Surgical anatomy and surgical approaches to the lateral ventricles

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Contents

Abstract

This study focuses on the surgical approaches to intraventricular tumors which have developed within the cavity of the lateral ventricle. The first section is dedicated to embryology and describes the wrapping of the telencephalic vesicles around the thalamus and the morphogenesis of basal nuclei and commissures. In the second section, the anatomy of the lateral ventricles is described, along with their arterial and venous vasculature, their relationship with the eloquent cortical areas and cortical sulci, and their relationship with white matter fascicles, especially the optic radiations. In the third part, the main surgical approaches to the frontal horn, to the ventricular atrium and to the temporal horn are detailed.

Keywords: Anatomy; surgical approach; lateral ventricle; tumor.

This study focuses on the surgery of intraventricular tumors which have developed within the cavity of the lateral ventricle. The authors have excluded:

- Tumors which arise from adjacent brain structures and then spread into the ventricles
- Tumors of the pineal area
- Trigonoseptal tumors extending to the frontal horn
- Tumors of the third ventricle growing into the lateral ventricles

Tumors of the lateral ventricle are rare, representing 0.8–16% of brain neoplasms. They affect young patients (average age is 40 years) and often present as benign lesions. They expand within an extensible cavity, leading to relatively minor disturbances despite their large size at the time of diagnosis [10, 15, 31].

Tumors of the lateral ventricle are particularly deep, overlaid by a cortical mantle which contains eloquent areas especially in the dominant hemisphere. The surgical approach is often difficult. The best treatment is surgery for most of histological types, particularly when the tumor volume is large. In posterior locations, surgical routes threaten the optic radiations which overlay the lateral ventricle, leading to a postoperative lateral homonymous hemianopia in 10–30% of patients. The overall surgical mortality rate varies from 0 to 14%, related to vascular complications, arterial but mostly venous, and CSF circulatory complications [3, 8, 10, 31, 37, 45].

Every case requires thorough preoperative planning based on imaging to understand the site of origin of the tumor and origin of the vascular pedicles. Neuronavigation may be necessary to improve the approach. Progressive removal (debulking) of the tumor volume is essential when the route is narrow. An initial clipping of the feeding vessels can be justified for hypervascular tumors. It is also possible to use stereotactic radiosurgery especially for recurrent or small remnant tumors.

A – Embryology [11, 13, 22]

The lateral ventricles are the fluid-filled cavities of the telencephalic vesicles.

The anterior communication of the primitive neural tube or anterior neuropore (AN) closes during the 11th stade (embryo of 2.5 mm to 4.5 mm-24th day). The anterior vesicle forms the prosencephalon. At the 32nd day two lateral evaginations appear communicating by the anterior portion of the prosencephalon which becomes the median telencephalon, future anterior area of the third ventricle (V3) and interventricular foramina (IVF). The remaining prosencephalon becomes telencephalon.

Closure of the AN is made by the lamina terminalis (LT) – the future anterior wall of the V3 which is the diencephalic ventricle that includes the white commissures: optic chiasma, anterior commissure (AC), fornix and corpus callosum.

The telencephalic evagination wraps around the thalamus resting against the neurocranium during its morphogenesis. It develops forward (future frontal horn), then behind (future ventricular body), extends toward the posterior neurocranium and curves ventrally and laterally in the temporal fossa (temporal horn). The occipital expansion is a diverticulum of the LV.

The lower part of the wall of the telencephalic vesicles includes a large cellular proliferation which creates the striatum and future basal nuclei of the brain. Ependymal epithelium gives rise to neurones and glial cells which will migrate toward the surface to form the cerebral cortex.

The LT constitutes an important inductor. Few diencephalic or archipallidal commissures have a simple transverse orientation: posterior commissure and AC. Others will wrap around the thalamus either partially like the corpus callosum (CC) or entirely like the fornix (F) which will form the internal wall of the LV. The portion of medial cortex of the telencephalic vesicles located between the winding of the corpus callosum and the fornix will form the septum pellucidum (Spel) (Figs. 1 and 2).

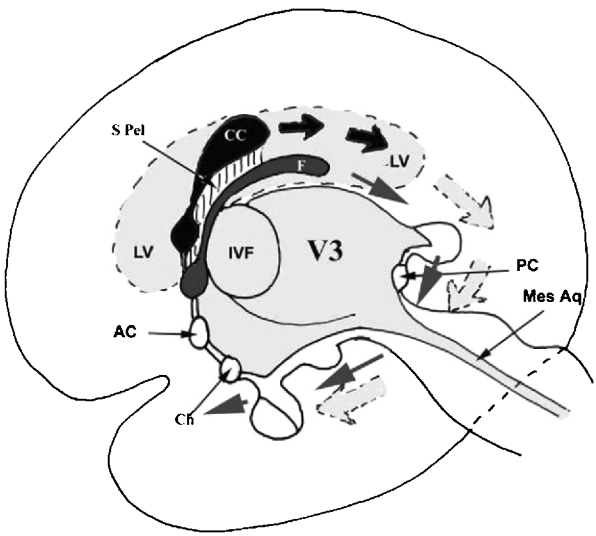


Fig. 1. Diencephalic winding on a medial sagittal section. Partial winding of the corpus callosum (black thick arrows). Complete winding of the fornix (thin black arrows) and of the LV (grey arrows). (PC: Posterior commissures; Mes Aq: Mesencephalic aqueduct)

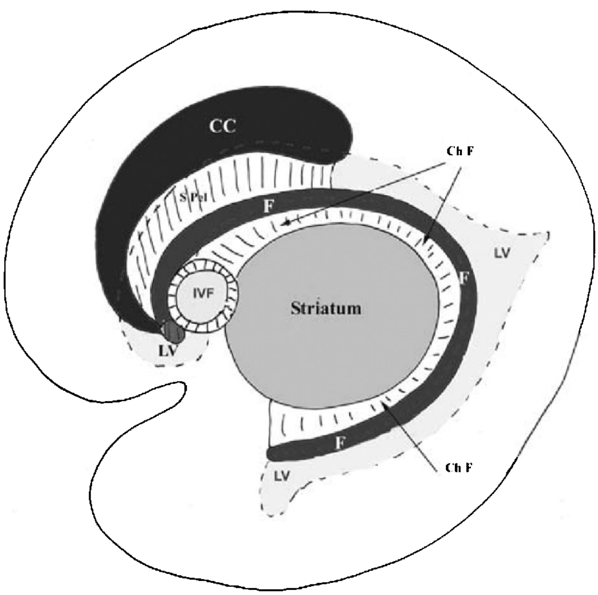


Fig. 2. Diencephalic winding and winding of the commissures (corpus callosum and fornix). Medial view of a telencephalic vesicle (ChF: choroidal fissure)

The LV behind the interventricular foramen (IVF) has a thick medial wall with an ependymal lining: it is the choroidal fissure (Ch F). This process is also completed during the development of the other ventricular cavities and constitutes the membrana tectoria of the third ventricle and the fourth ventricle. The mesencephalic vesicle will keep the aspect of the primitive neural tube: its cavity will form the aqueduct of the mesencephalon (Mes Aq).

The leptomeningeal layer proliferates and gives rise to the choroidal plexus when it reaches the ependymal epithelium. The choroidal plexus develops into the choroidal fissure and extends in a C-shaped arc from the foramen of Monro through the body, atrium, and temporal horn avoiding the occipital diverticula (during the 18th–44th day).

The last fundamental embryological process is the fusion between the diencephalic vesicle and the two telencephalic vesicles which grow considerably and finally cover it (20th–51th day). The motor area of the diencephalon is directed laterally because of the prominent thalamus: the pallidum will merge with a part of the striatum (putamen) to give the lenticular nucleus which has a double embryological origin (Figs. 3 and 4). This nucleus does not wrap around the thalamus.

On the other hand, corticospinal pathways detaches a striate fragment which wraps laterally around the LV to form the caudate nucleus (CN).

The boundaries of the junction between the telencephalic vesicles and the diencephalons give rise to the transverse cerebral fissure (TCF) with two parts: one is horizontal with a horseshoe form opened ventrally toward the diencephalon-mesencephalon junction, the other is vertical directed ventrally and runs between the fornix and the roof of the third ventricle. The TCF concentrates the choroidal tela of the third ventricle and draws the superior boundary of the attachment. The venous ampulla courses in the ambiens cisterna. The pineal corpus forms the junction between the two parts of the FCT.

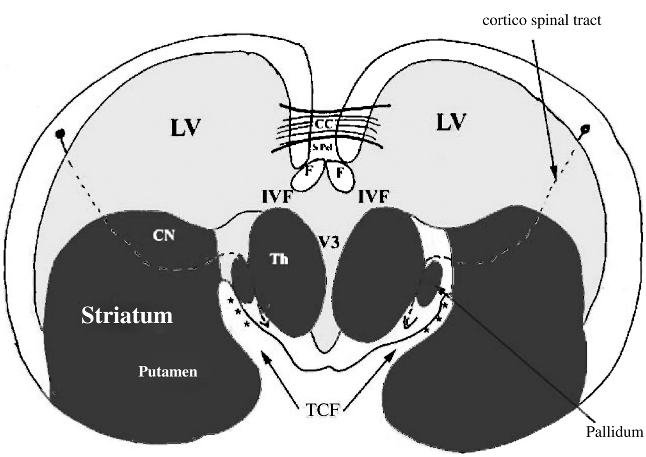


Fig. 3. Frontal section through the interventricular foramina before the joining between diencephalon and mesencephalon

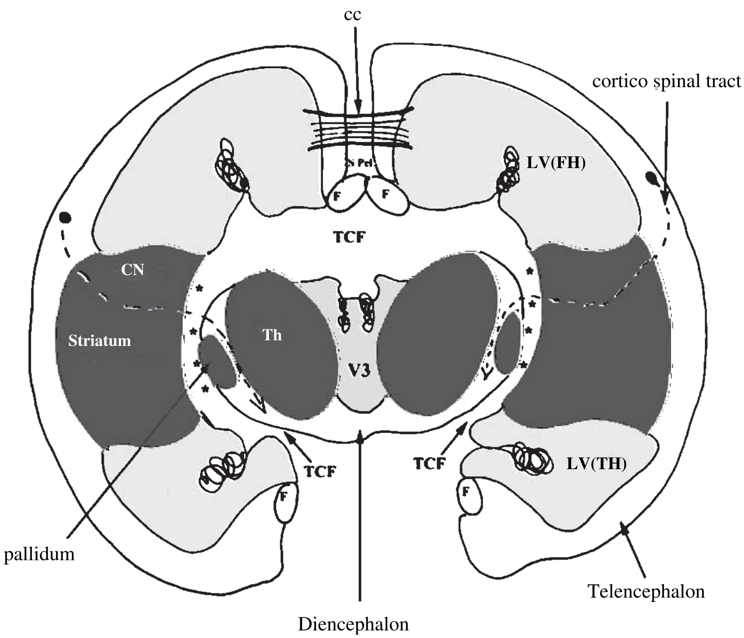


Fig. 4. Frontal section behind the interventricular foramina before the joining between the diencephalon and mesencephalon. LV(FH): lateral ventricle, frontal horn; LV(TH): lateral ventricle, temporal horn

B – Anatomy [1, 4, 5, 12, 19, 30, 34, 35, 38, 39, 40]

1. The cavity of the lateral ventricle (Figs. 5 and 6)

The lateral ventricles are two paired cavities deeply situated within each hemisphere. They have a horseshoe form as the result of embryological telencephalic winding. Each cavity contains about 10 cm^3 of cerebrospinal fluid and can be divided into:

- A frontal horn which has a ventral extremity in front of the interventricular foramen (IVF). Its length is approximately 6 cm
- A body between IVF and atrium
- A temporal horn or inferior horn or sphenoidal horn, whose length is 4 cm
- An atrium between these different parts

2. The walls of the lateral ventricle

2.1 The anterior frontal horn

The boundaries are:

- internal wall: septum pellucidum
- roof, anterior wall and floor: anterior wrapping of the corpus callosum, genu, rostrum and trunk

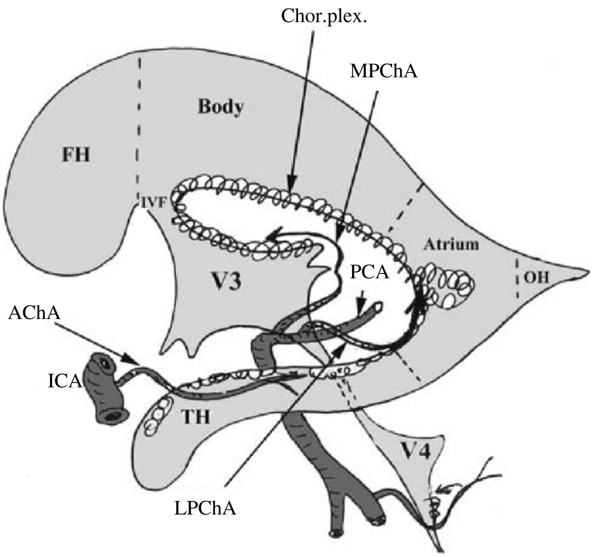


Fig. 5. Lateral view of the ventricular cavities and their vascular relationships. (Chor.Plex: choroidal plexuses-MPChA: medial posterior choroidal artery – PCA: posterior cerebral artery–AChA: anterior choroidal artery – LPChA: lateral posterior choroidal artery – ICA: internal carotid artery)

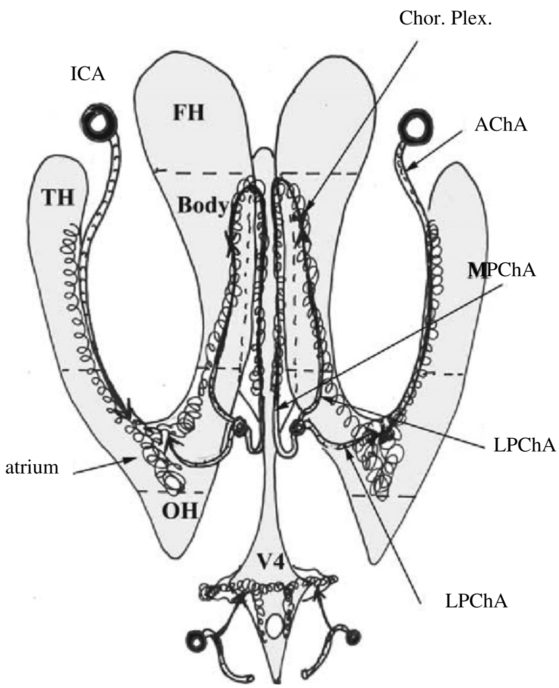


Fig. 6. Superior view of the lateral ventricular and arterial vasculature

– lateral wall: internal aspect of the head of the caudate nucleus.

2.2 The body of the frontal horn or central part of the LV (Fig. 7)

The boundaries are:

– internal wall: septum pellucidum and body of fornix
– roof: inferior aspect of the body of corpus callosum
– lateral wall: medial part of the body of the caudate nucleus
– floor: superoinferior aspect of thalamus between the thalamo-caudate sulcus and the tenia thalami (attach line of the choroidal plexus on the thalamus): this is the area of the lamina affixa. The thalamo-caudate sulcus contains the

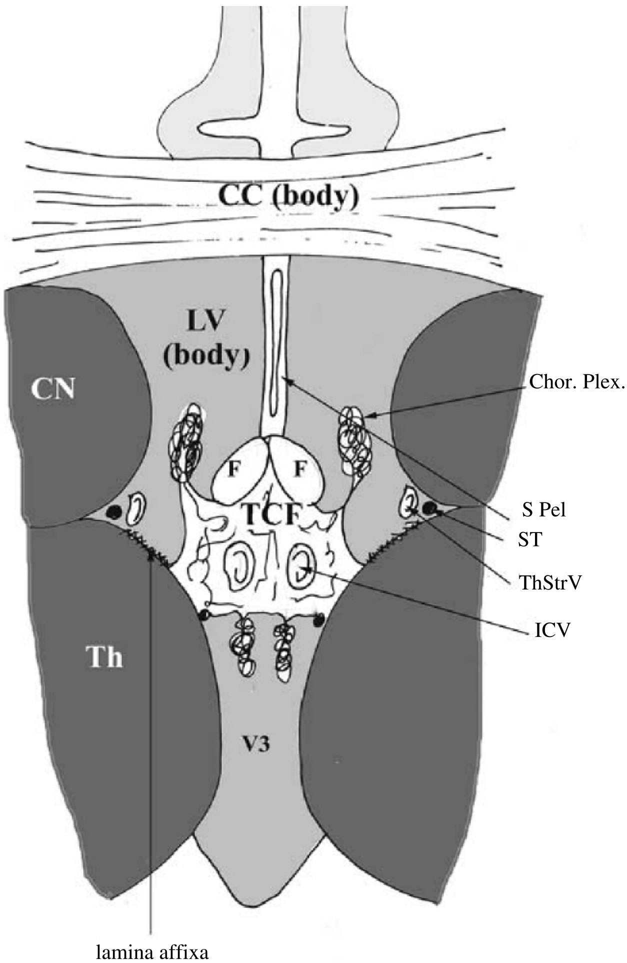


Fig. 7. Frontal section through the body of the LV

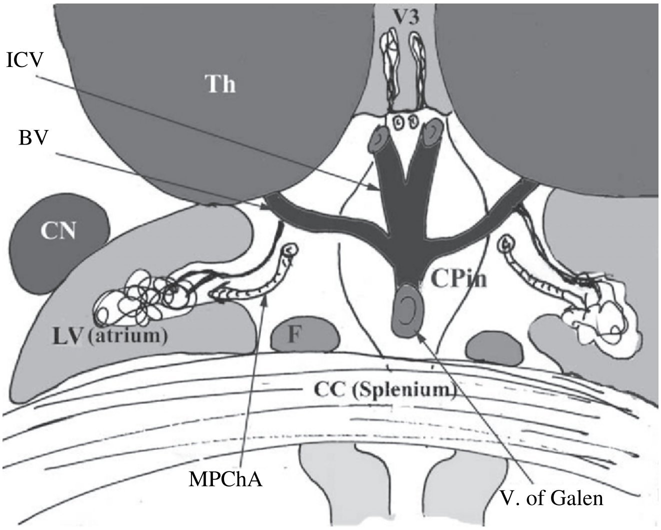


Fig. 8. Axial section of the atrium of the LV. (ICV: internal cerebral vein – BV: basal vein – CPin: pineal body)

stria terminalis (ST, white matter fasciculus connecting the amygdaloid nucleus with the hypothalamus and with the septal areas of the frontal cortex) and the thalamostriate vein (ThStrV).

2.3 The atrium (Fig. 8)

It communicates cranially, ventrally and medially with the frontal horn, dorsally with the occipital diverticle, and caudally, ventrally and laterally with the inferior horn. It overlies the pulvinar, posterior pole of the thalamus which constitutes the anterior wall. The fibers coming from the splenium constitute the roof. The choroidal fissura with the choroidal plexus (glomus) forms the medial wall and isolates the LV from the cisterna ambiens.

2.4 The occipital diverticulum (or occipital horn) (Fig. 9)

It extends towards the posterosuperior pole of the cerebral hemisphere. It does not concentrate choroid plexus. The walls are constituted by:

– internal wall: two prominences formed cranially and inferiorly by the fibers of the splenium of the corpus callosum (bulbar prominence) and the deep part of the calcarine sulcus (calcar alvis),
– floor: bulged by the collateral sulcus between T4 and T5 forming the collateral eminence,
– lateral wall: white matter of the tapetum formed by the external fibers of the splenium of the corpus callosum, overlaid laterally by the optic radiations (Opt.Rad) and then the inferior longitudinal fasciculus (Inf.Long.Fas.).

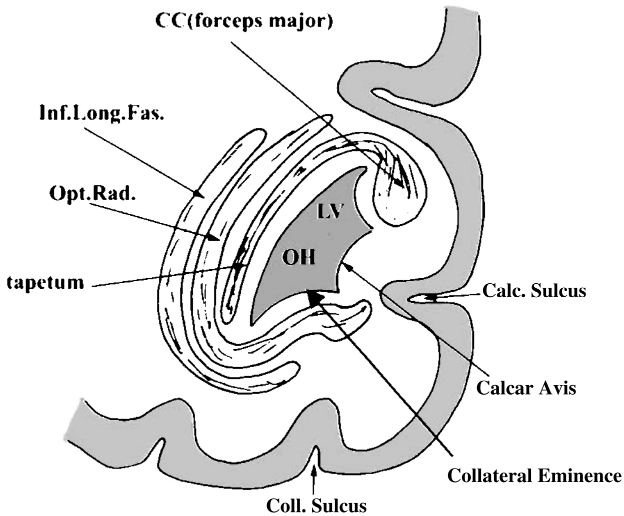


Fig. 9. Frontal section through the left occipital horn, anterior segment of the section (from Ebeling [12])

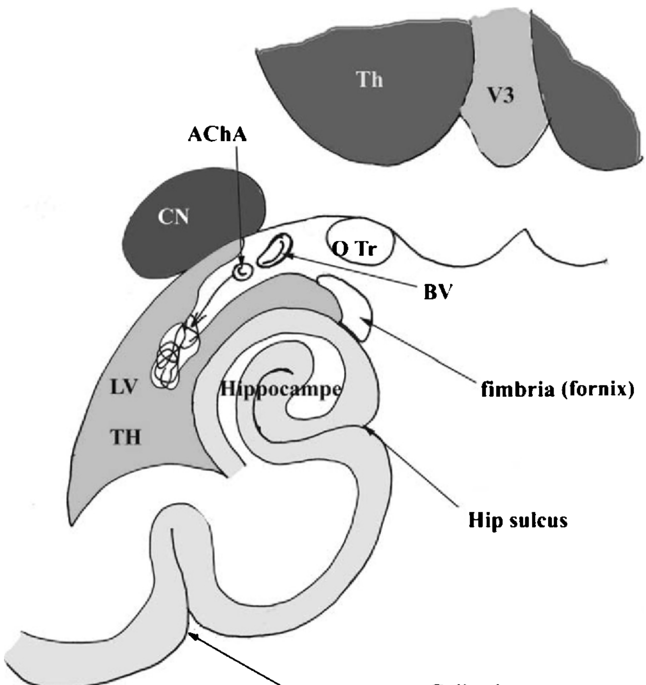


Fig. 10. Frontal section through the left temporal horn, anterior segment of the section (OTr: optic tract – BV: basal vein)

2.5 The temporal horn (Fig. 10)

It is formed by:

– floor: hippocampus or pes hippocampus and caudally the collateral eminence (prominence formed by the T4–T5 sulcus)
– roof: inferior aspect of the thalamus, tail of the caudate nucleus and deep white matter of the temporal lobe,
– internal wall: choroidal fissura and choroid plexus clinging to the fimbria which is the initial portion of the anterior crus fornicis and to the inferior aspect of the hemisphere.
– The anterior extremity is situated just behind the amygdaloid nucleus.

3. The interventricular foramen (Figs. 11 and 12)

The interventricular foramen is the communicating hole between the two LV's and the third ventricle. It is bounded on each side by the anterior pole of the thalamus and ventrally by the anterior crus fornicis. It has a diameter of 3–4 mm and presents a posterior concavity. It is marked by the reflexion of the choroidal plexus of the roof of the third ventricle which continues with the choroidal plexus of the LV and the venous angle between the thalamostriate vein and the internal cerebral vein.

4 Choroid plexus and CSF circulation

The choroid plexus is formed by the leptomeninx which leans on the ependymal epithelium bulging into the cavity of the LV at its medial portion through the choroidal fissura.

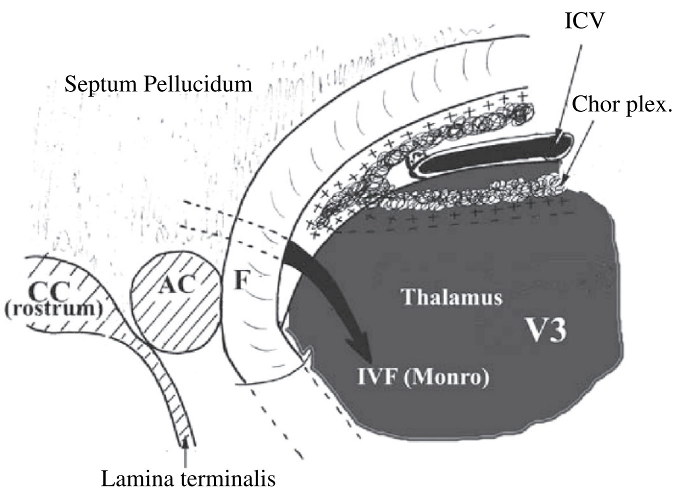


Fig. 11. Lateral view of the interventricular foramen (foramen of Monro)

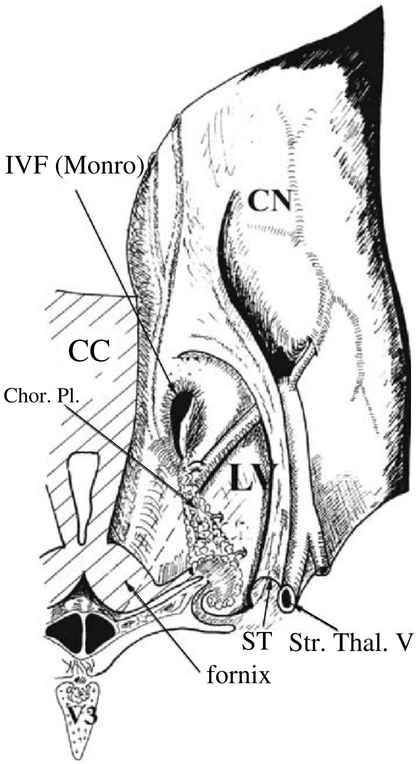


Fig. 12. Superior view through the frontal horn with the interventricular foramen (foramen of Monro)

The choroid plexus of the LV joins the choroidal plexus of the roof of the third ventricle through the interventricular foramen. It courses within the body, the atrium and the temporal horn. At level of the atrium, it is bulky and often presents with calcifications or cysts: it's the choroidal glomus.

The choroid veins mainly devious course over the choroid plexus and are well seen because they are bulky unlike the choroid arteries.

The CSF is secreted by the choroidal plexus with an active process via its main element the ependymal cell (blood-CSF barrier). This secretion is made in the LV with a circulation towards the IVF and the third ventricle. This can explain a possible cystic dilatation of a part of the LV (frequent at the level of the TH) caused by tumoral exclusion and disturbance of the CSF circulation.

5. Arterial vasculature of the VL (Figs. 1 and 13)

The choroid plexusi are supplied by choroidal arteries which have a small caliber and whose territory is not limited to plexusi but also includes telencephalic, diencephalic and mesencephalic adjacent nervous structures. Their number is vari-

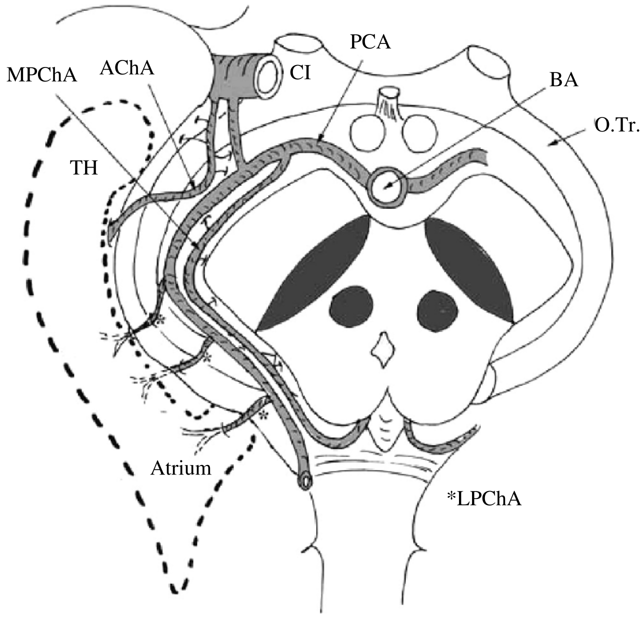


Fig. 13. Origin of the choroid arteries on an inferior view of the brain

able. They are deeply situated and reach the cavity of the VL on the medial face. They are hidden by the tumor and are not often exposed to the surgeon's sight.

5.1 Anterior choroid artery (AChA)

The AChA arises from the terminal segment of the internal carotid artery (C4) closer to the origin of the posterior communicating artery than the carotid bifurcation. The AchA has been reported to arise as a duplicate or double artery. It can divide quickly. Its origin is located on the posteromedial face of the internal carotid artery. It presents two segments: cisternal and plexal. The cisternal segment is concave laterally in a horizontal plan and concave rostrally in a sagittal plan; the plexal segment has a reversed course.

The cisternal segment (24 mm of average length) courses posteriorly below the optic tract. It encircles the lateral face of the cerebral peduncle. Then its course changes at the level of the lateral geniculate body to run through the choroidal fissure, reaching the superomedial part of the uncus to enter the anterior portion of the choroidal plexus within the temporal horn. The cisternal segment gives rise to its first large branch in the anterior portion of the temporal horn. It frequently anastomoses with branches of other choroidal arteries. The AChA sends branches (4 á 18) to adjacent nervous structures, and particularly the optic tract, the cerebral peduncle, the globus pallidus, the origin of the optic radiations. In approximately 50% of cases it sends a branch to the two posterior thirds of the internal capsule. This area of distribution is variable.

Moreover there is a balance between the territory of the AchA and the posterior communicating artery. Namely, their calibers often vary in the opposite direction.

5.2 Posterior choroid artery (PChA)

- The medial posterior choroid artery gives a few feeding vessels for the choroidal plexus of the VL except anterior anatomosis at the level of the interventricular foramen. It arises from the posterior cerebral artery posterior to the junction with the posterior communicating artery (P1 segment). It runs in the anterior portion of the cisterna of the transverse cerebral fissure and enters the ambiens cisterna to reach the choroidal tela of the third ventricle and its plexuses. Anastomoses are often found between the medial posterior choroidal artery and the lateral posterior choroidal artery (LPChA) through the interventricular foramen (IVF).
- The lateral posterior choroid artery (LPChA): their number per hemisphere ranges from 1 to 9 (average 4). It arises from either P2 segment or P3 segment of the PCA or from its branches. It runs laterally to the PCA and enters the choroidal fissura. The most important, arises from the P2 segment, sends branches to the glomus. Its area of distribution are the cerebral peduncle, fornix, pulvinar and caudate nucleus.

6. The veins of the lateral ventricles (Figs. 14–16)

These veins belong to the deep venous system of the brain and end in the internal cerebral veins (ICV) in the choroidal tela of the third ventricle and in the basal vein of Rosenthal which runs in the horizontal part of the transverse cerebral fissure with a circumpeduncular course where it sweeps over the PCA intersecting with the AChA.

- ***The choroidal veins*** are bulky and tortuous, easily seen, run over the plexus and only drain the plexus:
  - The superior choroid vein (12), very bulky, drains the glomus et runs ventrally towards the ventricle body to end close to the IVF either in the thalamostriate vein or in the ICV.
  - The inferior choroid vein (13) ends in the inferior ventricular veins and also in the basal vein at the same place.
  - The medial choroid veins course from the plexus of the ventricular body to the ICV.
- ***The veins of the ventricular walls*** drain not only the ependyma but also the adjacent parenchyma forming a deep venous territory draining the striatum, the internal capsule, the corpus callosum, the fornix and the septum pellucidum. There is a communication between the superficial venous system and the deep

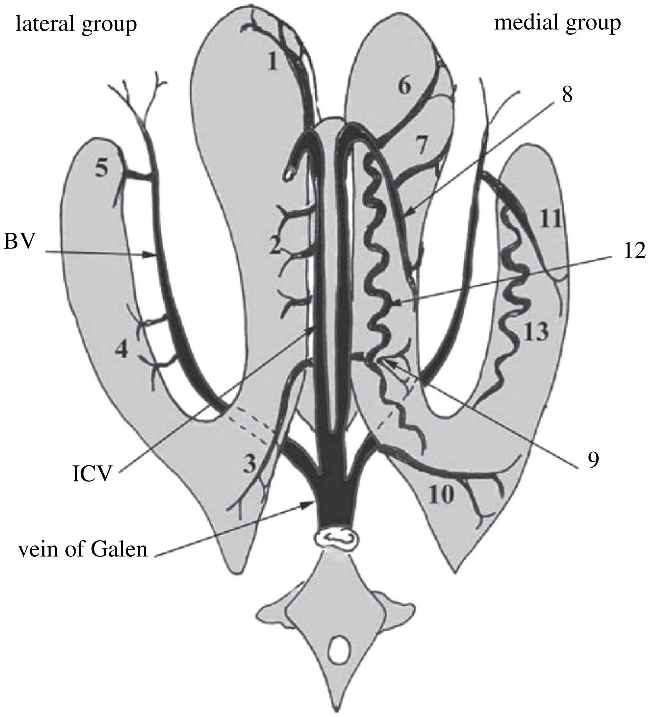


Fig. 14. Superior view of the ventricular veins

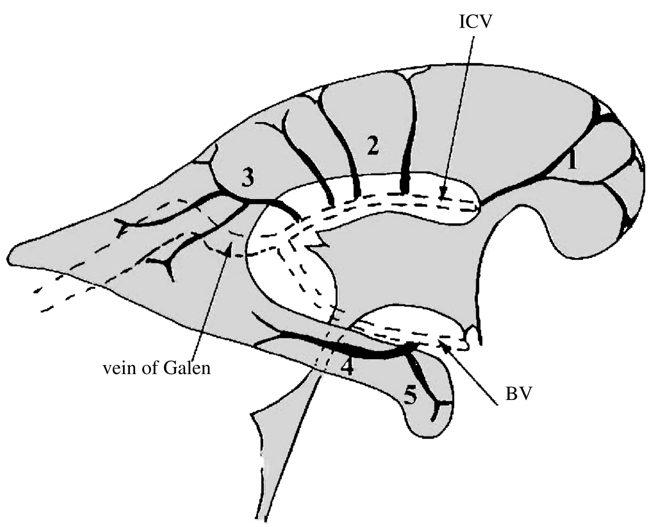


Fig. 15. Veins of the LV, medial group, lateral view

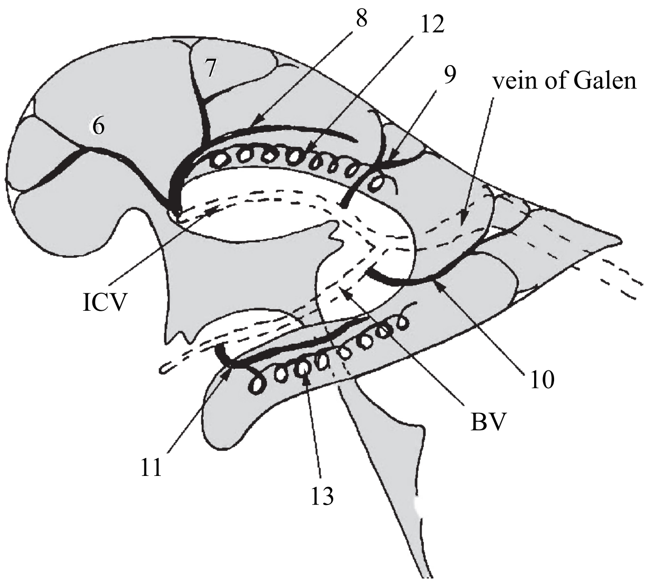


Fig. 16. ventricular veins, lateral group, lateral view

contrary to the arterial vasculature. However, these anatomoses do not protect the brain against venous infarction if they are sacrificed in approaching the LV. The ventricular veins can be divided into veins of the medial wall and veins of the lateral wall. They drain into the choroidal fissure.

- Veins of the medial wall of the LV:
  - Anterior septal vein (1), the most constant, drains into the venous confluent of the IVF.
  - Posterior septal veins (2) draining into the ICV.
  - Medial atrial veins (3) joining either the lateral atrial vein or the ICV or the medial occipital vein
  - Transversal veins of the hippocampus (4) draining into the basal vein or the ICV.
  - Vein of the amygdaloid body draining into the basal vein or into a transversal vein of the hippocampus.

- Veins of the lateral wall:
  - Anterior caudate veins (6), draining into the thalamostriate vein.
  - Thalamostriate vein (8), the most constant, runs in the thalamocaudate sulcus et forms the venous angle with the ICV through the IVF.
  - Posterior caudate veins (7) ending to the thalamostriate vein
  - Thalamocaudate vein (9) joins the ICV before the atrium. Its caliber is inversely proportional to the caliber of the thalamostriate vein.

– Lateral atrial veins (10) ending in the vein of Galien
– Inferior ventricular veins (11) in the CT converging in the basal veins.

7. Relationships of the lateral ventricles

They were mostly described in the section on the ventricular walls (corpus callosum for instance).

7.1 Cortical eloquent areas (Figs. 17 and 18)

Areas of comprehension of language (gyrus angularis, gyrus supra marginalis, middle temporal cortex and posterior cortex of the convexity) are close to the direct route to the ventricular atrium and hence a superior transparietal approach or a transcortical temporobasal incision are preferred.

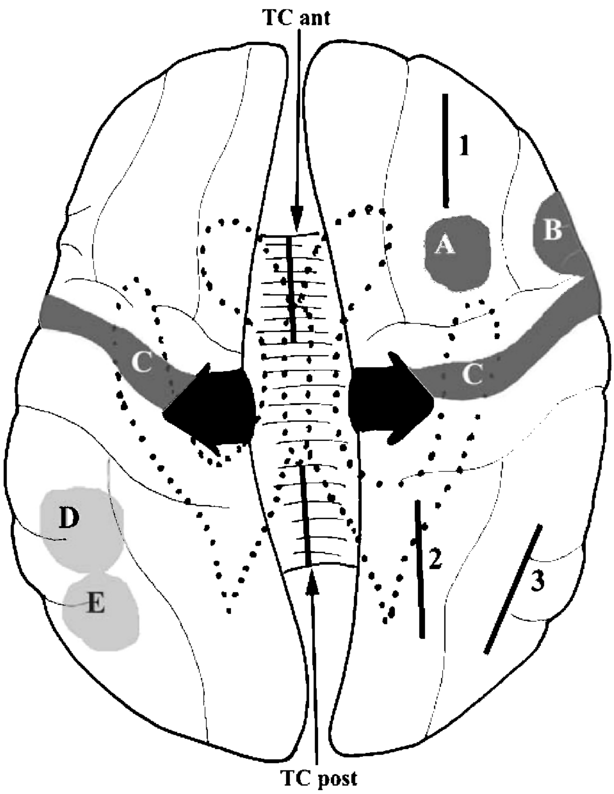


Fig. 17. Superior view of the cerebral hemisphere. (A, B, D, E: language cortical areas – C: motor cortex – 1: transfrontal transventricular approach – 2: posterior transparietal approach – 3: transparietal approach – TCant: anterior transcallosal approach – TCpost: posterior transcallosal approach)

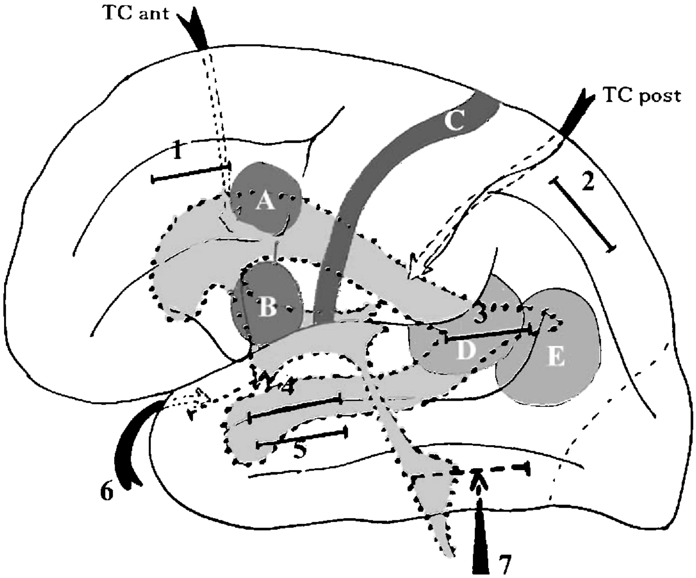


Fig. 18. Lateral view of the cerebral hemisphere. (A, B, D, E: speech cortical areas – C: motor cortex – 1: transfrontal transventricular approach – 2: posterior transparietal approach – 3: transparietal approach – 4: transsulcal T1T2 temporal approach – 5: T2 transcortical temporal approach – 6: transsylvian approach – 7: temporobasal or subtemporal transcortical approach – TCant: anterior transcallosal approach – TCpost: posterior transcallosal approach)

7.2 Distances between cortex and ventricular cavity (Fig. 19a and f)

The VL are deep structures which are developed on the medial face of the hemispheres at the diencephalomesencephalic junction. The CF and its cister-

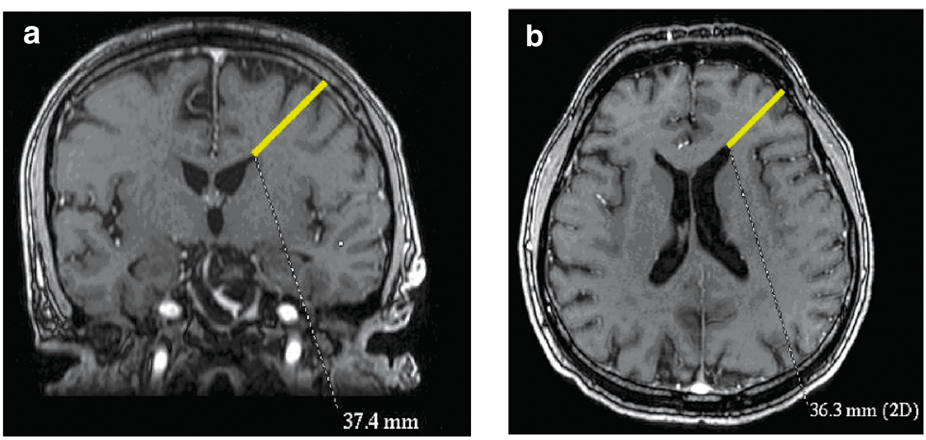


Fig. 19. (a, b) Distance between frontal cortex and frontal horn

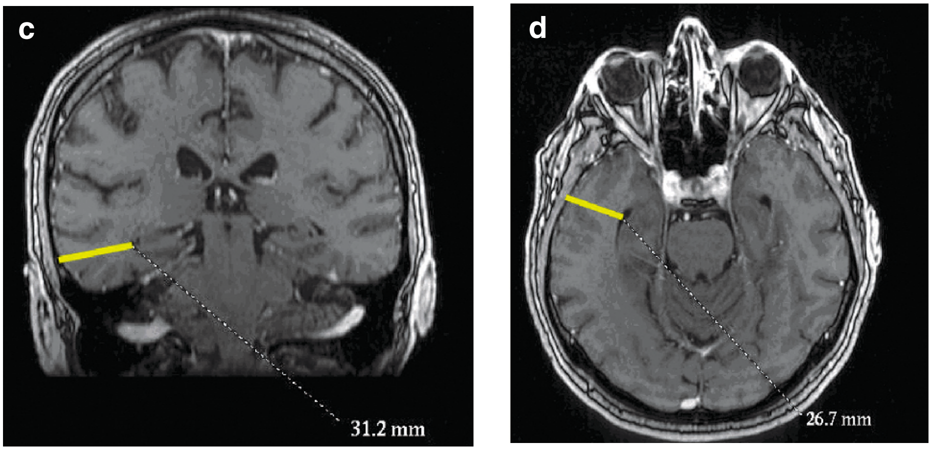


Fig. 19. (c, d) Distance between temporal cortex and temporal horn

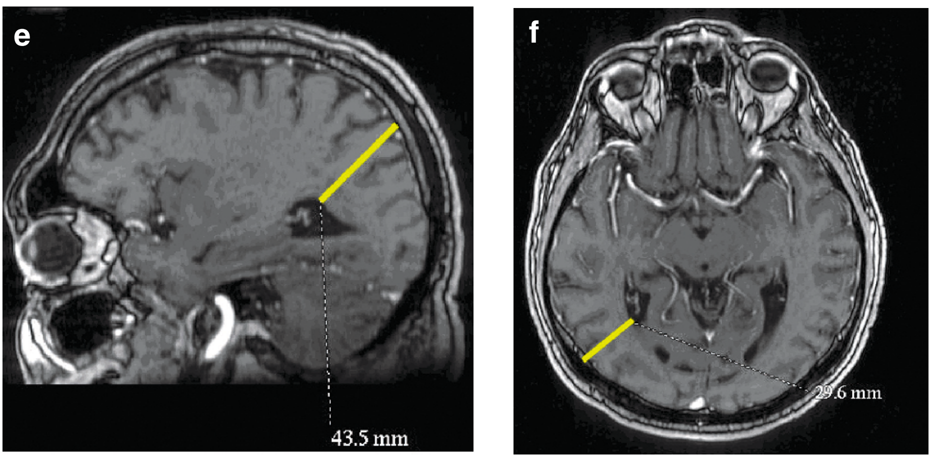


Fig. 19. (e, f) Distance between cortex and ventricular atrium

nal relationship, the transverse cerebral fissure, are the best anatomical landmarks. The neurosurgeon will prefer a route which is direct and straight but functional areas always play a decisive role for the final choice and will lead to changing the initial strategy.

Here are the average values from the literature:

- frontal cortex-IVF: maximum 60 mm
- frontal cortex – frontal horn: 35–40 mm
- temporal cortex – temporal horn: 25–30 mm
- cortex of the hemispheric cross-road – atrium: 30 mm
- parietal cortex – atrium: 50 mm
- occipital cortex – atrium: 55 mm

7.3 Relationships with the cortical sulci (Fig. 19g and h)

a – Anatomical relationships:

A few sulci bulge on the ventricular wall:

- *calcarine sulcus* forms the calcar alvis on the medial wall of the occipital horn.
- *Collateral sulcus* dividing the medial occipitotemporal sulcus (T5-O5, parahippocampal gyrus) and the lateral occipitotemporal sulcus (O4-T4, fusiformis gyrus) forms the collateral eminence on the floor of the temporal horn, of the atrium and of the occipital horn,
- *The hippocampal sulcus* raises on the medial wall of the temporal horn and forms the horn of Ammon.

b – Surgical relationships:

The sulci constitute a usable route reducing the length of the cortical passage and the brain injury. Microsurgical techniques reduce injury to the feeding vessels.

- *Longitudinal fissure of the brain* (interhemispheric fissure): it consitutes the transcallosal route, especially ventral. Only the corpus callosum which forms the roof must be incised. It reduces the cerebral lesions but does not reduce the distance to the frontal horn compared with the frontal F2 transcortical route. The bringing veins, sometimes the interhemispheric adherences, the presence of the anterior cerebral artery and its branches with interhemispheric anastomosis may provide challenges.
- *T1–T2 sulcus* is the deepest cortical sulcus, with the exception of the sulcus lateralis (scissure of Sylvius) and of the internal parietooccipital sulcus (in-

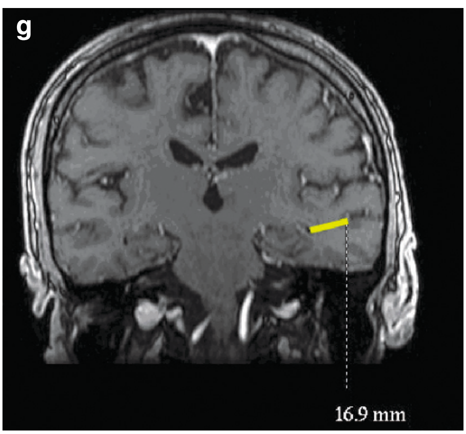


Fig. 19. (g) Distance between T1T2 sulcus and the temporal horn

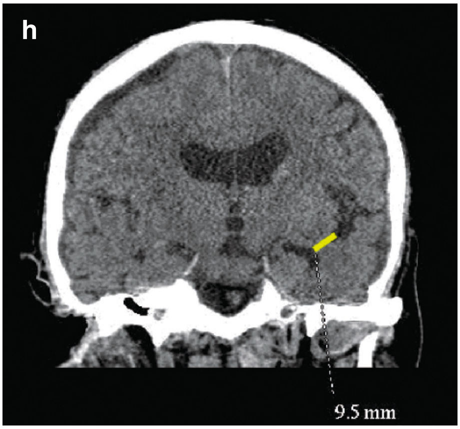


Fig. 19. (h) Distance between the sulcus lateralis and the temporal horn

ternal perpendicularis sulcus). It reduces by half the route to the temporal horn (Fig. 19g).

- *the sulcus lateralis* (scissure of Sylvius) reduces the route towards the temporal horn. Its opening allows passage through to the anterior and deep part of its temporal wall (Fig. 19h).

7.4 Relationships with white matter fascicles

These fascicles are crossed during VL approach. We can divide them into interhemispheric association fasciculi (or commissure), commissural fasciculi and projection fasciculi like for instance the optic radiations.

Some commissures (corpus callosum, fornix) have a known function whereas others have not. Nevertheless their surgical section is not insignificant. These fibers can be seen by diffusion tensor imaging (MRI tracking) (Fig. 20). This technique will provide tools for the planning of the operative trajectory, allowing a better understanding of the consequences of their surgical section.

a – Association fasciculi:

- The corpus callosum (Fig. 21)

The bulky interhemispheric commissure forms with its anterior part (rostrum and genu) the roof, the ventral extremity and the floor of the frontal horn of the LV. At the level of the ventricular body, the inferior face of the body of the corpus callosum forms the roof of the ventricular body. At the level of the atrium of the LV, the splenium of the corpus callosum breaks off the LV, separated by the crus fornicis. The fibers of the corpus callosum fan out in each hemisphere. The dense medial fibers bulge into the superomedial face of the occipital horn, above the calcar avis, prominence of the bulb. The thin lateral fibers fan out within the lateral wall of the occipital horn and form the tapetum.

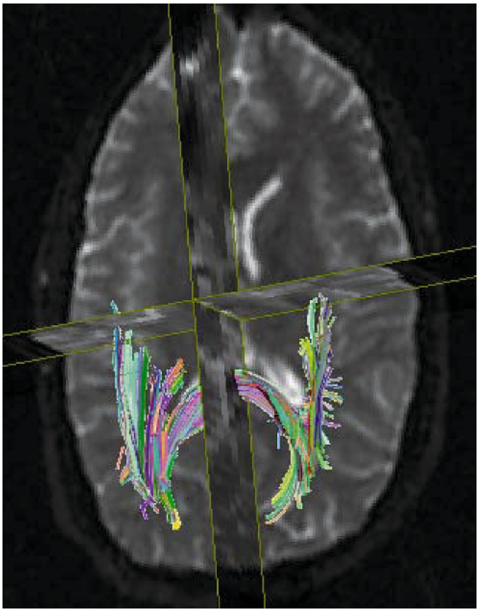


Fig. 20. Tracking of white matter fibers on MRI

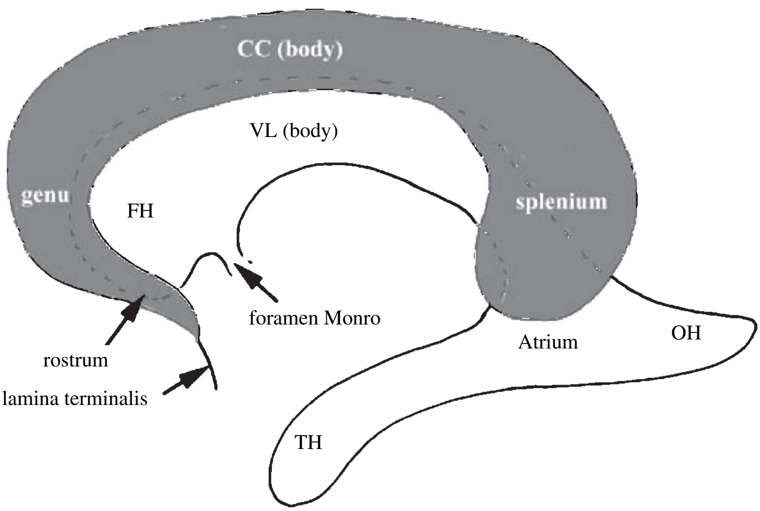


Fig. 21. Relationships of the corpus callosum with the cavity of the LV

- The fornix (Fig. 22)

It consitutes not only a projection fascicle from the hippocampal area to the mamillary body but also an association fascicle between two hippocampal segments thanks to the crus fornicis. From the hippocampus to the mamillary

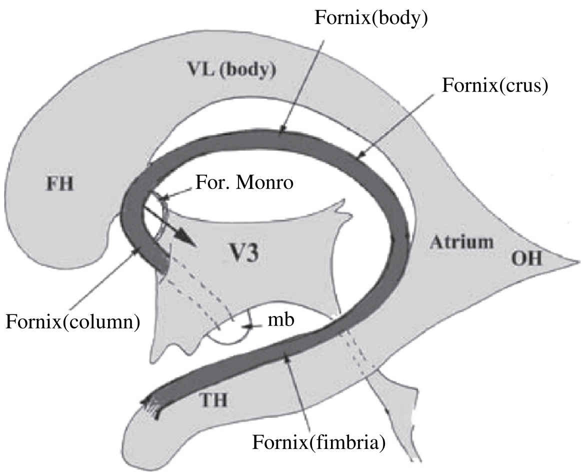


Fig. 22. Relationships of the fornix with the LV

body, it successively comprises the fimbria, the crura of fornix, the commissura, body and the columns which bound the IVF with the ventral pole of the thalamus. The fornix connects the choroidal structures (tenia fornicis) which run close to the choroidal incisura at the medial part of the temporal horn, of the atrium and of the floor of the ventricular body.

- Other intrahemispheric association fascicles:
  We will only detail the fascicles which are in the vicinity of the LV:
  - The subcallosal fascicle or superior longitudinal fascicle can be followed to the wall of the LV, where it connects the frontal lobe to the parietal, middle temporal and occipital lobes. This fascicle passes over the superolateral aspect of the caudate nucleus with a C-shaped arch.
  - Inferior occipitofrontal fasciculus interconnects the frontal lobe to the occipital lobe and courses superior to the optic radiations
  - Inferior longitudinal fasciculus connects the temporal pole to the occipital pole. It runs on the lateral wall of the temporal horn, of the atrium and of the occipital horn laterally to the optic radiations. It plays a role in visual memory.

b – Projection fascicles:

- Auditory radiations:

These fibers arising from the medial geniculate body course toward the transverse temporal gyrus of Heschl and constitute a lateral relationship with the inferior horn, atrium, optic radiations and a portion of the anterior commissure. They belong to the retrolenticular area.

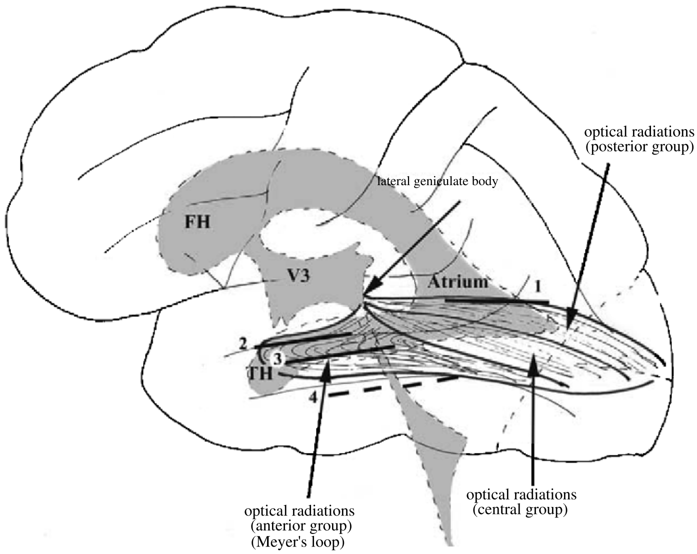


Fig. 23. Projection of the optic radiations on the wall of the LV. (1: parietal transcortical route – 2: T1T2 transsulcal temporal route – 3: temporal transcortical route – 4: temporobasal transcortical route)

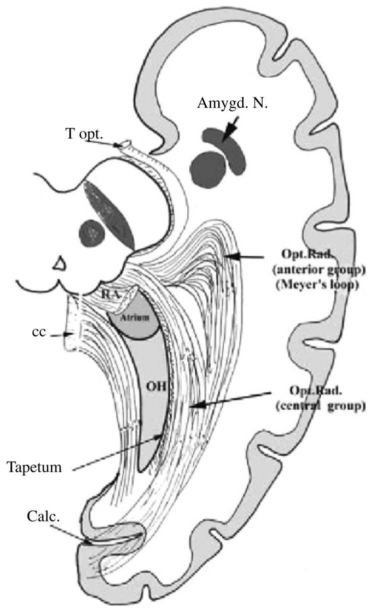


Fig. 24. Projection of the optic radiation on the wall of the LV. (Topt: optic tract – Amygd.N: amygdaloid nucleus – Opt.Rad.: optic radiations – RA: auditory radiations – CC: corpus callosum – OH: occipital horn – Calc: calcarine scissure)

- Optic radiations (Figs. 23 et 24):

They are the main relationship of the temporal horn, the atrium and the occipital horn of the LV. They arise from the deep face of the lateral geniculate body and reach the occipital cortex to join the upper and lower lips of the calcarine fissure. Campimetric deficit can be the objective signs of a tumor of the LV. Damage to these radiations is a major factor affecting surgical morbidity.

We divided the course of the optic radiations into three parts:

– the anterior group runs above the roof of the temporal horn and courses ventrally forming the Meyer loop which extends for an average distance of 27 mm behind the tip of the temporal lobe and up to 5 mm in front of the anterior extremity of the inferior horn. Then the fibers extend dorsally, in the vicinity of the lateral wall of the temporal horn, the atrium and the occipital horn and are the most ventral part of the optic radiations. They will end on the lower lip of the calcarine scissure (anterior part). They concentrate the fibers of the superior nasal homolateral visual field and superior temporal contralateral visual field. Their interruption will produce a lateral superior homonymous quadrantanopia on the opposite side of the lesion.
– the central group runs laterally, crosses the roof of the temporal horn and sweeps dorsally along the lateral wall of the atrium and the occipital horn. It is the most voluminous and concentrates the macular vision often preserved because of its bilateral projection. It ends on the two lips of the calcarine scissure occupying a great part of the primary visual cortex, dorsally to the peripheral visual field. Its damage will cause a lateral homonymous hemianopia on the opposite side of the lesion.
– the posterior group (or superior) passes directly behing the roof of the atrium to reach the superior lip of the calcarine scissure on its anterior part. It concentrates the fibers of the inferior nasal quadrant and inferior temporal contralateral of the peripheral visual field: its damage will produce a lateral inferior homonymous quadranopia on the opposite side of the lesion. It occupies the lower part of the optic radiations.

The optic radiations have a crescent shape at the level of the lateral wall of the temporal horn and atrium, and then horseshoe shape at the level of the occipital horn.

C – Surgical approaches

1. General considerations [15, 33–36, 42, 44]

Ventricular surgery requires working at depth, without the usual bone or vascular landmarks : the position of the patient must be simple and orthogonal. It is better to move the operative table or the operative microscope when the ventricular cavity has been safely opened than to change the route or modify the operative field.

Magnetic resonance imaging and neuronavigation can be useful to avoid arterial and venous vascular pitfalls and to improve the entry point and the orientation to reach the intraventricular target. The benefit of neuronavigation disappears when the ventricular cavity is opened as brain shifts. Intraoperative MR may prove useful in the future.

The height of the ventricular cavity is essential for the surgical strategy:

– If a part of the ventricular cavity is dilated or excluded and easily approachable, its draining during the approach allows hemispheric sagging. It facilitates tumoral dissection, hemostasis of the ventricular walls and access to the tumoral vascular pedicle often located on the opposite side to the surgeon during the approach.
– If there is no ventricular dilatation, cerebral pressure makes tumor removal difficult. Cerebral shift can be helped by either an anaesthesetic protocol, or contralateral ventricular drainage placed under neuronavigation or also a lumbar drainage placed at the beginning of the operation and opened after the craniotomy. The distance between the cortical surface and the LV is often important. The use of a microscope with a long focal length is necessary. This operation may also require long surgical tools and cottonoids with a string to avoid their disappearance within the ventricular cavity outside the operative field of the neurosurgeon.

Cerebral retractors must be used with caution. Pressure over 30 mmHg for more than 30 min reduces local cerebral blood flow by 80% with pressure over 50 mmHg local cerebral blood flow becomes non-existent. Excessive brain retraction may create venous infarcts especially where venous sacrifice have been necessary. The use of a retractor should only be temporary during a deep approach. It is preferable to modify either the pitch of the table or the operative microscope to expose correctly an anatomical area than to increase retraction of the brain.

In these difficult anatomical areas, it is preferable to debulk the tumor and to reduce tumoral volume before dissecting the walls to obtain a complete removal. A balance must be struck between complete removal and damage to periventricular structures given that most of these lesions are benign.

Surgery of the LV must respect the ependyma and the veins of the ventricular walls whose fragility leads to difficulties with hemostasis, dissection and exposure. The most perfect haemostasis does not always release obstructed CSF flow. Fenestration of the septum pellucidum is usually made and it is preferable to leave a CSF external drain postoperatively. This drainage can be left closed according to the quality of intraventricular haemostasis at the end of surgery. This procedure avoids potentially dangerous acute postopoerative hydrocephalus.

2. Tumors of the frontal horn

2.1 The transfrontal transventricular approach [3, 21, 24] (Figs. 25, 26, 34)

- Position

The patient is placed on the operating table in a supine position, the head straight and a little flexed (10°). Other authors state a preference for a head which is rotated by 30° toward the opposite side. We think that it is preferable to identify the deep anatomy when the head is straight.

- Scalp incision

The scalp incision can be a frontoparietal arc passing over the coronal suture (2 cm behind), at the level of the middle line medially and passing ventrally 5–6 cm in front of the coronal suture. Other authors prefer an incision parallel to the coronal suture passing 2 cm behind it extending from a preauricular and susauricular region to the other. Moreover this incision exposes the bone landmarks (coronal and sagittal sutures) and allows placement of the craniotomy at the correct place. It is preferable to avoid any bald areas and to pass far from the craniotomy. The shaving is limited to the scalp incision, but also enlarged behind the craniotomy to allow exit of the ventricular drainage in an aseptic area.

- The size of the craniotomy

The bone flap is rectangular, frontoparietal and placed close to the mid-line. A burr hole tangential to the midline is placed immediately behind the bregma. It is not helpful to expose the cortex dorsally to minimize any risks to the motor area. A second burr-hole is placed also tangential to the midline about 4–6 cm in front of the first burr hole. One to two burr holes on the vertex are sometimes necessary in accordance with the age of the patient and with the adherence of the dura, 4–6 cm laterally to the midline. Separation of the dura from the midline must be prudent avoiding damage to the superior sagittal sinus.

The transventricular transfrontal route does not require exposure of the midline. It is not necessary to expose either the superior sagittal sinus or its lateral side: a craniotomy performed 1 cm from the anatomical midline is sufficient.

After the opening of the dura, dural hitch stitches are tightened because of the cortical collapse, which is very important at the end of the procedure and related to ventricular drainage.

- Dural opening

Incision of the dura parallel to the sides of the craniotomy is used. It should be performed in the external third of the craniotomy and extended towards the midline under direct vision to avoid damage to frontal bridging veins which sometimes run in the thickness of the dura. The reflection and suspension of

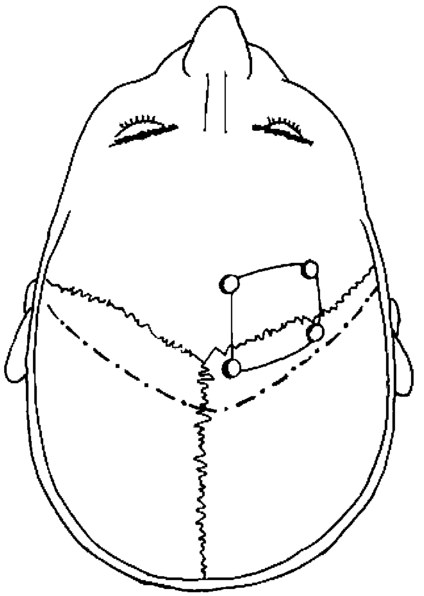


Fig. 25. Transfrontal transventricular route: scalp incision and craniotomy

the dural flap must be carefully inspected to avoid stretching of the cortical dural veins and decrease of sinus calibre by an excessive traction.

- Cortical incision

If the cortex is very tight, a ventricular puncture can be performed with a Cushing trochar towards the frontal horn of the LV. The introduction of the trochar can be made in the middle part of the frontal middle gyrus.

Otherwise, a cortical incision is performed parallel to the orientation of the frontal cortical sulci. It is placed in the middle of the middle frontal gyrus and measures 2 to 3 cm in length. After the cortical incision, splitting of the white matter towards the LV is relatively avascular. It can be very easy if the LV is dilated. The orientation of this dissection is performed towards the IVF, with the following landmarks:

– In a frontal plane, a line connecting the corticotomy and the internal canthus of the opposite side
– In a sagittal plan, a line joining a point placed 1 cm in front of the coronal suture and external ear.

The approach towards the LV must keep its length during incision of the white matter to avoid surgery through a funnel. When there is significant hydrocephalus, the surgeon must anticipate the shift of the brain in relation to the ventricular opening. The initial cortical incision should be placed more ventral than posterior.

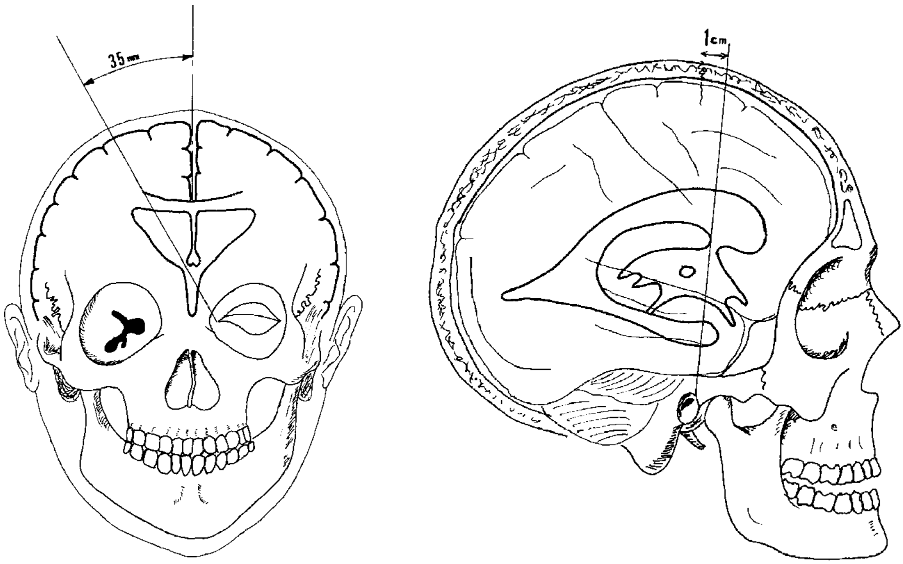


Fig. 26. Transventricular transfrontal approach: access to the LV

Other authors prefer that a glove finger around a Cushing trochar be introduced into the frontal horn of the LV. The swelling of this glove finger with a physiological fluid can dilate the route without cutting the frontal fibers.

The exposure of the cavity of the LV is oblique, oriented from cranial to caudal and from lateral to medial, centred on the IVF. We can imagine an incision through the superior frontal gyrus rather than through the middle frontal gyrus to obtain an optimal vertical trajectory. But this route seems to be illusory. An incision through the superior frontal gyrus risks damage to the bridging veins of the superior sagittal sinus and can intersect vessels of the cingulate sulcus. Moreover, the angulation obtained will never be as vertical as an interhemispheric transcallosal route.

• The entry into the LV results in cortical collapse due to CSF drainage. The walls of the corticotomy are carefully controlled with tamponade using cotton and surgical hemostatic agents such as Surgicel. Exploration of the field is performed with two retractors of 20–25 mm in width. They must be placed without excessive traction. Care must be taken not to obstruct the introduction of instruments in the operative field.

If there is a major ventricular dilatation, the septum pellucidum can bulge into the opened ventricle and hide the IVF. The septum pellucidum can then be opened in its middle portion cranially and dorsally to avoid damage to the fornix. The collapse of the contralateral ventricle restores the septum to the midline and restores the position of the fornix to expose the IVF.

The most frequent complications following transfrontal transventricular approach are transient mutism (11% of patients), epilepsy (26% of patients), hemiparesis (7% of patients), and short-term memory disturbances [3].

2.2 The anterior trancallosal approach [2, 7, 16, 17, 19, 23, 32, 34–36, 43, 45] (Figs. 27, 28, 35)

- Position and scalp incision

The position of the scalp incision can be similar to the transventricular transfrontal approach. Nevertheless, the transcallosal route is chosen particularly when there is no ventricular distension. If there is no obstacle to the pathways of the CSF, a lumbar drainage can facilitate the cortical collapse and access to the interhemispheric fissure.

- The size of the craniotomy

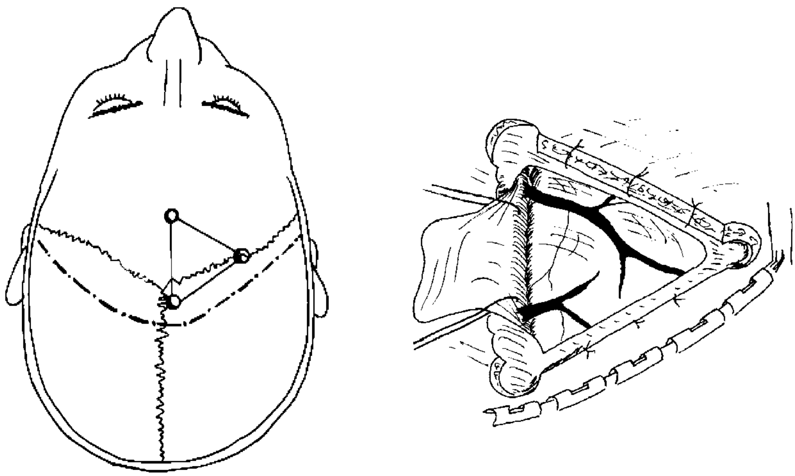
The craniotomy is similar to the craniotomy used for the transventricular transfrontal approach but can be smaller, particularly laterally where it is not necessary to expose so much frontal cortex. A first burr-hole tangential to the midline is placed immediately behind the bregma. A second burr-hole is also placed tangential to the midline, 5 to 6 cm in front of the precedent. Laterally only one burr-hole is required to perform a triangular shaped craniotomy.

Thorough analysis of the MRI allows anticipation of any difficulties with adjustment of the operative craniotomy. If there are many veins of large calibre, the risk of a venous sacrifice increases backwards towards the central (rolandic) area. This risk also increases with the extent and duration of the cerebral retraction.

The midline must be exposed. Care must be taken to separate the dura along the midline to avoid damage to the superior sagittal sinus. The use of a Gigli saw allows the craniotomy cut to be bevelled without risk to the venous sinus and to trim securely the internal table with an up cutting punch to expose the superior sagittal sinus. Care must be taken to respect the external table above the sinus and to avoid a deformation of the internal dural flap which can threaten the sinus during the procedure. Before the dura opening, dural hitch stiches are placed as there is cortical collapse at the end of surgery related to the ventricular drainage.

- Dural opening

The dural incision starts in the external third of the craniotomy with extension towards the midline performed under direct vision to evaluate the number and course of the bridging veins. Dural incision must be performed up to the corner of the superior sagittal sinus to expose perfectly the falx. If the craniotomy is correctly placed, the mooring veins do not inconvenience this exposure. If several



Figs. 27 and 28. Anterior transcallosal approach: scalp incision, craniotomy and dura opening

intradural veins prevent exposure of the falx, it is necessary to sacrify one. It is preferable to choose the more anterior veins because of their small caliber.

If the cerebral cortex does not relax despite lumbar drainage, or if this drainage has not been used, puncture of the frontal horn with a Cushing trochar can provide cerebral relaxation.

- Dissection of the interhemispheric scissure

This must be performed under operative microscope. The first stage consists in choosing the site of retraction of the frontal internal cortex to reach directly the IVF. More precise landmarks can be given by neuronavigation. When there is no neuronavigation, in a sagittal plane, a line between the coronal suture and the external auditory meatus (which can be palpated under the operative field) passes by the IVF.

After the use of a retractor along the medial face of the hemisphere, the dissection continues vertically along the falx. Small veins joining the medial hemispheric face to venous lakes are sometimes present: their interruption causes no problem because the flux of the medial venous drainage is centripetal. The depth of the falx increases dorsally and can be partially dehiscent. Opposite to the dehiscences or below the inferior wall of the falx, the dissection is more difficult because of an arachnoidal symphysis of the internal face of both frontal lobes. The dissection is sometimes possible whilst remaining in the arachnoidal plane. The medial faces of the two frontal lobes underneath the falx may also be very closely glued together or interdigitate and it is frequently impossible to nicely and cleanly separate the two pial layers [2].

The first artery encountered during the dissection may be the callosomarginal artery which runs above the cingulate gyrus. It may be confused with the pericallosal artery but the cingulate gyrus has not the usual white pearly color of the corpus callosum. 5 cm in front of the coronal suture, the sulcus cingularis is placed on average 25.7 mm below the superior side of the hemisphere. The real pericallosal artery will be identified later during the dissection. It runs in the callosal sulcus, sometimes hidden by the relief of the cingulate gyrus. We should keep in mind during the procedure the anatomical (number and course) variations of these pericallosal arteries. When the pericallosal arteries are exposed, the best solution is to separate them softly to perform an incision through the corpus callosum between them: this procedure spares the perforating branches which arise from their external and inferior side, and which course towards the corpus callosum itself and the internal face of the cerebral hemispheres. Some surgeons protect these arteries with patties socked in papavenine.

When the ventricular cavities are dilated, the pericallosal arteries may be invisible and hidden in the sulcus cingularis below cingulate gyrus. Care must be taken not to dissect them if the superior face of the corpus callosum is correctly exposed for the continuation of the operative procedure.

- Incision of the corpus callosum

This is performed between both pericallosal arteries in a longitudinal directionand has a length of 2 to 3 cm. The corpus callosum is avascular and its thickness varies between 6 to 7 mm. Once the corpus callosum is incised, the CSF flow emerging from the ventricular cavities relaxes the hemisphere. The hemispheric retractor is placed over cottonoids to protect the cortex. Its tip must raise the incised side of the corpus callosum. The retractor on the midline, against the falx, must be placed meticulously to avoid compression of the superior sagittal sinus.

As the corpus callosum is incised, recognition of the anatomical landmarks is essential to continue the procedure (Fig. 28).

– If the transcallosal approach leads to the ipsilateral LV, the anatomy of the IVF is exposed as planned and is recognized.
– If the anatomical landmarks (choroid plexus and thalamostriate vein) are visible but with inverse relationships, the transcallosal route has lead into the contralateral LV. This situation is not unusual for a right-handed surgeon. The septum pellucidum can be incised to obtain confirmation. The incision of the septum pellucidum is sometimes necessary as the transcallosal approach visualizes the homolateral LV because the septum pellucidum can bulge into the LV and obstrue the IVF when there is a hydrocephalus.
– If the transcallosal approach leads into a ventricular cavity without veins or choroid plexus, it may indicate a cavum septi pellucidi. This should have been anticipated from the pre-operative MRI.

The anterior transcallosal approach can be complicated by transient mutism (18% of patients), visual and verbal disconnection syndrome which tends

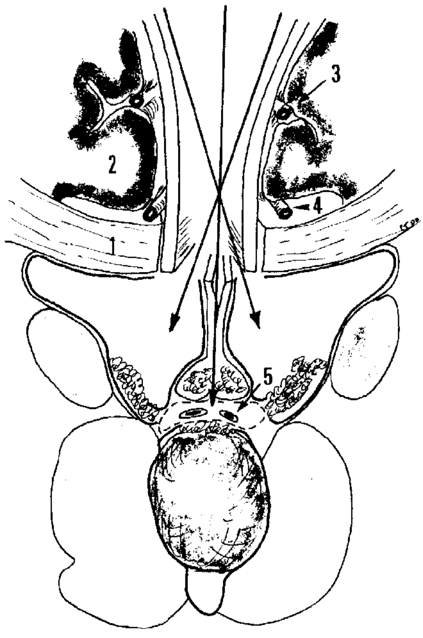


Fig. 28. Anterior transcallosal approach. (1: corpus callosum – 2: cingulate gyrus – 3: callosomarginal artery 4: pericallosal artery – 5: internal cerebral vein)

to disappear within the first month. Diencephalic lesions occur in one third of patients, with short-term memory disturbance, apraxia and anomia [28, 42].

3. Tumors of the temporal horn
[6, 8–10, 17, 25, 26, 28, 29, 34–37, 39] (Figs. 29, 30)

- Position and size of craniotomy

  The patient is placed in the supine position, either in the dorsal decubitus postion with bolsters under the ipsilateral shoulder if the spine is flexible, or in the lateral decubitus. A frontotemporal crossbow scalp, which is pulled down to the base of the temporal lobe facilitates an anterior and middle temporal craniotomy reaching the temporal floor and the pterion ventrally. The superficial sylvian vein and the vein of Labbé must be preserved.

- Access to the LV

  Several approaches to reach the LV are possible:

  – Opening of the Sylvian fissure allows access via the anterior and deep parts of its opercula towards the ventricular cavity.
  – The transsulcal T1T2 route uses a very deep sulcus which almost leads to the external wall of the LV where this is dilated. This approach is difficult and

close to the sulci vessels that must be preserved. There is major functional risk in the dominant hemisphere. It must be reserved for small tumors.

– The transcortical route uses a cortical incision through T2 rather than T1 to avoid the Sylvian fissure and to spare the T1 cortex of the dominant hemisphere

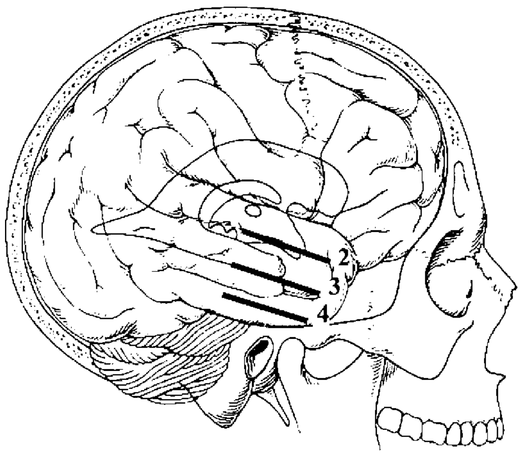


Fig. 29. Approaches to the temporal horn of the LV. (2: transsulcal T1T2 route – 3: transcortical T2 route – 4: transcortical T3 route)

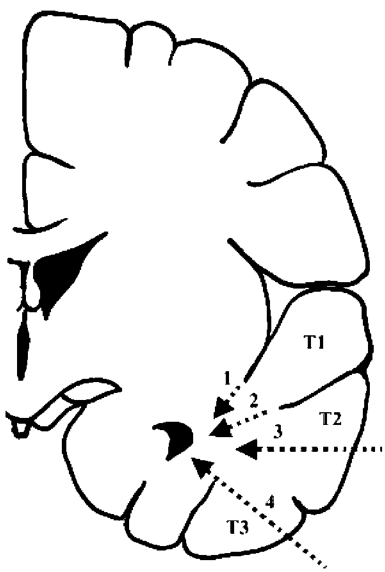


Fig. 30. Approaches of the temporal horn on a frontal section. (1: through the sylvian fissure – 2: T1T2 transulcal route – 3: T2 transcortical route – 4: T3 transcortical route)

– A cortical incision through T3 can be used with maximal rotation of the head to reach the ventricular cavity, but the vein of Labbé must be protected to avoid venous infarction. T3 is far from the language area of the dominant temporal lobe and this route avoids the anterior bundle of the optic radiations along the inferior horn. However, this route threatens the petrosal nerves. A transient partial upper-quadrant inopia can occur but it is often not perceived by patients in daily activities [39].

Each approach usually gives access to the choroidal arterial pedicle whose occlusion facilitates debulking of the tumor.

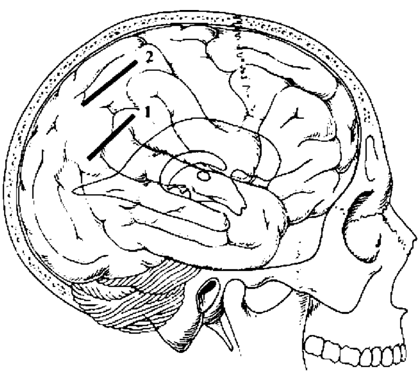
4. Tumors of the ventricular atrium

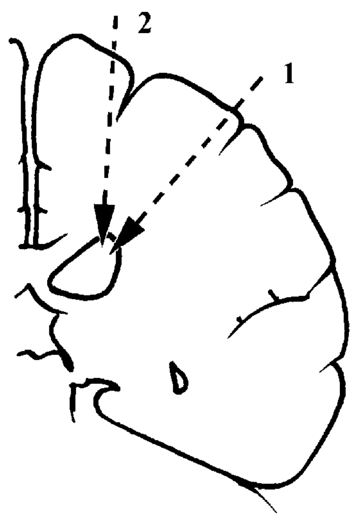
[8, 14, 17, 21, 27, 34–38, 44] (Figs. 31, 32, 33, 36, 37)

This route is easier in the minor hemisphere than in the dominant hemisphere but the campimetric risk is the same on both sides.

4.1 Minor hemisphere: transparietal route

The patient is placed in the lateral decubitus position. A parietal craniotomy centred on the atrium allows an incision through P2 towards the ventricular cavity. A high located incision is preferable to avoid the optic radiation





Figs. 31 and 32. Approaches to the atrium. (1: transparietal route – 2: posterior transparietal route) (Fig. 31, left and Fig. 32, right) which lies ventrally opposite to the atrium (Fig. 24). Care must be taken to respect the cortical vessels and hemispheric collapse can induce the rupture of parietal or rolandic mooring veins. Retraction of the pulvinar during the procedure can lead to langage disturbances (associative cortex) [34, 35].

4.2 Dominant hemisphere: posterior transparietal approach

The projection of the language cortex requires a more dorsal and more posterior cortical incision through P1. Care must be taken not to pass the ascending parietal gyrus ventrally, and not to reach the calcarine fissure dorsally. This incision must be placed at a sufficient distance from the internal face of the hemisphere to avoid the sulci.

The patient is placed in the prone position. It is a deep approach, which necessitates the systematic use of neuronavigation to optimize the cortical incision and the orientation of the trajectory. The tumoral vascular pedicle is reached at the end of the procedure as it is located on the opposite side to the operator. After surgery, a Gertsmann's syndrome is present in 33% of patients [37].

4.3 Interhemispheric parasplenial approaches

The posterior transcallosal approach is not logical because the corpus callosum does not form the roof of the ventricular cavity dorsally. It increases the risks of posterior callosal disconnection.

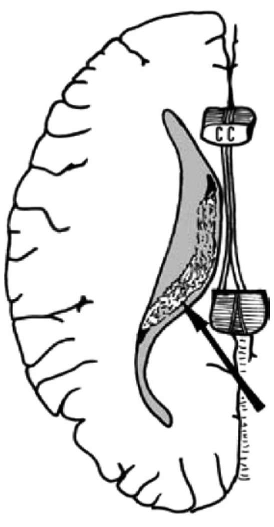
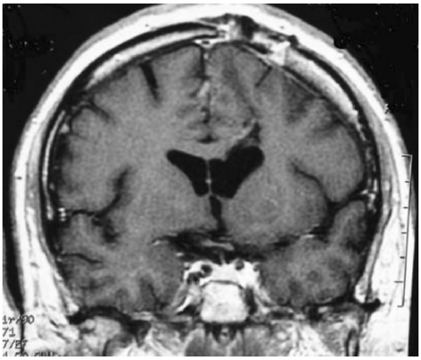
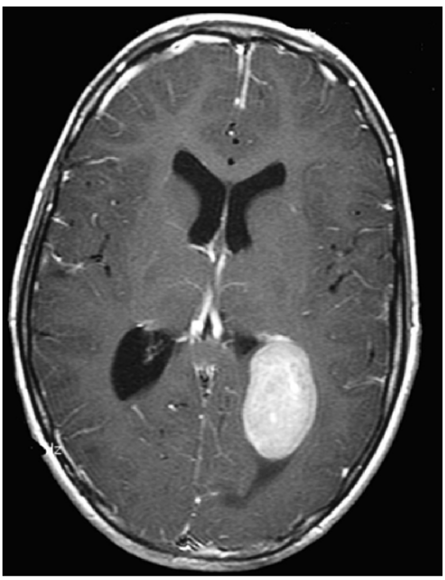


Fig. 33. Access to the atrium through the paraplenial route. (CC: corpus callosum, severed)

Some authors have described an interhemispheric parasplenial occipital approach, which gives access to the medial face of the atrium through the internal parietal cortex [8]. This route is performed in the prone position (Fig. 33). However it causes interruption of several bridging parietal veins and can cause hemianopia by retraction of the internal surface of



Figs. 34 and 35. Post operative MRI coronal planes after transfrontal transventricular approach (Fig. 34, left) and anterior transcallosal approach (Fig. 35, right)



Figs. 36 and 37. Atrial meningioma, preoperative MRI axial plane (Fig. 36, left), and postoperative MRI axial plane after posterior transparietal approach (Fig. 37, right) the hemisphere. It requires an approach close to the vein of Galien, but on the other hand, allows access to the choroidal vessels at the beginning of the procedure.

5. Variants of atrium tumors

5.1 Tumors of the atrium extending to the frontal horn

Reaching the frontal horn first will expose the difficulty of approaching the atrium because of the orientation. The posterior transparietal route allows orientation of the surgical trajectory to expose the atrium and then the frontal horn. During the intervention, the removal of the tumoral portion in the atrium and the control of the vascular pedicle often allows the tumoral portion within the frontal horn to be gently teased away.

5.2 Tumors of the atrium extending to the temporal horn

For the minor hemisphere, the T1T2 transsulcal or the T2 transcortical routes can be used by extending the incision dorsally.

This cortical extension can not be used in the dominant hemisphere. The only viable route is the posterior transparietal approach with an orientation adjusted to gain access to the temporal horn. Care must be taken to control the anterior vascular choroidal pedicle.

5.3 Tumors of the atrium extending to the occipital horn

The approach of these tumors is similar to the access to the atrium except where there is a preoperative hemianopia: in this case, a transcortical occipital route in the prone position can be used.

Conclusion

The approaches to the LV are narrow and deep and often offer a limited access to the ventricular cavity especially if it is not too dilated. The preoperative planning based on the imaging must identify the main surgical difficulties and choose the best compromise between the security of the surgical procedure and the functional risks. Neuronavigation gives invaluable help when crossing the cortical mantle and remains reliable up to the opening of the ventricular cavity. The frontal horn is relatively easily accessible. On the other hand, access to the temporal horn and to the atrium may induce visual field defects and language dysfunction in operations on the dominant hemisphere.

Annexe

Table 1. *Most frequent intraventricular tumors with usual location and imaging characteristics*

Histological types	Main location	Imaging (T1-weighted MRI with gadolinium)	Main population
Meningioma	Atrium	Hyperintense lesion Homogenous	$>$40 years
Ependymoma	Body	Heterogenous signal Cystic component	$<$40 years
Central Neurocytoma	Anterior horn and body	Heterogenous signal Central calcifications	$<$40 years
Subependymoma	Intraventricular foramen	Hypointense signal No calcification	$<$40 years
Papilloma	Atrium	Asymetric hydrocephalus	Childhood
Oligodendroglioma	Anterior horn	Peripheral nodular calcifications	$<$40 years

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