in neuro-anatomy courses.

A laboratory outline has not been included because the author is opposed to thus stereotyping the laboratory component of his own course and because he is convinced that other teachers of neuro-anatomy prefer to develop their own laboratory procedures.

Acknowledgments are due the author's students who have conscientiously reported misprints and other errors in the first edition; to Miss Waneeta Stevic who has prepared the line drawings for the atlas of the brain stem; to Mr. Glenn Mills and Billie Wheeler who photographed the brain-stem sections and prepared the photographs for combination with the line drawings; to Mrs. Doris McChesney who stained and mounted the sections; and to Miss Marian Farnan who has provided secretarial assistance. The author's wife, Mrs. Grace A. Buchanan, has devoted many long and arduous hours to proofreading both the first and second editions. The author particularly wishes to thank those students in medical schools other than that of the University of Colorado who have taken time to write of their reactions to the first edition.

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PREFACE TO THE FIRST EDITION

During fifteen years of teaching neuro-anatomy to medical students the author has consistently worked toward the evolution of a method of presentation of the subject that would serve to refute the traditional belief among students that the nervous system must remain a deep and unsolved mystery, so far as they are concerned, until the professor has given his last lecture and the day of the final examination is at hand. This attitude of mind concerning neuro-anatomy appears to have developed as the result of the practice, in former years, of presenting the course as a series of levels of the central nervous system. Each level was meticulously described and each structure designated by name. When this had been accomplished the remaining time (if any) was devoted to cursorily tracing the ascending and descending pathways through the central nervous system. Since this final putting together of the various levels was usually done just before the final examination the reason for the time-honored and erroneous concept regarding this particular section of the medical school curriculum is apparent. Unfortunately most neuro-anatomy texts are still mainly concerned with "level anatomy" of the nervous system and thus continue to contribute to the prevailing misconception concerning, and lack of interest in, the subject.

The present text, a revision and an amplification of a mimeographed syllabus which has been available to the author's classes in neuro-anatomy, utilizes a strictly functional approach to the subject. Ascending and descending tracts are traced from origin to termination at the time of their first mention in the text. Clinical applications of neuro-anatomy are discussed within the body of the text rather than being relegated to a brief chapter near the back of the book or to fine print at the end of each chapter. It has proven to be successful in holding the interest of the students throughout the period allotted to the course. This appears to be due to the fact that the function, composition, course, and practical significance of the lateral spinothalamic tract, for example, are considered together rather than as isolated parts of a jig saw puzzle which may eventually be properly assembled by the student.

Crowded medical school curricula do not apportion a great deal of time to the subject of neuro-anatomy; the average number of hours ranges between ninety and one hundred. It therefore becomes important that the student have available a text which is written with the definite objective of presentation of essential material within as few pages as are compatible with an understanding of the subject. This text is not intended to be an exhaustive presentation of the subjects of neuro-anatomy and neurophysiology. It is designed, rather, to present the subject in as simple and direct a manner as possible and in a manner conducive to the rapid assimilation of a working knowledge of the nervous system.

Simplification, including elimination of extraneous details, has also been striven for in the preparation of the illustrations. All figures representing cross-sections of the nervous system are based upon tracings of actual sections prepared in this Department. Rather than include all representative sections of a given division of the brain stem in a single chapter, the same section may appear several times,

and in various chapters, each time being designed to demonstrate a certain relationship to the exclusion of many others not pertinent to the current discussion. All figures not credited to other sources were originally prepared by the author from appropriate sections or gross specimens. The rough sketches were then reproduced in finished form by Miss Waneeta Stevic. Semidiagrammatic line drawings have been used throughout because the nervous system lends itself so well to this type of illustration and because the author has found, from experience, that students learn more from one simple line drawing placed on the blackboard than from any number of photographic reproductions of appropriately stained sections of the nervous system. The identification of important structures in stained preparations such as are included in the student loan sets is facilitated more through the use of such diagrammatic illustrations than by the use of highly involved and carefully reproduced half-tone illustrations which make a point of having every single structure labelled whether or not it is readily apparent in the picture.

Laboratory work in connection with the course in neuro-anatomy can be better correlated with this text than with the conventional "level" system of presentation. Instead of examining a section of the medulla, with directions that each structure be carefully identified, the student is asked to identify the medial lemniscus, for example, in sections of medulla, pons and mesencephalon. As the various pathways and nuclei are studied the same sections are referred to again and again so that the student becomes more and more familiar with each representative level of the nervous system without the need of memorization of details not pertinent to the function currently being considered.

Reference to the literature has been kept to a minimum since it is obvious that the medical student, in the limited time available, does not have opportunity to consult many original sources. The authors cited are mainly those whose work, in recent years, has contributed to a better and more accurate knowledge of the nervous system from the standpoint of function.

The author wishes to acknowledge the painstaking coöperation of Miss Waneeta Stevic in the preparation of the illustrations. The careful and accurate preparation of the final manuscript by Mrs. Elizabeth Atkeson is also acknowledged, as is the typing of several preliminary drafts by Miss Elizabeth McNary. Weil-stained sections of the central nervous system, upon which many of the figures are based, were painstakingly prepared by Mrs. Doris McChesney. Dr. Alice E. Parker has contributed valuable suggestions and criticisms which are greatly appreciated. Drs. I. E. Wallin and Ernst A. Scharrer have carefully read the manuscript and have suggested many changes which have been incorporated into the final draft; they have devoted many hours to this arduous task which I gratefully acknowledge.

A. R. BUCHANAN

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FUNCTIONAL NEURO-ANATOMY

CHAPTER I

DEVELOPMENT AND HISTOGENESIS OF THE NERVOUS SYSTEM

THE nervous system is responsible for maintaining contact between the individual and his external and internal environments and for the proper adjustments to those environments. Contact with the external environment is maintained through receptors at the surface of the body and with the internal environment through receptors in muscles, joints and ligaments and within the visceral organs of the thorax and abdomen. Adjustments to the environment are facilitated by reflex arcs consisting of afferent neurons, centers within the spinal cord or brain, and efferent neurons. The efferent neurons carry motor impulses from the central nervous system to effector mechanisms including smooth and striated muscle and glandular structures.

The **neural groove** develops as an infolding of the ectodermal layer of the embryo in its dorsal midline (Fig. 1). All divisions of the adult nervous system result from

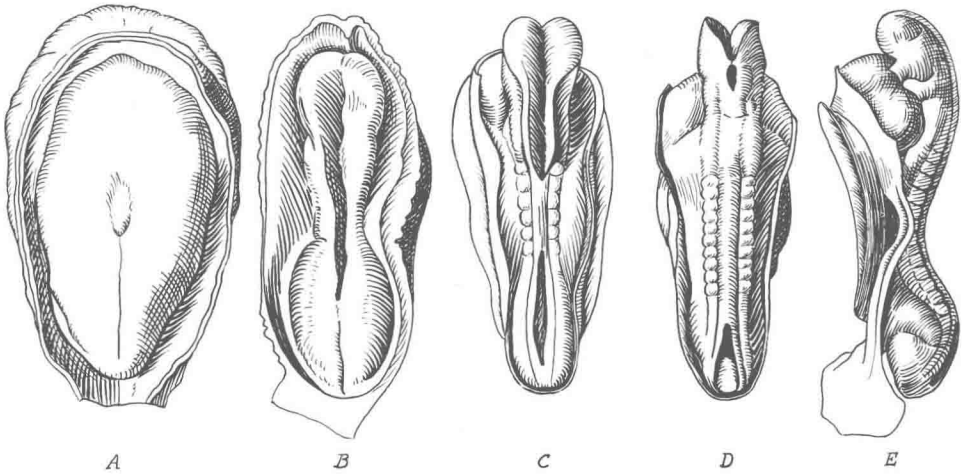

FIG. 1.—Developmental stages of the human neural groove and tube (after Streeter). *A*, Presomite embryo with beginning neural groove. *B*, Neural groove deepened. *C*, Closure of neural groove beginning. *D*, Closure extending rostrally and caudally. *E*, Lateral view of embryo with closure complete except for anterior and posterior neuropores.

the further modifications of this ectodermal structure. As development continues the neural groove closes dorsally to form the neural tube which then loses its attachment to the outer or ectodermal layer of the embryo and comes to lie just dorsal to the notochord where it is surrounded by mesoderm (Fig. 2).

The primitive **neural tube** consists of a caudal *myelon* and a rostral *encephalon;* the encephalon is at first subdivided into three primitive brain vesicles which are, from the myelon forward, the rhombencephalon, mesencephalon, and prosen-

cephalon (Fig. 3). A constriction in the central region of the rhombencephalon divides it into two secondary vesicles designated as *myelencephalon* and *metencephalon*. The secondary vesicles that result from a similar constriction of the prosencephalon are termed *telencephalon* and *diencephalon* (Fig. 4).

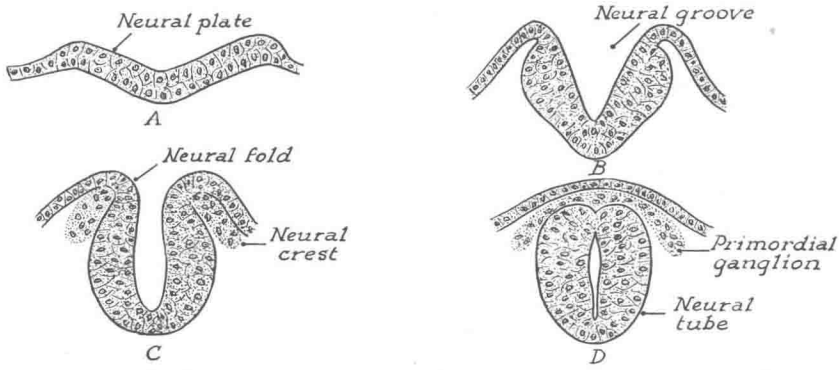

FIG. 2.—Stages in the development of the neural tube as seen in cross-sections of early embryos (after Arey).

At this stage in its development two prominent flexures of the encephalon appear. The first, or *cephalic flexure*, occurs at the mesencephalic level and the second, or *pontile*, at the junction of metencephalon and myelencephalon (Fig. 4).

The final stage in the development of the telencephalon is apparent in the *cerebral hemispheres* of the adult brain (Fig. 8). The adult *diencephalon* and *mesencephalon* arise from the corresponding vesicles and become, respectively, the

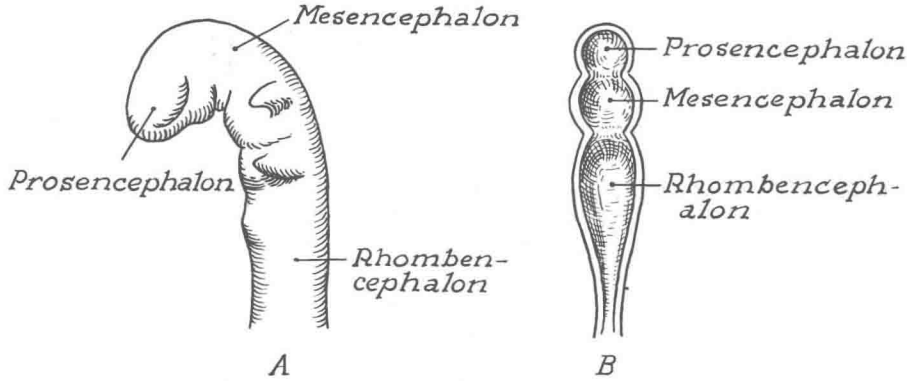

FIG. 3.—*A*, Lateral view (after Pölitzer) and *B*, Longitudinal section (after Arey) of early human brain. The three primitive brain vesicles are indicated.

first and second divisions of the brain stem. The *pons*, which is the third division of the brain stem, results from the further development of the metencephalon and the *medulla oblongata*, or fourth division, comes from the myelencephalon.

The **cerebellum** develops from the *rhombic lips;* it eventually assumes a position dorsal to the pons and medulla (Fig. 8). The rhombic lips are dorso-laterally located in the region of the pontile flexure (Fig. 4).

The **myelon** becomes the spinal cord; as it develops it is seen to be faintly segmented. The segments are called *neuromeres;* opposite each neuromere is a *mesodermal somite* and a corresponding segment of ectoderm known as a *dermatomere.*

A pair of spinal nerves grows out from each neuromere into the surrounding mesoderm and ectoderm. When the muscles are differentiated from the mesoderm and migrate to their ultimate locations and when the ectoderm is carried out with the developing limb buds, the nerve fibers are carried along and the distribution of the nerves to the muscles and skin, as seen in gross anatomy dissections, is thus accounted for.

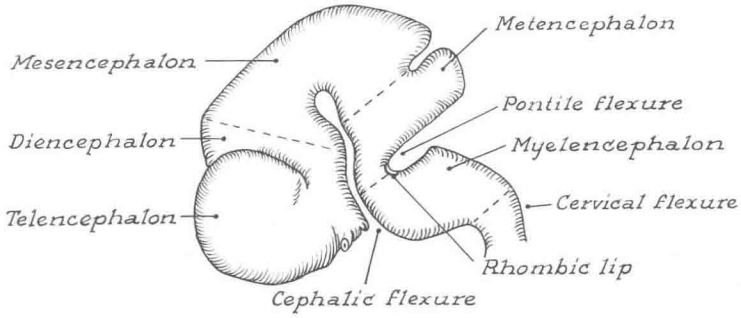

FIG. 4.—Flexures and secondary vesicles in the brain of a human embryo (after Arey).

The **neural crests** (Fig. 2) separate from the dorsal lips of the neural groove as the groove closes to form the neural tube. The crests migrate ventrally without losing their connections with the neural tube and finally, through segmentation, give rise to the dorsal root ganglia of the spinal nerves, the sensory ganglia of the cranial nerves and, quite probably, to the ganglia of the autonomic system and the adrenal medulla.

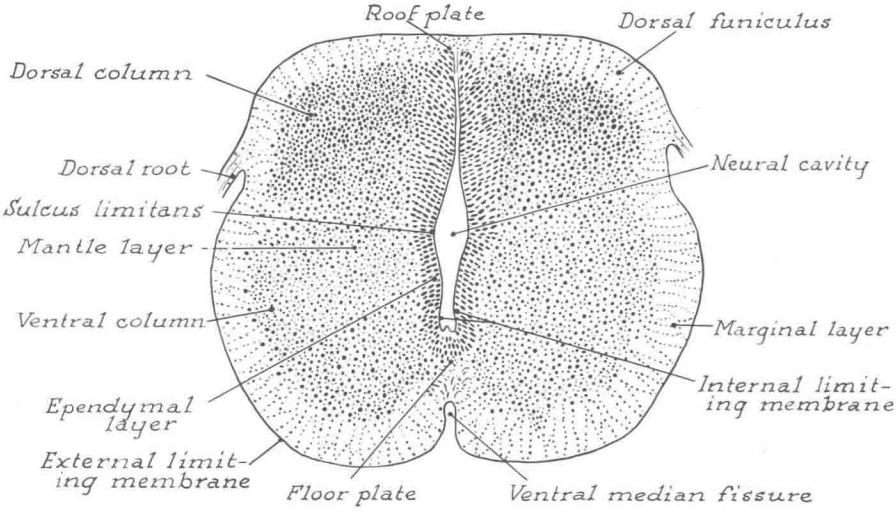

FIG. 5.—Transverse section of developing spinal cord of a 20 mm. human embryo (after Prentiss-Arey).

The **sulcus limitans**, a longitudinal groove, appears in the midline of each lateral wall of the developing neural tube (Fig. 5). That portion of each lateral half of the neural tube which lies dorsal to the sulcus constitutes the dorsal or alar lamina and that portion lying ventral to it is termed the ventral or basal lamina. In general the *alar lamina* comes to have a sensory function and the *basal lamina* a motor one. The basal and alar laminae each differentiate into three layers: An

inner or *ependymal*, an intermediate or *mantle*, and an outer or *marginal*. The *ependymal layer* continues, in the adult nervous system, to line the central canal of the spinal cord and the ventricular system of the brain. The *mantle layer* becomes the gray matter of the spinal cord when the developing neurons migrate into it. The *marginal layer* becomes the white matter after it is invaded by the ascending and descending processes of nerve cells in the gray matter and in the dorsal root ganglia. The relationship of the gray and white matter in the adult spinal cord corresponds to that of the mantle and marginal layers in the developing neural tube. There is, however, considerable modification of this arrangement in the brain as will become obvious when that part of the nervous system comes under consideration.

Histogenesis in the nervous system is initiated in the ependymal layer of the neural tube which contains a row of elongated nuclei among which are found the large mitotic nuclei of the *germinal cells*. The division of the germinal cells gives rise to *neuroblasts*, *medulloblasts* and *spongioblasts*. Neuroblasts, through their subsequent development, become adult neurons. Medulloblasts are indifferent cells which, through further differentiation, may develop into either neuroblasts or spongioblasts. The spongioblasts develop into *astroblasts* and *oligodendroblasts* and these, in turn, become adult *astrocytes* and *oligodendrocytes* (Fig. 6).

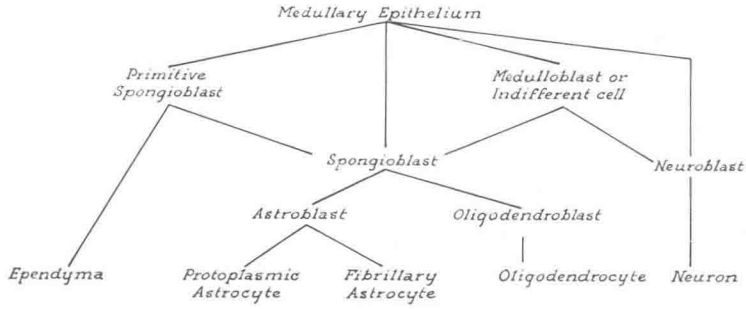

FIG. 6.—Cell-lineage in the central nervous system (after Ranson).

The *primitive spongioblast* is an intermediate stage which may intervene between the germinal cell and the more mature spongioblast. Ependymal cells also develop from the primitive spongioblasts. The processes of the primitive spongioblasts, at first, are attached to both the internal and external limiting membranes of the neural tube (Fig. 5). Those which lose their attachments to the internal limiting membrane and, in most instances, to the external membrane as well, assume the characteristics and potentialities of true spongioblasts while those which retain their attachments to the internal limiting membrane, develop into adult ependymal cells and line the central canal and ventricles of the adult spinal cord and brain.

Near the end of intrauterine life mesodermal cells migrate into the central nervous system and develop into so-called *microglial cells* which are sometimes designated as mesoglial because of their origin from the mesoderm. The structure, distribution, and functions of the three types of glia cells (astrocytes, oligodendrocytes, and microgliacytes) will be discussed at some length in a later chapter (Chapter XXIX).

Gray matter of the adult type results from the migration of neuroblasts into the mantle layer of the neural tube. The cell bodies and dendrites of neurons continue to occupy the gray matter while their axons are distributed upward or downward

within the *white matter* or to the periphery by way of the efferent roots of cranial and spinal nerves.

Neurons, consisting of nerve cell bodies and all the processes which spring from them, are classified according to the number of those processes as unipolar, bipolar, and multipolar (Fig. 7).

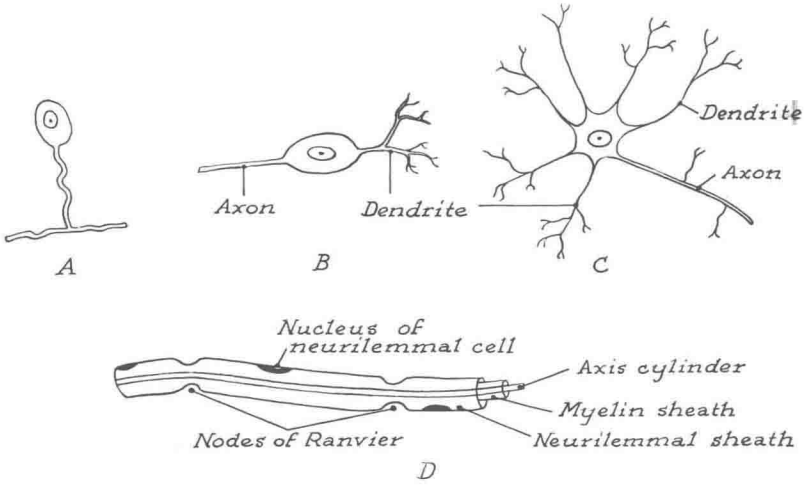

FIG. 7.—*A*, Unipolar neuron. *B*, Bipolar neuron. *C*, Multipolar neuron. *D*, Segment of a myelinated nerve fiber showing details of structure (after LeGros Clark).

Unipolar neurons have a single process which results from fusion of the two processes of embryologically bipolar neurons. They are found in the dorsal root ganglia of spinal nerves and in most of the sensory ganglia associated with the cranial nerves. Their single processes divide into peripheral and central divisions. Both divisions possess the physical characteristics of axons as they are found in bipolar and multipolar neurons. They therefore consist of an axis cylinder composed of neurofibrils, a myelin sheath, and a neurilemmal sheath. The myelin sheath is segmented by constrictions of the neurilemmal sheath called nodes of Ranvier (Fig. 7). According to the observations of most investigators some of the processes of sensory ganglion cells having to do with the transmission of pain and thermal impulses are unmyelinated; others are very lightly myelinated.

The fact that the peripheral divisions of the processes of sensory ganglion cells have the structure of axons is responsible for their ability to transmit sensory impulses over the long distances traversed by spinal and cranial nerves. Dendrites are actually cytoplasmic expansions of the cell bodies of neurons and are covered by corresponding extensions of the cell membrane; they are obviously not adapted to distribution over long distances.

Bipolar neurons possess an axon and a single dendrite (Fig. 7). They are found in the olfactory mucous membrane, in the ganglia of the eighth cranial nerve, in the retina of the eye, and in the cerebellar cortex.

Multipolar neurons (Fig. 7), possessing an axon and two or more dendrites, are distributed throughout the central nervous system; they vary in size and fall into two main categories. Those with long axons are designated as Golgi Type I and those with short and freely branching axons are classified as Golgi Type II. Multipolar neurons are also found in the peripheral ganglia of the autonomic nervous system.

CHAPTER II

DIVISIONS OF THE NERVOUS SYSTEM; FUNCTIONAL COMPONENTS OF CRANIAL AND SPINAL NERVES; ORIGIN AND DISTRIBUTION OF SPINAL NERVES

THE adult nervous system may be divided into *central* and *peripheral divisions*. The former includes the spinal cord and brain. The main sub-divisions of the brain are *cerebrum, cerebellum,* and *brain stem.* The brain stem consists of the *diencephalon, mesencephalon, pons,* and *medulla oblongata* (Fig. 8).

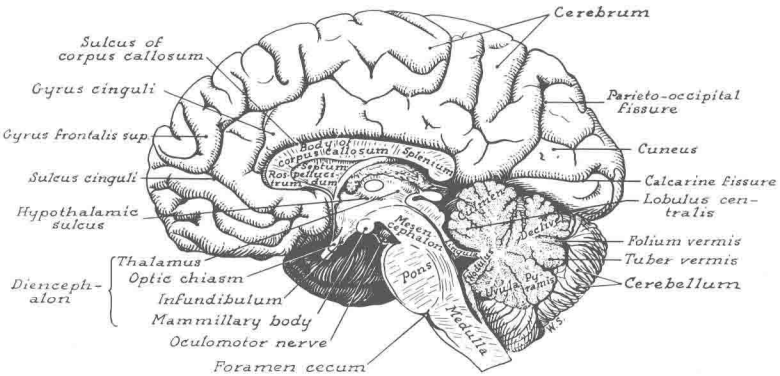

FIG. 8.—Median sagittal section of adult brain (after Rauber-Kopsch).

The **peripheral nervous system** includes the cranial and spinal nerves and the numerous ganglia and plexuses concerned with visceral innervation. The *cranial* (or cerebral) and *spinal nerves* contain seven functional types of fibers: General somatic afferent, special somatic afferent, general visceral afferent, special visceral afferent, somatic efferent, general visceral efferent, and special visceral efferent. As will be noted below, no given nerve contains all seven types of fibers.

General somatic afferent fibers are present in all the spinal nerves and in a number of cranial nerves. Their cell bodies are in sensory ganglia and they conduct impulses to the central nervous system from receptors in skin, muscle, and connective tissues.

Special somatic afferent fibers are found only in the optic and acoustic nerves. Those in the optic nerve conduct visual impulses from the retina to the brain and arise from cell bodies within the retina. The acoustic nerve is composed of the axons of bipolar neurons whose cell bodies are in the spiral and vestibular ganglia. The dendrites of these neurons are distributed to special receptors in the internal ear.

General visceral afferent fibers are present in the spinal nerves and in some of the cranial nerves. They are distributed to receptors in the visceral structures of the neck, thorax, abdomen, and pelvis, and to blood vessels and glandular structures everywhere. Their cells of origin are in the sensory ganglia of spinal nerves and in those of certain cranial nerves.

Special visceral afferent fibers are concerned only with the special senses of smell and taste; we therefore find them in the olfactory, glossopharyngeal, and vagus nerves, and in the nervus intermedius. The cell bodies of the olfactory nerves are

in the olfactory mucous membrane, those of the glossopharyngeal are in the petrosal ganglion, those of the vagus in the nodose ganglion, and those of the nervus intermedius in the geniculate ganglion.

Somatic efferent fibers arise from motor cells in the spinal cord and brain stem. They are distributed to striated muscles of mesodermal somite origin and are found in all spinal nerves and in the oculomotor, trochlear, abducens, and hypoglossal nerves.

General visceral efferent fibers are present in the oculomotor, intermediate, glossopharyngeal, and vagus nerves, in all the thoracic nerves, the upper two or three lumbar nerves, and in the middle three sacral nerves. They arise from cell bodies in certain nuclei of the brain stem and in the gray matter of the spinal cord; they are distributed to the peripheral ganglia of the autonomic system. The axons of the ganglion cells are then distributed to smooth muscle and glands throughout the body.

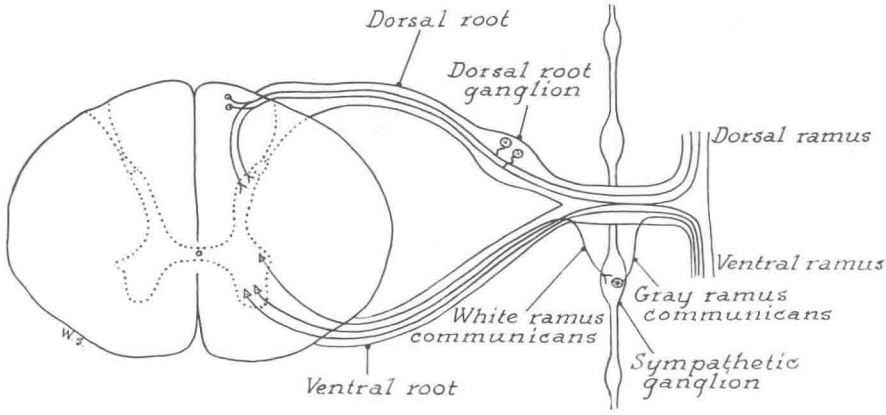

FIG. 9.—Cross-section of thoracic spinal cord with spinal nerve attached. The components of the nerve are diagrammatically shown.

The term "*special visceral efferent*" is unfortunate in that these fibers are distributed to striated or voluntary muscles, but only to those which originate from the mesoderm of the branchial or visceral arches. These include the muscles of the larynx, pharynx, and soft palate, the muscles of mastication, and the muscles of expression. Special visceral efferent fibers are therefore found in the vagus, spinal accessory, glossopharyngeal, trigeminal, and facial nerves. The spinal accessory also supplies the upper portions of the trapezius and sternocleidomastoid muscles which are supposed to be of branchial origin.

Each **spinal nerve** is attached to the spinal cord by two roots—an anterior or ventral and a posterior or dorsal; these unite to form the nerve trunk which then divides into ventral and dorsal rami (Fig. 9). The anterior or ventral rami of the spinal nerves form the cervical, brachial, lumbar, sacral, and coccygeal plexuses and, in the thoracic region, the intercostal and subcostal nerves. The posterior or dorsal rami are distributed to the skin and muscles of the back.

The *ventral roots* of all spinal nerves contain somatic efferent fibers (Fig. 9). Those of the thoracic, upper lumbar, and middle sacral nerves also contain general visceral efferent fibers which end in relation to ganglionic cells of the autonomic system.