18th edition

Correlative Neuroanatomy & Functional Neurology

JOSEPH G. CHUSID, MD

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Preface

This volume is intended for the beginner in clinical neurology. It is meant to serve as an aid or supplement to standard neurologic texts and literature rather than as a substitute for them. It has become increasingly popular with students, house staff members, and practitioners in this country and abroad over the past 4 decades.

The author's principal objective has been to present briefly and clearly some of the important structural and functional features of the nervous system as they relate to problems encountered in clinical neurology. Concise format, charts, diagrams, and illustrations have been prepared with this purpose in mind, and efforts have been made to include recent important advances in neurology. More than 475 illustrations and over 60 tables have been assembled for this edition.

With the appearance of the Eighteenth Edition, I am pleased to report that Spanish, Italian, Japanese, Portuguese, Polish, German, and Serbo-Croatian editions have been published and have been well received. French and Indonesian editions are now in preparation.

I would like to express my appreciation and gratitude to my friends and colleagues at St. Vincent's Hospital and Medical Center of New York for their continued support. Dr. Michael Garofalo and Dr. Hyman Donnenfeld deserve special mention, and Dr. Gail P. Ballweg provided several fine photographs. Dr. Michael J. Chusid of the Medical College of Wisconsin revised the chapter on infectious diseases of the central nervous system.

I wish to extend my sincere thanks to the publishers, editors, and authors who graciously permitted the reproduction of illustrations and charts in this book. The helpful suggestions and criticisms of students, readers, and physicians from many parts of the world are gratefully acknowledged and are most welcome.

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Table of Contents

IV. CENTRAL NERVOUS SYSTEM DISORDERS

Section I: Central Nervous System

The Brain | 1

The brain is the greatly modified and enlarged anterior portion of the CNS. It is surrounded by 3 protective membranes (meninges) and is enclosed within the cranial cavity of the skull. Division into cerebral cortex, basal ganglia, thalamus and hypothalamus, midbrain, brain stem, and cerebellum provides a useful basis for the study of brain localization.

THE CEREBRAL HEMISPHERES

The 2 cerebral hemispheres, which make up the largest portion of the brain, are separated by the deep **longitudinal cerebral fissure.** The **falx cerebri,** a crescent-shaped extension of dura mater, projects into the longitudinal cerebral fissure. The **corpus callosum** is the great white central commissure that crosses the longitudinal cerebral fissure. The body of the corpus callosum is arched; its anterior curved portion, the genu, continues anteroventrally as the rostrum. The thick posterior portion terminates in the curved splenium, which overlaps the midbrain.

The surfaces of the cerebral hemispheres are dorsolateral, medial, and basal. They contain many grooves, or furrows, known as fissures and sulci. The portions of brain lying between these grooves are called convolutions, or gyri. Some gyri are relatively constant in location and contour, whereas others show considerable variation. The **lateral cerebral fissure** (fissure of Sylvius) separates the temporal from the frontal lobe. Starting at the base of the brain as a deep cleft lateral to the anterior perforated substance, it divides into 3 branches: the anterior horizontal ramus, which ascends into the inferior frontal gyrus; the anterior ascending ramus, which also ascends into the inferior frontal gyrus but farther posteriorly; and the posterior ramus, which continues backward and upward to terminate in the parietal lobe.

The **central sulcus** (fissure of Rolando) arises about the middle of the hemisphere, beginning near the longitudinal cerebral fissure and extending downward and forward to about 2.5 cm above the lateral cerebral fissure. The **parieto-occipital fissure** passes along the medial surface of the posterior portion of the cerebral hemisphere, runs downward and forward as a deep cleft with much buried cortex, and joins the calcarine fissure. The **calcarine fissure** begins on the medial surface, near the occipital pole, and extends forward to an area slightly below the splenium of the corpus callosum. The rostral portion is deeper and more constant in location and structure. The **cingulate sulcus** begins below the anterior end of the corpus callosum on the medial surface of the hemisphere, continues parallel to the corpus callosum, and finally curves up to the superior medial border a short distance behind the upper end of the central sulcus. The **circular sulcus** (circuminsular fissure) surrounds the **insula,** or island, of Reil and separates it from the adjacent frontal, parietal, and temporal lobes.

Main Divisions of the Cerebrum

The cerebral hemisphere may be divided into the frontal, parietal, occipital, and temporal lobes, the insula, and the rhinencephalon.

A. Frontal Lobe: The frontal lobe extends from the frontal pole to the central sulcus behind and the lateral fissure at the side. The **precentral sulcus** passes anterior and parallel to the central sulcus. It is subdivided into the superior and inferior precentral sulci. The **superior and inferior frontal sulci** extend forward and downward from the precentral sulcus, dividing the lateral surface of the frontal lobe into 3 parallel gyri: the **superior, middle, and inferior frontal gyri.** The inferior frontal gyrus is divided into 3 parts by the anterior horizontal and ascending rami of the lateral cerebral fissure: the orbital part lies rostral to the anterior horizontal ramus; the triangular part is the wedge-shaped portion between the anterior horizontal and anterior ascending rami; the opercular part is between the ascending ramus and the precentral sulcus.

The **orbital sulci and gyri** are irregular in contour and location. The **olfactory sulcus** lies beneath the olfactory tract on the orbital surface; lying medial to it is the gyrus rectus, or **straight gyrus.** The **cingulate gyrus** is the crescentic or arched convolution on the medial surface between the cingulate sulcus and the corpus callosum. The **paracentral lobule** is the quadrilateral gyrus around the end of the central sulcus on the medial surface of the hemisphere.

B. Parietal Lobe: The parietal lobe extends from the central sulcus to the parieto-occipital fissure and laterally to the level of the lateral cerebral fissure. The **postcentral sulcus** extends behind and parallel to the lateral (rolandic) fissure and consists of a superior and

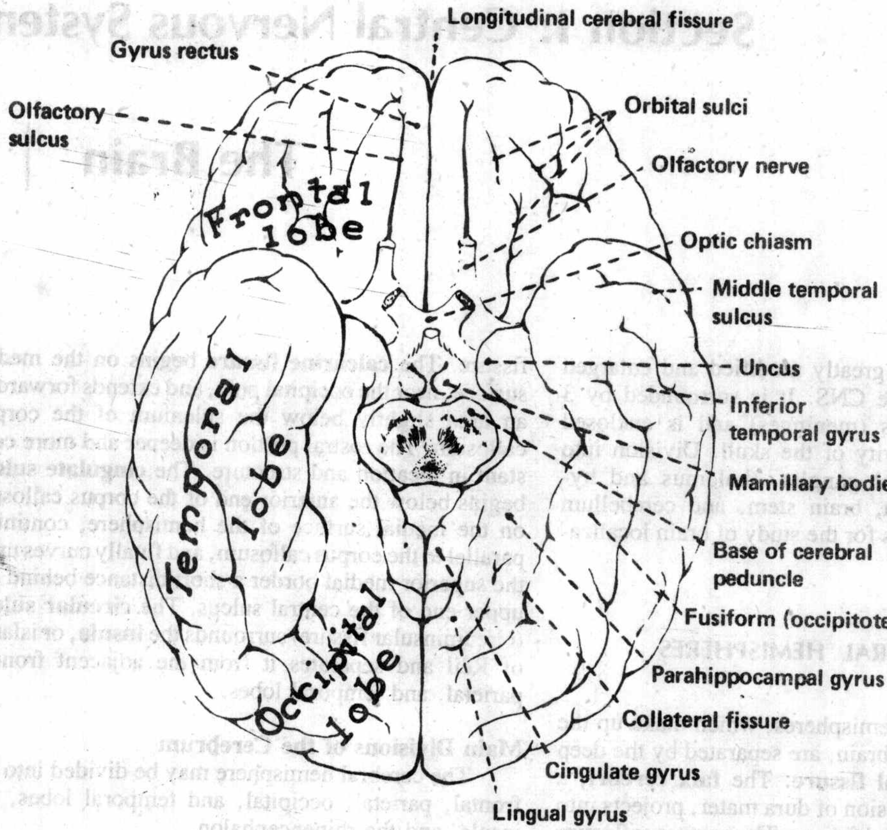

Figure 1–1. Basal view of cerebrum.

an inferior portion. The **intraparietal sulcus** is a horizontal groove that sometimes unites with the postcentral sulcus. The **superior parietal lobule** lies above the horizontal portion of the intraparietal sulcus, and the **inferior parietal lobule** lies below.

The **supramarginal gyrus** is that portion of the inferior parietal lobule which arches above the ascending end of the posterior ramus of the lateral cerebral fissure. The **angular gyrus** is that part which arches above the end of the superior temporal sulcus and becomes continuous with the middle temporal gyrus. The **posterior central gyrus** lies between the central and postcentral sulci. The **precuneus** is the posterior portion of the medial surface between the parieto-occipital fissure and the ascending end of the cingulate sulcus.

C. Occipital Lobe: The occipital lobe is the pyramid-shaped posterior lobe situated behind the parieto-occipital fissure. The **lateral occipital sulcus** extends transversely along the lateral surface, dividing the occipital lobe into a **superior** and **inferior gyrus.** The **calcarine fissure** divides the medial surface of the occipital lobe into the cuneus and the lingual gyrus. The wedge-shaped **cuneus** lies between the calcarine and parieto-occipital fissures. The **lingual gyrus** is between the calcarine fissure and the posterior part of the collateral fissure. The posterior part of the **fusiform gyrus** is on the central or basal surface of the occipital lobe.

D. Temporal Lobe: The temporal lobe portion of the cerebral hemisphere lies inferior to the lateral cerebral (sylvian) fissure and extends back to the level of the parieto-occipital fissure. The **superior temporal sulcus** extends across the temporal lobe parallel to the lateral cerebral fissure. The **middle temporal sulcus** runs parallel to the superior temporal sulcus at a lower level. The **superior temporal gyrus** is the part of the lateral surface of the temporal lobe between the lateral cerebral fissure and the superior temporal sulcus. The **middle temporal gyrus** lies between the superior and middle temporal sulci. The **inferior temporal gyrus** is below the middle temporal sulcus and extends posteriorly to connect with the inferior occipital gyrus. The **transverse temporal gyrus** (Heschl's gyrus) occupies the posterior part of the superior temporal surface (the inferior border of the lateral cerebral fissure). The **inferior temporal sulcus** extends along the inferior surface of the temporal lobe from the temporal pole in front to the occipital pole behind. The **fusiform, or occipitotemporal, gyrus** is medial and the **inferior temporal gyrus** lateral to the inferior temporal sulcus. The **hippocampal fissure** extends along the inferomedian aspect of the temporal lobe from the area of the splenium of the corpus callosum to

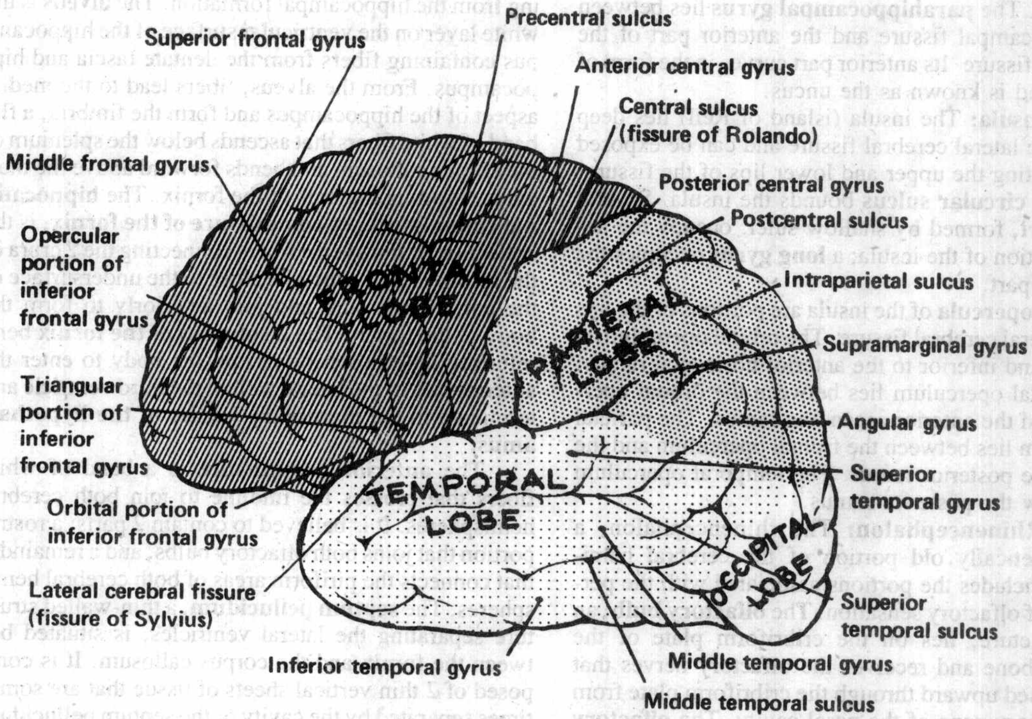

Figure 1–2. Lateral view of left cerebral hemisphere.

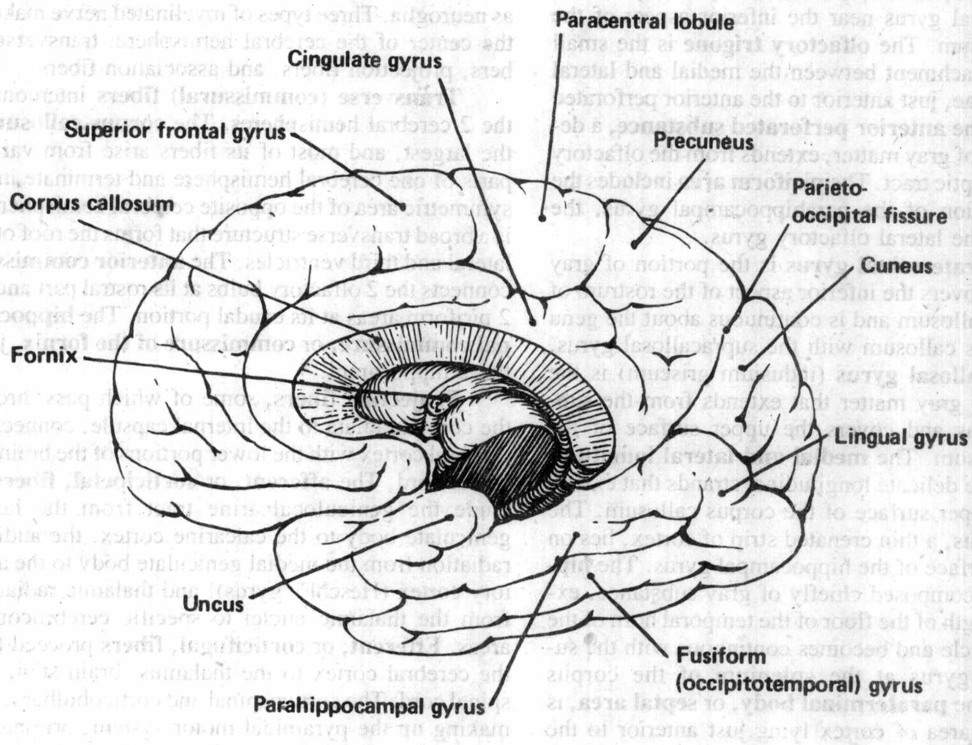

Figure 1–3. Medial view of right cerebral hemisphere.

the uncus. The **parahippocampal gyrus** lies between the hippocampal fissure and the anterior part of the collateral fissure. Its anterior part curves in the form of a hook and is known as the uncus.

E. Insula: The insula (island of Reil) lies deep within the lateral cerebral fissure and can be exposed by separating the upper and lower lips of the fissure. The deep **circular sulcus** bounds the insula. Several **short gyri,** formed by shallow sulci, occupy the anterior portion of the insula; a **long gyrus** occupies the posterior part.

The **opercula** of the insula are portions of the lips of the lateral cerebral fissure. The orbital operculum is anterior and inferior to the anterior horizontal ramus. The frontal operculum lies between the orbital operculum and the anterior ascending ramus. The parietal operculum lies between the frontal operculum and the end of the posterior ramus. The temporal operculum lies below the posterior ramus.

F. Rhinencephalon: The rhinencephalon, a phylogenetically old portion of the cerebral hemisphere, includes the portions associated with the perception of olfactory sensation. The **olfactory bulb,** an oval structure, lies on the cribriform plate of the ethmoid bone and receives the olfactory nerves that have passed upward through the cribriform plate from the olfactory zone of the nasal cavity. The **olfactory tract** lies in the olfactory sulcus on the orbital surface of the frontal lobe. As it passes posteriorly, it divides into the **lateral olfactory stria,** which passes laterally, then medially, to enter the uncus; and the **medial olfactory stria,** which passes medially and up toward the subcallosal gyrus near the inferior aspect of the corpus callosum. The **olfactory trigone** is the small triangular attachment between the medial and lateral olfactory striae, just anterior to the anterior perforated substance. The **anterior perforated substance,** a depressed area of gray matter, extends from the olfactory striae to the optic tract. The **piriform area** includes the anterior portion of the parahippocampal gyrus, the uncus, and the lateral olfactory gyrus.

The **paraterminal gyrus** is the portion of gray matter that covers the inferior aspect of the rostrum of the corpus callosum and is continuous about the genu of the corpus callosum with the supracallosal gyrus. The **supracallosal gyrus** (indusium griseum) is the thin layer of gray matter that extends from the subcallosal gyrus and covers the upper surface of the corpus callosum. The **medial and lateral longitudinal striae** are delicate longitudinal strands that extend along the upper surface of the corpus callosum. The **dentate gyrus,** a thin crenated strip of cortex, lies on the upper surface of the hippocampal gyrus. The **hippocampus,** composed chiefly of gray substance, extends the length of the floor of the temporal horn of the lateral ventricle and becomes continuous with the supracallosal gyrus at the splenium of the corpus callosum. The **paraterminal body,** or **septal area,** is a triangular area of cortex lying just anterior to the lamina terminalis.

The **fornix** is an arched white fiber tract extending from the hippocampal formation. The **alveus** is the white layer on the ventricular surface of the hippocampus containing fibers from the dentate fascia and hippocampus. From the alveus, fibers lead to the medial aspect of the hippocampus and form the fimbria, a flat band of white fibers that ascends below the splenium of the corpus callosum and bends forward above the thalamus, forming the crus of the fornix. The **hippocampal commissure,** or **commissure of the fornix,** is the collection of transverse fibers connecting the 2 crura of the fornix. The 2 **crura** lie close to the undersurface of the corpus callosum and join anteriorly to form the body of the fornix. The 2 **columns of the fornix** bend inferiorly and posteriorly from the body to enter the anterior part of the lateral wall of the third ventricle and terminate in the **mamillary bodies of the hypothalamus.**

The **anterior commissure** is a band of white fibers that crosses the midline to join both cerebral hemispheres. It is believed to contain 2 parts: a rostral portion that joins both olfactory bulbs, and a remainder that connects the piriform areas of both cerebral hemispheres. The **septum pellucidum,** a thin-walled structure separating the lateral ventricles, is situated between the fornix and the corpus callosum. It is composed of 2 thin vertical sheets of tissue that are sometimes separated by the cavity of the septum pellucidum (cavum septi pellucidi).

White Substance

The white substance of the cerebral hemisphere contains medullated nerve fibers of many sizes as well as neuroglia. Three types of myelinated nerve make up the center of the cerebral hemisphere: transverse fibers, projection fibers, and association fibers.

Transverse (commissural) fibers interconnect the 2 cerebral hemispheres. The **corpus callosum** is the largest, and most of its fibers arise from various parts of one cerebral hemisphere and terminate in the symmetric area of the opposite cerebral hemisphere. It is a broad transverse structure that forms the roof of the lateral and third ventricles. The **anterior commissure** connects the 2 olfactory bulbs at its rostral part and the 2 piriform areas at its caudal portion. The **hippocampal commissure,** or **commissure of the fornix,** joins the 2 hippocampi.

Projection fibers, some of which pass through the corona radiata to the internal capsule, connect the cerebral cortex with the lower portions of the brain and spinal cord. The **afferent,** or **corticipetal, fibers** include the geniculocalcarine tract from the lateral geniculate body to the calcarine cortex, the auditory radiation from the medial geniculate body to the auditory cortex (Heschl's gyrus), and thalamic radiations from the thalamic nuclei to specific cerebrocortical areas. **Efferent,** or **corticifugal, fibers** proceed from the cerebral cortex to the thalamus, brain stem, and spinal cord. The corticospinal and corticobulbar tracts, making up the pyramidal motor system, originate in the motor cortex and proceed inferiorly via the internal capsule. Corticopontine tracts from the cerebral cortex to the pons include a frontopontine tract, which originates in the frontal lobe cortex and goes to the pontine nuclei; and a temporopontine tract, which terminates similarly but originates in the temporal lobe cortex. Corticothalamic fibers pass from the cerebral cortex to the thalamic nuclei. A corticorubral tract extends from the frontal lobe to the red nucleus of the midbrain. The fornix projects in part to the midbrain after originating in the hippocampus.

Association fibers connect the various portions of the same cerebral hemisphere. Short association fibers connect adjacent gyri; those located in the deeper portion of the cortex are known as intracortical fibers, whereas those just beneath the cortex are called subcortical fibers. Long association fibers connect more widely separated areas: the **uncinate fasciculus** crosses the bottom of the lateral cerebral fissure and connects the inferior frontal lobe gyri with the anterior temporal lobe. The **cingulum,** a white band lying within the cingulate gyrus, connects the anterior perforated substance and the parahippocampal gyrus. The **arcuate fasciculus** sweeps around the insula and connects the superior and middle frontal convolutions with the temporal lobe and temporal pole. The **superior longitudinal fasciculus** connects portions of the frontal lobe with occipital and temporal areas. The **inferior longitudinal fasciculus,** extending parallel to the lateral border of the inferior and posterior horns of the lateral ventricle, connects the temporal and occipital lobes. The **occipitofrontal fasciculus** extends backward from the frontal lobe, radiating into the temporal and occipital lobes. The **fornix** for the most part connects the hippocampus with the mamillary body.

Microscopic Structure of Cortex

The cortex of the cerebrum may be conveniently considered as being of 2 types: allocortex and isocortex. The **allocortex** is found predominantly in the rhinencephalon, or portions concerned with olfaction. The **isocortex** (neocortex) is the type found more commonly in most of the cerebral hemispheres. It is composed of 6 layers of cells that have their embryologic origin in the mass of gray matter surrounding the ventricles: The outermost **molecular layer (I)** contains fibers that come from within the cortex. The **external granular layer (II)** is a rather dense layer composed of small cells. The **external pyramidal layer (III)** contains pyramidal cells, frequently in row formation. The **internal granular layer (IV)** is usually a thin layer with cells similar to those in the external granular layer (II). The **ganglionic layer (V)** in most areas contains pyramidal cells that are fewer but larger than in the external pyramidal layer (III). The **fusiform layer (VI)** is composed of fusiform irregular cells whose axons enter adjacent white matter.

Medullated fiber layers between the cortical layers give the appearance of white lines. The **line of Gennari** in the striate area of the occipital lobe is quite prominent, visible to the naked eye, and forms the outer portion of the internal granular layer (IV). The same line present elsewhere in the cortex is thinner and is known as the **external line of Baillarger.** The **internal line of Baillarger** is formed by the inner portion of the ganglionic layer (V).

Division and classification of the cortex has been attempted by many investigators on the basis of cytoarchitecture, and inferences concerning its structure and function are drawn largely from observations on animals, especially monkeys and chimpanzees. The most commonly employed systems are those of von Economo and Brodmann. Von Economo differentiated 5 main types of isocortex based on the characteristics of lamination, or layering. Using numbers, Brodmann labeled individual areas that he believed were different from others (Figs 1–10 and 1–11). The areas have been used as a reference base for the localization of physiologic and pathologic processes.

Ablation and stimulation, electrically and with various chemicals, have led to functional localizations. Some of the principal areas are as follows:

(1) Frontal lobe: Area 4 is the principal motor area. Area 6 is a part of the extrapyramidal tract circuit. Area 8 is concerned with eye movements and pupillary changes. Areas 9, 10, 11, and 12 are frontal association areas.

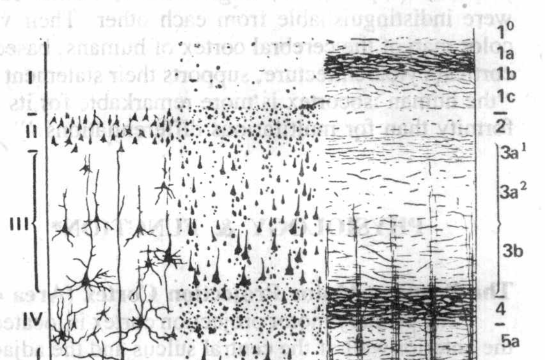

Figure 1–4. Diagram of the structure of the cerebral cortex. *A:* Golgi neuronal stain. *B:* Nissl cellular stain. *C:* Weigert myelin stain. I = molecular layer; II = external granular layer; III = layer of pyramidal cells; IV = internal granular layer; V = ganglionic layer; VI = layer of fusiform or polymorphic cells; 3a^1 = band of Bechterew; 4 = outer band of Baillarger; 5b = inner band of Baillarger (Brodmann.) (Reproduced, with permission, from Ranson SW, Clark SL: *The Anatomy of the Nervous System*, 10th ed. Saunders, 1959.)

(2) Parietal lobe: Areas 3, 1, and 2 constitute the postcentral principal sensory area. Areas 5, 7, 39, and 40 are sensory association areas.

(3) Temporal lobe: Area 41 is the primary auditory cortex. Area 42 is the secondary, or associative, auditory cortex. Areas 38, 20, 21, and 22 are association areas.

(4) Occipital lobe: Area 17 is the striate cortex, the principal visual cortex. Areas 18 and 19 are visual association areas.

Flechsig used the myelogenetic method to make a detailed subdivision of the cerebral cortex by studying the time and pattern of myelination of fibers in white substance immediately beneath the cortex. Initially, Flechsig described 40 cortical fields; this number was later increased.

Bailey and von Bonin have made a tentative sectoral map of the human cerebral cortex (Fig 1–9); they felt that the subdivision into sectors was more logical than the customary division into lobes. The map is based principally on the distribution of corticothalamic afferents. The boundaries of the sectors are only roughly approximate, and density of radiation is not uniform throughout the sectors. The authors felt that the microscopic appearances of cortical sections from parietal, temporal, and large areas of frontal cortex were indistinguishable from each other. Their vivid color map of the cerebral cortex of humans, based on cortical cytoarchitecture, supports their statement that "the human isocortex is more remarkable for its uniformity than for multifarious differentiations."

PHYSIOLOGY & FUNCTION*

The Primary Motor Projection Cortex (Area 4)

The primary motor projection cortex is located on the anterior wall of the central sulcus and the adjacent portion of the precentral gyrus, corresponding generally to the distribution of the giant pyramidal (Betz) cells. These cells control voluntary movements of skeletal muscle on the opposite side of the body, with the impulses traveling over their axons in the corticobulbar and corticospinal tracts to the nuclei of the cerebrospinal nerves. The inverted arrangement within the motor areas appears in Figs 1–6 and 1–7. Conjugate deviation of the head and eyes occurs upon stimulation of the posterior part of the middle frontal gyrus (areas 6 and 8). Irritative lesions of the motor centers may cause convulsive seizures, beginning as focal twitchings and spreading to involve large muscle groups (jacksonian epilepsy), modification of consciousness, and postconvulsive weakness or paralysis.

Destructive lesions of the motor cortex (area 4) produce contralateral flaccid paresis or paralysis of affected muscle groups. Spasticity is more apt to occur if area 6 and also the intermediate cortex are ablated. The paralysis following ablation of area 4 is more pronounced in the distal portions of the extremities. Section of the pyramidal tract in the medulla oblongata produces a flaccid paralysis similar to that from cortical ablation of area 4. Therefore, the presence of spasticity is believed to indicate interruption of extrapyramidal pathways.

The portion of the cerebral cortex most excitable to motor stimulation is area 4. It is believed that the ganglionic layer (V), which contains the Betz cells, significantly affects the excitability of this area. Transient reduction in excitability occurs in the motor cortex on continuous stimulation; after about 15 seconds, **"extinction"** may occur, in which the motor cortex becomes temporarily unexcitable. **Facilitation** is that phenomenon by which a subthreshold stimulus becomes adequate for stimulation (as through serial repetition). **Suppression** refers to the phenomenon associated with inhibition of striated muscle responses following cerebrocortical or subcortical stimulation.

Stimulation of the "premotor area" (area 6) produces movements similar to those of the motor area (area 4). However, after ablation of area 4 or interruption of fibers between areas 4 and 6, stimulation then produces stereotyped movements accompanied by head turning and torsion of the body. Following premotor ablations in monkeys, forced grasping may become evident, best demonstrated with the subject in the lateral position and the affected side uppermost.

The Primary Sensory Projection Cortex (Areas 3, 1, 2)

The primary sensory projection cortex for the reception of general sensations is located in the postcentral gyrus and is called the somesthetic area. It receives fibers from the thalamic radiations conveying skin, muscle, joint, and tendon sense from the opposite side of the body. Irritative lesions of this area produce paresthesias—eg, numbness, formication, "electric shock," and "pins-and-needles" sensations—on the opposite side of the body. Destructive lesions produce objective impairment in sensibility—eg, inability to localize or measure the intensity of painful stimuli and impaired perception of various forms of cutaneous sensation. Complete anesthesia on a cortical basis is rare.

Experimental studies indicate that a relatively wide portion of the adjacent frontal lobe (areas 4 and 6) may also receive sensory stimuli; conversely, motor responses can be achieved by stimulation of the primary sensory areas (3, 1, 2). The primary sensorimotor area may therefore be considered capable of functioning as both motor and sensory cortex, with the portion of the cortex anterior to the central (rolandic) sulcus predominantly motor and that behind this sulcus predominantly sensory.

Topographic organization exists in both the sensory and motor areas (Figs 1–5 and 1–6). Recent findings indicate that the primary motor and primary sensory areas are arranged topographically on the cerebral cortex as contiguous mirror images.

*Numbers in the text refer to Brodmann areas. See Figs 1–10 and 1–11.

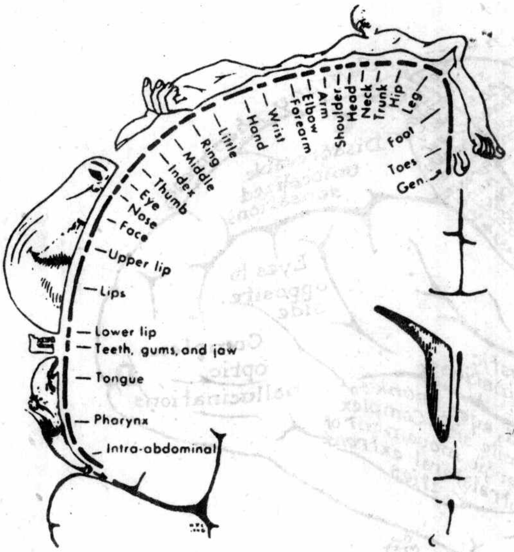

Figure 1–5. Sensory homunculus, drawn overlying a coronal section through the postcentral gyrus.

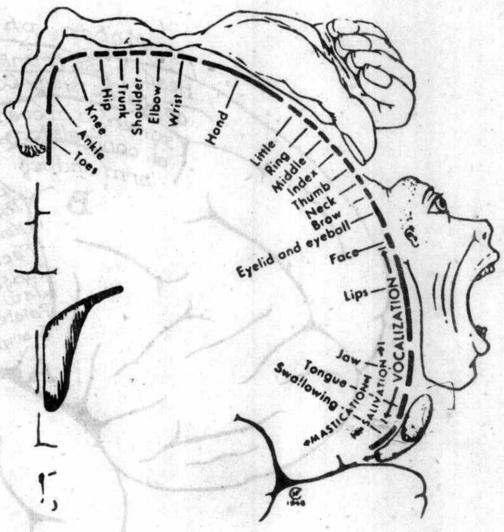

Figure 1–6. Motor homunculus, drawn overlying a coronal section through the precentral gyrus.

(*Note:* Figs 1–5 and 1–6 represent the location of cortical representation of the various parts. The size of the various parts is proportionate to the amount of cortical area devoted to them. [Reproduced, with permission, from Penfield & Rasmussen: *The Cerebral Cortex of Man: A Clinical Study of Localization of Function.* Macmillan, 1950.])

The cortical taste area is located in the facial sensory area and extends onto the opercular surface of the lateral cerebral fissure.

The Primary Visual Receptive Cortex (Area 17)

The primary visual receptive cortex is located in the occipital lobe in the cortex of the calcarine fissure and adjacent portions of the cuneus and the lingual gyrus. Irritative lesions may produce visual hallucinations, eg, flashes of light, rainbows, brilliant stars, or bright lines. Destructive lesions may cause contralateral homonymous defects in the visual fields without destruction of macular vision. Cortex containing macular representation receives overlapping blood supply from the middle and posterior cerebral arteries.

In primates, the posterior portion of the occipital pole is primarily concerned with macular vision, whereas the more anterior parts of the calcarine fissure are concerned with peripheral vision. Visual association is a function of areas 18 and 19, and injury to these areas may produce visual disorganization with defective spatial orientation in the homonymous halves of the visual field. Area 19 can receive stimuli from the entire cerebral cortex; area 18 receives stimuli mainly from area 17.

Field defects may also be caused by lesions of the parietal or temporal lobes that interfere with the optic pathways. Visual hallucinations from temporal lobe lesions may be of formed objects, people, buildings, etc. (See Figs 4–6 and 4–7.)

The Primary Auditory Receptive Area (Area 41)

The primary auditory receptive area is located in the transverse temporal gyrus (Heschl's gyrus), which lies buried in the floor of the lateral cerebral fissure. It receives the auditory radiation from the medial geniculate body, which conveys impulses from the cochlea of each ear; lesions of this area cause only mild deafness except when bilateral. Point-to-point projection of the cochlea upon the acoustic area occurs; in humans, the low tones are in the frontolateral portion and the high tones in the occipitomedial portion of area 41. In the cochlea, low tones are detected near the apex and high tones near the base.

Stimulation of the region near the primary auditory receptive area in humans causes buzzing and roaring sensations.

The Olfactory Receptive Area

The olfactory receptive area is located in the uncus and adjacent portions of the parahippocampal gyrus of the temporal lobe. Destruction of the olfactory pathways or cortex produces anosmia. Irritative lesions may cause olfactory hallucinations known as "uncinate fits," characterized by sensations of peculiar odors and tastes and often associated with a dreamy state. These may occur as an epileptic aura.

The Association Areas

The association areas are connected with the various sensory and motor areas by association fibers. They are of importance in the maintenance of higher mental activities in humans, although it is not possible to localize any specific mental faculty or fraction of conscious experience. Aphasias or speech defects resulting from cortical lesions illustrate the significance

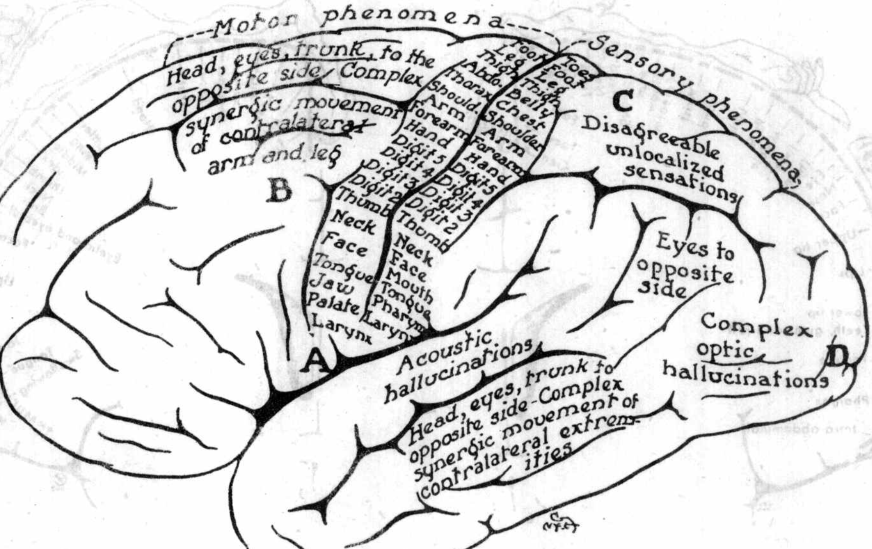

Figure 1–7. Results of electrical stimulation of the cerebral cortex. *A:* Chewing, licking, and swallowing movements. *B:* Eyes turned to the opposite side without visual aura. *C:* Sensory aura in opposite leg followed by complex synergistic movements. *D:* Unformed optical phenomena such as flames and lights. (After Foerster. Reproduced, with permission, from Bailey: *Intracranial Tumors.* Thomas, 1933.)

of association areas. In right-handed individuals, these are produced by lesions in the left hemisphere (the dominant hemisphere). Motor aphasia may result from destruction of the triangular and opercular portions of the inferior frontal gyrus (area 44). An individual can move lips and tongue but is unable to carry out the coordinated movements required in speaking. Agraphia—inability to write words—is often associated with motor aphasia. Sensory aphasia results from lesions in the posterior part of the left superior temporal gyrus (area 39). The patient may hear the spoken word but cannot comprehend its meaning. Word blindness—the inability to understand written words although vision is unimpaired—may result from lesions of the angular gyrus (area 39).

The frontal lobe, in its portions anterior to the precentral motor area, has long been known as an area concerned with higher intellectual and psychic functions. Classically, destructive lesions of this area may produce facetiousness (Witzelsucht), change in moral and social attributes, disinterest in environment and former interests, intellectual deterioration, and distractibility. The orbitofrontal area (areas 9, 10, 11, and 12) receives projections from the dorsomedial nuclei of the thalamus, which in turn has connections with the hypothalamus. Surgical procedures that affect the connections between this portion of the frontal cortex and the thalamus have been used. In general, when used they were most successful in surgical treatment of obsessions, anxiety, schizophrenic psychoses, and intractable pain. Frontal leukotomy and lobotomy severed the cortical-subcortical connections in the frontal lobe, usually at about the level of the anterior limit of the lateral ventricles. Topectomy referred to the removal of cortical areas of the brain, usually areas 9 and 10 on both sides. Cortical undercutting was less commonly used; it consisted of interrupting the connections just below the cortex. Thalamotomy created a lesion, usually in the dorsomedial nucleus of the thalamus, by means of stereotaxic devices. Other methods have also been used to produce uniform subcortical destructive lesions. Radio frequency waves have been applied to stereotactically placed electrodes. In the hope of avoiding the dangers of hemorrhage and sepsis, the Bragg peak of a proton beam has been used to produce precise intracerebral lesions. Surgical section of the cingulum (anterior cingulotomy) is preferred to frontal leukotomy in some centers.

The posterior portion of the orbital surface (area 47) and the contiguous portion of the anterior half of the insula produce pronounced autonomic effects upon electrical stimulation; inhibition of respiration and alteration of blood pressure may also be readily induced. Upon stimulation of the anterior cingulate area (area 24), which lies on the medial aspect of the cerebral hemisphere, pronounced autonomic effects and inhibition of skeletal muscle tone may occur. Following ablation of this area, aggressive male monkeys become relatively tame, manageable, and less fearful and anxious.

Parietal lobe (areas 5 and 7) association centers are necessary for the correlation of cutaneous sensations, thus enabling individuals to recognize familiar objects placed in their hands (with their eyes closed), a

Table 1–1. Classification of human cerebral cortex by Bailey and von Bonin.* (See Fig 1–8.)

	Terminology of Map	Legend
Allocortex	Allocortex	
Isocortex		
Eulaminate variants		
1. Inferior parietal	Homotypical isocortex	
2. Superior parietal	Homotypical isocortex	
3. Preoccipital	Homotypical isocortex	
4. Inferior frontal	Homotypical isocortex	
5. Inferior temporal	Homotypical isocortex	
Agranular variants		
1. Simple precentral	Agranular cortex	
2. Gigantopyramidal precentral	Agranular gigantopyramidal cortex	
3. Limbic juxtallocortical	Mesocortex	
Koniose variants		
1. Occipital striate	Koniocortex	
2. Postcentral	Koniocortex	
3. Supratemporal	Koniocortex	
Limitrophic variants		
1. Occipital, postcentral, and supratemporal parakoniocortical	Parakoniocortex	
2. Temporal juxtallocortical	Juxtallocortex	
3. Frontal dysgranular	Dysgranular cortex	

*See Chusid JG: Black-and-white supplement for the color brain map of Bailey and von Bonin. *Neurology* 1964;14:154.

function referred to as stereognostic sense. In lesions of the parietal cortex, this ability may be lost (astereognosis).

Cerebral Dominance

Studies of patients in whom the corpus callosum has been surgically divided suggest that the major, or dominant, cerebral hemisphere is functionally distinct from the opposite, or minor, hemisphere. The dominant cerebral hemisphere (usually the left in humans) is concerned mainly with verbal, linguistic, arithmetic, calculating, and analytic functions. The minor cerebral hemisphere is concerned with nonverbal, geometric, spatial, visual, pattern, musical, and synthetic functions.

Cerebral dominance usually is not fully established until the third or fourth year of life. It may be related to structural differences between the cerebral hemispheres. Asymmetries that have been noted in the auditory region and in the lateral cerebral fissure may be related to language lateralization and hand preference. The best-defined asymmetries have been found in the upper surface of the temporal lobe in the cortical area behind Heschl's gyrus (area 41). This posterior cortical area, sometimes referred to as the planum temporale, is reported to be larger in the left cerebral hemisphere in the majority of brains examined.

Secondary or Second Motor & Sensory Areas

These have been demonstrated in the opercular cortex (parietal lobe) forming the superior wall of the lateral cerebral fissure. These areas have extensive communications with the primary motor and sensory areas.

Supplemental Motor & Sensory Area

Electrical stimulation of a circumscribed zone of cerebral cortex situated on the medial aspect of the cerebral hemisphere, just anterior to the principal motor area for the foot, is capable of producing characteristic motor responses and, occasionally, sensory responses.

Rhinencephalon (Limbic System)

Clinical observations and animal experiments indicate that rhinencephalic structures have important functions other than those concerned with olfaction. In primates, a variety of autonomic, somatomotor, and somatosensory responses may be produced by electrical stimulation of the anterior limbic, subcallosal, and