ANATOMY OF THE NERVOUS SYSTEM

by

OLOF LARSELL, M.A., PH.D., SC.D.

Professor of Anatomy, University of Oregon Medical School, Portland

Introduction by

A. T. RASMUSSEN, PH.D.

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PREFACE

In this second edition of *Anatomy of the Nervous System* the book has been completely reorganized and rewritten. The gross anatomy of the central nervous system and its membranes and of the channels of the cerebrospinal fluid is presented in the first two chapters. Although many features of gross anatomy of the brain and spinal cord are treated in greater detail in textbooks of descriptive anatomy, a comprehensive description with numerous figures is given of the gross anatomical subdivisions that must be known before the connections and relations of the functional pathways can be understood and before the finer structure of the nervous system is studied.

Because an understanding of the complex structure of the adult brain must be based upon knowledge of the developmental stages through which it has passed, the chapter on development of the nervous system has been expanded to include the principal phases of differentiation of the nervous tissues, the spinal cord and spinal nerves, and the subdivisions of the brain. Although the histology of the nervous tissues and the receptor and effector nervous mechanisms is treated in textbooks of histology, chapters on these topics are included both for the sake of unifying a description of the nervous system in one volume and for the convenience of the student in reviewing and expanding his knowledge of these subjects. In the descriptions of the sensory organs emphasis is placed on the nervous receptor apparatus. In the descriptions of the eye and ear, however, the important accessory structures are described and illustrated more fully because of their significance in the functioning of these organs. In addition to histological descriptions of nerves and nerve fibers, the functional classification of fibers, based on conduction rates, is included because of its significance in the comprehension of conducting pathways. The more recent concepts of synaptic transmission are also given due attention. The gross anatomy, embryology, and histology of the nervous system and its receptors and effectors are thus brought together in the first five chapters in sufficient detail to introduce the nervous mechanism as an anatomical and functional unit of the body without need of constant reference to textbooks of anatomy, histology, and embryology.

A chapter on the blood supply of the brain and spinal cord has been added because of the importance of the subject to the medical student, for whom the book is primarily intended, in understanding many of the neurological lesions he will encounter in the clinics and hospitals. This chapter also deals with the innervation of the meninges. It is made the final one in the volume because knowledge of the nerve centers described in the preceding chapters is necessary before the significance of the vascular patterns can be realized.

The remainder of the volume has been revised and expanded to deal more fully with the minute anatomy of the subdivisions of the nervous system and their fiber tracts. The latter are treated from the functional point of view, but with first attention

to their anatomical relationships. Illustrative lesions and other clinical examples are largely omitted from this edition. Although valuable in helping the student to organize his knowledge of neuroanatomy and the functional significance of nerve centers and fiber tracts, such illustrations can be supplied by the instructor and, in cooperation with the clinical neurologist, even more instructively by demonstration of actual patients.

In introducing such complex subdivisions of the nervous system as the cerebellum, the thalamus, the basal ganglia, and the cerebral cortex for further consideration than is given in Chapter 1, comparative anatomy has been invoked to some extent with the purpose of simplifying for the student the structural patterns of these organs. To this end descriptions and figures of the brains of lower vertebrates have been used in several of the chapters.

The cerebellum and pons are treated in the same chapter because of their close phylogenetic and functional relationships. The account of the cerebellum has been expanded and includes the newer morphological and functional interpretations of this organ. The tegmental portion of the rhombencephalon, or medullary tegmentum, in keeping with its phylogenetic and ontogenetic relationships, is described as a part of the medulla oblongata rather than as the tegmentum or pars dorsalis of the pons.

Although most of what we know of the structure of the nervous system is based on the more strictly neuroanatomical methods of investigation, the experimental methods of the neurophysiologist, especially oscillography, have given meaning to numerous anatomical features. The results have been included insofar as they elucidate or give significance to structure and to functional pathways.

The olfactory system and related structures have been presented in considerable detail because of increased interest in this field and because many of the details, although long known, are not readily available to the student. The book includes the recent analyses of the human thalamus, of connections between thalamus and cerebral cortex, and of the functional areas of the cortex and the lobes. The newer concepts of the pyramidal and extrapyramidal systems and their inter-relationships are also discussed.

An attempt has been made to condense the vast amount of information obtained in recent years by the experimental neurologist and the neurosurgeon on the cerebral cortex and its subdivisions. A more detailed account of the structural features of the cerebral cortex is given than is usually available in English, save in the larger monographs and in the journals.

The illustrations, including those of sections of the brain stem and cerebral hemispheres, are scattered through the text of the appropriate chapters. This arrangement facilitates reference so that figures can be quickly consulted as the corresponding text is read. When so used, together with the diagrams of nervous pathways, they should enable the reader to visualize more readily the functional connections.

Many new figures, both detailed drawings and diagrams, have been introduced. For the skilfull execution of most of them I am indebted to Mrs. Clarice Ashworth Francone. A number of new figures of microscopic features have been prepared from sections in the collection of human embryos and infants gathered by my colleague, Dr. A. A. Pearson. Numerous other figures have been borrowed or adapted from the sources acknowledged in the legends. Throughout the book, figures illustrating human

material have been used so far as possible. For the privilege of using the borrowed figures I express my thanks. The Blakiston Company has been especially generous in permitting reproduction of a number of illustrations prepared under my supervision for Morris's *Human Anatomy,* edited by Dr. J. Parsons Schaeffer. Professor F. de Castro has kindly loaned the original drawings for Figures 98 and 167.

Lists of references follow the individual chapters. Although this involves some repetition of titles it makes for convenience in consulting the literature on any specific subject. The references, for the most part, are to the more recent literature and will open the way to other sources.

The English equivalents of the B.N.A. terminology have been used so far as possible. For the fiber tracts the origins and terminations are designated by the names, without particular consideration of B.N.A. terms. In the confused terminology of the thalamus the Latin names of the nuclei, as applied by Toncray and Krieg to the human thalamus, have been used in the text describing them, although in other parts of the text and in the figures of the brain stem the English equivalents are employed.

Suggestions and criticisms of great value in revising the book have been received from many colleagues, to whom I extend my acknowledgments. Dr. A. A. Pearson and Dr. W. A. Stotler have offered most useful comments on many phases of the revision, and Dr. A. T. Rasmussen has read the proof and made valuable suggestions.

To the publishers I express my appreciation for patient and generous cooperation.

OLOF LARSELL

INTRODUCTION

It has been a pleasure to look over the page proof of this second edition of Larsell's *Anatomy of the Nervous System* and to see the many additions to and rearrangements of an already splendid book. It strikes the reviewer as being a satisfactory compromise between the various approaches to this difficult field. The nervous system must be viewed as a whole and yet many intricate details must be mastered before they can be integrated into a working scheme. This demands considerable foresight and judgment and necessitates constant recurrence to important regions, which introduces the problem of the extent to which illustrations should be repeated in order to have them close to the text. Progression is clearly planned to proceed from the general to the detailed. A fair amount of histogenesis adds understanding to many normal adult features and is of great value to the pathological anatomy.

One gains confidence in the generalizations presented when it is realized that the author is an outstanding authority on various aspects of the subject and is schooled in the broad basis of comparative anatomy as well as in the special techniques required to analyze the baffling morphology that often confronts investigators of neural structure. The carefully selected list of references to those older results that have withstood the onslaught of time as well as to the latest contributions, at the end of each chapter, is further assurance of the author's wide acquaintance with the contributions of others. Keeping abreast of the accelerated progress being made in neurology is no minor task. The bibliography further opens up an ever broadening vista to the inquisitive mind.

The incorporation of numerous realistic external views of the brain stem with superimposed well-planned fiber tracts is a commendable feature, serving as a visual aid to the orientation of essential circuits, which are so apt to get lost in such a bewildering complexity. Important cell groups in the brain stem are emphasized by maps which accompany the usual Weigert sections. Since the finer structure of the sense organs is frequently allocated to the course in neuroanatomy, Dr. Larsell has wisely included the essentials on the ear and the eye as well as on the other receptors.

Nowhere else in the domain of the medical sciences is it more urgent that structures be interpreted in the light of the role they play. The amalgamation of form and function permeates this entire text; nor has the clinical application been ignored. These dynamic approaches provide incentives to toil midst discouragement that all too often is evident, especially during the early part of the course.

Among new topics is a closing chapter on the important subject of the blood supply. This brings up again the meninges (covered generally in an early chapter) with special reference to the dural sinuses.

The spirit of the book is open-minded. The various unsettled details that crop up beckon to those who might plan to pursue research in neuroanatomy, which after all is in its infancy, our fund of usable knowledge in this field being the product of only

a hundred years. Adequate technique to display the general morphology of the building blocks of the nervous system has been available for less than seventy years. Neurological technique is being constantly refined along the line of microchemistry, electron microscopy and cathode ray oscillography, offering new hope for a better understanding of a most vital organ.

From the very beginning of anatomy the nervous system has been a special challenge. Philosophers even hoped that the unraveling of its structure might expose something of the nature of the soul. The challenge still stands. Thus, as an example, the much simpler problem of the seat of consciousness is still debatable. In spite of the helping hand of numerous zoologists, surgeons, clinical neurologists, psychiatrists and especially physiologists, many additions to our store of knowledge will be required before the full significance of many neural structures can be stated with reasonable certainty. It is, therefore, highly necessary for students and teachers alike to take a tentative attitude. Happily, over-simplification has been avoided, since this could defeat the purpose of a text such as this, designed as it is for a stepping stone to the rapidly advancing science of neurology.

A. T. RASMUSSEN

University of Minnesota
Minneapolis, Minnesota

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THE GROSS ANATOMY OF THE BRAIN AND SPINAL CORD

The nervous system is the mechanism for conduction and integration of stimuli and for governing the activities of the body, both the internal and those in relation to the outside world. It consists of the brain, spinal cord, cranial and spinal nerves with their ganglia, and the autonomic system of nerves and ganglia. The brain and spinal cord form the central nervous system, while the cranial and spinal nerves and the autonomic system, together with the cranial and spinal root ganglia and the ganglia of the autonomic or visceral nerves, constitute the peripheral nervous system. The latter is closely tied up with the central nervous system by anatomical attachment and by functional arrangement.

The brain is encased in the cranial cavity and is protected by the vault of the skull (Fig. 1), while the spinal cord lies in the spinal canal, surrounded by the bodies, arches, and laminae of the vertebrae. The cranial nerves emerge from the skull through foramina in its floor, while the spinal nerves, and with them the fibers leading to the visceral nerves, find their exit from the spinal canal through the intervertebral foramina. Both the brain and the spinal cord are covered by three membranes, namely, the dura mater, the arachnoid, and the pia mater, which collectively are called the meninges.

The brain is divided into five main divisions: (1) the *forebrain* (*telencephalon*), (2) the *betweenbrain* (*diencephalon*), (3) the *midbrain* (*mesencephalon*), (4) the *cerebellum* (*metencephalon*), and (5) the *medulla oblongata* (*myelencephalon*). Their morphological relations are most readily seen in the brains of embryos and of lower vertebrates (Fig. 2). The lower end of the medulla oblongata is continuous with the spinal cord. In man the forebrain is so large that, viewed from above when the cranial cavity is opened, it covers and hides the rest of the brain, but parts of all five divisions are visible from the basal or medial aspects.

CEREBRAL HEMISPHERES

The forebrain is divided into two cerebral hemispheres (Fig. 3) by the *longitudinal cerebral fissure,* also called the *sagittal fissure,* into which dips a fold of dura mater, the *falx cerebri.* The fissure extends from the upper to the lower surfaces of the hemispheres and completely separates them, save in the middle region. Here the hemispheres are connected across the midplane by a large band of nerve fibers, the *corpus callosum,* which forms a great commissure. Posteriorly the sagittal fissure extends to

the tentorium cerebelli, a transverse process of the dura mater, which separates the occipital part of the cerebrum from the cerebellum. The falx cerebri is attached to the tentorium cerebelli.

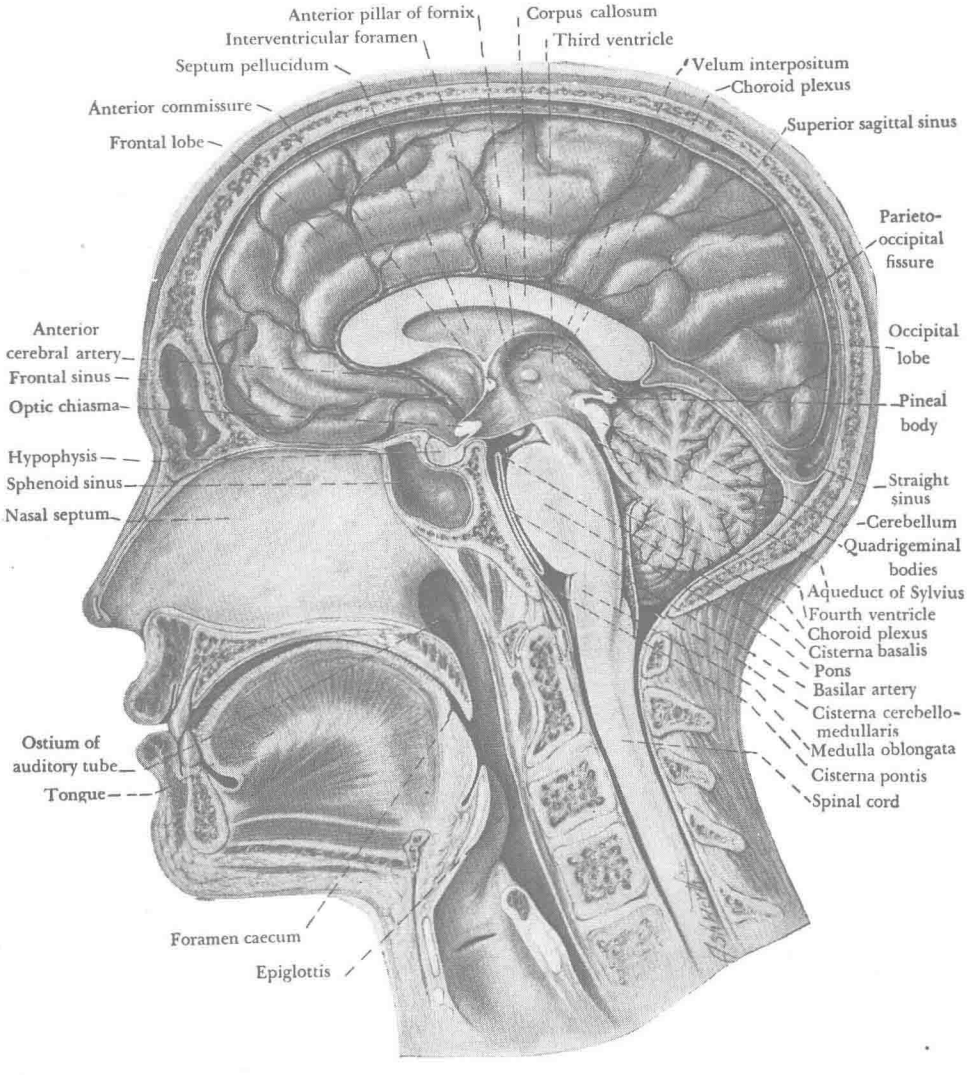

Fig. 1. Medial sagittal section of head and upper part of neck, showing the brain and upper cervical spinal cord in situ.

(From Larsell in Schaeffer-Morris: *Human Anatomy*, ed. 11, The Blakiston Company.)

The surface of the hemispheres, which is grayish in color owing to a superficial layer of gray substance, called the *cerebral cortex*, is folded into numerous convolutions or *gyri*, separated by furrows of varying depth. The deeper and more constant furrows are known as *fissures*, while the shallower and more variable ones are called *sulci*. The

convolutions and sulci form a pattern which, while varying considerably in individual brains, is, in general, similar and characteristic for the various parts of the cortex.

Fissures. The most prominent fissure in each hemisphere is found on the inferior and lateral surfaces and is known as the *lateral cerebral fissure* or *fissure of Sylvius*. It begins as a short *stem* which extends from a depression on the basal surface of the brain at the lateral angle of the anterior perforated substance and passes forward and upward. On reaching the lateral brain surface it divides into three branches, the *anterior horizontal ramus,* the *anterior ascending ramus,* and the *posterior horizontal ramus*. The last-named is the longest, extending back onto the lateral surface of the posterior part of the hemisphere.

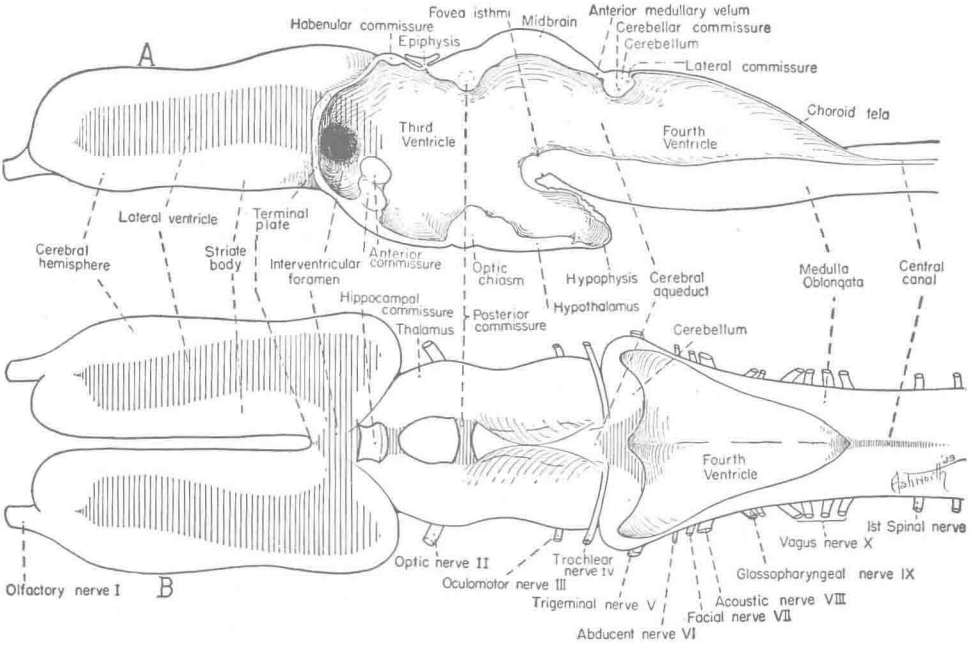

Fig. 2. Diagram of vertebrate brain, based on the brain of the salamander.
A, sagittal section; B, viewed from above. (From Larsell in Schaeffer-Morris: *Human Anatomy,* ed. 11, The Blakiston Company.)

Located about the middle of the upper medial, superior, and lateral surfaces of each hemisphere is found the *central sulcus* or *fissure of Rolando*. It begins on the upper medial surface of the hemisphere, a little posterior to the middle of the longitudinal fissure, and runs downward and forward on the lateral surface, ending about 25 mm. behind the anterior ascending ramus of the lateral fissure and above the posterior ramus.

These and other fissures and sulci to be described, together with certain arbitrary lines between them, divide the cerebral hemispheres into five lobes, namely, the temporal, frontal, parietal, occipital, and central. The central lobe is often called the insula, or island of Reil. A limbic lobe, or rhinencephalon, including structures that make up parts of the other lobes, is also recognized. The division into lobes is largely topographical, but it is convenient in describing the brain.

Lobes and Gyri. The **frontal lobe** (Figs. 3, 4, 5) is the most anterior lobe of the cerebral hemisphere. Its upper, convex surface begins with the frontal pole and is bounded posteriorly by the central sulcus, the posterior ramus of the lateral fissure, and the forward and downward continuation of the lateral fissure. Its medial surface is delimited from the parietal lobe by a curved line extending forward and downward from the medial end of the central sulcus, in the paracentral lobule, to the sulcus cinguli; the boundary continues forward a short distance along the sulcus cinguli and

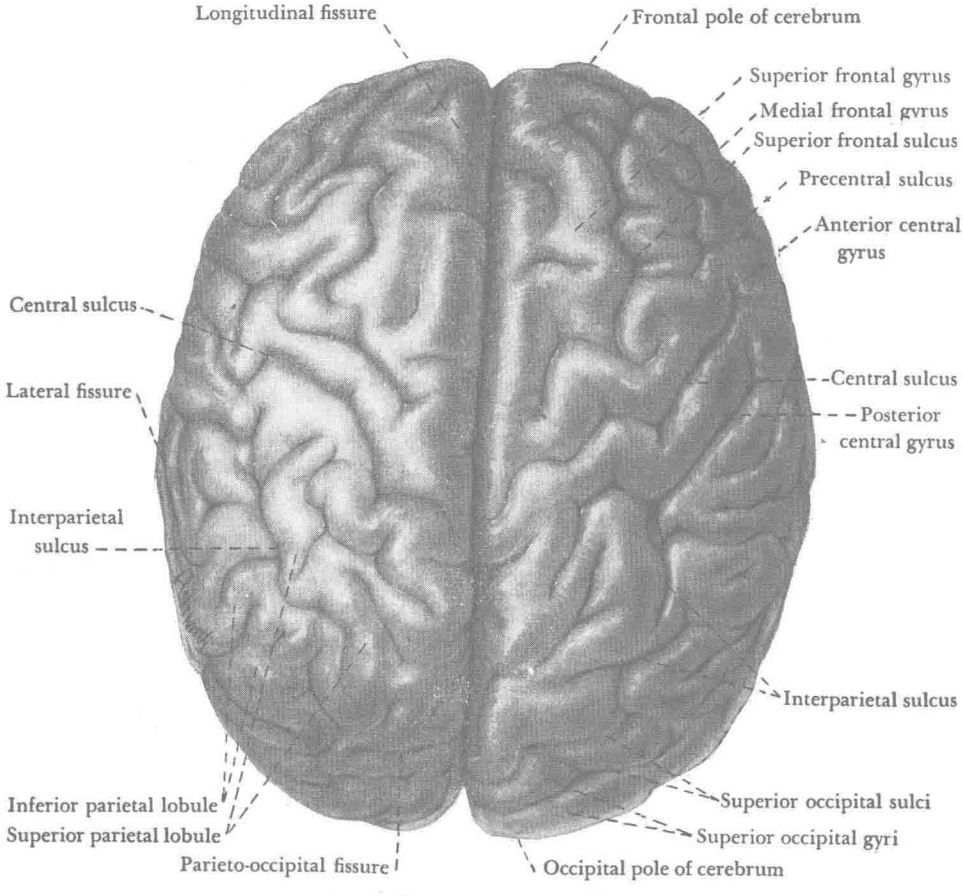

Fig. 3. Cerebral hemispheres viewed from above.

then extends downward in a curved line to the corpus callosum, thus including the rostral part of the gyrus cinguli in the frontal lobe. As thus defined, the boundary between frontal and parietal lobes has a functional significance in that it demarcates the motor area in the frontal lobe from the somesthetic sensory area in the parietal lobe as far as the sulcus cinguli on the medial surface. Below the sulcus cinguli the boundary delimits certain areas of the gyrus cinguli which are more fully described in the discussion of cerebral cortex (Chapter 18). The basal surface of the frontal lobe extends from the frontal pole to the stem of the lateral fissure.

The convex surface of the frontal lobe (Figs. 3, 4) includes the *anterior central gyrus*—which lies between the central sulcus and the precentral sulcus—and the superior, the middle, and the inferior frontal gyri. The *superior frontal gyrus* extends from the precentral sulcus toward the frontal pole. It is bounded from the *middle frontal gyrus,* which consists of a superior and an inferior portion, by the *superior frontal sulcus*. A shallow *middle frontal sulcus* frequently divides the middle frontal gyrus. The *inferior frontal gyrus,* separated from the middle gyrus by the *inferior frontal sulcus,* extends forward from the lower part of the precentral sulcus and is continuous with the *lateral* and the *posterior orbital gyri* on the basal surface of the

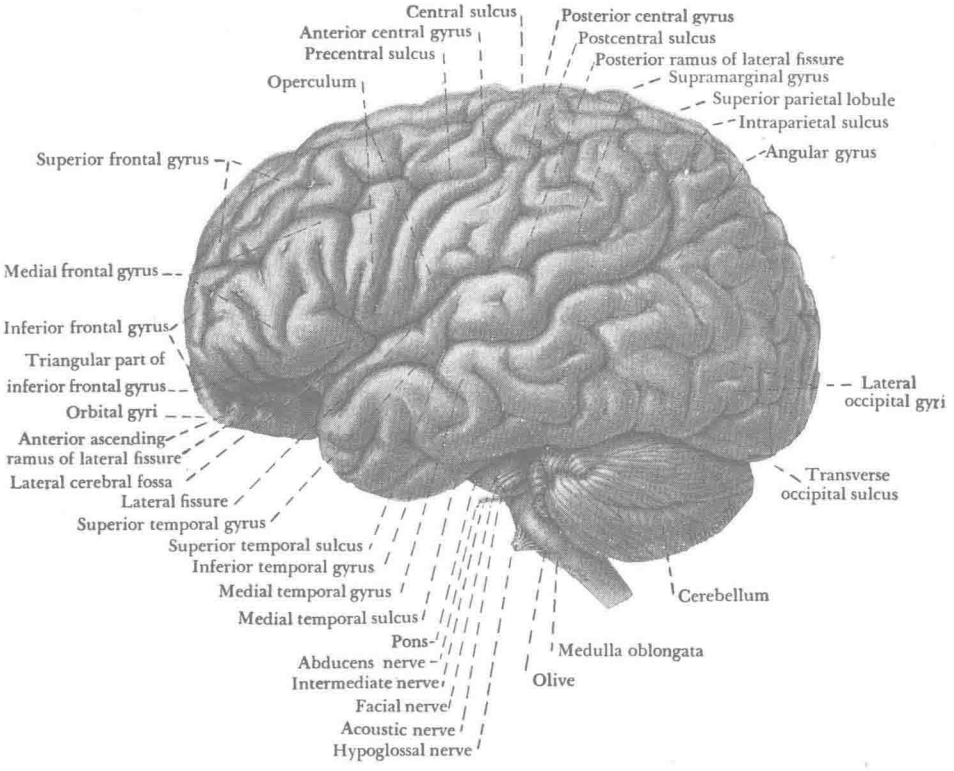

Fig. 4. Lateral view of brain.
(From Larsell in Schaeffer-Morris: *Human Anatomy,* ed. 11, The Blakiston Company.)

frontal lobe. The inferior frontal gyrus is divided into an *opercular portion,* which lies behind the ascending ramus of the lateral fissure; a *triangular portion,* situated between the ascending and the anterior horizontal rami of the lateral fissure; and an *orbital portion,* which lies below the anterior horizontal ramus of the anterior fissure. The opercular portion of the left hemisphere is known as the *convolution of Broca,* having been described by Broca as the area of coordination for the muscles of speech. It is now recognized that control of speech also involves the triangular portion. In left-handed persons the corresponding portions of the right hemisphere are involved in this function.