Chapter 8
Microsurgical Anatomy of the White Matter Tracts

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Key Points

- There are three types of white matter tracts: association, projection, and commissural.
- The internal capsule is formed by projection fibers, and the external capsule is formed by the claustrocortical fibers and joins with the internal capsule to create the corona radiata and continues upward to form the centrum semiovale with the callosal radiations and association fibers. The extreme capsule is constituted by the inferior fronto-occipital and uncinate fasciculi.
- There are three important regions where groups of white matter tracts exist: the centrum semiovale, the sagittal stratum, and the temporal stem.
- The median plane is formed by the following: (1) the corpus callosum, (2) the cingulum bundle, (3) the fornix, (4) the thalamic peduncles, (5) the anterior commissure, and (6) the sledge runner fasciculus.

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- The paramedian plane is constituted by the following: (1) superior longitudinal fasciculus, (2) corona radiata, (3) arcuate fasciculus, (4) claustro cortical fibers, (5) frontal aslant tract, (6) optic radiations, (7) middle longitudinal, (8) inferior fronto-occipital, (9) uncinate, and (10) inferior longitudinal fasciculi.

8.1 Introduction

White matter tracts (WMT(s)) are complex system of interconnecting circuits located in the subcortical region. Together with several regional processing hubs, the WMT network functions to subserve the dynamic functions of human thought, memory, emotion, and physical ability. WMT anatomy was first studied by Vesalius. Further contributions by Vicq d'Azyr, Gall, Spurzheim, and Meynert led to the organization of WMTs into commissural, association, and projection fiber groups, based on their primary direction or plane, and principal function [1–3]. To elaborate, commissural fibers, which are situated in the coronal plane, function to connect hemispheres. Association fibers, which are situated in the sagittal plane, function to connect ipsilateral lobes within each hemisphere. Lastly, projection fibers, which are situated in the axial/craniocaudal plane, function to connect or transmit information from distal sensorimotor regions to central processing units, governing where each signal should go [4].

In order to better expose and describe WMTs, a cadaveric dissection technique was introduced in 1935 by Klingler [3]. Following this early period, advancements in neuroimaging provided the ability to visualize WMTs, especially with the MRI-DTI work of Basser in 1994. More recently, a large-scale scientific effort, namely the Human Connectome Project, attempted to categorize and more accurately describe WMTs with the construction of a multicentric map and tractography model, and further revealing a host of functionally-based neural connections previously undescribed [5].

In this chapter, we will attempt to organize and describe the relative position, orientation, and function of WMTs, according to a systematic anatomical framework, namely the "Chassis", which is based on sagittal and parasagittal planes and each subdivided into axial planes (dorsal and ventral) [4]. The median plane is located at the sagittal level of the third ventricle, the paramedian plane at the level of the external capsule or the claustrum, the dorsal axis at the level of the corpus callosum, and the ventral axis at the level of the insula. Each WMT will be described

Table 8.1 White matter tracts: Role functional

Tracts	Function	
	Dominant hemisphere	Non-dominant hemisphere
Median-dorsal tracts		
CC	Exchange of information, integration of inputs to one or both hemispheres and facilitation or inhibition of cortical functions; It communicates perceptual, sensory, motor, high level cognitive signals, learned, and volitional information The topographical organization in the posterior regions are visual, auditory and somatosensory information and in the anterior region, higher cognition.	
CB	Serves as an interface between limbic states and neocortical judgment. Functionally, it serves to control self-control, self- awareness, memory, adaptive, and problem-solving processes. Alertness, reward, persistence, cognitive control, autonomic coordination, complex motor planning, muscular coordination, eye coordinated movement, motivation, conflict response, emotional processing, and emotional content of pain perceptions.	
Fornix	Limbic connectivity; Regulation of emotional behavior and motivational processes, transference of information of episodic memory; Verbal memory visuospatial memory.	
Median-ventral tracts		
AC	Processes information of complementary visual information, and transfers information between hemispheres related to auditory, olfactory and gustatory systems.	
APS	Role within the olfactory system, which is still not clear.	
SRF	Part of the system of integration of visual stimuli with place recognition and visuospatial imagery.	
TP	Afferent and efferent pathway between the brain cortex and the thalamic nuclei.	
Paramedian-dorsal tracts		
CR	Interconnection between all the lobes of the brain with subcortical structures.	
SLF I	Regulation of the motor functions, initiation of the motor activity, activation in resting state; Higher order control of body-centered action.	
SLF II	Attention and visuo-spatial awareness.	
SLF III	Articulatory aspects of language.	Prosody, musical processing and visuo-spatial attention.
AF	Phonological, lexical and semantic language processing.	Prosodic activation of language.
FAT	Speech production initiating the motor activity of language.	Visuomotor processing for hand movements.
CCF	Integration center of tasks that requires the simultaneous activation of different sensorial domains; In addition, it has been described as a multisensory integrator; The most common convergences observed are somato-olfactory, somato-visceral, and somato-nocioceptive.	
Paramedian-ventral tracts		
MdLF	Part of a redundant compensatory network of language semantics and phonologics.	Processing the spatial features of sound, attention and visuospatial ability.
IFOF	Semantical processing, syntactic and grammatical control, awareness and visual-guided movement.	Awareness and visual-guided movement, visual recognition and conceptualization, goal-orientated behavior and visual turning tasks.

(continued)

Table 8.1 (continued)

	Function	
Tracts	Dominant hemisphere	Non-dominant hemisphere
ILF	Indirect pathway for the transmission of semantical information during language processing tasks, object identification, discrimination, and recognition.	Object identification, discrimination and recognition, visual memory, reading and emotional processing.
UF	Semantic processing and redundant aspects of language like verbal memory.	Regulates the emotional response to the auditory stimuli, provides emotional value of visual information, supports recognition memory and is involved in cognitive tasks linked to emotion, empathy, and autonoetic self-awareness.
Vr	Selective attention, spatial attention and awareness, audiovisual integration and language, as well as higher cognition including reading, writing, math, and computational processing.	Selective attention, spatial attention and awareness, and audiovisual integration.
OR	Transmission of visual information from the retina to the primary visual cortex.	

AC anterior commissure, *AF* arcuate fasciculus, *APS* anterior perforated substance, *CC* corpus callosum, *CB* cingulum bundle, *CCF* claustro cortical fibers, *CR* corona radiata, *FAT* frontal aslant fasciculus, *IFOF* inferior fronto occipital fasciculus, *ILF* inferior longitudinal fasciculus, *MdLF* middle longitudinal fasciculus, *OR* optic radiations, *SRF* sledge runner fasciculus, *SLF* Superior Longitudinal Fasciculus, *UF* uncinate fasciculus, *Vr* vertical rami.

according to their relative cortical, ventricular and regional connectivity to surrounding WMTs. We describe the function of the WMTs in Table 8.1.

8.2 Median Dorsal Tracts

8.2.1 Corpus Callosum (CC) (Fig. 8.1)

The Corpus Callosum (CC), first described in the human brain by Vesalius in 1543, is the largest neocortical commissural tract that bidirectionally connects both cerebral hemispheres [6].

8.2.1.1 Anatomy

In 1989, Witelson described the CC, which comprises of five segments: rostrum, genu, body, isthmus, and splenium [7, 8]. In addition, there are callosal radiations, which arise from either the rostrum as the forceps minor, from the genu and anterior part of the body as the frontal callosal fibers, from the posterior part of the body as the parietal callosal fibers, and from the posterior part of the body and splenium as the tapetum and forceps major [9, 10]. The tapetum extends laterally and downward into the temporal lobe between the lateral ventricles and optic radiations.

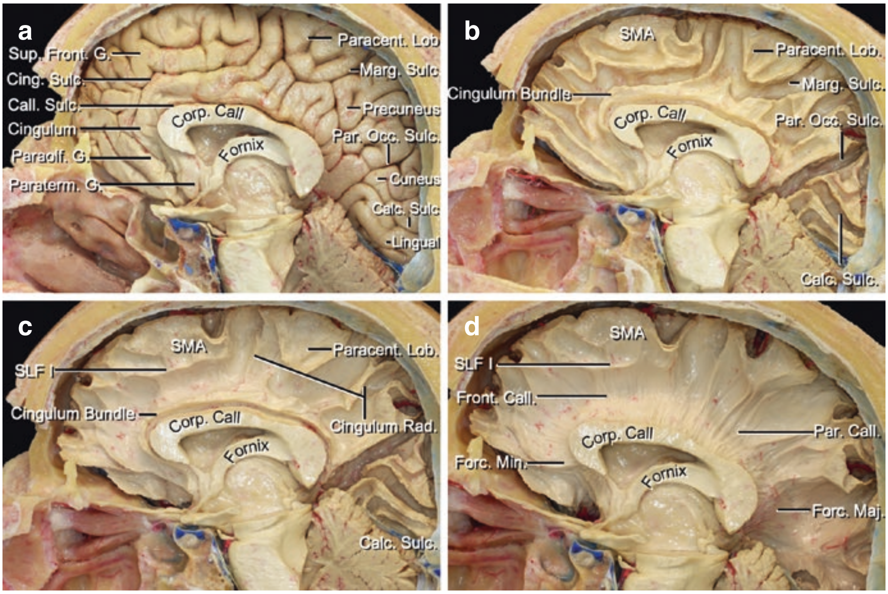


Fig. 8.1 White matter tracts of the medial surface of the brain. (**a**) Sulci and gyri. (**b**) The cortex was removed and the u–fibers are observed. (**c**) The u–fibers were resected and SLF and CB are shown. (**d**) Deepest layer reveals the corpus callosum. *Calc* calcarine, *Call* callosal, *Corp* corpus, *Cing* cingulum, *Forc* forceps, *Front* frontal, *G* gyrus, *Maj* major, *Mar* marginal, *Min,* minor, *Par* parietal, *Par. Occip* parietooccipital, *Paracent* Paracentral, *Paraolf* paraolfactory, *Paraterm* paraterminal, *Rad* radiations, *SLF* superior longitudinal fasciculus, *SMA* supplementary motor area, *Sulc* sulcus, *Sup* superior

8.2.1.2 Cortical Connectivity

The CC has two types of connections: (1) Homotopical, which communicates homologue regions, and (2) Heterotopical, where fibers are situated in asymmetrical brain regions [9, 11].

The genu contains fibers from the orbitofrontal cortex, the anterior body of the CC contains fibers from prefrontal, premotor and supplementary motor cortices, and the posterior body of the CC contains primary motor, somesthetic and posteroparietal fibers. The ventral portion of the splenium contains fibers from the occipital cortex, and the dorsal portion of the splenium contains fibers of the temporal and parietal lobes [7].

8.2.1.3 Ventricular Projection

The rostrum constitutes the floor of the frontal horn. The genu forms the anterior surface of the frontal horn [12, 13]. The body of the CC covers the roof of the frontal horn, body of the lateral ventricle, and atrium [12]. The forceps major covers the medial wall of the atrium and the occipital horn [13]. The tapetum covers the lateral wall of the temporal horn, the lateral and superior wall of the atrium, and the lateral and superior wall of the occipital horn.

8.2.1.4 Relationship with Other WMTs

The cingulum bundle (CB), is located superior and medial to the body of the CC, medial and anterior to the genu and rostrum of the CC, posterior to the splenium, and medial to the forceps major (Fig. 8.4b, c). The posterior part of the body of the CC is above the fornix. SLF I is located medial and superior to the frontal and parietal callosal fibers. The fibers of the corona radiata are related lateral to the callosal fibers. The fibers of the CC continue upward to form the centrum semiovale.

8.2.2 Cingulum Bundle (CB) (Fig. 8.1)

This tract has a "ring-like belt" shape and was named by Quain in 1878 as the white matter of the fornicate gyrus [14].

8.2.2.1 Anatomy

The CB can be divided into two parts: (1) Anterior, which courses from the subcallosal region to the isthmus, and (2) Posterior, which courses from the supracallosal area to the parahippocampus. As described by Jones, there are three subdivisions of the CB from a lateral to medial orientation: the parahippocampal subdivision laterally, the subgenual forebrain medially and the retrosplenial region situated in between them. In contrast, Wu et al., described five CB segments [15].

8.2.2.2 Cortical Connectivity and Projection

The CB connects the cingulate gyrus (CG) with the orbital, medial prefrontal, presupplementary motor area, paracentral, precuneus, retrosplenial, and ventral temporal cortex [16]. The CB projects to the subcallosal cortex and the paraterminal gyri, the CG, the isthmus, the parahippocampal, and the entorhinal cortex [17]. In addition, the CB has several additional connections with the thalamus [18].

8.2.2.3 Ventricular Projection

The cingulum is related with the inferior, superior, and anterior walls of the frontal horn of the lateral ventricle. It covers the superior portion of the body. The cingulum is related with the medial and superior surfaces of the atrium and with the inferior surface of the temporal horn [13].

8.2.2.4 Relationship with Other WMTs

The CB is medial to frontal aslant tract (FAT), at the basal surface the ILF is located lateral to the CB and the UF is anterior to the CB at the temporal pole. The CB is inferior to SLF I and superior to the CC. Its relationship with the callosal fibers was described previously.

8.2.3 Fornix (Fig. 8.1)

The fornix constitutes the major fiber system of the hippocampus, which was first described by Galen.

8.2.3.1 Anatomy

It has five components: (1) the fimbria, which originates from the hippocampal formation at the subiculum and entorhinal cortex, courses posteriorly to form the crus, (2) the crus of the fornix, which arches superomedially, and over the thalami joins with its homologue at the hippocampal commissure, (3) the body of the fornix is located anterior to the hippocampal commissure and is divided in two columns at the level of the foramen of Monro, (4) the columns divide inferiorly into two components, and (5) the pre- and post-commissural components are separated at the anterior commissure; the former ends at the septal region and nucleus accumbens and the latter reaches the mammillary bodies [19].

8.2.3.2 Ventricular Projection

The fimbria is located at the level of the medial part of the temporal horn, the crus courses along the anterior wall of the atrium, and the body of the fornix is located on the medial third of the floor of the body of the lateral ventricle. The fornix is located between the roof of the third ventricle and the floor of the body of the lateral ventricle. The columns are related with the anterior wall of the third ventricle.

8.2.3.3 Relationship with Other WMTs

The fimbria is an anteroposterior tract located lateral to the posterior one-third of the cerebral peduncle, whereas the terminal stria runs medial and parallel to the fornix. The fornix locates inferiorly to the posterior part of the CC.

8.3 Median Ventral Tracts

8.3.1 Anterior Commissure (AC)

The AC has the shape of a handlebar, connecting one hemisphere to another, and is located at the basal and anterior pole of the globus pallidus and between the two amygdalas [8].

8.3.1.1 Anatomy

This commissure follows a mediolateral and slightly anteroposterior trajectory, lies superior to the accumbens nucleus, inferior to the putamen, and inferior to the caudal surface of the globus pallidus to create the Gratiolet conduct.

The AC is formed by a body and expands at the level of the superior wall of the temporal horn of the lateral ventricle into two limbs, anterior and posterior. The former runs to the temporal pole, whereas the latter penetrates the sagittal stratum, sprains at the Gratiolet conduct where its inferior fibers target the occipital lobe; whereas the posterior temporal regions are reached by its superior fibers.

8.3.1.2 Cortical Connectivity and Projection

This commissure interconnects the temporal pole, the inferotemporal region, the parahippocampal gyrus (PhG), and the orbitofrontal cortex with their homologues in the contralateral hemisphere.

8.3.1.3 Ventricular Projection

It is located anterior to the foramen Monro and ventral to the supraoptic recess of the third ventricle; the AC crosses the midline. The anterior limb runs to the inferior part of the frontal horn and the occipital extension relates with the lateral two inferior thirds of the atrium; whereas the temporal extension passes anterior and superior to the temporal horn.

8.3.1.4 Relationship with Other WMTs

The AC is a white matter tract almost completely surrounded by gray matter. The AC crosses the midline inferior to the medial and ventral aspects of the anterior limb of the IC and anterior to the columns of the fornix at the superior ending of the lamina terminalis. This commissure along with the columns of the fornix create the vulvar recess (triangular fossa of Schwalbe).

Some fibers of the AC merge ventrally with the UF and dorsally with the Meyer's loop. The AC is lateral to the olfactory tract and stria terminalis. The AC forms part of the fibers of the temporal stem and the stratum sagittal.

8.3.2 Sledge Runner Fasciculus (SRF)

The SRF was named due to its peculiar sledge-like shape and was described in 2014 by Vergani et al. [20].

8.3.2.1 Anatomy

The SRF is an oblique thin fascicle, divided into a superior and an inferior part. The superior part is medial to the forceps major of the CC, and the inferior part is medial to the medial wall of the atrium of the lateral ventricle.

8.3.2.2 Cortical Connectivity and Projection

The SRF courses between the medial surface of the occipital cortex, coursing in a dorsomedial to ventrolateral trajectory. It is located under the U-shaped fibers of the calcarine fissure and parieto-occipital sulcus [6]. The SRF connects the anterior half of the cuneus (Cu), the posterior part of the precuneus (pCu), anterior half of the lingual gyrus (LiG), the isthmus of the CG and the posterior part of PhG [21].

8.3.2.3 Ventricular Projection

This tract descends vertically in a medial orientation towards the posterior two thirds of the atrium of the lateral ventricle [13].

8.3.2.4 Relationship with Other WMTs

The SRF is related with the forceps major of the CC medially and posteromedially with the fibers of the CB.

8.3.3 Thalamic Peduncles (TPs)

The thalamic peduncles are afferent and efferent groups of projection fibers situated between the brain cortex and the thalamic nuclei, constituting the most medial component of the internal capsule (IC) [22].

8.3.3.1 Anatomy

The TPs are divided into four groups according to its cortical connections: anterior, superior, inferior, and posterior.

The posterior thalamic peduncle (TP) runs from the calcarine and parietal region to the caudal parts of the thalamus. The inferior TP connects the orbitofrontal cortex with the polar reticular thalamic nucleus. The anterior thalamic peduncle courses from the frontal cortex to the anterior and midline thalamic groups. The superior TP courses from the paracentral lobule (PCL) and the anterior parietal cortex to the ventral nuclear group of the thalamus [1].

8.3.3.2 Cortical Connections

The anterior TP is composed of frontopontine and frontothalamic fibers, the superior TP is formed by the thalamoprecentral and thalamopostcentral fibers, the inferior TP is integrated by the pulvinotemporal fibers, and the posterior TP is constituted by the geniculocalcarine and pulvinoparietooccipital fibers [8, 22].

8.3.3.3 Ventricular Projection

The anterior TP runs lateral to the two-inferior thirds of the frontal horn, the superior TP courses lateral to the superior third of the frontal horn and the two anterior thirds of the body of the lateral ventricle. The posterior TP is located lateral to the posterior one-third of the body and the upper third of the atrium, and the inferior TP relates laterally to the temporal horn and the two inferior thirds of the atrium [13].

8.3.3.4 Relationship with Other WMTs

The TP are lateral to the callosal fibers [13]. The others fibers of the corona radiata are located lateral to the corticothalamic fibers [22].

8.4 Paramedian-Dorsal Tracts

8.4.1 Corona Radiata (CR) (Fig. 8.2)

The term corona radiata was introduced by Christian Reil in 1809, and is defined as the projection fibers which travel upwards and downwards between the superior border of the internal capsule and the cortex [13, 23].

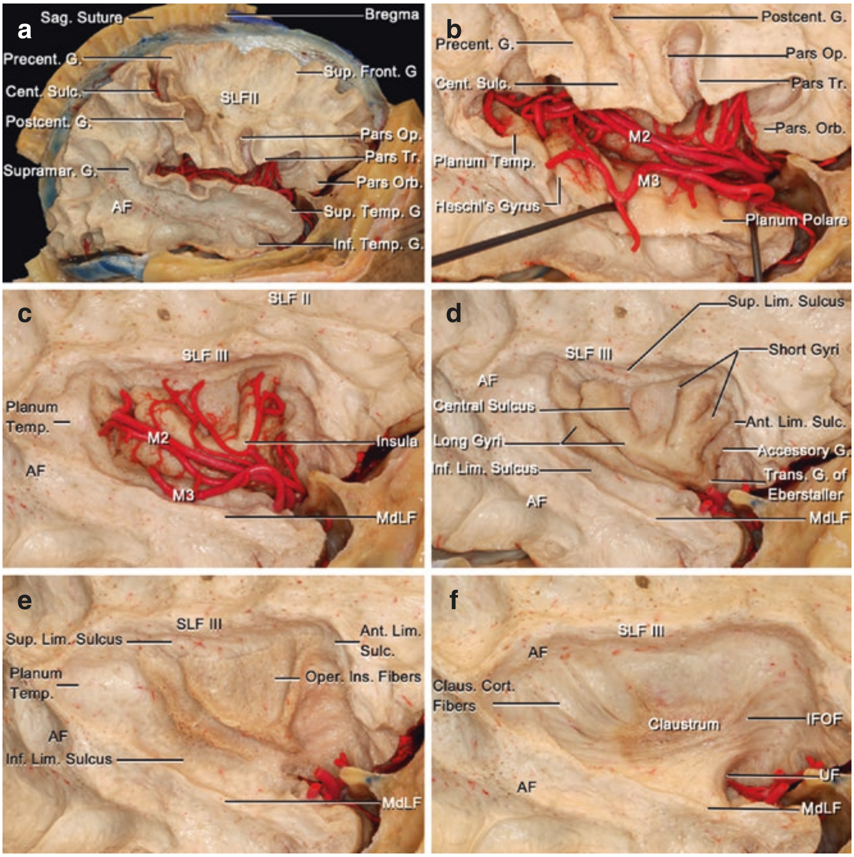


Fig. 8.2 Central core, anatomical dissection from lateral to medial (**a**) Panoramic view of white matter tracts (WMTs) and Sylvian fissure. (**b**) Closeup view of the sylvian fissure and opercula. (**c**) The opercula was removed, showing WMTs surrounding the insula. (**d**) The gyri and sulci of the insula are observed. (**e**) The cortex of the insular was removed and the operculo-insular fibers are shown (**f**) The operculo-insular fibers were removed and the CCF are observed. (**g**), The extreme, external and internal capsule are observed. (**h**) Anterior half of the lenticular nucleus was removed allowing for observation of the anterior commissure and internal capsule. (**i**) The caudate and foramen of Monro are visualized. (**j**) The head of the caudate was removed and the frontal horn is observed. *A* artery, *AF* arcuate fasciculus, *Ant* anterior, *Caud* caudate, *Cent* central, *Claus claustrum*, *Com* commissure, *Cort* cortical, *FAT* frontal aslant tract, *G* gyrus, *Glob. Pall* globus pallidus, *IFOF* inferior fronto-occipital fasciculus, *Inf* inferior, *Lent* lenticulostriate, *Lim* limiting, *MdLF* middle longitudinal fasciculus, *N* nucleus, *Precent* precentral, *Op* opercularis, *Oper. Ins* operculo insular, *Orb* orbitalis, *Postcent* postcentral, *Sag* sagittal, *SLF* superior longitudinal fasciculus, *Sulc* sulcus, *Sup* superior, *Supram* supramarginal, *Temp* temporal, *Tr* triangularis, *UF* uncinate fasciculus

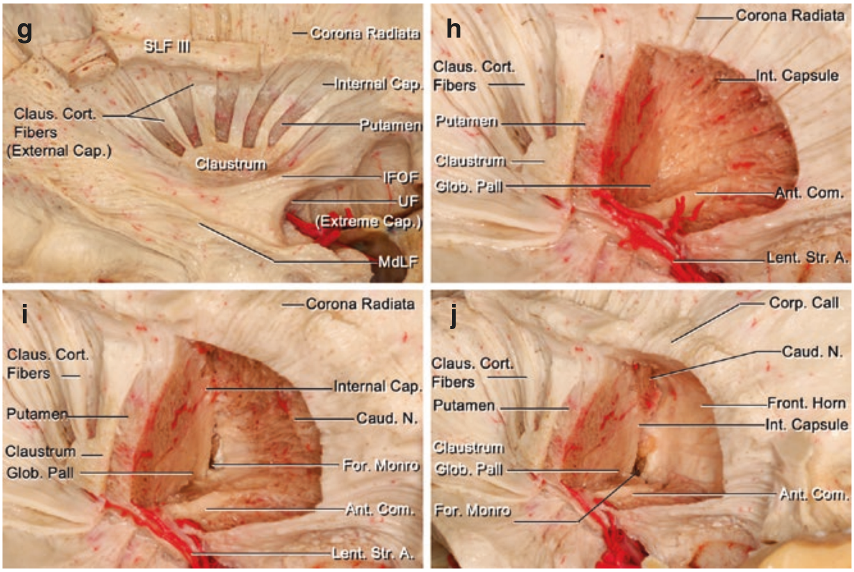


Fig. 8.2 (continued)

8.4.1.1 Anatomy

The CR continues downwards with the IC and then upwards merge with the fibers of the centrum semiovale. The IC is a complex of WMTs, which is limited by the caudate nucleus and the thalamus medially, and by the lenticulate nucleus laterally. The IC is composed of five subdivisions: anterior limb, genu, posterior limb, retro and sublenticular parts. The external capsule is formed by the claustrocortical fibers located between the claustrum and the putaminal nucleus, and is composed by a ventral and a dorsal portion [8, 23]. The UF and IFOF form the extreme capsule (EmC) [8, 13].

8.4.1.2 Cortical Connections

The anterior limb is constituted by frontopontine and frontothalamic fibers; the genu contains the bulboprecentral and the thalamoprecentral fibers; the posterior limb is composed by the corticospinal, the thalamopostcentral, the corticopontine, and the corticotegmental fibers; the retrolenticular portion contains the parietopontine, the occipitopontine, the geniculocalcarine, and the occipitoparietothalamic fibers; and the sublenticular region contains the temporopontine fibers, the auditory radiation, and the Meyer's loop.

8.4.1.3 Ventricular Projection

The anterior limb of the IC runs lateral to the frontal horn and the anterior third of the body of the lateral ventricle. The genu is medial to the interventricular foramen. The posterior limb runs lateral to the posterior third of the body of the ventricle. The sublenticular and retrolenticular components course laterally towards the temporal horn and the inferior third of the atrium in order to join with the sagittal stratum [13, 23].

8.4.1.4 Relationship with Other WMTs

The CR is situated lateral to the callosal radiations [8] and medial to the claustrocortical fibers. The centrum semiovale is formed by corona radiata, association, and commissural fibers [13].

8.4.2 Superior Longitudinal Fasciculus (SLF) (Fig. 8.3)

The superior longitudinal fasciculus was described for the first time by Reil and was further detailed by Burdach in 1822. In 1984, Petrides and Pandya separated the SLF bundle into three portions [24].

8.4.2.1 Cortical Connectivity and Projection

SLF is a WMT complex, which connects frontal, parietal, and temporal lobes. SLF-I is located on the medial surface of the hemisphere and courses above the CB and under the paracentral lobule. In addition, connects the superior frontal gyrus (SFG) and the pCu (Fig. 8.4c). The SLF-II connects the angular gyrus (AG) with the middle third of the middle frontal gyrus (MFG) passing through the superior portion of the supramarginal gyrus (SMG), the middle third of the postcentral (PoCG) and precentral gyri (PrCG). The SLF-III is situated superficially at the lateral surface. It connects the SMG to the pars opercularis and pars triangularis gyri of the inferior frontal gyrus (IFG), travelling within the PrCG and PoCG [25].

8.4.2.2 Ventricular Projection

The SLF-II is located in a dorsolateral position to the frontal horn, body, atrium and occipital horn. The SLF-III is located laterally with respect to the frontal horn, the body, and the atrium.

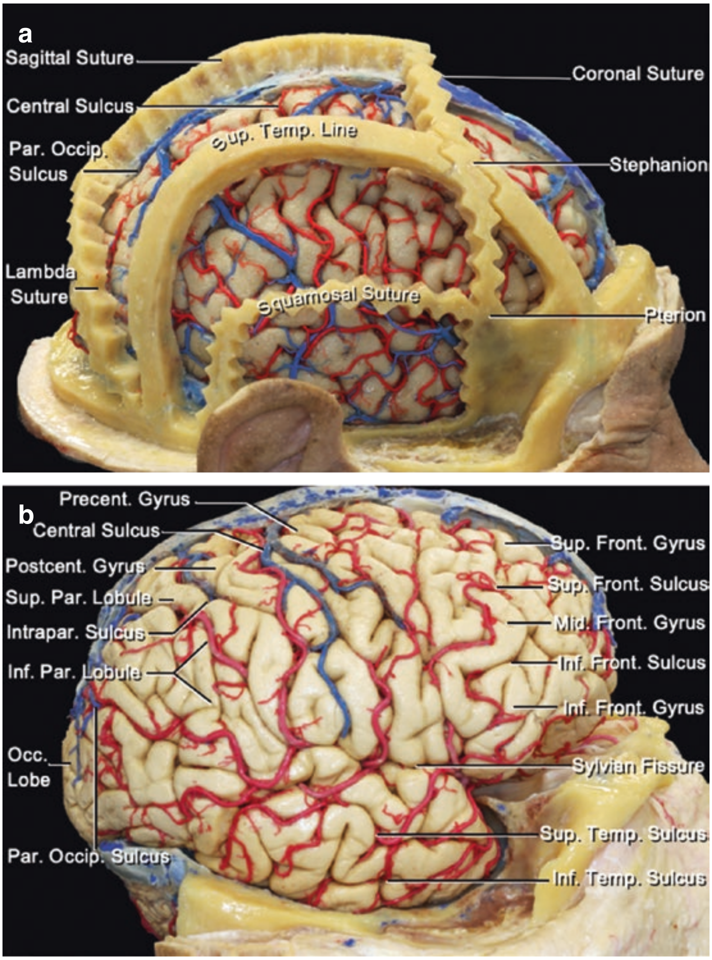
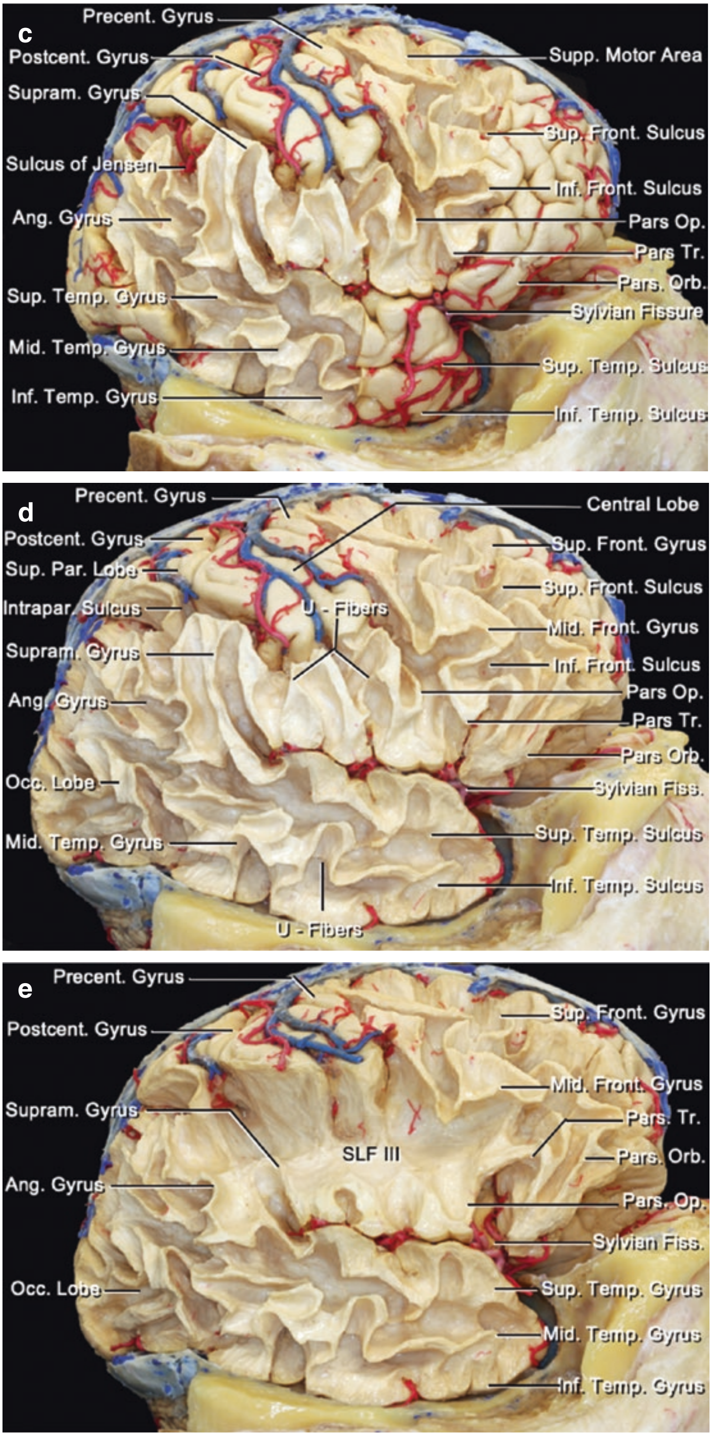


Fig. 8.3 Lateral view of brain. Anatomical dissection from lateral to medial, step-by-step to show the main white matter tracts of the cerebrum. (**a**) Relevant osseous landmarks such as sutures and craniometrical points are preserved to show their relationship with the cortex. The stephanion is the point where the coronal suture and the superior temporal line meet. The pterion is located between the sphenoid, temporal, parietal and frontal bones. (**b**) Gyri and sulci. (**c**) The cortex was removed, where FAT and AF are projected. The central lobe is shown for reference. (**d**) The cortex was removed and the central lobe is preserved. (**e**) The u-fibers were removed from the pars opercularis to the supramarginal gyrus exposing SLF III. (**f**) The u-fibers of the middle frontal gyrus were removed, showing SLF II. (**g** and **h**) One part of SLF II and SLF III. The u-fibers of the parietal and occipital were removed showing SLF II. The parietal and temporal u-fibers were resected to observe AF. (**i**) The superior temporal gyrus u-fibers were removed to observe the MdLF. (**j**) The insula was removed, showing IFOF, UF and CCF. (**k** and **l**) Panoramic and close view of the main tracts of the lateral surface, in addition the temporal stem and the stratum sagittal are observed. *AF* arcuate fasciculus, *Ang* angular, *CCF* claustro cortical fibers, *Claus* claustrum, *Cort* cortical, *FAT* frontal aslant tract, *Fiss* fissure, *Front* frontal, *IFOF* inferior frontooccipital fasciculus, *Inf* inferior, *Intrapar* intraparietal, *MdLF* middle longitudinal fasciculus, *Mid* middle, *Occ* occipital, *Op* opercularis, *Orb* orbitalis, *Par* parietal, *Par. Occip* parietooccipital, *Precent* precentral, *Postcent* postcentral, *Sag* sagittal, *SLF* superior longitudinal fasciculus, *SMA* supplementary motor area, *Sup* superior, *Supp* supplementary, *Supram* supramarginal, *Temp* temporal, *Tr* triangularis, *UF* uncinate fasciculus



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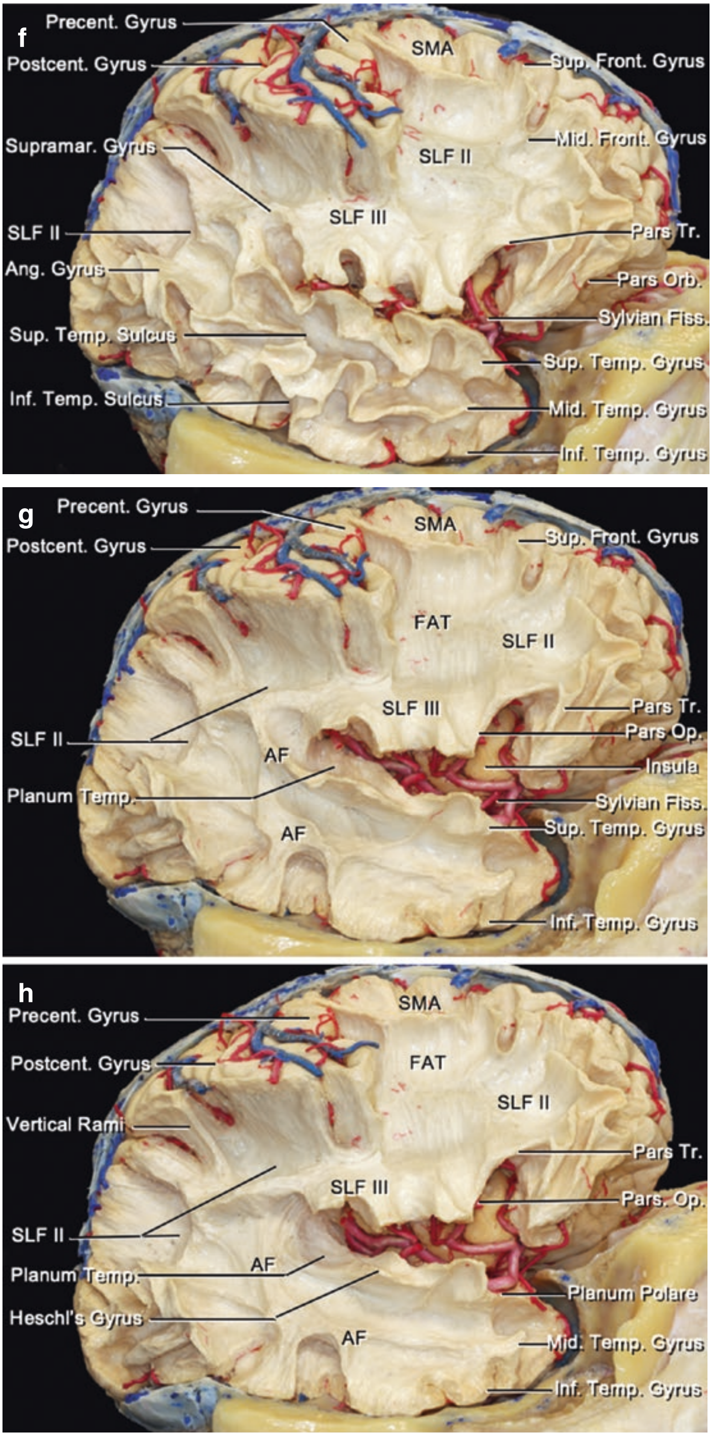

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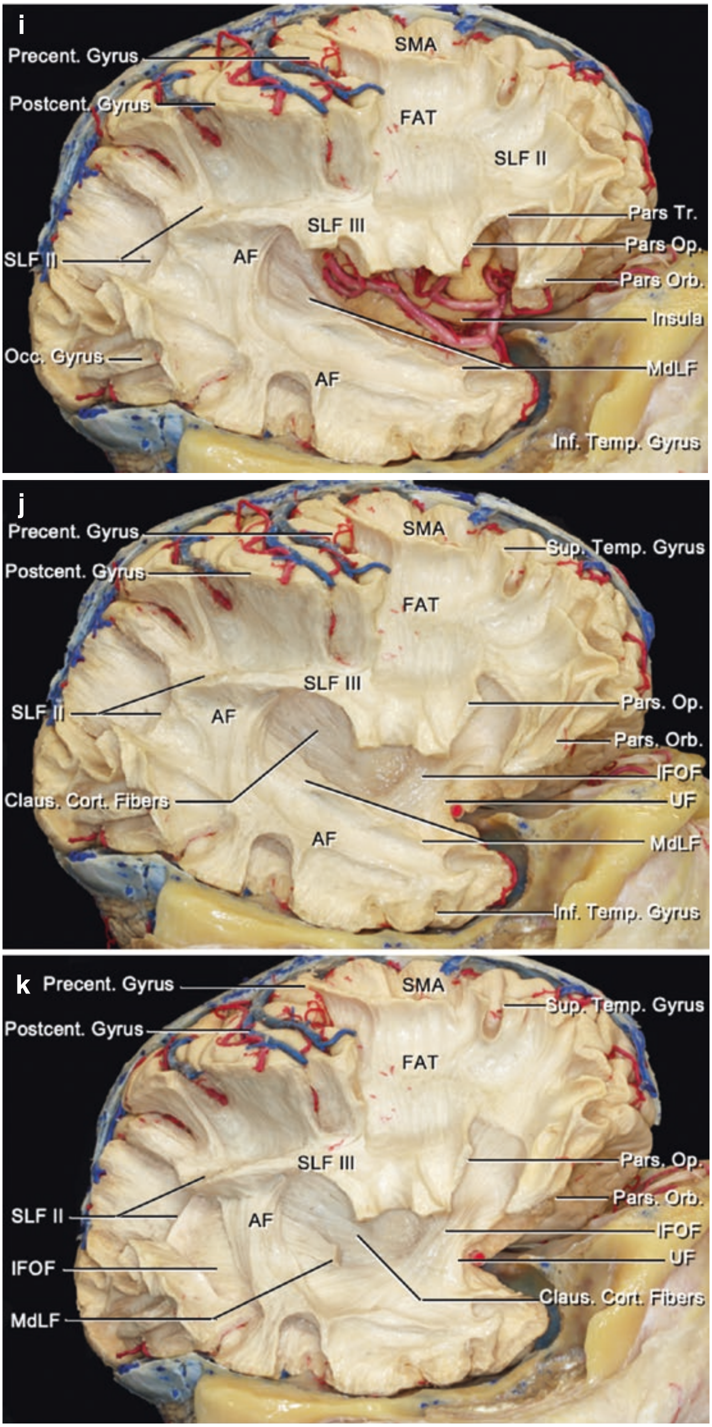

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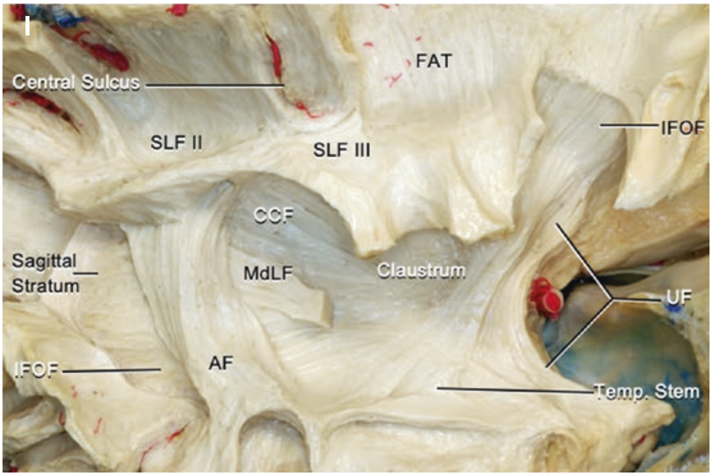

Fig. 8.3 (continued)

8.4.2.3 Relationship with Other WMTs

The SLF I is located superior to the CB and medial to the callosal fibers and frontal aslant tract. The SLF II is lateral to the IFOF, FAT, and claustrocortical fibers; in addition, it is situated superior and medial to SLF III. The SLF III is located lateral to the IFOF, FAT, and claustro cortical fibers, it is located inferior to SLF II, and the AF is situated inferomedial to the SLF III. At the level of the pars opercularis and triangularis, there are four tracts (IFOF, FAT, AF, and UF) related to SLF III (Figs. 8.1i–l and 8.2a–c). The vertical rami (Vr), which was previously described by our team, can be considered as an interconnecting fiber, between the SLF and AF, but also as vertical extension of the SLF. Explicitly, the Vr is a small set of fibers which vertically extend from the SLF and course from the supramarginal gyrus and terminate at the superior parietal lobule [1, 26] (Fig. 8.2).

8.4.3 Arcuate Fasciculus (AF) (Fig. 8.3)

Reil described the arcuate fasciculus for the first time; afterwards Dejerine and Burdach described it more in detail, leading to its name as the *fasciculus arcuatus of Burdach*. The AF is an interconnecting fiber located in the temporal, parietal, and frontal lobes, surrounding the sylvian fissure.

8.4.3.1 Anatomy

There are three main theories in the nomenclature and description of the AF: (1) It is considered as a component of SLF [8, 27], (2) The SLF and AF are completely different pathways [28], and (3) Both tracts can be mentioned interchangeably. In this study, we consider the AF as a unique and physically separate fiber tract. AF is divided into two segments, dorsal and ventral [13].

8.4.3.2 Cortical Connectivity and Projection

The ventral segment of AF connects the middle and posterior portion of the superior temporal gyrus (STG), and middle portion of the middle temporal gyrus (MTG) passing beneath the SMG, inferior third of PrCG, and PoCG with the pars opercularis and pars triangularis; while the dorsal segment connects the posterior part of the MTG and the middle and posterior region of the ITG passing through the posterior parts of the MTG, ITG, AG, middle third of PrCG, and PoCG, with the pars opercularis and the most posterior portion of the MFG [29].

8.4.3.3 Ventricular Projection

The AF runs laterally along the two superior thirds of the frontal horn and the body of the lateral ventricle, the anterior two thirds of the atrium, and is lateral to the posterior part of the temporal horn.

8.4.3.4 Relationship with Other WMTs

It is located inferomedial to the SLF II and SLF III, lateral to the IFOF at the level of the frontal lobe and lateral to the MdLF and the IFOF at the parietal lobe. FAT is medial to AF at the level of the IFG and MFG, the IFOF is medial to the AF at the MFG and sometimes UF is medial to the AF at the IFG. In the temporal lobe, the AF is superior and lateral to MdLF, IFOF and ILF.

8.4.4 Frontal Aslant Tract (FAT) (Fig. 8.3)

The FAT was described by in Lawes et al. 2008 [30]. The name was given due to its oblique trajectory from supero-medial to infero-lateral surfaces of the frontal lobe. In 2018, Baker et al. [31] proposed a "crossed FAT", indicating that FAT fans across medially and descends to CC before crossing to the contralateral side until it reaches the contralateral SMA and premotor area.

8.4.4.1 Anatomy

The FAT is described as a thin layer of WMT which has the shape of a triangle with its base on the SFG and its apex on the pars opercularis.

8.4.4.2 Cortical Connectivity and Projection

The FAT connects the SFG and IFG [32], communicating the SMA complex with the pars opercularis, pars triangularis, ventral PrCG, and posterior third of the MTG, coursing all over under these structures.

8.4.4.3 Ventricular Projection

The FAT is mainly related with the posterior one third of the frontal horn of the lateral ventricle and the foramen of Monro.

8.4.4.4 Relationship with Other WMTs

Its relations are lateral to AF, SLF II and SLF III, and medial to the fibers of the CR.

8.4.5 Claustrocortical Fibers (CCF) (Figs. 8.2 and 8.3)

The description of the claustrum was made by Vicq d'Azyr; afterwards Trolard and Dejerine described the connections of the claustrum with the brain cortex, defining the CCF as a part of the EC [8].

8.4.5.1 Anatomy

This system consists of fiber bundles with a characteristic spoke-and-wheel pattern, which emerge and converge from the dorsal claustrum [8, 33].

8.4.5.2 Cortical Connections

The connections of the CCF have been classified into four groups: anterior, posterior, superior, and lateral. The anterior group communicates the claustrum with the prefrontal and anterior entorhinal cortices, the posterior group connects the claustrum with the visual regions and occipitotemporal, the superior group run from the claustrum to the somatomotor areas, and the lateral group connects the claustrum with the temporal and inferior frontal regions [34].

Furthermore, connections between the claustrum with contralateral cortices and its contralateral homologue have been shown via the CC and in a small degree through the AC, reaching the precentral, postcentral, motor and prefrontal cortices of the contralateral hemisphere.

8.4.5.3 Ventricular Projection

The CCF run in a centrifugal way, covering the lateral and superior posterior-one-third surfaces of the frontal horn and body of the lateral ventricle, and the superior third of the atrium [13].

8.4.5.4 Relationship with Other WMTs

As a part of the EC, the CCF joins CR; this confluence happens at the level of the superior edge of the putamen nucleus.

8.5 Paramedian: Ventral Tracts

8.5.1 Middle Longitudinal Fasciculus (MdLF) (Fig. 8.3)

The MdLF was described in 1999 by Makris [35].

8.5.1.1 Anatomy

The MdLF courses from the temporal pole and superior surface of the STG to the AG. In addition, this fiber divided into two portions: anterior and posterior [37].

8.5.1.2 Cortical Connectivity and Projection

The MdLF extends from the temporal pole to AG, coursing along of the STG and the inferior limitans sulcus [36].

8.5.1.3 Ventricular Projection

The MdLF is divided into two portions: the anterior extends from the temporal pole to the posterior insular point and runs above the temporal horn; the posterior portion is located posterior to the posterior insular point and runs laterally to the middle one-third of the atrium to reach the AG [13].

8.5.1.4 Relationship with Other WMTs

The MdLF runs medial to the AF, and superior and lateral to the IFOF, and the claustrocortical fibers.

8.5.2 *Inferior Frontooccipital Fasiculus (IFOF) (Fig. 8.3)*

The IFOF was first described by Burdach in 1819 [38]. It is a longest association tract which connects the anterior frontal lobe with parieto-occipital regions.

8.5.2.1 Anatomy

Several studies have proposed different segmentations of this tract. Martino et al. [39] divided the IFOF at the level of the ventral portion of the extreme capsule, into two components based on its posterior connections: (1) superficial and dorsal, and (2) deep and ventral component.

Duffau et al. [40] in 2012 segmented the IFOF based on its anterior connections: (1) superficial layer and (2) deep layer, this last segment is subdivided into three portions: posterior, middle and anterior. More recently, Wu et al. [38] in 2016 proposed a five-segment composition. The segmentation was based on anterior and posterior connections. Güngör et al. [13] studied the IFOF into two portions based on its relations with the insular central sulcus and lateral ventricle. The last segmentation was made by Panesar et al. [41] in 2017. The frontal region was divided into two layers: (1) a superficial one which is ventrolateral, and (2) a deep one, which is subdivided in dorsomedial and ventromedial components.

8.5.2.2 Cortical Connectivity and Projection

The main anterior connections course from the orbitofrontal cortex, pars triangularis, pars opercularis and MTG to the occipital gyri, superior parietal lobule (SPL) and posterior portion of the fusiform gyrus (FuG). The IFOF projects to the anterior third of the MFG and IFG, the frontal pole, the STG, the MTG, the SMG, the AG, and the occipital lobe.

8.5.2.3 Ventricular Projection

The IFOF projects laterally to the inferior third segment of the frontal horn, superiorly to the temporal horn and laterally to the atrium [13].

8.5.2.4 Relationship with Other WMTs

The IFOF is related with tracts situated in the temporal stem and sagittal stratum. In the frontal lobe, the IFOF is related at the level of the MFG medial to SLF II and lateral to the CCF and at level of the frontal operculum; it is medial to SLF-III, FAT, and AF and lateral to the UF. At the level of limen insulae, the IFOF is located posteriorly and superiorly to the UF and constitutes the lateral limit of the claustrocortical fibers. The IFOF is related superiorly to ILF at the level of the temporal lobe. In the sagittal stratum, the IFOF is located medial to the MdLF and the AF and lateral to the CCF.

8.5.3 Uncinate Fasciculus (UF) (Figs. 8.3 and 8.4)

The UF was studied for the first time by Reil in 1809. The UF was given its name due its “hook-shaped” structure [42], which arches anterior to the Sylvian fissure.

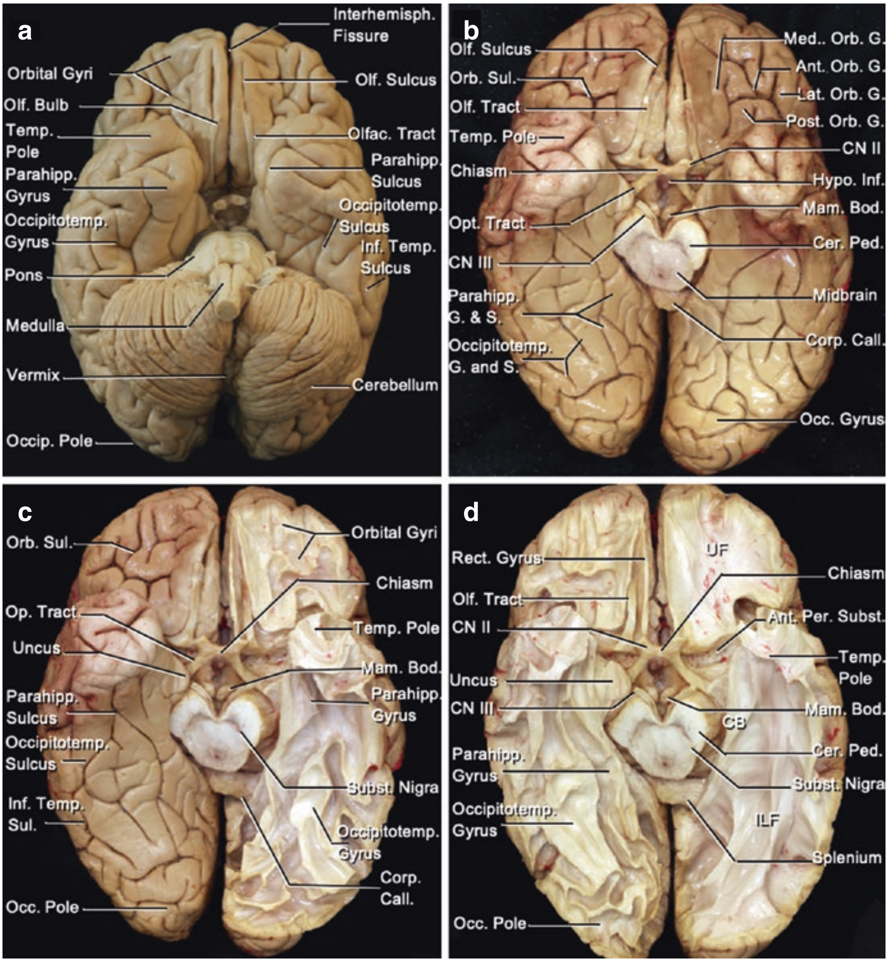

Fig. 8.4 Basal Surface of the brain. (**a** and **b**) Gyri and sulci along with the ventral surface of the brainstem. (**c**) U-fibers of the basal surface on the right side while left side cortex was preserved. (**d**) On the right side the u-fibers were removed and the UF, CB and ILF are observed. On the left side, the cortex was removed showing the u-fibers. (**e**) The CB radiations and part of ILF was removed showing the temporal horn and hippocampus. (**f**) The optic radiations are observed. (**g**) Closeup view of the temporal horn and visual pathway. *Ant* anterior, *Cer cerebral, CB*. cingulum bundle, *Chor*. choroid, *CN* cranial nerve, *Corp. Call* corpus callosum, *Forc* forceps, *G* gyri, *Gen* geniculate, *ILF* inferior longitudinal fasciculus, *Inf* inferior, *Interhemisp* interhemispheric, *Lat* lateral, *Maj* major, *Mam* mamillary, *Med* medial, *Occ* occipital, *Occipitotemp* occipitotemporal, *Olf* olfactory, *Op* optic, *Orb* orbital, *Ped* peduncle, *Plex* plexus, *Parahipp* parahippocampal, *Subst* substantia, *Pit* pituitary, *Post* posterior, *Rad* radiations, *Rect* rectus, *S* sulci, *Sulc* sulcus, *Temp* temporal, *UF* uncinate fasciculus

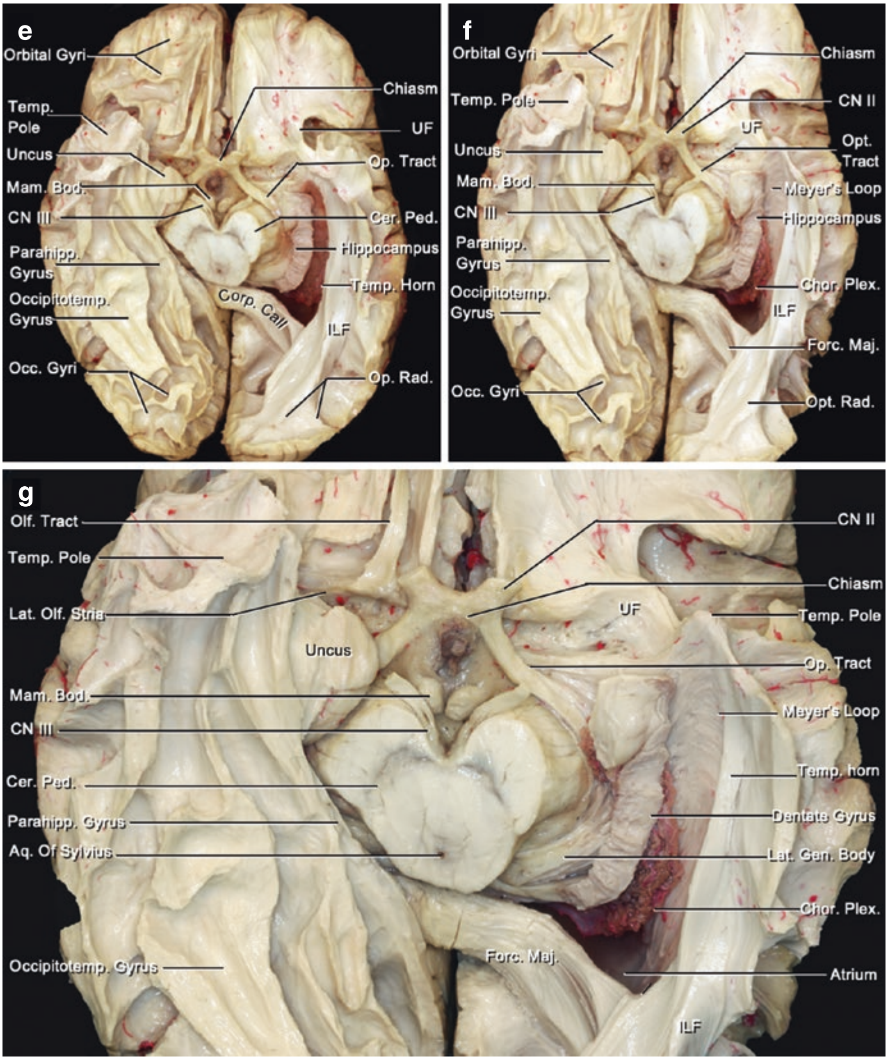

Fig. 8.4 (continued)

8.5.3.1 Anatomy

The UF is considered as an interconnecting fiber and is located in the anterior temporal stem forming a compact fasciculus at the level of the insular limen. At this point, it extends as a fan upwards towards the frontal lobe and downwards towards the temporal pole [43].

Ebeling and Cramon in 1992 [43] defined two components, a ventromedial and a dorsolateral one; the former connects the uncus, amygdala and ITG with the gyrus rectus and subcallosal area; the latter extends from the STG and MTG to the retro-orbital cortex. Hau et al. [44] in 2016 described five subcomponents: (1) dorsolateral segment linking SFG, MFG, and all of the parts of IFG with STG, MTG, and ITG; (2) horizontal ventrolateral segment connecting temporal pole, MTG, and ITG with orbitofrontal area; (3) ventromedial component linking orbitofrontal and TP gyri; (4) short posteromedial segment communicating orbitofrontal and rectum gyri with TP and fusiform gyri; and (5) an anteromedial component linking orbitofrontal cortex and rectum gyrus with the anterior-most part of STG, and ITG.

8.5.3.2 Cortical Connectivity and Projection

The UF connects the temporal pole, the STG, the MTG, the ITG, and the temporomesial region with the frontal areas of the orbitofrontal and medial frontal cortices, the frontal pole, the pars triangularis, the pars opercularis, the MFG, and the CG [45, 46]. The cortical projection of the UF is with the basal portion of the frontal lobe, the insular limen, and the temporal pole.

8.5.3.3 Ventricular Projection

The UF projects to the inferior and inferolateral surfaces of the frontal horn, and anterior to the temporal horn of the lateral ventricle [13].

8.5.3.4 Relationship with Other WMTs

The UF is related at the orbitofrontal region and limen insula with the IFOF inferiorly and at the IFG with the SLF III, the FAT, the AF, and the IFOF. In addition, with the MdLF, the AC, and the ILF at the temporal pole, and with the CB on the medial surface of the temporal lobe.

8.5.4 Inferior Longitudinal Fasciculus (ILF) (Figs. 8.3 and 8.4)

In 1822, Burdach first described the ILF as a long association fiber tract that intervenes in the occipitotemporal processing system [13].

8.5.4.1 Anatomy

Latani et al. [47] described four segments of the ILF based on its posterior connections: fusiform, dorsolateral, lingual and cuneal regions; all of them have the same anterior connections to the rostral regions of the temporal lobe. More recently, Panesar et al. [48] distinguished two subfascicles, a ventral and a dorsal one, according to a distinctive dorso-ventral connectivity pattern.

8.5.4.2 Cortical Connectivity and Projection

The ILF connects the hippocampus, the PhG, the amygdala and the temporal pole [8, 49] with the occipital extrastriate region [48]. Its cortical projection is to the FuG.

8.5.4.3 Ventricular Projection

The ILF projects inferolateral to the temporal horn and the atrium of the lateral ventricle [13, 48].

8.5.4.4 Relationship with Other WMTs

The ILF has an inferolateral relation with the optic radiations [49, 50]. The fibers of the posterior portion of the ILF are related inferiorly to the IFOF. In addition, there is close contact with other tracts, such as the UF, the AC, and the MdLF at the temporal pole. The AF along its inferior segment of the temporal lobe is lateral to the ILF.

8.5.5 Visual Pathway (VP) (Figs. 8.4 and 8.5)

The optic radiations were described for the first time by Gratiolet in 1854. Following this, in 1896, Flechsig described the curvatures of the optic radiations (OR), and finally in 1907, Meyer identified a temporal loop of the OR to the anterior bundle, which today is referred to as "Meyer's loop". The present classification of the OR was described by Ebeling and Reulen [51].

8.5.5.1 Anatomy

The white matter of the visual pathways are composed of the following: the optic nerve (ON), the optic chiasm, the optic tract (OT) and the optic radiations (OR) [8].

ON: The ON is composed of axons originating from the ganglionar cells within the innermost layer of the retina [52], and emerge from the optic canal, traversing to the suprasellar region and the anterior incisural space; it is covered by the falciform process, which is a reflex sheet of dura mater that extends from the anterior clinoid process to the lesser wing of the sphenoid to reach the chiasm [53]. The ON can be anatomically divided into intrabulbar/intraocular, intraorbital, intracanalicular, and intracranial segments based on its relative position and course.

Chiasm: The chiasm is located superior to the prechiasmatic sulcus within the suprasellar cistern [52], situated between the optic recess of the third ventricle and the infundibular recess. The nasal (medial) fibers of the ON decussate to the contralateral side and the temporal (lateral) ones stay on the same side [8].

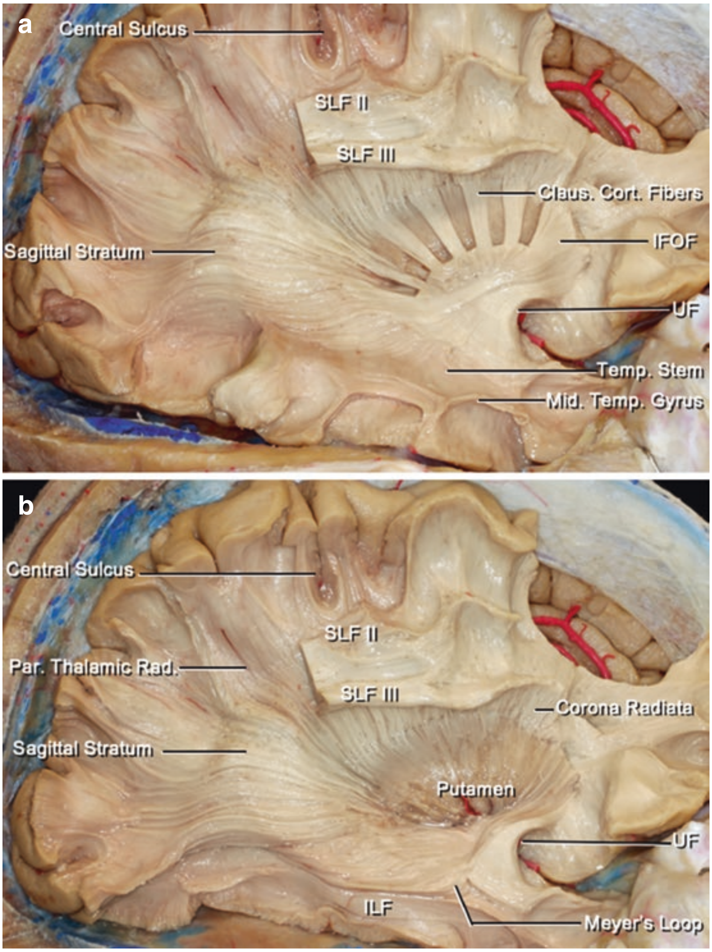

Fig. 8.5 Lateral view of the optic radiations. (**a**) The temporal stem is observed and u–fibers from the middle temporal gyrus and the inferior temporal gyrus, in addition, the stratum sagittal is shown. (**b**) The u-fibers of the temporal lobe at the level of the middle temporal gyrus were removed and the optic radiations are observed. In addition, the ILF and UF are observed relative to the Meyer's loop. (**c**) The optic radiations bundles are observed. Meyer's loop is located above ILF. (**d**) The posterior bundle of the optic radiations was cut and the tapetum is observed. (**e**) The temporal horn and atrium are observed after resection of the optic radiations and tapetum. *Ant* anterior, *Call* callosal, *Claus* claustrum, *Com* commissure, *Cort* cortical, *CST* corticospinal tract, *Front* frontal, *IFOF* inferior fronto-occipital fasciculus, *ILF* inferior longitudinal fasciculus, *Inf* inferior, *Mid* middle, *Occ* occipital, *Par* parietal, *Par. Occip* parietooccipital, *Post* posterior, *Rad* radiations, *SLF* superior longitudinal fasciculus, *Temp* temporal, *UF* uncinate fasciculus

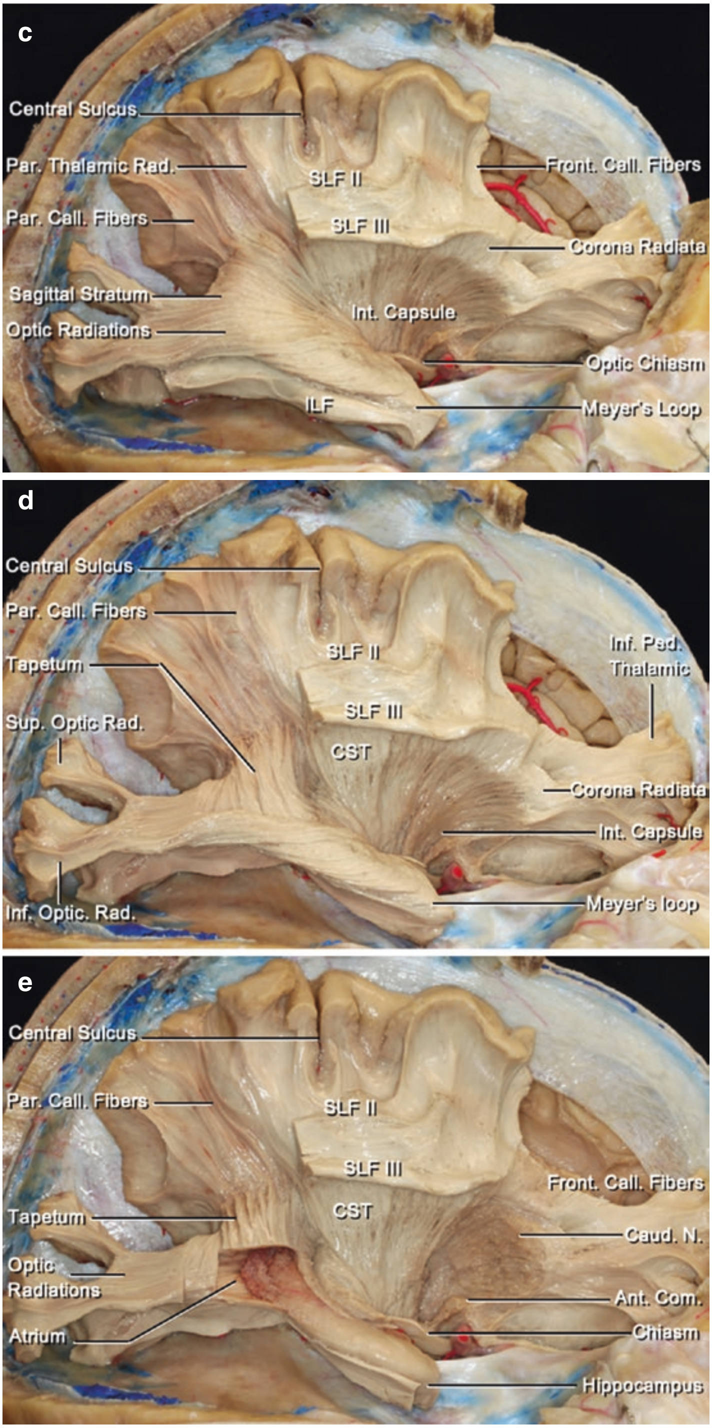

Fig. 8.5 (continued)

OT. The OT courses in a posterolateral direction along of the cerebral peduncles [53] to reach the lateral geniculate nucleus [52].

OR: Also known as the geniculocalcarine tract, the OR courses within the sublenticular and retrolenticular portions of the IC [54]. The OR constitute the deepest white matter tract of the lateral surface of the brain [55].

The OR are divided into three portions: anterior, central and posterior bundles. The anterior bundle or Meyer's loop carries information of the superior visual fields to the inferior lip of the calcarine fissure; the central bundle carries information from the macula and; the posterior bundle takes information of the inferior visual fields to the superior lip of the calcarine fissure.

8.5.5.2 Cortical Connectivity and Projection

The anterior bundle or Meyer's loop is located at the level of the middle temporal gyrus [54] (Fig. 8.2c, d). The optic radiations project to the inferior parietal lobe medially and the surface of the occipital lobe laterally.

8.5.5.3 Ventricular Projection

The chiasm is located where the floor and the anterior wall of the third ventricle meet [53]. The OR entirely covers the lateral wall and roof of the temporal horn, and at the end of its course the fibers runs lateral to the atrium and occipital horn [56].

8.5.5.4 Relationship with Other WMTs

The fibers of the AC are superior to the OR. The anterior bundle of the OR is related posterior to the UF, inferior to the AC, and IFOF, medial to the AF and lateral to the tapetum. The OR are related medially to the IFOF at the level of the lateral surface of the atrium of the lateral ventricle, lateral to the tapetum and superolateral to the ILF. The anterior third of the central bundle of the OR intertangles with the acoustic radiation.

8.6 Conclusion

Subcortical white matter tracts are a complex and intricate system of neural circuits, whose location, orientation, and course are essential to the critical functions provided by the human cerebrum. Incremental advancements in cadaveric dissections, optical technology, and radiological imaging have allowed us to study WMT anatomy with more precision and accuracy. A detailed knowledge of the WMT anatomy is especially important when planning and executing surgery to the subcortical area, all in an effort to minimize patient and preserving neurological function.

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