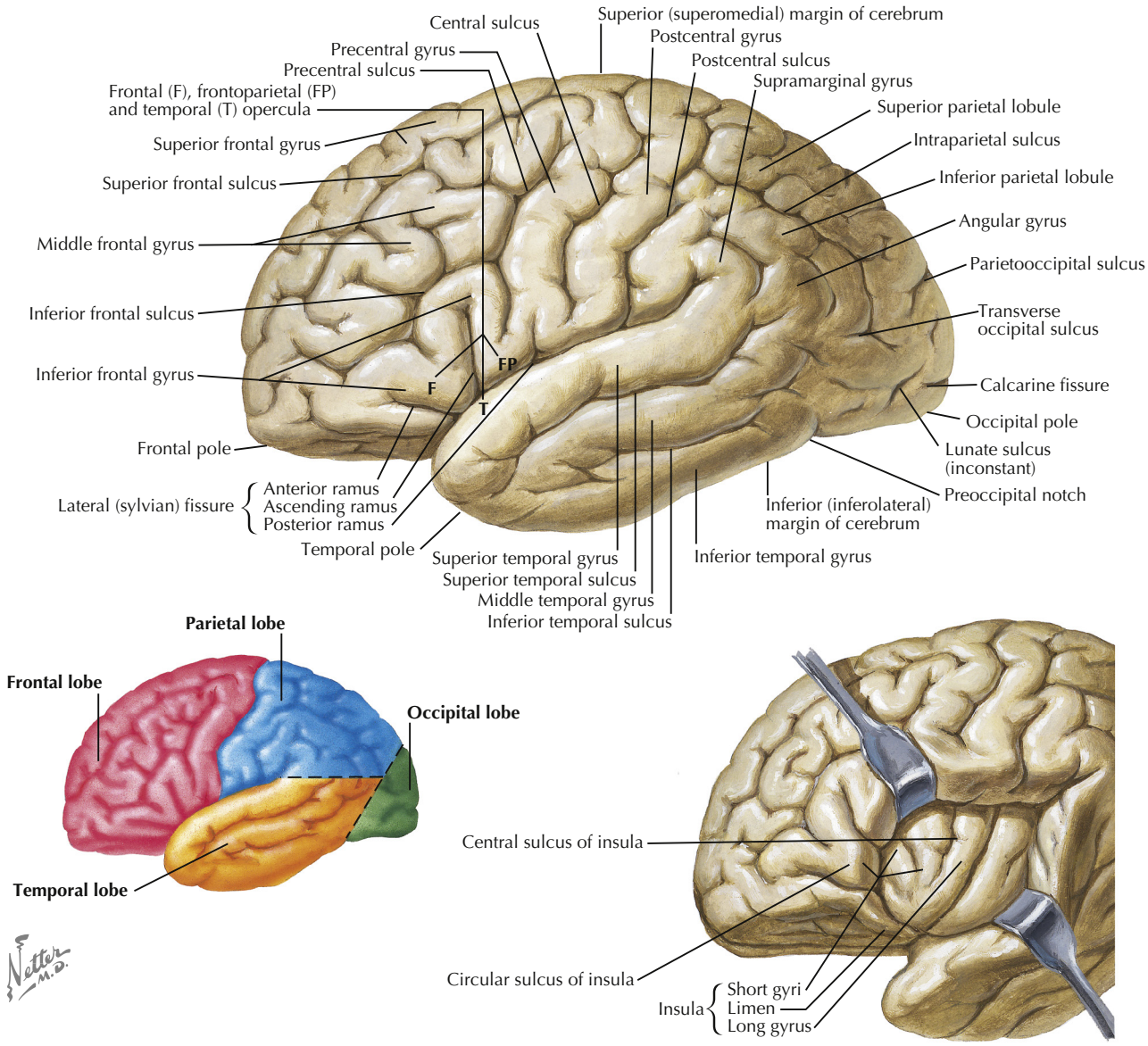
3

BRAIN

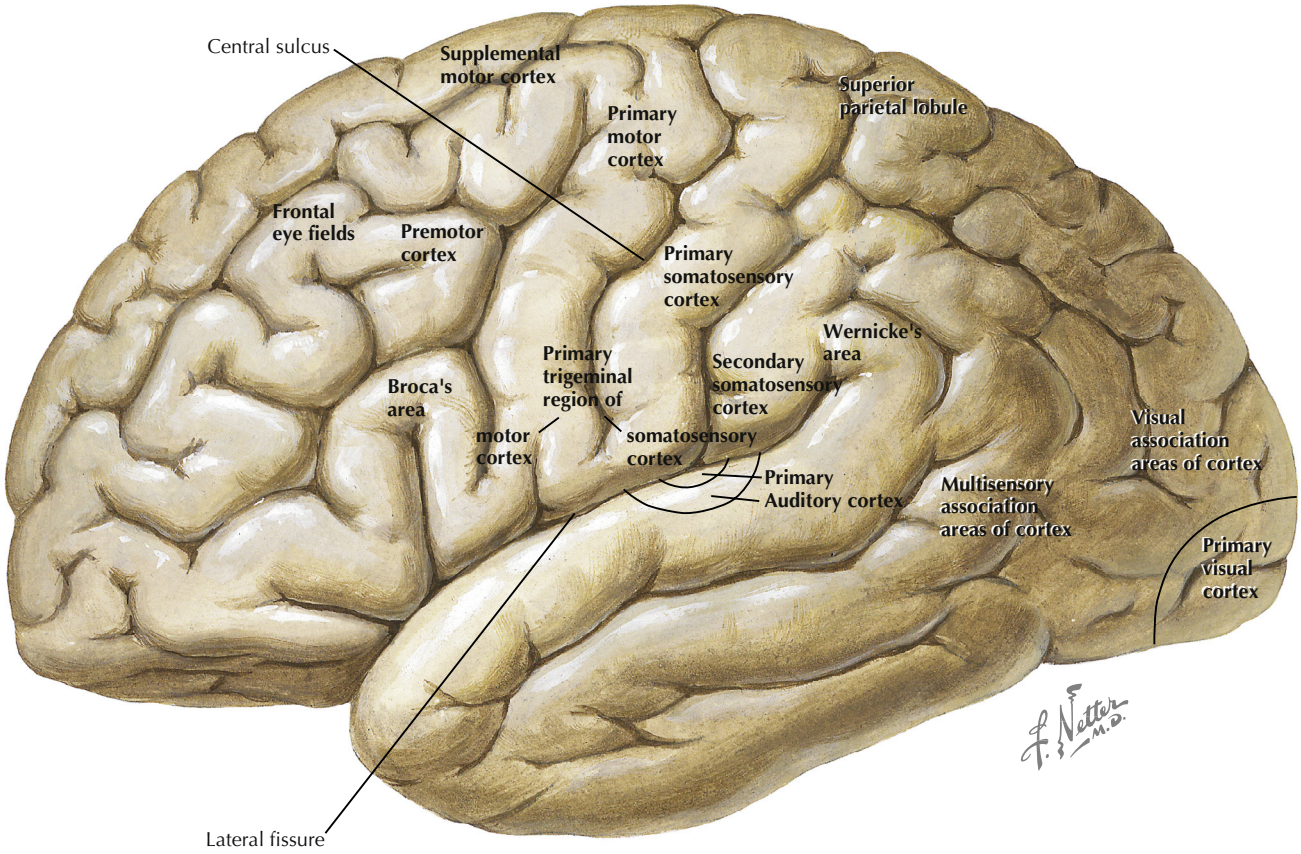


3.1 SURFACE ANATOMY OF THE FOREBRAIN: LATERAL VIEW

The convolutions of the cerebral cortex permit a large expanse of cortex to be compactly folded into a small volume, an adaptation particularly prominent in primates. Major dependable landmarks separate the forebrain into lobes; the lateral (sylvian) fissure separates the temporal lobe below from the parietal and frontal lobes above, and the central sulcus separates the parietal and frontal lobes from each other. Several of the named gyri are associated with specific functional activities, such as the precentral gyrus (motor cortex) and the postcentral gyrus (primary sensory cortex). Some gyri, such as the superior, middle, and inferior frontal and temporal gyri, serve as anatomical landmarks of the cerebral cortex. The insula, the fifth lobe of the cerebral cortex, is deep to the outer cortex and can be seen by opening the lateral fissure.

CLINICAL POINT

Some **functional characteristics of the cerebral cortex**, such as long-term memory and some cognitive capabilities, cannot be localized easily to a particular gyrus or region of cortex. However, other functional capabilities are regionally localized. For example, the inferior frontal gyrus on the left contains the neuronal machinery for expressive language capabilities; the occipital pole, particularly along the upper and lower banks of the calcarine fissure, is specialized for visual processing from the retino-geniculo-calcarine system. Some very discrete lesions in further processing sites such as vision-related regions of the temporal lobe can result in specific deficits, such as agnosia for the recognition of faces or the inability to distinguish animate objects. This knowledge provides some clues about how feature extraction in sensory systems might be achieved in neuronal networks.

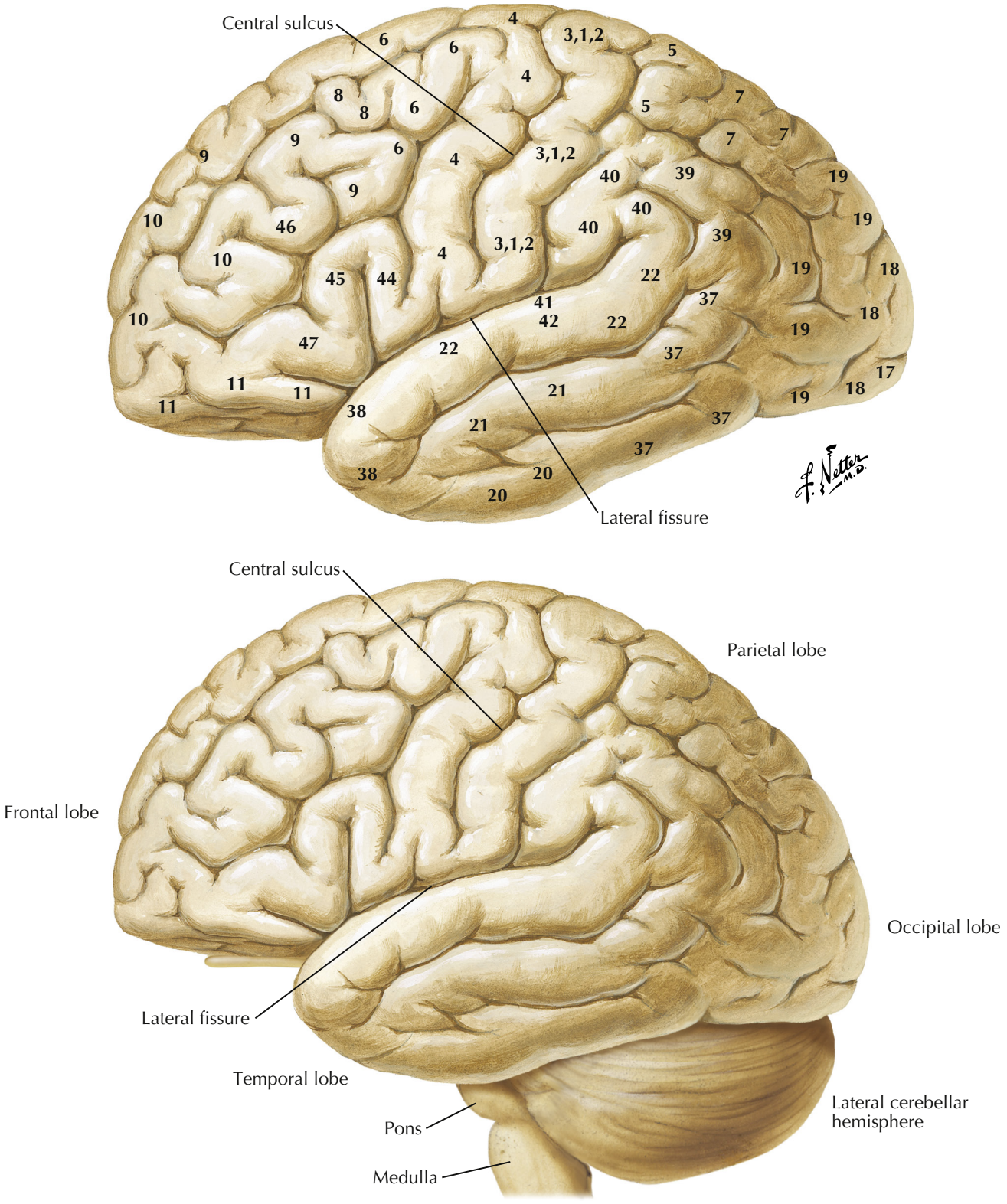


3.2 LATERAL VIEW OF THE FOREBRAIN: FUNCTIONAL REGIONS

Some circumscribed regions of the cerebral hemisphere are associated with specific functional activities, including the motor cortex, the supplemental and premotor cortices, the frontal eye fields, the primary sensory cortex, and other association regions of the sensory cortex. Part of the auditory cortex is visible at the inferior edge of the lateral fissure (the transverse temporal gyrus of Heschl). Part of the visual cortex is visible at the occipital pole. Language areas of the left hemisphere include Broca's area (expressive language) and Wernicke's area (receptive language). Damage to these cortical regions results in loss of specific functional capabilities. There is some overlap between functional areas and named gyri (e.g., the motor cortex and the precentral gyrus), but there is no absolute concordance.

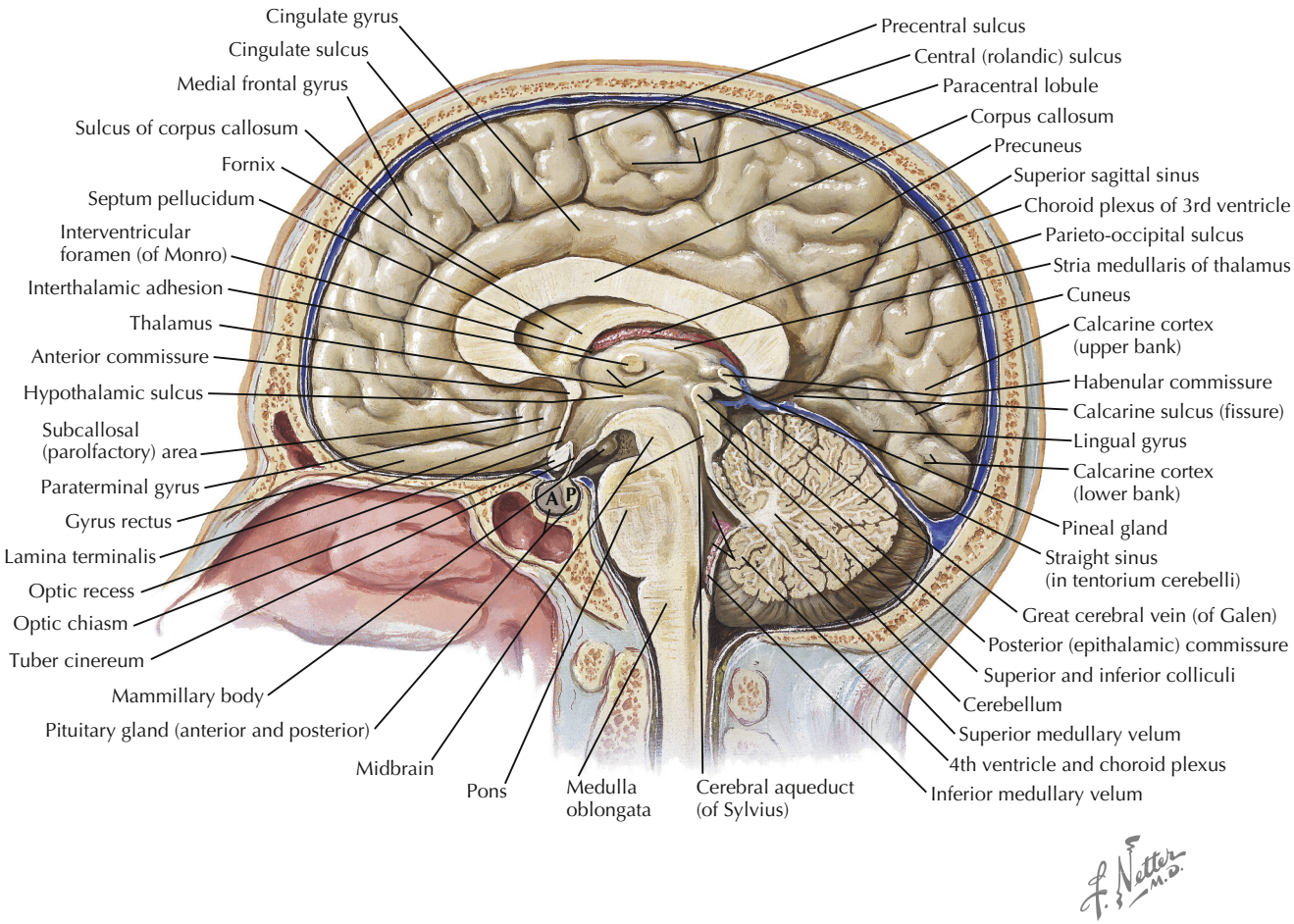
CLINICAL POINT

Some **specific regions (gyri) of the cerebral cortex**, such as the precentral gyrus (primary motor cortex) and the postcentral gyrus (primary somatosensory cortex), demonstrate topographic organization. Thus, information from the contralateral hand and arm is localized laterally, the body is represented more medially, and the lower extremity is represented along the midline and over the edge into the paracentral lobule. The face and head are represented in far lateral regions of these gyri, just above the lateral fissure. This has important functional implications; damage to selected regions such as the midline territory, which is supplied with blood from the anterior cerebral artery, results in somatosensory loss and paresis in the contralateral lower extremity, while sparing the upper extremity.



3.3 LATERAL VIEW OF THE FOREBRAIN: BRODMANN'S AREAS

Brodmann's areas of the cerebral cortex have unique architectural characteristics in terms of the thickness and layering of the cerebral cortex; this knowledge is based on histological observations originally made by Korbinian Brodmann in 1909. His numbering of cortical areas is still used as a shorthand for describing the functional regions of the cortex, particularly those related to sensory functions. Some overlap exists among functional areas. For example, the motor cortex is area 4; the primary sensory cortex includes areas 3, 1, and 2; and the primary visual cortex is area 17. In this lateral view, the lateral surface of the spinal cord, medulla, and caudal pons can be seen, as well as the lateral surface of the cerebellum. The temporal lobe overlies the more rostral portions of the brainstem.

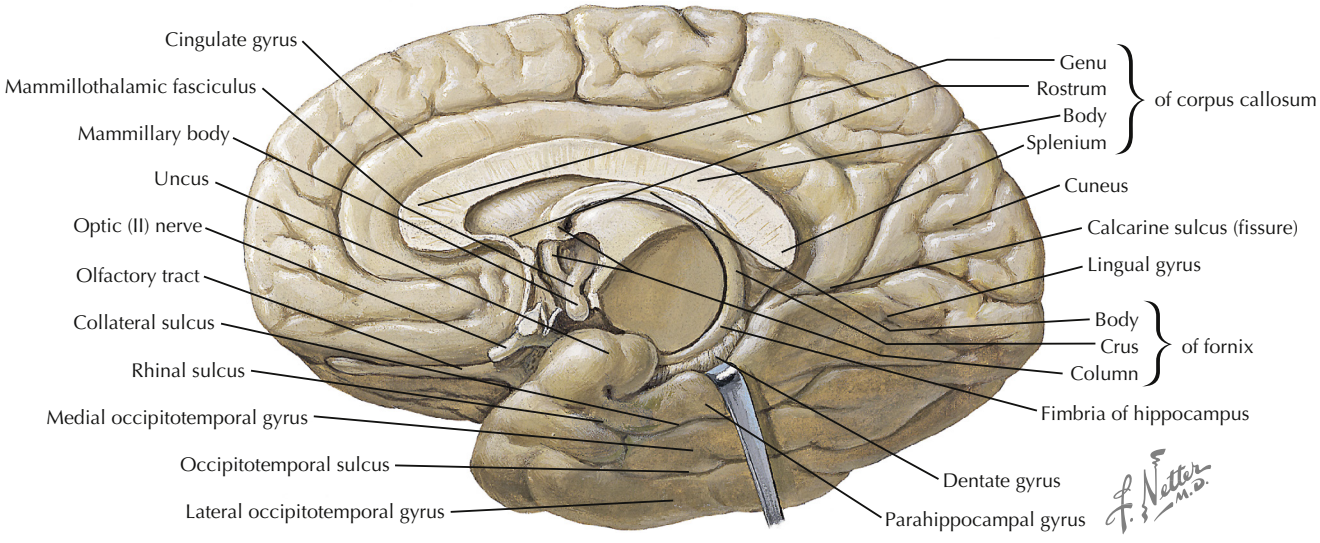


3.4 ANATOMY OF THE MEDIAL (MIDSAGITTAL) SURFACE OF THE BRAIN IN SITU

The entire extent of the neuraxis, from the spinomedullary junction through the brainstem, diencephalon, and telencephalon, is visible in a midsagittal section. The corpus callosum, a major commissural fiber bundle interconnecting the two hemispheres, is a landmark separating the cerebral cortex above from the thalamus, fornix, and subcortical forebrain below. The ventricular system, including the interventricular foramen (of Munro); the third ventricle (diencephalon); the cerebral aqueduct (midbrain); and the fourth ventricle (pons and medulla), is visible in a midsagittal view. This subarachnoid fluid system provides internal (the ventricular system) and external (cerebrospinal fluid in the subarachnoid space) protection to the brain and also may serve as a fluid transport system for important regulatory molecules. The thalamus serves as a gateway to the cortex. The hypothalamic proximity to the median eminence (tuber cinereum) and the pituitary gland reflects the important role of the hypothalamus in regulating neuroendocrine function. A midsagittal view also reveals the midbrain colliculi, sometimes called the visual (superior) and auditory (inferior) tecta. See Video 3.1.

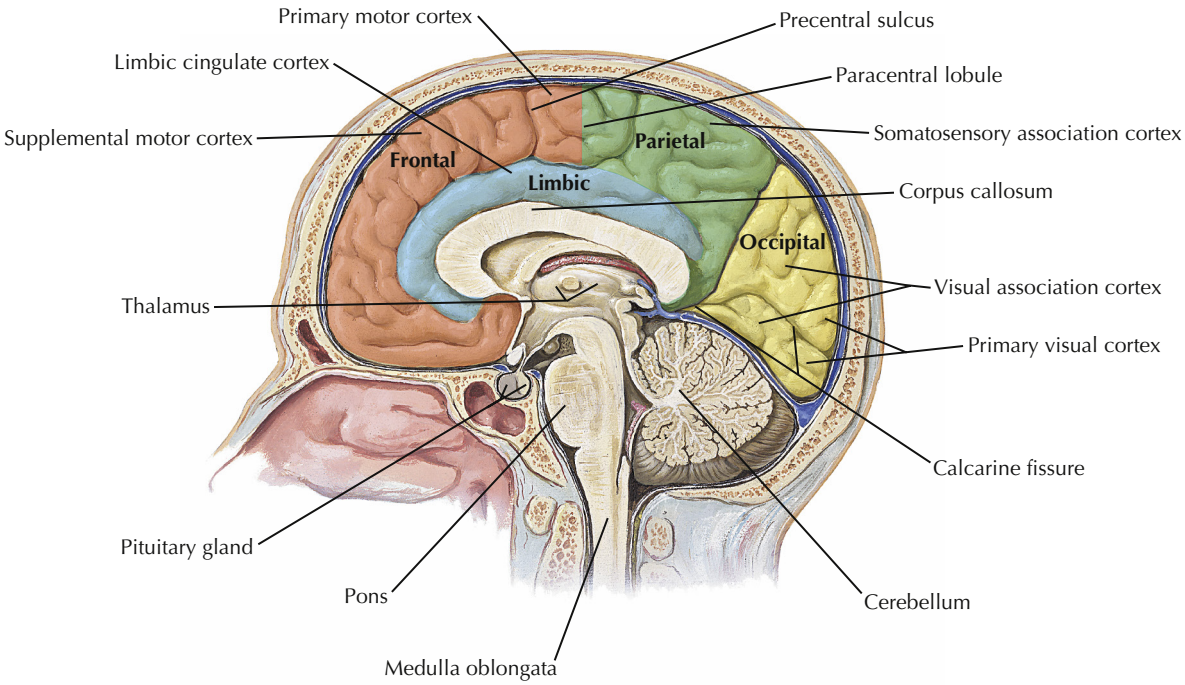
CLINICAL POINT

The right and left hemispheres are interconnected by **commissural fiber bundles**. The largest is the corpus callosum, which interconnects all lobes with their counterparts. The anterior commissure interconnects regions of the temporal lobes. When these commissural fiber bundles are disconnected (split brain), the hemispheres do not know what their counterparts are doing, and inputs to one hemisphere cannot produce an appropriate response from the opposite hemisphere. With a split brain, only a more generalized recognition of mood states occurs between the two hemispheres, presumably communicated through interconnections between lower structures, such as the diencephalon and brainstem.

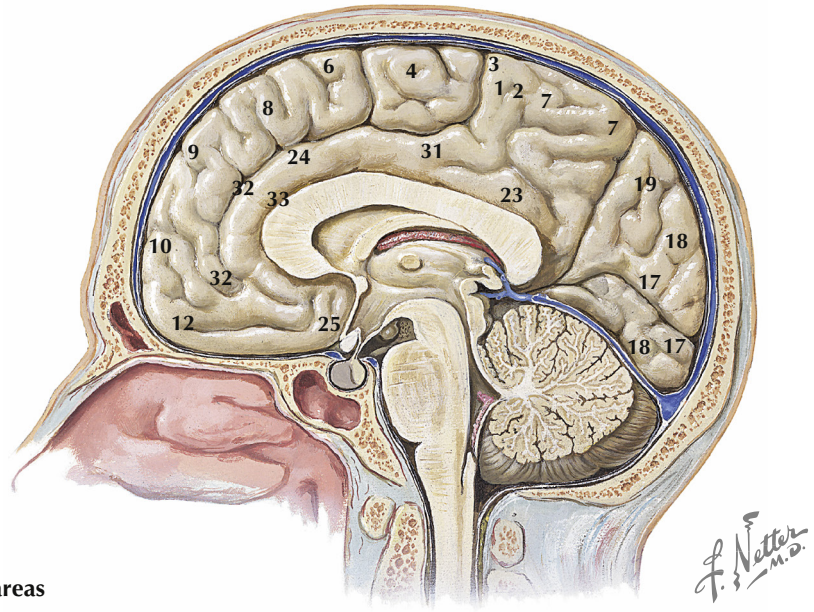


3.5 ANATOMY OF THE MEDIAL (MIDSAGITTAL) SURFACE OF THE BRAIN, WITH BRAINSTEM REMOVED

When the brainstem is removed, a midsagittal view reveals the C-shaped course of the fornix, extending from the hippocampal formation in the temporal lobe to the septum and hypothalamus. Temporal lobe structures, such as the parahippocampal cortex, the dentate gyrus and fimbria of the hippocampus, and the uncus (olfactory cortex) also are visible. In the hypothalamus, the caudal mammillary bodies and the interconnecting pathway to the thalamus, the mammillothalamic tract, are revealed.



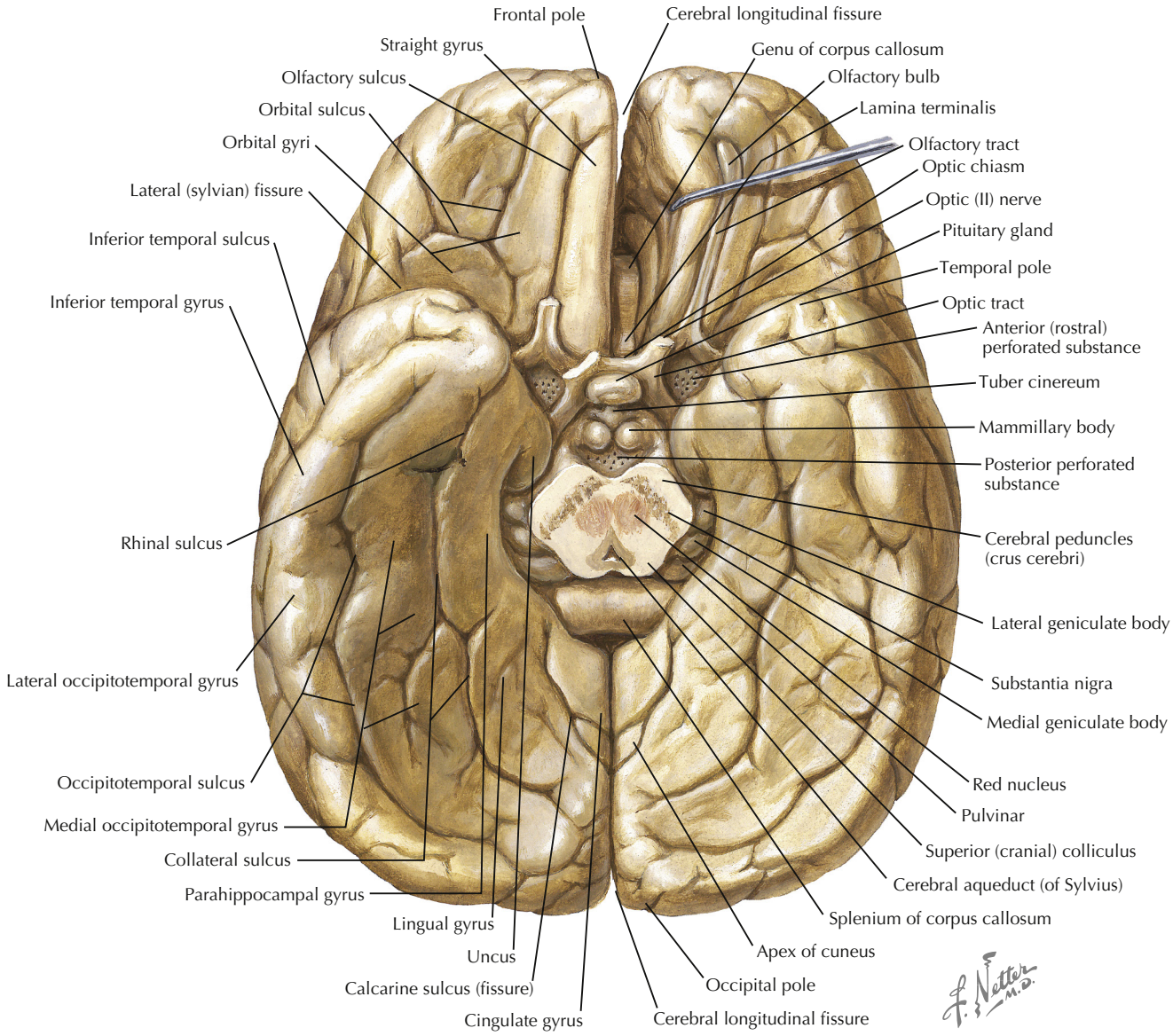
A. Lobes and functional areas



B. Brodmann's areas

3.6 MEDIAL SURFACE OF THE BRAIN

A, Lobes and functional areas. The cingulate cortex is labeled the limbic lobe, reflecting its association with other limbic forebrain structures and with hypothalamic control of the autonomic nervous system. Functional areas of the cortex, particularly those involved with vision, are best seen on a midsagittal view. The sensory and motor cortices associated with the lower extremities are located medially and are supplied with blood by the anterior cerebral artery. This region is selectively vulnerable to specific vascular (anterior cerebral artery infarct) and mass (parasagittal meningioma) lesions that result in contralateral motor and sensory deficits of the lower extremity. **B,** Brodmann's areas of the cerebral cortex are labeled on this midsagittal view of the brain. The major regions are the primary (17) and associative (18, 19) visual cortices and the continuation of areas 4 (motor) and areas 3, 1, and 2 (primary sensory) onto the paracentral lobule in the midline.



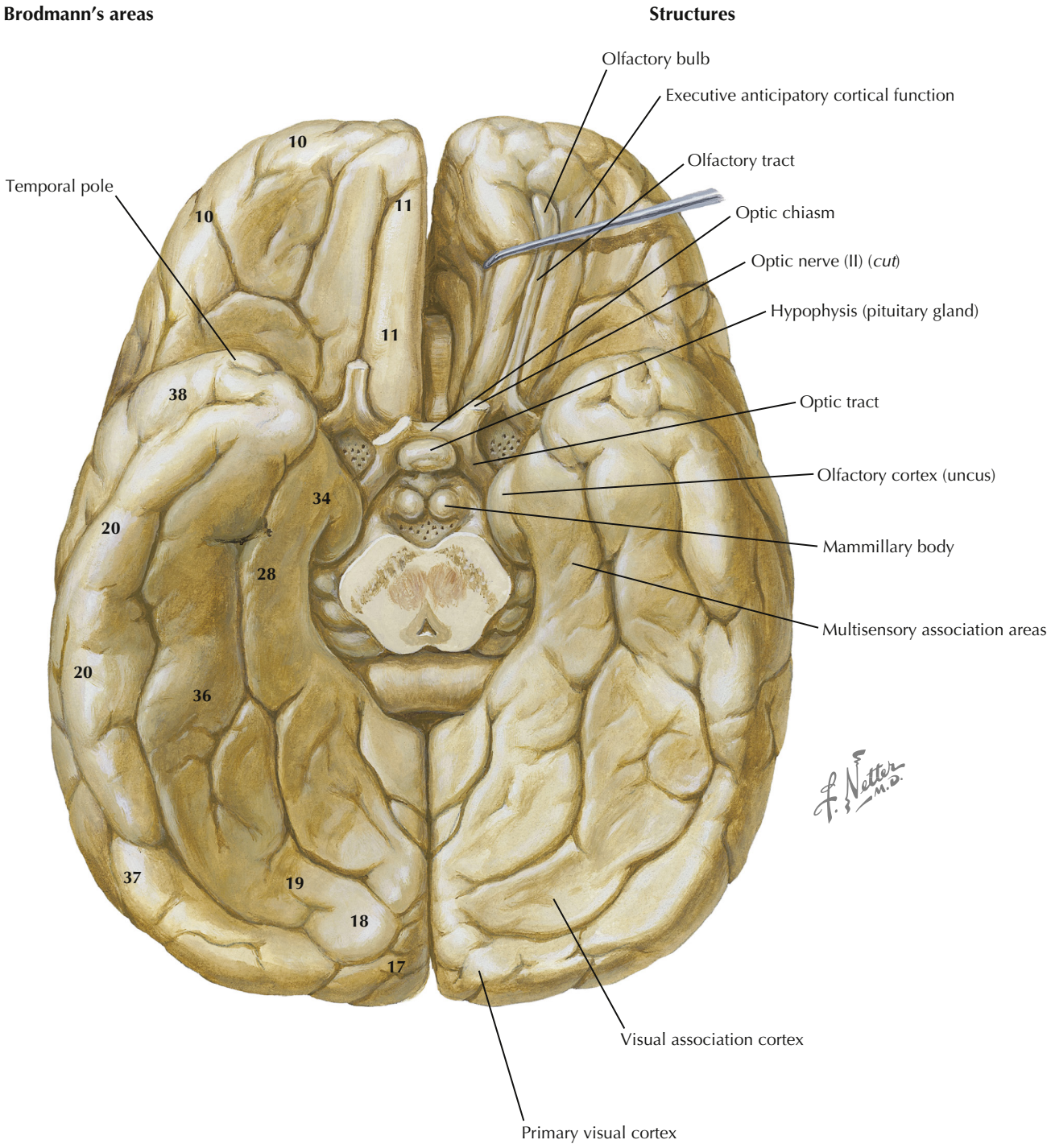
3.7 ANATOMY OF THE BASAL SURFACE OF THE BRAIN, WITH THE BRAINSTEM AND CEREBELLUM REMOVED

Removal of the brainstem and cerebellum by a cut through the midbrain exposes the underlying cerebral cortex, the base of the diencephalon, and the basal forebrain. Basal hypothalamic landmarks, from caudal to rostral, include the mammillary bodies, tuber cinereum, pituitary gland, and optic chiasm. The proximity of the pituitary to the optic chiasm is important because bitemporal hemianopsia can result from optic chiasm fiber damage, often an early sign of a pituitary tumor. The genu and splenium of the corpus callosum are revealed in this view. In the cross-section of the midbrain, the superior colliculus, cerebral aqueduct, periaqueductal gray, red nucleus, substantia nigra, and cerebral peduncles are shown.

CLINICAL POINT

The **olfactory bulb and tract** send connections directly into limbic forebrain structures, such as the uncus (the primary olfactory cortex), amygdala, and other limbic regions. This is the only sensory system with direct access to forebrain structures without prior screening through the diencephalon. This reflects the evolutionary importance of olfaction to functions vital for survival, such as detection of food, defense, and reproduction. Olfactory damage can alter emotional behavior. In addition, complex partial seizures involving the temporal lobe frequently are accompanied by an olfactory aura. Changes in olfactory function and gene expression may be among the earliest signs of Alzheimer's disease.

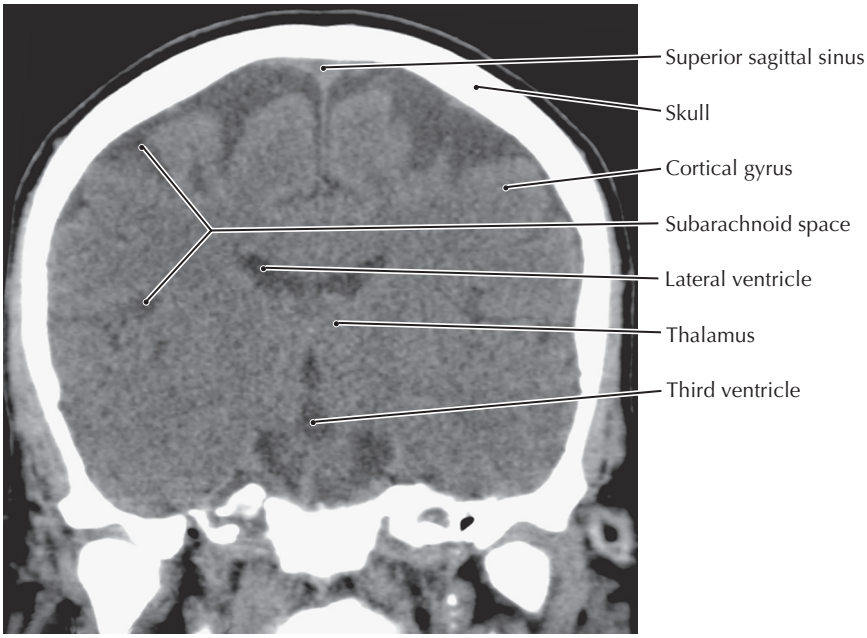
The **optic nerve, chiasm, and tract** can be seen extending toward the lateral geniculate body (nucleus), the pulvinar, and the superior colliculus. Optic nerve damage can result in ipsilateral blindness; optic chiasm damage can result in bitemporal visual field deficits; and optic tract damage can result in contralateral hemianopsia. Additional visual input from the optic tract enters the hypothalamus and ends in the suprachiasmatic nucleus. This visual input conveys information of total light flux and exposure, permitting visual influence over diurnal rhythms such as the cortisol rhythm. Disruption of this diurnal input can produce altered production of hormones such as melatonin, and metabolic consequences such as the propensity for abdominal obesity resulting from disruption of the diurnal cortisol rhythm.

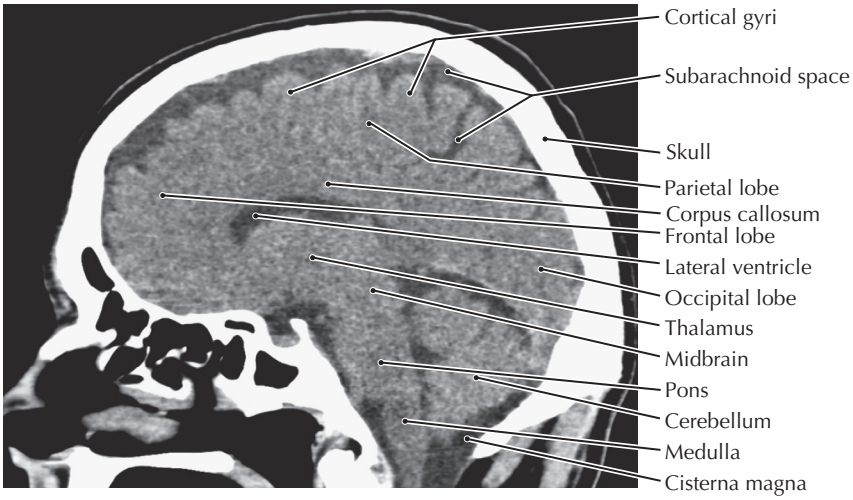


3.8 BASAL SURFACE OF THE BRAIN: FUNCTIONAL AREAS AND BRODMANN'S AREAS

This view provides information about the medial temporal lobe on the left side of the brain, especially cortical regions associated with the hippocampal formation, the amygdaloid nuclei, and the olfactory system. On the right side of the brain, Brodmann's areas are noted.

A. Coronal view



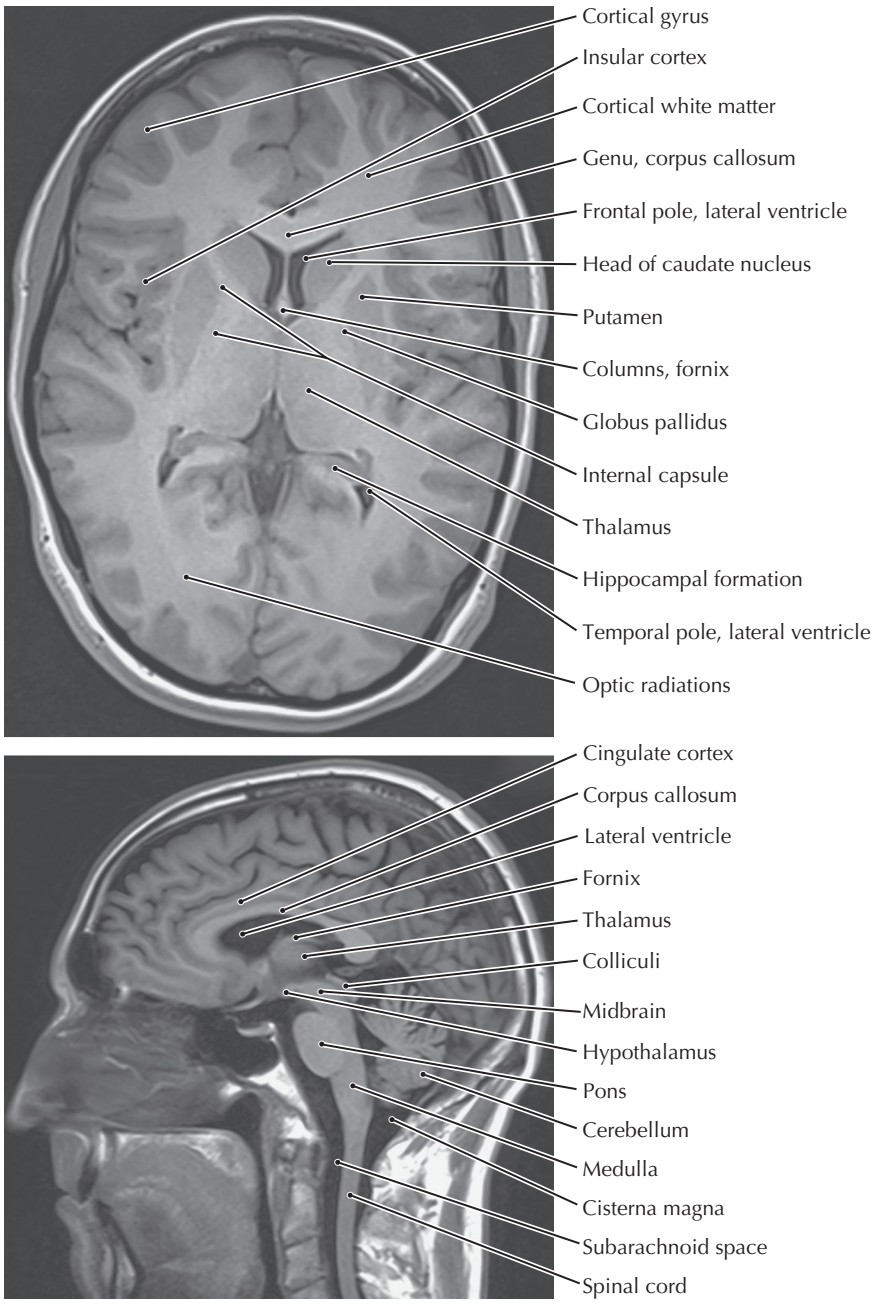


B. Sagittal view

3.9 BRAIN IMAGING: COMPUTED TOMOGRAPHY SCANS, CORONAL AND SAGITTAL

A and **B,** Computed tomography (CT) is an x-ray-based imaging approach that is used to view the brain, particularly when looking for differences in tissue density such as the presence of blood. The use of spiral (helical) scanners can quickly provide access to views of slices through the brain at a desired thickness. CT delineates soft tissue, fluid, and bone and can be used with contrast to image blood vessels or to reveal the presence of a tumor caused by a disrupted blood-brain barrier, which allows leakage of the contrast agent into the surrounding extracellular space of the brain.

A. Axial view

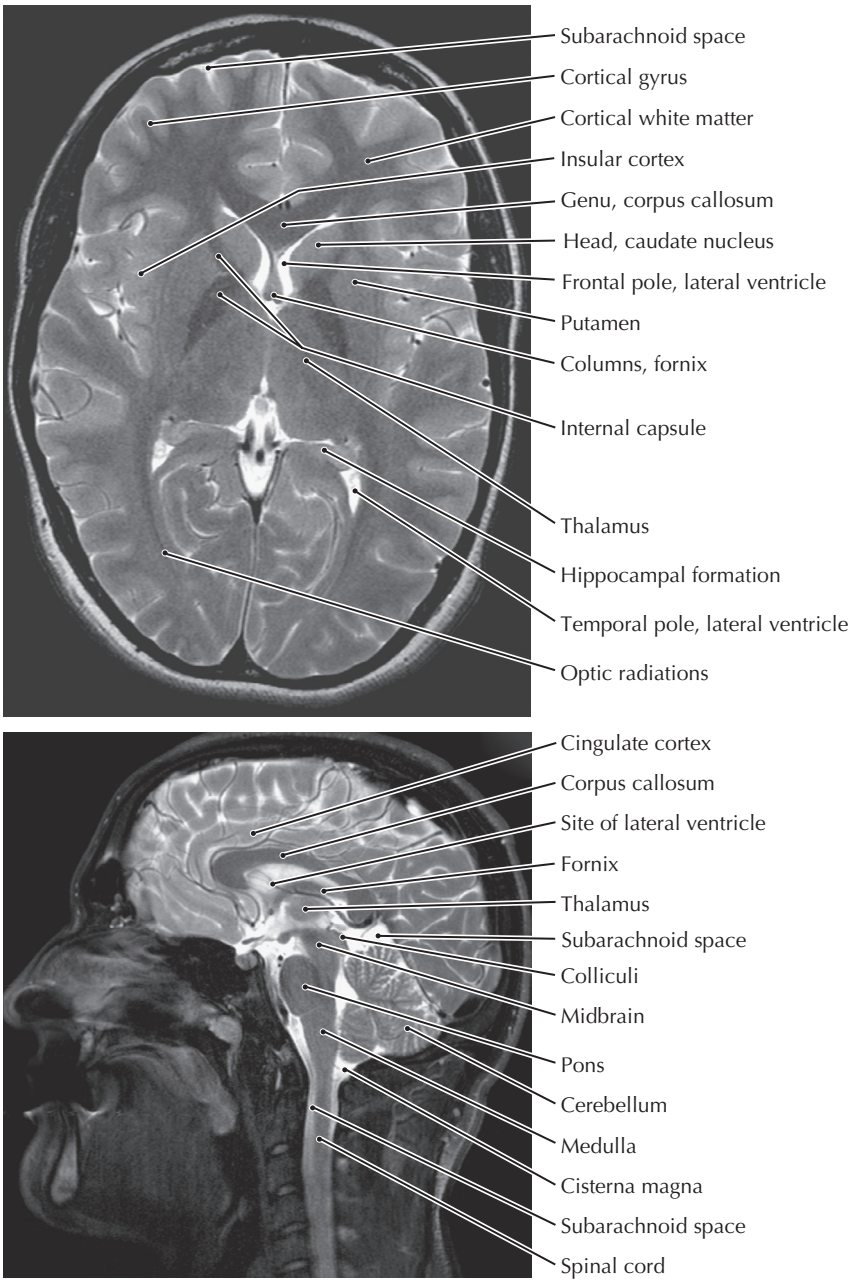


B. Sagittal view

3.10 BRAIN IMAGING: MAGNETIC RESONANCE IMAGING, AXIAL AND SAGITTAL T1-WEIGHTED IMAGES

A, Axial view. **B,** Sagittal view. Magnetic resonance imaging (MRI) uses short bursts (radiofrequency pulses) of electromagnetic waves that are sent into the magnet and are absorbed by protons in the tissues of the patient in the scanner. The pulses cause alignment of the protons as the result of raised energy levels that is followed by a relaxation phase in which the protons return to a lower energy level. During the relaxation process, a detector records the emitted energy, and a computer provides a uniform image of the scanned tissue. The intervals (milliseconds) between the pulses (repetition time, TR) and the intervals between the collection times of the emitted energy (echo time, TE) provide various contrast information, which are indicated by contrast weighting. Short TR and TE intervals result in Tl-weighted images, whereas longer TR and TE intervals result in T2-weighted images. The Tl-weighted images are particularly useful for viewing normal brain structures and are particularly useful for viewing the brainstem and the cervical and thoracic spinal cord. The ventricular system and subarachnoid space in T1-weighted images appear dark. The T2-weighted images are particularly useful for revealing pathology, such as infarcts, tumors, edema, and demyelination. A contrast agent such as gadolinium can be used to delineate a tumor because of its ability to leak across the blood-brain barrier.

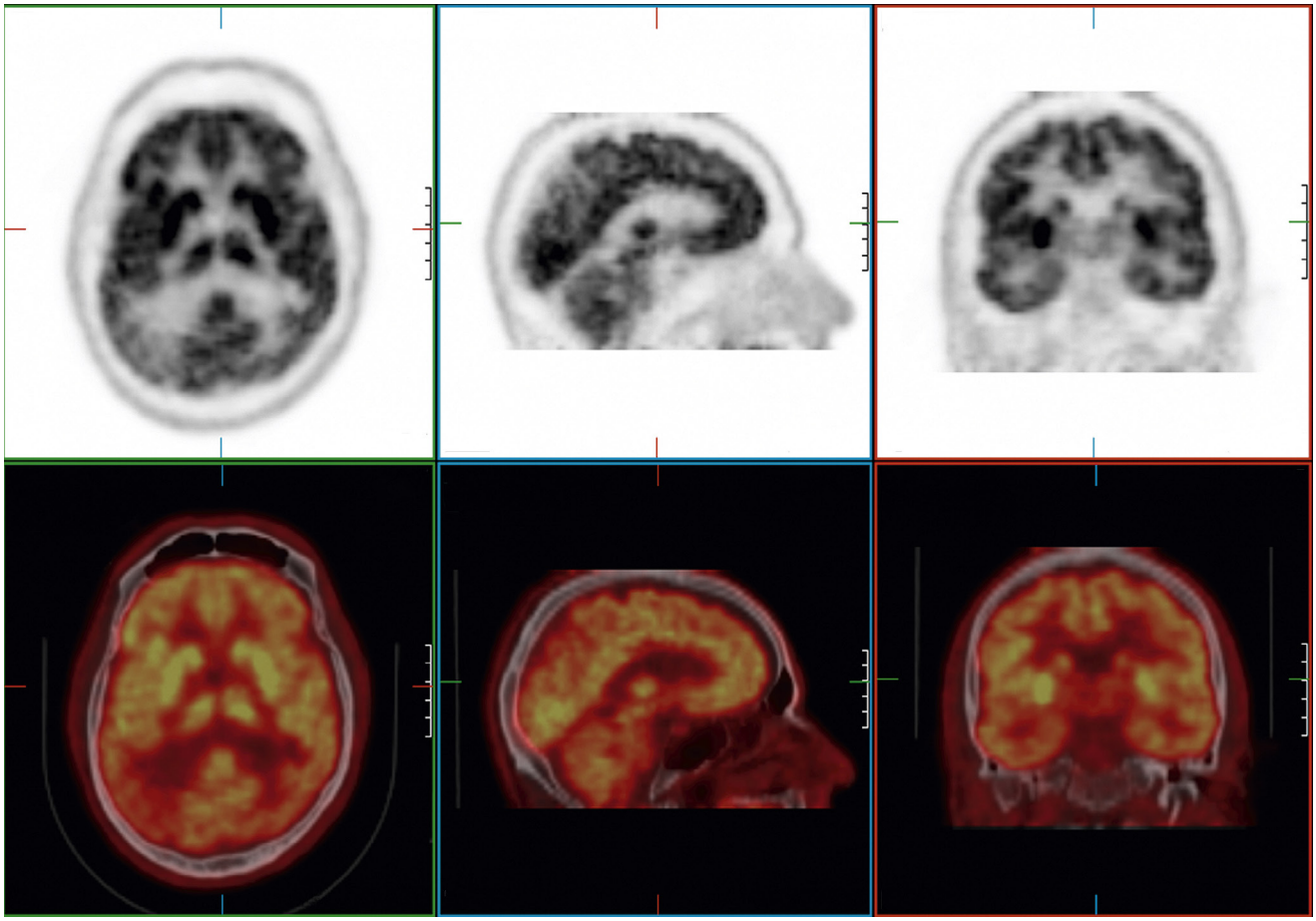
A. Axial view



B. Sagittal view

3.11 BRAIN IMAGING: MAGNETIC RESONANCE IMAGING, AXIAL AND SAGITTAL T2-WEIGHTED IMAGES

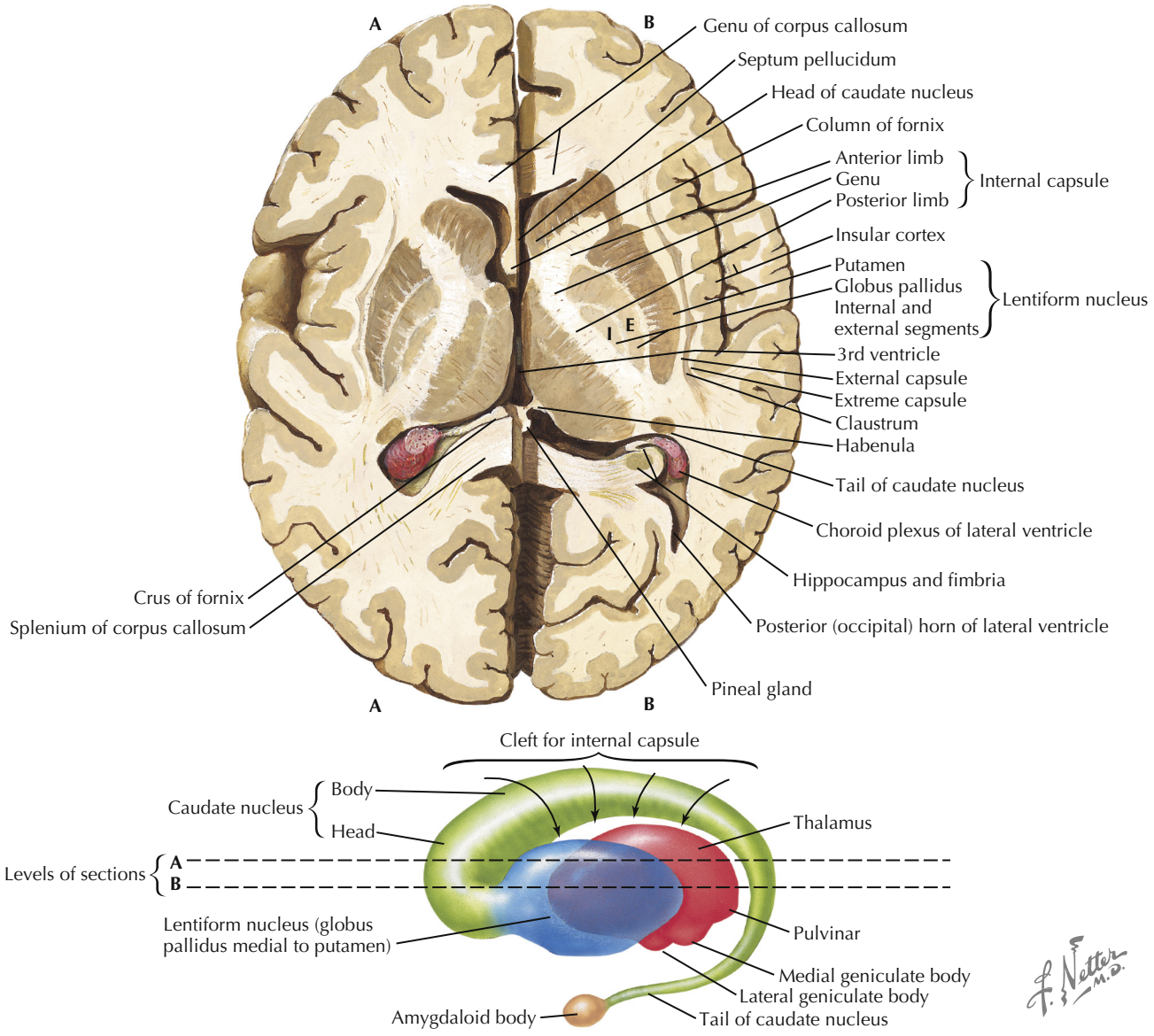
A, Axial view. **B,** Sagittal view. T2-weighted images are particularly useful for imaging the ventricular system and the cisterns of cerebrospinal fluid. The ventricular system and subarachnoid space in T2-weighted images appear white.



3.12 POSITRON EMISSION TOMOGRAPHY SCANNING

Positron emission tomography (PET) scanning is designed to assess the distribution of tracers labeled with positron-emitting nuclides, such as carbon-11 (^{11}C), nitrogen-13 (^{13}N), oxygen-15 (^{15}O), and fluorine-18 (^{18}F). Fluorodeoxyglucose (FDG), a glucose analogue labeled with ^{18}F, can cross the blood-brain barrier. The metabolic products of FDG become immobile and trapped where the molecule is first used, thereby permitting FDG to be used to map glucose uptake in the brain.

This is a valuable tool for investigating subtle physiological processes related to neurological diseases. The distribution of FDG can be localized and reconstructed using standard tomographic techniques that show the tracer distribution throughout the body or brain. In this example of axial, sagittal, and coronal views, the transmission measurement and correction was performed immediately following PET acquisition using a 16-slice CT unit. The PET and CT images were automatically fused by anatomical coregistration software (shown as colored images).



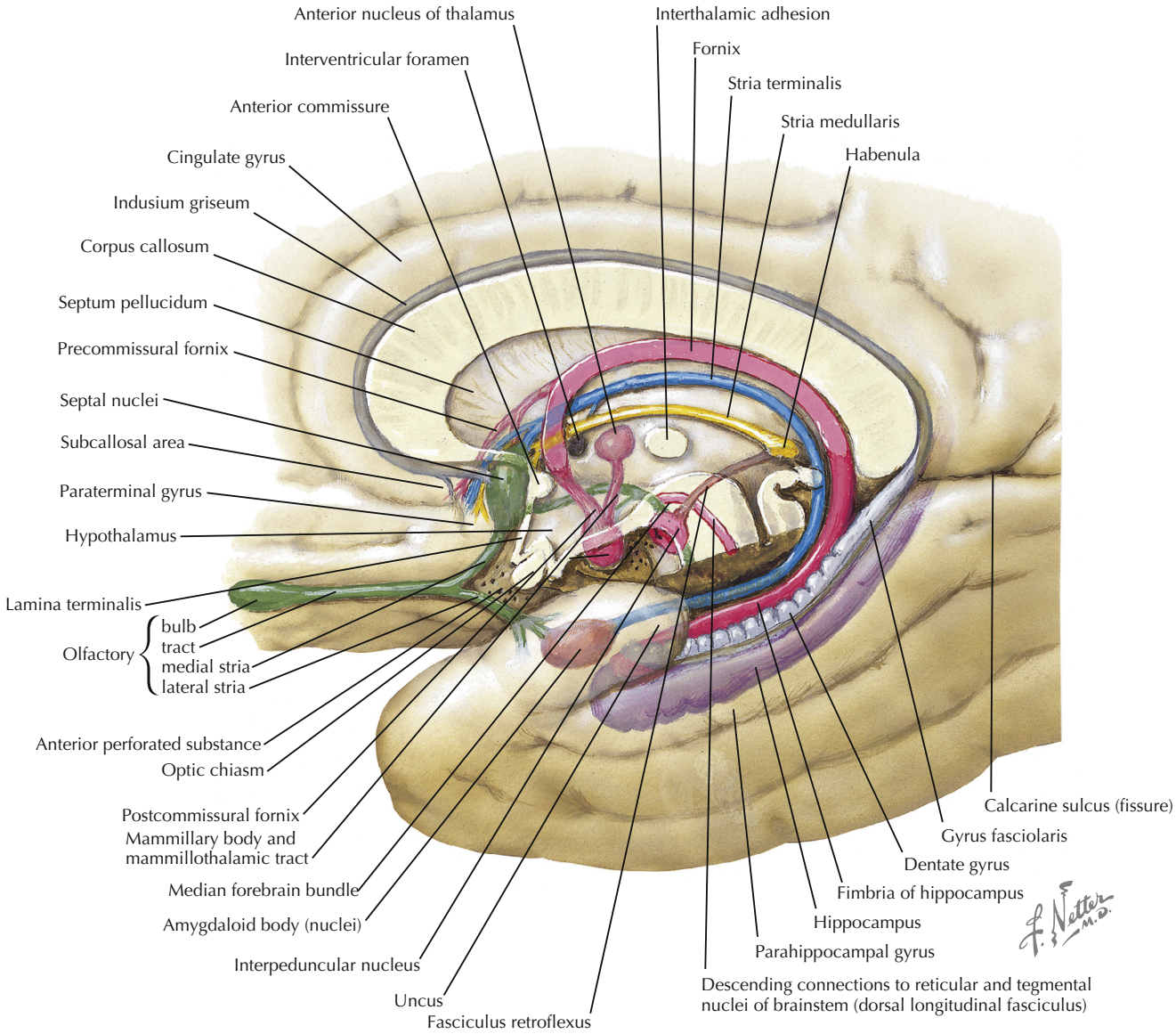
Schematic illustration showing interrelationship of thalamus, lentiform nucleus, caudate nucleus, and amygdaloid body (viewed from side).

3.13 HORIZONTAL BRAIN SECTIONS SHOWING THE BASAL GANGLIA

Two levels of horizontal sections through the forebrain reveal the major anatomical features and the relationships among the basal ganglia, the internal capsule, and the thalamus (schematically shown in the lower illustration). The caudate nucleus is a C-shaped structure that sweeps from the frontal lobe into the temporal lobe; a horizontal section passes through this nucleus in two distinct places (head and tail). The anterior limb, genu, and posterior limb of the internal capsule contain major connections into and out of the cerebral cortex. The head and body of the caudate are medial to the anterior limb, whereas the thalamus is medial to the posterior limb. These relationships are important for understanding imaging studies and for understanding the involvement of specific functional systems in vascular lesions or strokes. The internal and external segments of the globus pallidus are located medial to the putamen. The external capsule, claustrum, extreme capsule, and insular cortex, from medial to lateral, are located lateral to the putamen. The fornix, also a C-shaped bundle, is sectioned in two sites, the crus and the column.

CLINICAL POINT

The **basal ganglia** (caudate nucleus, putamen, and globus pallidus) form characteristic anatomical relationships with the internal capsule. The head and body of the caudate nucleus are found medial to the anterior limb; the thalamus is found medial to the posterior limb; and the globus pallidus and putamen are found lateral to the anterior and posterior limbs. Basal ganglia disorders are characterized by movement disorders, although emotional and cognitive symptoms also are seen. Some movement disorders involve actual degeneration of basal ganglia and related structures; these disorders include Huntington's chorea and degeneration of the head of the caudate nucleus as well as Parkinson's disease and degeneration of the dopaminergic pars compacta of substantia nigra. Other movement disorders involve altered inhibitory and excitatory activity of specific portions of basal ganglia circuitry; reordering this circuitry may require pharmacologic treatment, therapeutic ablation procedures, or deep brain stimulation.



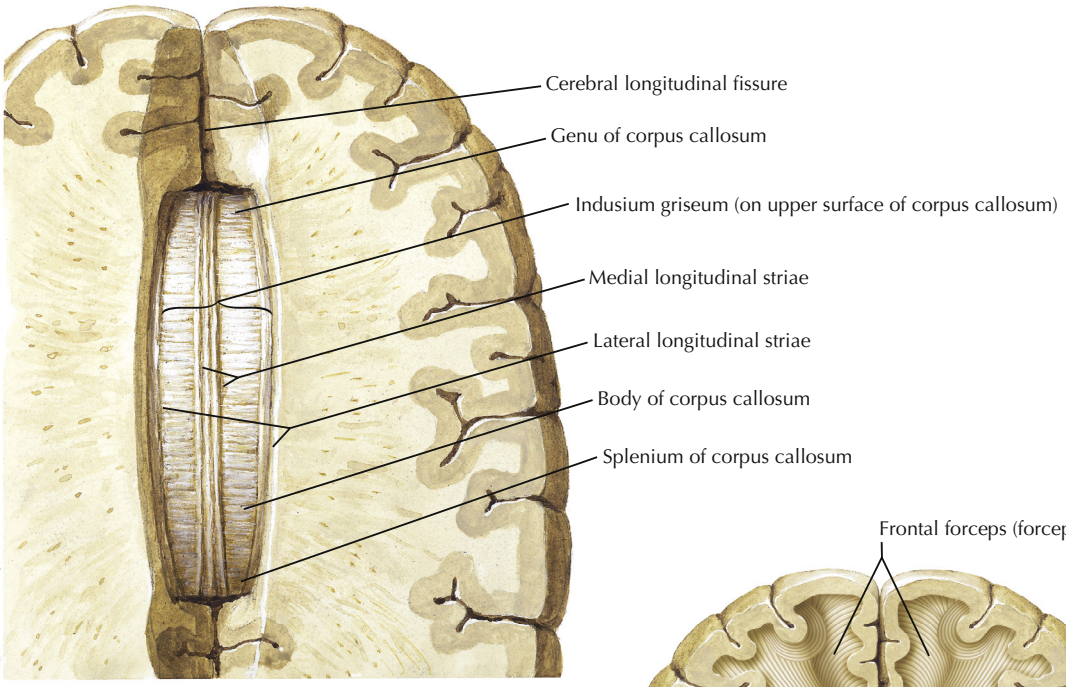
3.14 MAJOR LIMBIC FOREBRAIN STRUCTURES

The term *limbic* is derived from *limbus,* meaning ring. Many of these structures and their pathways in the limbic system form a ring around the diencephalon. They are involved in emotional behavior and individualized interpretations of external and internal stimuli. The hippocampal formation and its major pathway, the fornix, curve into the anterior pole of the diencephalon, forming precommissural (to the septum) and postcommissural (to the hypothalamus) connections in relation to the anterior commissure. The amygdaloid nuclei give rise to several pathways; one, the stria terminalis, extends in a C-shaped course around the diencephalon into the hypothalamus and basal forebrain. The olfactory tract communicates directly with several limbic forebrain areas; it is the only sensory system to entirely bypass the thalamus and terminate directly in cortical and subcortical zones of the telencephalon. Connections from the septal nuclei to the habenula (stria medullaris thalami) connect the limbic forebrain to the brainstem. The amygdaloid nuclei and hippocampus (shaded) are deep to the cortex.

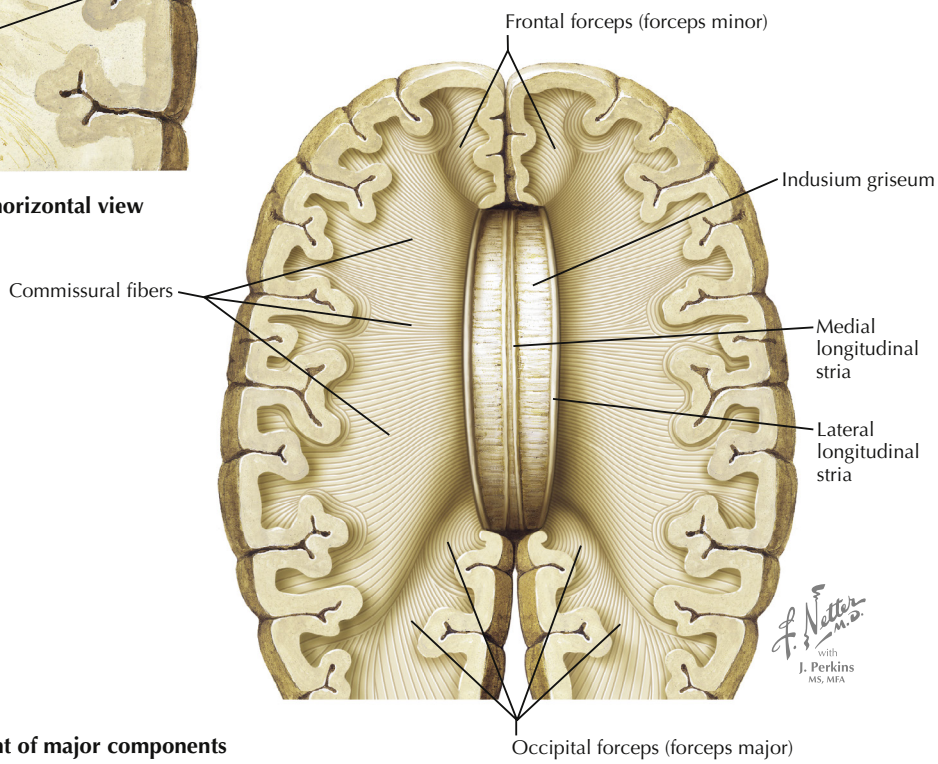
CLINICAL POINT

Many of the **limbic forebrain structures** are connected with the hypothalamus by C-shaped structures, such as the hippocampus and the fornix, and with the amygdala and the stria terminalis. The amygdala has additional direct connections into the hypothalamus via the ventral amygdalofugal pathway. The amygdaloid nuclei receive multimodal sensory information from cortical regions and provide context for this input, particularly emotions related to fear responses. Bilateral amygdaloid damage results in the loss of the fear response and also in failure to recognize facial responses of fear in others.

The hippocampal formation processes abundant information from the temporal lobe, subiculum, and entorhinal cortex and sends connections through the fornix to the hypothalamus and septal nuclei, with subsequent connections through the thalamus to the cingulate cortex. These structures are part of the so-called Papez circuit. The hippocampal formation is particularly vulnerable to ischemia; damage bilaterally results in the inability to consolidate new information into long-term memory. A common pattern may be observed in older persons who forget who has talked with them minutes before or forget what they had for breakfast (or even whether they had breakfast) but can recall details from the past that have some degree of accuracy.



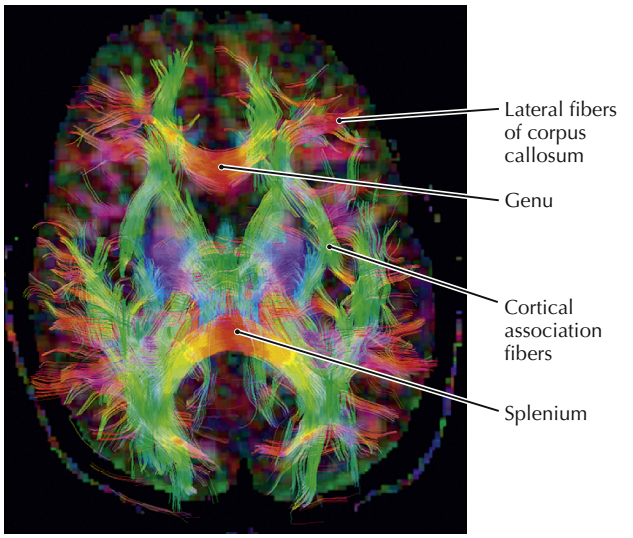
A. Anatomy of the corpus callosum: horizontal view



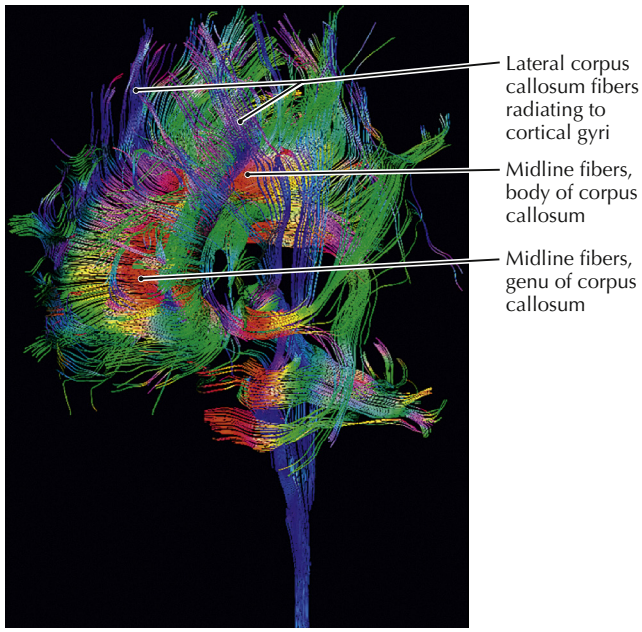
B. Schematic view of the lateral extent of major components

3.15 CORPUS CALLOSUM

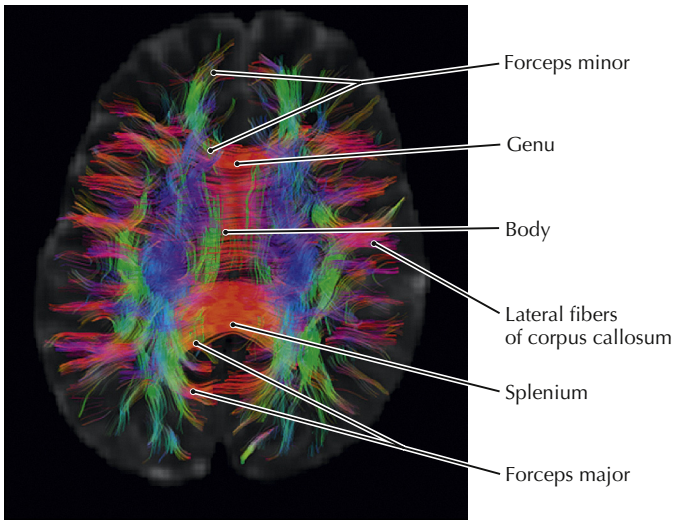
A, Anatomy of the corpus callosum, horizontal view. The corpus callosum, the major fiber commissure between the hemispheres, is a conspicuous landmark in imaging studies. It is viewed from above after dissection of tissue just dorsal to its upper surface. Horizontal cuts taken deeper (more ventrally) section the genu anteriorly and the splenium posteriorly (see Fig. 3.13). **B,** Schematic view of the lateral extent of major components. Many of the commissural fibers of the corpus callosum, particularly the forceps of commissural fibers that interconnect frontal areas with each other and occipital areas with each other, extend rostrally and caudally, respectively, after crossing the midline. These interconnections allow communication between the hemispheres for coordinated activity of these two "separate" hemispheres.



A. Axial view



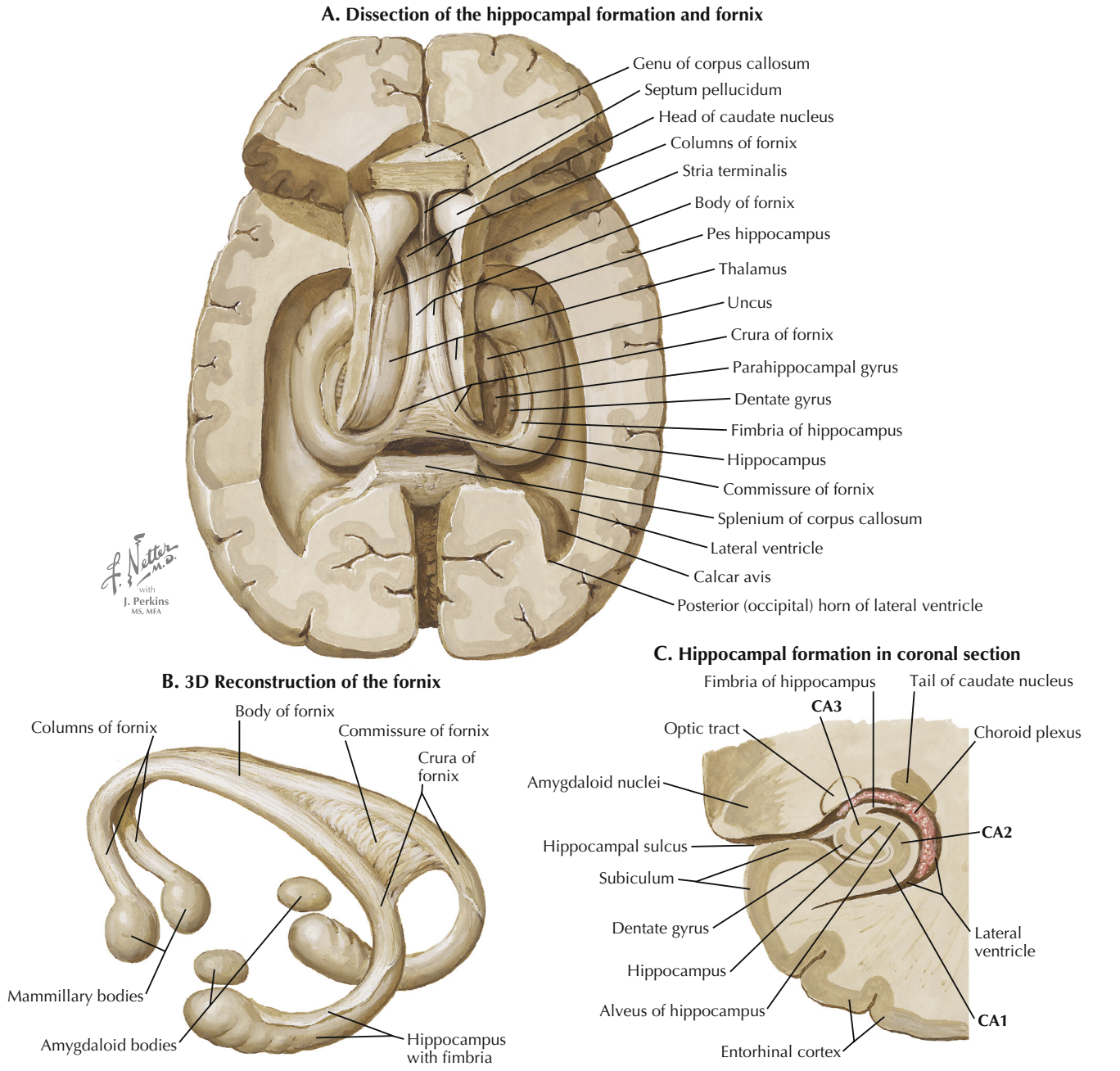
B. Oblique sagittal view



C. Axial view

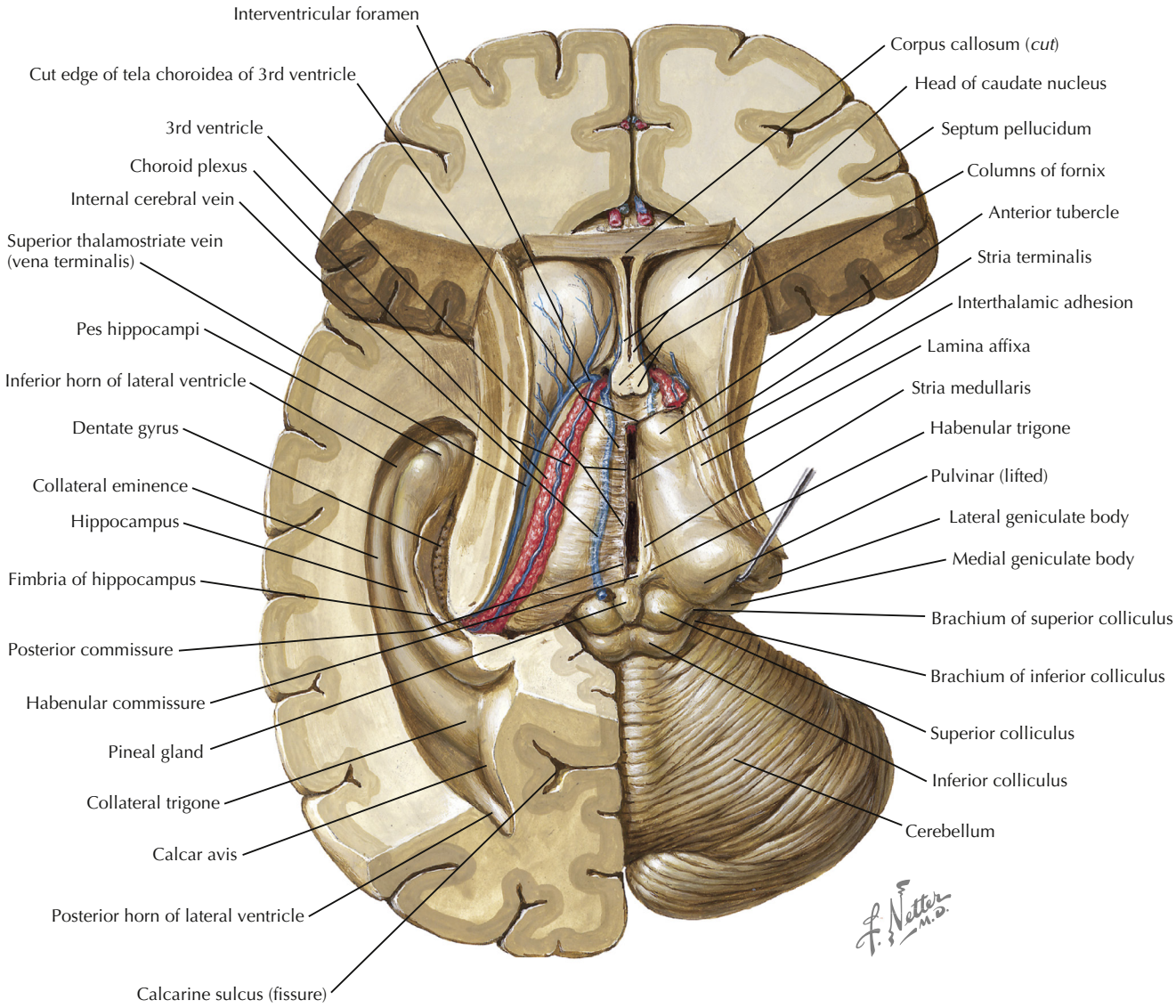
3.16 COLOR IMAGING OF THE CORPUS CALLOSUM BY DIFFUSION TENSOR IMAGING

A–C, Diffusion-weighted imaging (DWI), also called diffusion tensor imaging (DTI), provides unique information about tissue viability, architecture, and cellular function. In many tissues, restricted water diffusion is isotropic or independent of direction. In structured tissues, such as cerebral white matter and peripheral nerves, diffusion is anisotropic because of cellular arrangements. By using diffusion sensitivity that projects in multiple directions, such diffusion can be evaluated in the form of a tensor. Tensor field calculations for six or more diffusion-weighted measurements are based on an analytical solution of the Stejskal and Tanner diffusion equation system. Diffusion tensor imaging permits reconstruction of axonal tracts in brain and spinal cord; the three-dimensional architecture of the white matter tracts can be traced based on eigenvectors of the diffusion tensor. To discriminate fiber bundles that radiate in different directions, a color scheme is adopted in which green represents eigenvectors pointing in anteroposterior directions; red represents eigenvectors radiating in left-right directions; and blue represents eigenvectors pointing in the superoinferior direction. In these images of the corpus callosum, components of this major commissural bundle are represented in red. See Video 3.2.



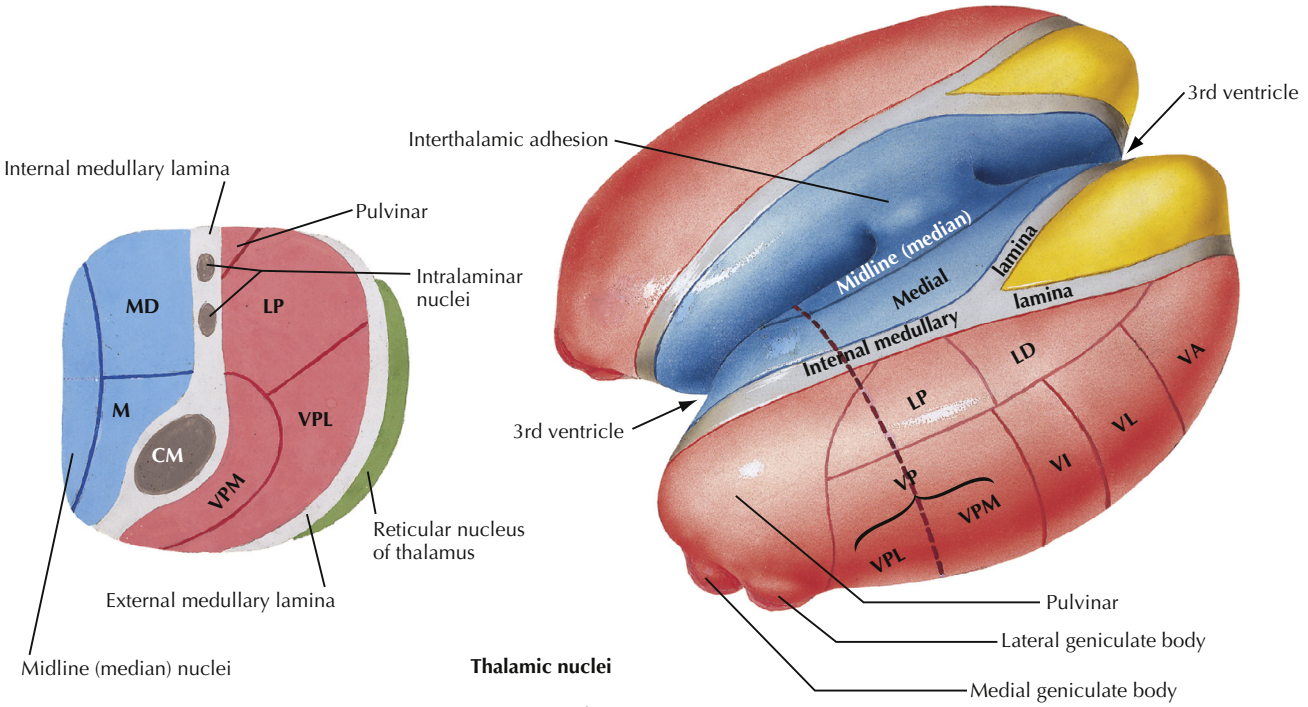
3.17 HIPPOCAMPAL FORMATION AND FORNIX

In this dissection, the cortex, white matter, and corpus callosum have been removed. The lateral ventricles have been opened, and the head of the caudate nucleus and the thalamus have been dissected away quite close to the midline, allowing a downward view of the full extent of the hippocampal formation, including the dentate gyrus and the associated fornix. This view reveals the relationship between the hippocampus proper and the dentate gyrus. The two limbs of the fornix sweep upward medially, eventually running side by side at their most dorsal position, just beneath the corpus callosum. The full extent of this arching, C-shaped bundle is shown in the left lower image. The hippocampal formation occupies a large portion of the temporal pole of the lateral ventricle. The dentate gyrus is adjacent to subcomponents of the cornu ammonis (CA) regions of the hippocampus proper (the CA1 and CA3 regions), the subiculum, and the entorhinal cortex). Pyramidal neurons in the CA1 region are particularly sensitive to ischemic damage, and their counterparts in the CA3 region are sensitive to damage from high levels of corticosteroids (cortisol). Damage to pyramidal cells in both regions that has been caused by ischemia and/or high levels of corticosteroids is synergistic.



3.18 THALAMIC ANATOMY

The thalamus is viewed from above. The entire right side of the brain, just lateral to the thalamus, has been removed, the head of the caudate nucleus has been sectioned, the corpus callosum and all tissue dorsal to the thalamus have been removed, and the third ventricle has been opened from its dorsal surface. The pineal gland is present in the midline, just caudal to the third ventricle; it produces melatonin, a hormone that helps regulate circadian rhythms, sleep, and immune responses. The superior and inferior colliculi are shown, depicting the dorsal surface of the midbrain. On the left, the temporal horn of the lateral ventricle, with the hippocampal formation, has been exposed to show the relationship of these structures to the thalamus. The terminal vein and choroid plexus accompany the stria terminalis along the lateral margin of the thalamus. The stria medullaris runs along the medial surface of the dorsal thalamus.



Schematic section through thalamus
(at level of broken line shown in figure at right)

Thalamic nuclei

CM	Centromedian
LD	Lateral dorsal
LP	Lateral posterior
M	Medial group
MD	Medial dorsal
VA	Ventral anterior
VI	Ventral intermedial
VL	Ventral lateral
VP	Ventral posterior (ventrodorsal)
VPL	Ventral posterolateral
VPM	Ventral posteromedial

Schematic representation of thalamus
(external medullary lamina and reticular nuclei removed)

Lateral cell mass
Medial cell mass
Anterior cell mass

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3.19 THALAMIC NUCLEI

The thalamus is subdivided into nuclear groups (medial, lateral, and anterior) that are separated by medullary (white matter) lamina. Many of these thalamic nuclei are "specific" thalamic nuclei that are reciprocally connected with discrete regions of the cerebral cortex. Some nuclei, such as those embedded within the internal medullary lamina (intralaminar nuclei such as the centromedian and parafascicular nuclei) and the outer, lateral shell nucleus (reticular nucleus of the thalamus), have very diffuse, nonspecific associations with the cerebral cortex.

CLINICAL POINT

Thalamic syndrome (posterolateral thalamic syndrome, or Dejerine-Roussy syndrome) results from obstruction of the thalamogeniculate arterial supply to the region of the thalamus where the ventral posterolateral nucleus is located. Initially, all sensation is lost in the contralateral body, epicritic more completely than protopathic. Commonly, severe spontaneous pain occurs contralaterally, described as stabbing, burning, or tearing pain; it is diffuse and persistent. Even light stimulation can evoke such pain (hyperpathia), and other sensory stimuli or emotionally charged situations can result in these painful sensations. Even when the threshold for pain and temperature sensation (protopathic sensations) is elevated, the thalamic pain may be present; it is called analgesic dolorosa. If the vascular lesion includes the subthalamic nucleus or associated basal ganglia circuitry, the patient may also experience hemiballismus (or choreiform or athetoid) movements in addition to the sensory deficits.