# Schwalbe's Triangular Fossa: Normal and Pathologic Anatomy on Frozen Cadavers. Anatomo-Magnetic Resonance Imaging Comparison and Surgical Implications in Colloid Cyst Surgery

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■ BACKGROUND: **The fornix is a region of greatest neurosurgical interest in regards to its complex anatomy and surgical approaches to this area. The objective of this study was to evaluate the morphology of the triangular recess (TR) and its role in the growth pattern of the colloid cysts (CC) within the third ventricle and in the choice of the surgical approach for their removal. Furthermore, to compare the results of the dissections with measurements performed on a magnetic resonance imaging scan.**

■ METHODS: **In the anatomic study, 20 cadaveric specimens were dissected and analyzed. In the radiologic study, a magnetic resonance imaging scan was performed in 20 healthy volunteers. In the clinical study, a retrospective analysis of all the patients affected with CCs microsurgically removed at our institute between 2010 and 2018 was conducted.**

■ RESULTS: **In the anatomic study, the width, height, and the area of the TR were respectively 0.31 cm, 0.33cm, and 0.051 cm$^2$. In the radiologic study, 3 different typologies of TR were identified: open recess in ventriculomegaly (7 patients); open recess in physiologic ventricular system (3 patients); closed or blind recess (10 patients). Three different growth patterns of CCs were identified: type 1) CCs localized at the foramen of Monro growing behind the fornix and below the third ventricular roof; type 2) CCs growing rostrally between the column of fornix; and type 3) CCs growing above the plane of the third ventricular roof.**

■ CONCLUSIONS: **The anatomy of the TR influences the growth pattern of CC within the ventricular cavity and determines the surgical strategy for their removal.**


## INTRODUCTION

The fornix represents the main efferent system of the hippocampal formation and is the main component of the Papez circuit, a complex neural network comprising other neural structures such as the hippocampus, mammillary bodies, the Vicq d'Azyr fasciculus, and the cingulus involved in the genesis of the factual content of memories.[1-5] The complex anatomic conformation of the fornix is of pivotal importance from a neurosurgical point of view, because this structure contributes to constitute the roof and anterior wall of the third ventricle and is commonly encountered in most of the surgical approaches to this area.[1-7]

In correspondence of the third ventricle anterior wall, the columns of the fornix tend to diverge passing mainly behind the anterior commissure to reach the mammillary bodies.[1-5,8,9] The triangular area identified by the column of the fornix and the anterior commissure has been the subject of anatomic debates regarding its anatomic boundaries and its denomination.[10,11] The terms used by neuroanatomists to describe this portion of the third ventricle anterior wall varied throughout history. They include triangular recess (TR), Schwalbe's triangular fossa, and even vulva cerebri.[11] The dimension of this triangular area is characterized by a significant interindividual variability, and is influenced by pathologic conditions such as hydrocephalus or

**Key words**
- Colloid cyst
- Fornix
- Surgery
- Third ventricle
- Triangular recess

**Abbreviations and Acronyms**
**CC**: Colloid cysts
**MRI**: Magnetic resonance imaging
**TR**: Triangular recess

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intraventricular mass.[2,10,12,13] However, the individual width of the triangle in each subject, which mainly depends on the distance between the columns of fornix, can in turn influence the growth pattern of lesions located within the third ventricle such as colloid cysts (CC).[10,12-14]

In this work, we performed an anatomic study of the TR by performing dissections and measurements of this region on brains fixed according to Klingler's technique. The measurements have also been performed on magnetic resonance imaging (MRI) (volumetric sequences) and compared with the results of the dissections.

A historical excursus regarding the etymology of the term "fornix" and the various denominations given to this region is also given.[11,15-52]

Finally, we analyzed the neurosurgical applications of our anatomic study by illustrating how the distance between the column of fornix, and consequently the dimension and the morphology of the TR, can influence the growth pattern of the CC within the third ventricle and the choice of the surgical approach for their removal. With this purpose, some illustrative cases of operated CC are presented.

## METHODS

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

### Klingler's Dissection

Twenty human cerebral hemispheres were placed in a 10% formalin solution for at least 40 days. Ten hemispheres were dissected with the aim to expose all the components of the fornix. The first step was the removal of the arachnoidal and vascular structures under microscopic magnification. The hemispheres were frozen at −15 C° for at least 14 days, and dissections were carried out through different sized wooden spatulas. The Klingler's dissection was performed with the aim to expose all the main components of the limbic system.

Starting from the basal surface, we were able to progressively expose the floor of the lateral ventricle with the head of the hippocampus, the collateral eminence, the alveus, the dentate gyrus, and the initial part of the fimbria hippocampi. Subsequently, the dissection was continued following a mediolateral orientation.

As the first step, the cortex from the medial surface of the cerebral hemispheres was removed starting at the cingulate sulcus following the cingulate gyrus until the cingulate isthmus. In the second phase, the dissection was continued by removing the cortex of the parahippocampal gyrus and exposing the remaining portion of the fimbria and the crura of the fornix until the psalterium fornices. The exposure of the body fornix was accomplished by cutting the body and the splenium of the corpus callosum, and the lateral wall of the frontal horn, body, and atrium of the lateral ventricle. This maneuver allowed to visualize the neural layer of the third ventricular roof composed by the body fornix separated from the thalamus by the choroidal fissure. The roof of the third ventricle was entirely exposed until the initial part of the column of fornix. Eventually, the genu and the splenium of the callosum were removed and we were able to follow both the postcommissural and the precommissural components of the column of fornix to the mammillary bodies and the septal, lateral preoptic and anterior thalamic nuclei, as well as the bed nucleus of the stria terminalis.

In addition, in the remaining 10 hemispheres, coronal sections centered at the anterior wall of the third ventricle were obtained. In these sections, the relationships between the columns of fornix and anterior commissure as well as the morphology of the TR were analyzed. Morphometric data of the recess were obtained from these hemispheres.

### MRI Study

Twenty healthy volunteers (10 men and 10 women; mean age 55 years ranging from 37–77) were enrolled for this study.

In all the patients, a volumetric brain 3T MRI-scan was performed, acquiring both T1- and T2-weighted sequences. Given their capacity to detect the white matter tracts, the fluid attenuated inversion recovery (FLAIR) sequences were found to be particularly suitable for the aim of this study. The sequences obtained had the following characteristics: voxel size 0.43 × 0.43 × 0.9 mm, TR (repeat time) 1.570 ms, TE (echo time) 3.29 ms, TI (inversion time) 800 ms, flip angle 15°, field of view 416 × 512 voxels (178.9 × 220.1 mm), coronal plane of acquisition.

In all the MRI performed, the dimension of the ventricular system was analyzed according to the Evan's index.

We applied the term "ventriculomegaly" according to the following criteria:[53]

- Evan's index superior to 0.30 (men, women) in patients <65 years;
- Evan's index superior to 0.34 (men)/0.32 (women) in patients of age comprised between 65–69;
- Evan's index superior to 0.36 (men)/0.33 (women) in patients of age comprised between 70–74;
- Evan's index superior to 0.37 (men)/0.34 (women) in patients of age comprised between 75–79;
- Evan's index superior to 0.37 (men)/0.36 (women) in patients of age comprised between 80–84.

### Measurements

In the 10 coronal sections of frozen hemispheres centered at the anterior wall of the third ventricle through the aid of a Vernier calliper we performed measurements of the TR dimensions by selecting the following parameters:

- Width of the recess (distance between the column of fornix in correspondence of the anterior commissure);
- Height of the recess (distance between the superior margin of the middle point of the anterior commissure and the meeting point of the column of fornix);
- Area of the recess.

The same parameters were measured on volumetric MRI sequencesv on coronal projections.

## Clinical Study

We retrospectively reviewed pre- and postoperative MRI of all the patients affected with CC microsurgically removed at our institute between 2010 and 2018. Clinical data, localization of the cyst, and surgical approach selected for cyst removal were reported.

Three illustrative cases were selected to explain the rationale behind our management strategy.

# RESULTS

## Anatomic Study

***Fornix.*** The fornix represents the main efferent system of the hippocampal formation (Figures 1–3). Its origins are as fimbria hippocampi on the floor of the temporal horn of the lateral ventricle. The fimbria is a fringe-like medial extension of the alveus in the temporal lobe that extends backward and diverges from the hippocampal tail and then extends posteriorly to form the crura. Subsequently, both crura wrap around the pulvinar of the thalamus arching superomedially beneath the splenium of the corpus callosum. At this level, transverse fibers cross the midline constituting the hippocampal commissure or psalterium fornices. Once both crura unify to form the body of the fornix, the fornix itself begins to be separated from the corpus callosum by the septum pellucidum, at the inferior margin of which the body fornix runs anteriorly until reaching the anterior margin of the thalamus. In proximity of this region, the 2 fornices separate again to form the columns of fornix. In their way toward the mammillary

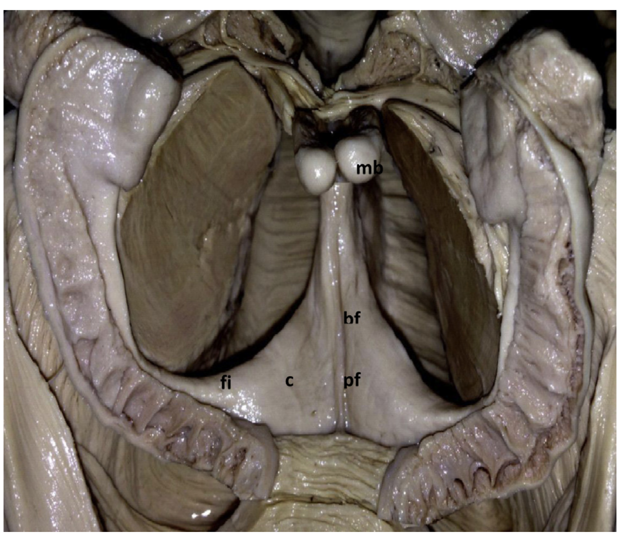


**Figure 1.** Anatomic dissection, Klingler's technique, inferior view of the fornix. The fornix begins as fimbria hippocampi (fi). The fimbria diverges from the hippocampal tail and then extends posteriorly to form the crura (c). Beneath the splenium of the corpus callosum the 2 crura are connected by transverse fibers constituting the psalterium fornices (pf). From this point, the 2 fornices run parallel as body fornix (bf) until the anterior margin of the thalamus. At this level, the 2 fornices separate again to form the columns of fornix. Most of the fibers belonging to the columns terminate at the mammillary bodies (mb) passing behind the anterior commissure (postcommissural fibers), whereas little contingent pass anteriorly as precommissural fibers.

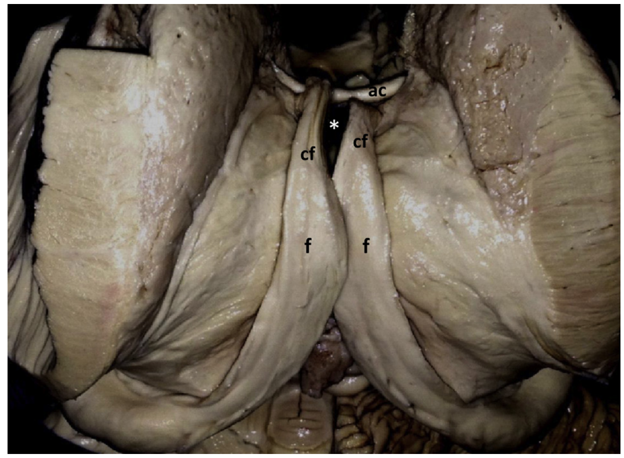


**Figure 2.** Anatomic dissection, Klingler's technique, posterosuperior view of the fornix. In this photograph, it can be observed how, at the level of the roof of the third ventricle, the 2 fornices (f) run parallel in strict association constituting the "body fornix." At the anterior pole of the thalamus the fornices diverge becoming columns of fornix (cf). The triangular space identified by the columns and the anterior commissure (ac) is the triangular recess (*).

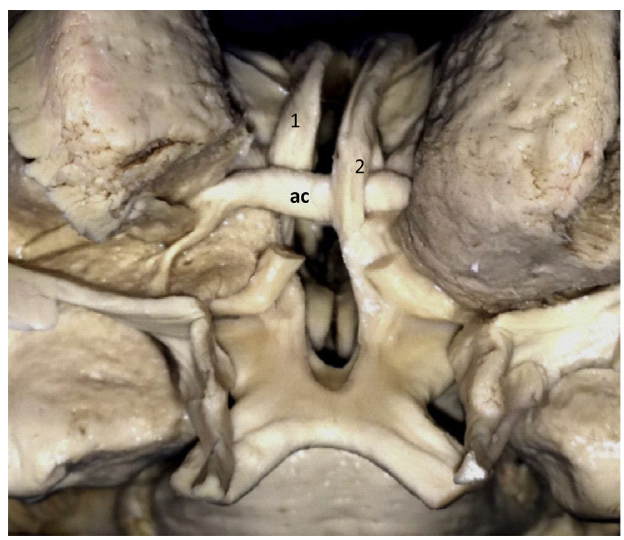


**Figure 3.** Anatomic dissection, Klingler's technique, anterior view. In this dissection, the relationships between the columns of fornix and the anterior commissure (ac) can be understood. On the right side, the precommissural fibers have been removed to show the postcommissural contingent (1) running toward the mammillary bodies. On the left side, precommissural fibers (2) are visible. In this cadaver, the columns of fornix are extremely divergent, and the triangular recess is particularly wide.

bodies, the columns of fornix arch anteroinferiorly encircling the foramina of Monro constituting their anterosuperior boundary. Eighty percent of the fibers of the fornix pass posteriorly to the anterior commissure (postcommissural fibers), whereas only a small amount run anteriorly (precommissural fibers). Precommissural fibers extend to the septal, lateral preoptic, diagonal band, and anterior hypothalamic nuclei. Postcommissural fibers project predominantly to the mamillary bodies, although some of the fibers project to the midbrain tegmentum, the anterior thalamic nucleus, and the bed nucleus of the stria terminalis.

***Anterior Commissure and TR.*** The exposure of the anterior commissure requires the removal of the extreme capsule, claustrum, uncinate fasciculus, inferior fronto-occipital fasciculus, and the anterior pole of the putamen (Figure 4).

The anterior commissure is accommodated within a neural channel localized at the anterior and basal pole of the globus pallidus just ventral to the supraoptic recess of the third ventricle. It appears as a "handlebar" of white matter crossing the midline and connects the 2 temporo-mesial regions, particularly the 2 amygdala.

The anterior commissure is formed by 2 distinct components also called "crus." The anterior crus connect the olfactory systems of the 2 hemispheres constituting the olfactory commissure. The posterior crus can be further subdivided into 2 distinct portions: temporal and occipital. It passes at the level of the basal portion of the globus pallidus, perpendicular to the optic radiation, and medial to the uncinate fasciculus. A limited portion of the posterior crus fibers intermingles with the uncinate fasciculus reaching the temporal pole, whereas the larger amount is directed posteriorly becoming part of the inferior longitudinal fasciculus and the sagittal stratum.

Topographically, the anterior commissure is localized rostrally in respect to most of the fibers of the columns of fornix, above the optic chiasm and the lamina terminalis. In front of the anterior commissure, the gray matter of the head of the caudate nucleus and the putamen meet each other in a region called ventral striatum constituted by 2 distinct nuclei: nucleus accumbens and nucleus of Meynert. This region contains the amygdalofugal fibers that constitute the diagonal band of Broca (hence the name of the extended amygdala). These fibers also project at the level of the septal region.

The TR is the area identified by the 2 divergent columns of fornix and the anterior commissure. Its identification was possible in all the dissections performed. Coronal sections of frozen, formalin fixed specimens obtained through a cut performed at the level of the anterior wall of the third ventricle permitted us to clearly observe the relationships between the columns of fornix and the anterior commissure.

## MRI Study

The columns of fornix were clearly visible on axial, coronal, and sagittal projections in all the MRI performed. The anterior commissure could be identified on axial and coronal projections in all the MRI performed.

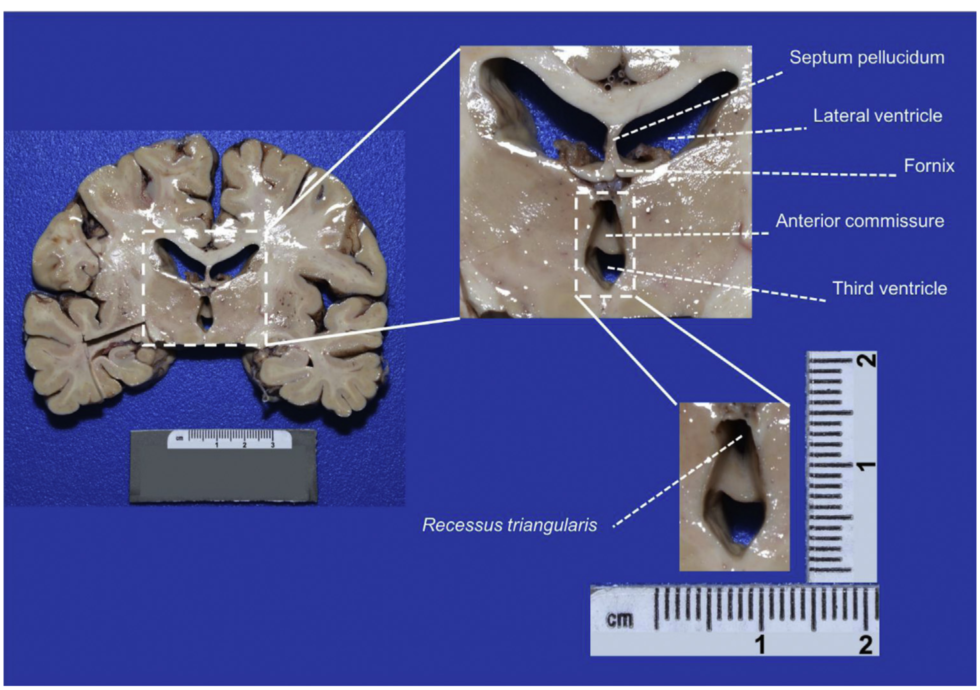


**Figure 4.** Human brain fixed according to the Klingler's technique. A coronal cut performed at the level of the anterior wall of the third ventricle has been performed and the triangular recess can be clearly identified. (For courtesy of the Cook County Medical Examiners Office of Chicago, Illinois.)

In 7 of the 20 volunteers, according to the earlier mentioned revised Evan's index criteria, a condition of ventriculomegaly was identified.

The exact plane of localization of the TR could be defined in all the MRI performed. According to the neuroimaging data, we were able to distinguish 3 different typologies of TR (Figure 5):

- Open recess in ventriculomegaly (7 patients): average width 0.38 cm (ranging from 0.31–0.66 cm); average height 0.40 cm (ranging from 0.33–0.52 cm); average area 0.076 cm$^2$ (ranging from 0.051–0.171 cm$^2$);
- Open recess in physiologic ventricular system (3 patients): average width 0.32 (ranging from 0.25–0.57 cm); average height 0.36 cm (ranging from 0.28–0.46 cm); average area 0.057 cm$^2$ (ranging from 0.035–0.131 cm$^2$);
- Closed or blind recess (10 patients): not visible, not measurable.

Data of the MRI study including sex, age, Evan's index, and morphology of the recess of the healthy volunteers are summarized in Table 1.

### Measurements

Measurements of the TR both on frozen hemispheres and on MRI are summarized in Tables 2 and 3.

### Clinical Study

Between 2010 and 2018, 28 patients affected with CC underwent microsurgical removal of the lesion. According to tumor localization and development, 3 different growth patterns could be identified:

***Type 1 (22 Patients).*** CC localized at the foramen of Monro growing behind the fornix and below the third ventricular roof. In this group are also included cysts of remarkable dimension that may cause a generalized deformation of the third ventricle without violating the limits of the ventricular cavity (the space between the neural structures delimiting the third ventricle is not wide enough to allow the lesion to grow between the structures themselves) (Illustrative case 1).

***Type 2 (4 Patients).*** CC growing rostrally between the column of fornix. In these cases, the neural structures of the anterior wall (anterior commissure, lamina terminalis, rostrum of the corpus callosum) tend to be displaced rostrally, whereas the 2 columns of fornix are dislocated laterally (Illustrative case 2).

***Type 3 (2 Patients).*** CC growing above the plane of the third ventricular roof. In these cases, despite the absence of enough space to allow the cyst grow rostrally between the columns of fornix, the separation of the 2 fornices at the level of the roof/anterior wall junction allows the cyst to grow cranially dislocating upward 1 of the 2 fornices (Illustrative case 3).

CC belonging to the first type have been approached through an ipsilateral interhemispheric transcallosal transforaminal approach.

In the second typology of cysts, the interhemispheric subcallosal approach has been used in 2 cases, whereas in the other 2 cases a transcallosal transrostral approach was chosen.

CC belonging to the third typology have been removed through a contralateral interhemispheric transcallosal trans septum pellucidum approach.

Total removal was obtained in all the patients of this series. No major complications were reported. Transient memory deficit was recorded only in 2 cases (both approached through a classic ipsilateral transcallosal transforaminal approach for type 1 CC). In both cases, total recovery of memory functions was documented after few weeks from the surgical procedure.

### Illustrative Case 1

A 70-year-old woman came to our attention for recurrent and drug resistant headache. Brain MRI documented the presence of a CC localized in correspondence of the left foramen of Monro (Figure 6). Preoperatively, the patient underwent neuropsychological evaluation. The controlled Oral Word Association Test, Spatial Recall Test, Benton Visual Retention Test, Boston Spatial Quantitative Battery Apraxia Subtest, and

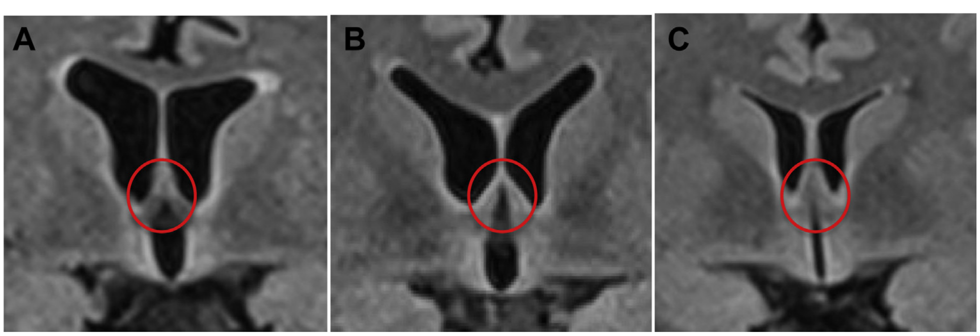


**Figure 5.** The 3 different typologies of triangular recess on magnetic resonance imaging (*red circle*) are shown: (**A**) open recess in ventriculomegaly; (**B**) open recess in normal ventricular system; and (**C**) closed or blind recess.

**Table 1.** Summarizing Age, Sex, Evan's Index, Presence/Absence of Ventriculomegaly and Triangular Recess Morphology of the 20 Healthy Volunteers of the Magnetic Resonance Imaging Study

| Patient | Age (Years) | Sex (M/F) | Evan's Index Value | Ventriculomegaly (Yes/No) | Triangular Recess Morphology |
|---|---|---|---|---|---|
| 1 | 37 | F | EI < 0.30 | No | Blind |
| 2 | 38 | M | EI > 0.30 | Yes | Open |
| 3 | 40 | M | <0.30 | No | Blind |
| 4 | 42 | F | <0.30 | No | Open |
| 5 | 42 | M | <0.30 | No | Blind |
| 6 | 45 | F | >0.30 | Yes | Open |
| 7 | 47 | F | <0.30 | No | Blind |
| 8 | 50 | F | <0.30 | No | Blind |
| 9 | 51 | M | <0.30 | No | Blind |
| 10 | 55 | M | >0.30 | Yes | Open |
| 11 | 57 | M | <0.30 | No | Open |
| 12 | 58 | F | >0.30 | Yes | Open |
| 13 | 59 | M | <0.30 | No | Blind |
| 14 | 59 | F | <0.30 | No | Blind |
| 15 | 61 | F | >0.30 | Yes | Open |
| 16 | 63 | F | <0.30 | No | Open |
| 17 | 65 | M | >0.34 | Yes | Open |
| 18 | 66 | M | <0.34 | No | Blind |
| 19 | 72 | M | >0.36 | Yes | Open |
| 20 | 77 | F | <0.34 | No | Blind |

M, male; F, female.

the Hooper Visual Organization Test were considered in the range of normal by our team of neuropsychologists.

The patient underwent surgical excision of the lesion through a left interhemispheric transcallosal transforaminal approach (Figures 7A and 7B). Postoperative course was uneventful. The patient was discharged on postoperative day 3. At 6-months follow-up, neuropsychologic evaluation was unaltered.

**Table 2.** Summary of the Measurements of the Triangular Recess on Frozen Brain

| Measurements of the Triangular Recess | Average | Range |
|---|---|---|
| Width (cm) | 0.31 | 0.09—0.69 |
| Height (cm) | 0.33 | 0.19—0.54 |
| Area ($cm^2$) | 0.051 | 0.008—0.18 |

**Table 3.** Summary of the Measurements of the Triangular Recess on Magnetic Resonance Imaging Study

| | Open Recess in Ventriculomegaly | Open Recess in Normal Ventricular System | Blind Recess |
|---|---|---|---|
| Width | | | Not measurable |
| Average | 0.38 cm | 0.32 cm | |
| Range | 0.31—0.66 cm | 0.25—0.57 cm | |
| Height | | | Not measurable |
| Average | 0.40 cm | 0.36 cm | |
| Range | 0.33—0.52 cm | 0.28—0.46 cm | |
| Area | | | Not measurable |
| Average | 0.076 $cm^2$ | 0.057 $cm^2$ | |
| Range | 0.051—0.171 $cm^2$ | 0.035—0.131 $cm^2$ | |

### Illustrative Case 2

A 20-year-old woman came to our attention in a comatose state. A brain computed tomography scan showed the presence of a voluminous CC located at the anterior portion of the third ventricle, causing hydrocephalus. After a ventricular drainage was positioned, a brain MRI with gadolinium was performed. The MRI confirmed the presence of the CC. The lesion seemed to originate in correspondence of the foramen of Monro and expanded anteriorly displacing the rostrum of the corpus callosum anterosuperiorly and the neural structures of the anterior wall of the third ventricle anteriorly (Figure 8A and 8B).

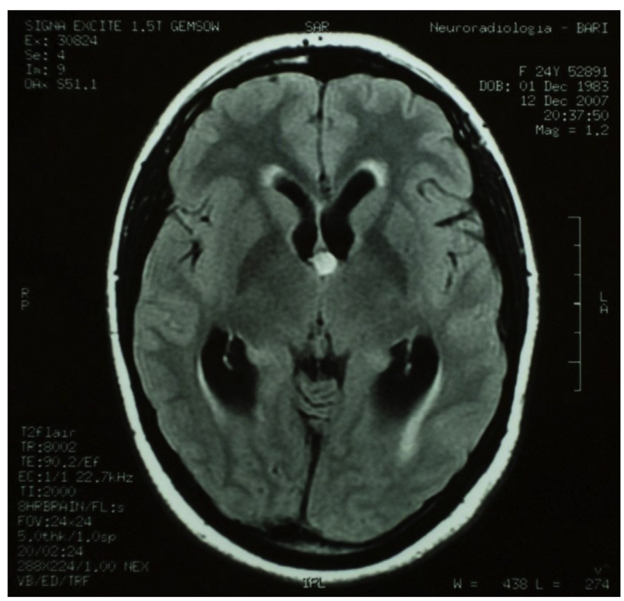


**Figure 6.** Preoperative magnetic resonance imaging documenting the presence of a left sided colloid cyst sited at the foramen of Monro and developing within the ventricular cavity.

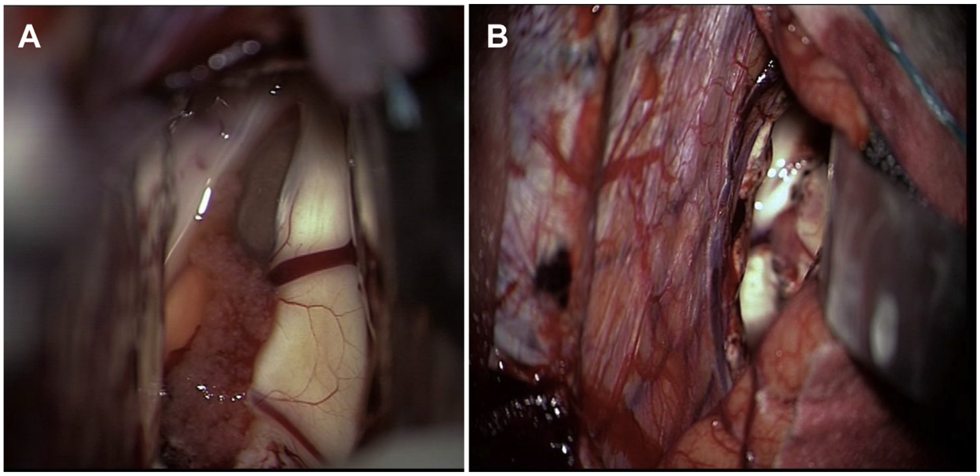


**Figure 7.** (**A**) Intraoperative photographs. An ipsilateral interhemispheric transcallosal approach has been performed. In correspondence of the foramen of Monro the cyst can be visualized. (**B**) Through a transforaminal route the cyst was removed.

Following these neuroradiologic findings, we decided to perform an interhemispheric-transcallosal approach to the third ventricle. Once the ventricular cavity of the frontal horn was entered and the septum pellucidum opened, the tumor bulging was observed on the floor of the frontal horn, in correspondence of the rostrum of the corpus callosum. By opening the rostrum, the cyst was exposed (Figure 9A).

Given the remarkable dimensions of the lesion, the cyst walls were opened to allow its fluid content to drain. Once the cyst was decompressed, its capsule was carefully dissected from the third ventricle walls and from the subependymal veins (Figure 9B). The removal was performed piecemeal and when an adequate cyst volume reduction was reached, we removed the last portion en block cutting the last adhesion to rostrum (Figure 9C). Postoperative MRI documented the complete removal of the lesion (Figure 10). The patient was discharged on postoperative day 8.

### Illustrative Case 3

A 45-year-old woman came to our attention because of a clinical history characterized by recurrent headache accompanied by nausea and vomiting. Neurologic examination showed a mild convergent squinting associated with bilateral sixth nerve palsy.

A computed tomography scan documented the presence of a 3 cm CC causing hydrocephalus. As a consequence, the patient underwent a ventriculoperitoneal shunt. Postoperative course was uneventful, and the patient was discharged on postoperative day 3.

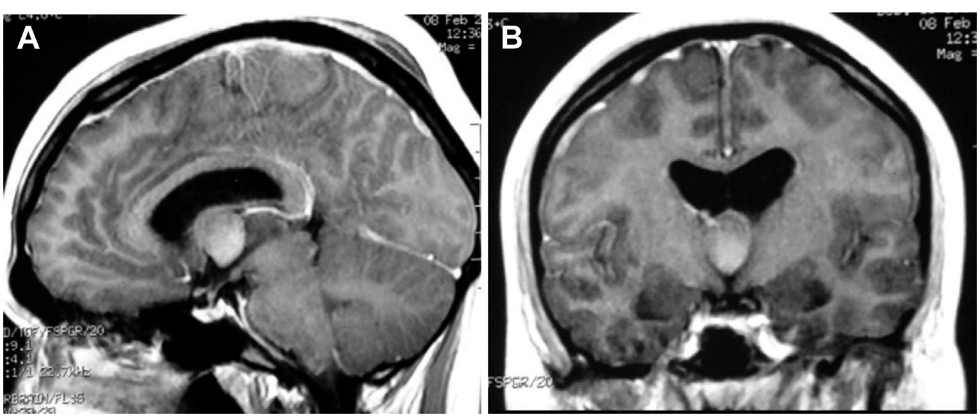


**Figure 8.** Preoperative magnetic resonance imaging, sagittal (**A**) and coronal (**B**) projections. A colloid cyst originating from the foramen of Monro expands anteriorly displacing anterosuperiorly the rostrum of the callosum and anteriorly the neural structures constituting the anterior wall of the third ventricle.

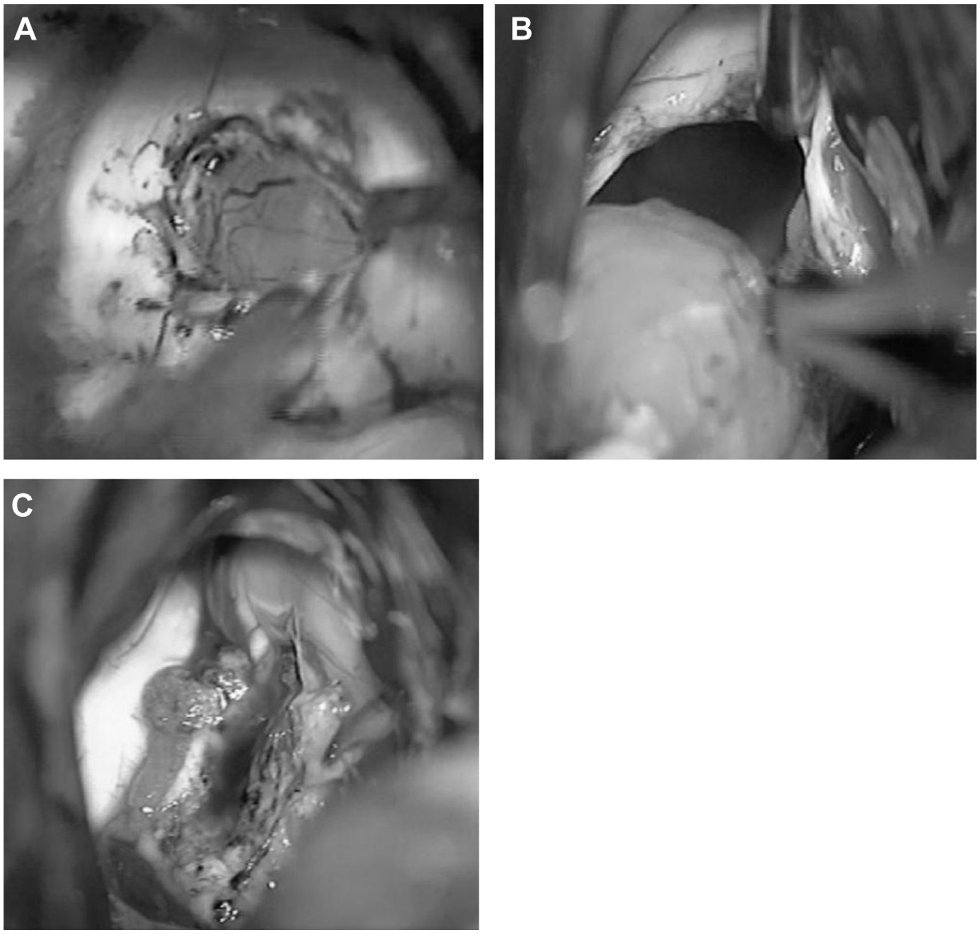


**Figure 9.** (**A**) Intraoperative photographs. The interhemispheric transcallosal approach and the pellucidotomy have been performed. On the roof of the frontal horn, in correspondence of the rostrum of the corpus callosum the tumoral bulging can be observed. By opening the rostrum, the upper pole of the cyst can be identified. (**B**) Dissection of the cyst from the ventricular wall and subependymal veins. (**C**) The cyst has been removed.

After 3 months, the patient was readmitted at our department because of recurrent headache. Brain MRI showed an increase of the cyst dimension exceeding 4 cm. The cyst displaced the left fornix more cranially in respect to the contralateral one (Figure 11). The mass occupied the upper portion of the third ventricle extending within the left lateral ventricle that was dilatated. Conversely, the right lateral ventricle was compressed by the mass and appeared significantly reduced in dimension. On sagittal projections, the cyst reached the inferior portion of the corpus callosum. Neuropsychological tests including the Controlled Oral Word Association Test, Spatial Recall Test, Benton Visual Retention Test, Boston Spatial Quantitative Battery Apraxia Subtest, and the Hooper Visual Organization Test did not show pathologic alterations.

Therefore, we performed a right parasagittal craniotomy contralateral to the side of main development of the lesion to gain access through a transcallosal route. A small incision of the corpus callosum and a pellucidotomy was performed and the mass identified. After opening of the cyst wall and suctioning of its fluid content, the lesion size was significantly reduced. This maneuver permitted us to identify and incise the cyst implant/adhesion on the foramen of Monro. Postoperative course was uneventful. Three months later, MRI documented the complete removal of the lesion without any sign of recurrence or damage to the fornix. Postoperative neuropsychological evaluation of the patient was excellent and did not show alterations compared to the preoperative evaluation.

## DISCUSSION

### Etymology

***Fornix.*** Although currently the term "fornix" is almost exclusively used for the description of anatomic structures (fornix of

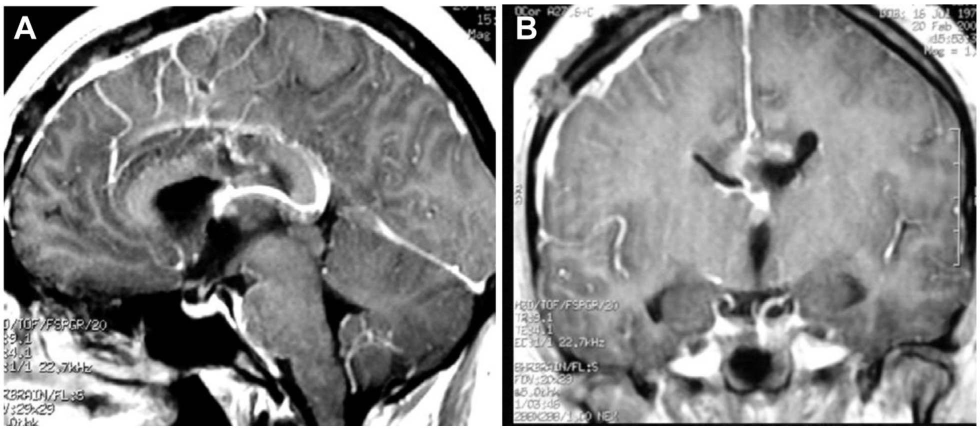

**Figure 10.** Postoperative magnetic resonance imaging on sagittal (**A**) and coronal (**B**) projections documenting the complete removal of the lesion.

conjunctiva, fornix of vagina, and so on), in the past the word held an architectural connotation, coming from the Latin for "arch."[11]

During the first century BC, Roman architects used to build wooden rooms with vaulted ceilings that were called "fornices." These wood-vaulted rooms were used expressly for the prostitution trade in ancient Rome (hence the term fornication).[11]

The first neuroanatomist ever to use this term to describe the white matter hippocampal efferent system was the 17th-century Englishman Thomas Willis. The real etymology of the term "fornix" concluded Olry and Haines, "is therefore related to the form of the roof of the third ventricle, but also to the sexual intercourse that occurred in such rooms, these rooms being compared to this ventricle."[11]

***Triangular Recess.*** The term "triangular recess" refers to a small recess between the anterior commissure and the division of both columns of the fornix.[11,15-52]

This area of the third ventricle anterior wall has been also denominated Schwalbe's triangular fossa or "vulva cerebri."[38]

This term has been sometimes attributed to Vieussens,[52] but wrongly, for this term was to be found as early as 7 years before.[16]

Indeed, the origin of this term seems to be much older (mid 16th century) and has been attributed to the Italian anatomist Matteo Realdo Colombo.[20] It is not surprising that the tradition ascribes to Colombo the discovery of the clitoris.[15,22,33,34,36] By the early 17th century, the term became a matter of controversy.

In 1708, Philip Verheyen wrote in the German translation of his Corporis humani anatomiae: "eine Spalte [. . .] die man sehr unverschämet Vulvam nennet" (a groove [. . .] that we impudently call vulva).[50]

ln 1752, the French anatomist and surgeon César Verdier criticized the term as follows:"cette fente, que l'on a appelée vulva, mais que l'on appelle aujourd'hui avec plus de raison, ouverture

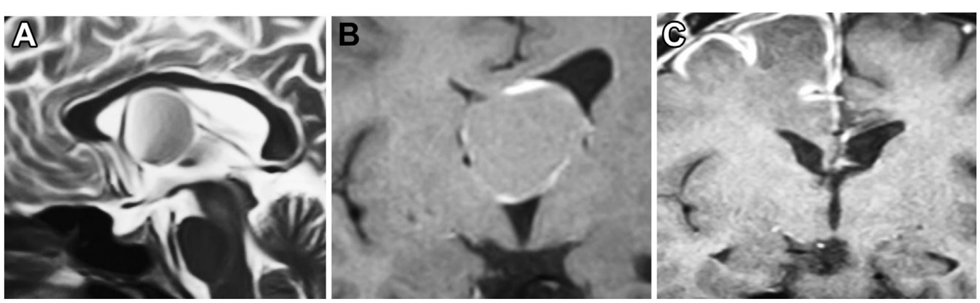

**Figure 11.** (**A**) Preoperative magnetic resonance imaging, sagittal projections. Note how the left fornix has been displaced cranially by the cyst. (**B**) Coronal projections showing the asymmetrical growth pattern of the cyst. (**C**) Postoperative magnetic resonance imaging documenting the complete removal of the lesion obtained through a contralateral interhemispheric approach accompanied by pellucidotomy.

commune antérieure" (this groove, that we called vulva, but that we rightly call today, common anterior opening).[48]

The term vulva remained, however, in use for a long time.[18,20,24,29,30,40,44,48]

Only some authors cautiously mentioned the term: "créé par les ancients anatomistes" (coined by the ancient anatomists)[21]; "créé par les ancients"[19]; "la prétendue vulve" (the so-called vulva).[25]

## Anatomic Study and MRI Study

Although the third ventricle has been the subject of several anatomic and surgical studies, some controversies still exist regarding the anatomic organization of the upper portion of its anterior wall.[10,54] This region, known as Schwalbe's triangular fossa or triangular recess, has a triangular shape and is comprised between the 2 divergent columns of fornix running toward the mammillary bodies and the anterior commissure. The 2 columns represent the sides of the triangle, whereas the anterior commissure constitute the base of the triangle.

In this anatomo-radiologic correlational study, we give a detailed morphometric description of this area with the purpose to better define its morphology, boundaries, and dimension.

The Klingler's technique permitted us to identify both the neural structures composing the triangle and the triangular opening of the recess in all the brains studied. The width of the triangle (measured as the distance between the 2 columns of fornix) and its height (defined as the length of the line running perpendicular to the anterior commissure from its middle until the meeting point of the column of fornix) showed a significant

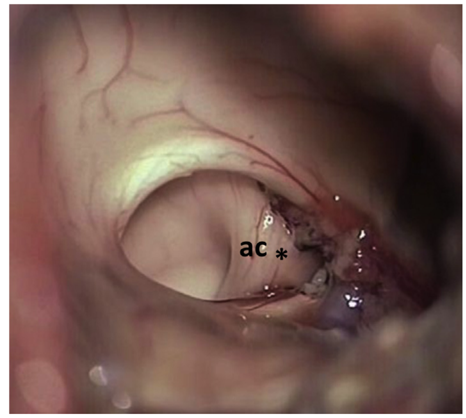


**Figure 13.** Intraoperative view of the triangular recess. This patient was operated for the removal of a left frontal intraparenchymal hemorrhage violating the left frontal horn. Once the ventricular cavity was opened, through an enlarged foramen of Monro, it was possible to visualize the anterior commissure (ac) and the triangular recess (*).

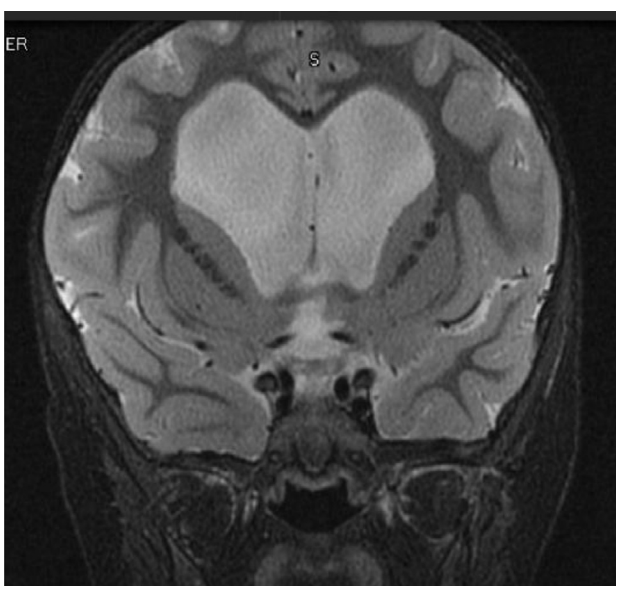


**Figure 12.** Pathologic conditions such as hydrocephalus or intraventricular mass influence the dimension of the triangular recess. This magnetic resonance image shows an enlarged triangular recess in a young patient affected with hydrocephalus caused by a craniopharyngioma.

interindividual variability. This variability is influenced by several factors such as pathologic conditions (intraventricular mass, hydrocephalus) (**Figures 12** and **13**), dimensions of the ventricular system (non-hydrocephalic ventriculomegaly, cerebral atrophy), and interindividual variability.[2,8,10,12,13] However, as we will discuss later, the distance between the columns of fornix represent one of the most important factors influencing the growth pattern of lesions localized within the third ventricular boundaries.[14] In fact, this space can be either wide enough to represent a natural corridor for the rostral development of intraventricular mass, or, however, so tight to force the lesion to follow other growth directions.[14]

Once the anatomic study clarified the architecture of the triangular fossa, data obtained through anatomic dissections were compared with MRI.

Measurements of the width and height of the triangle were performed on volumetric MRI on coronal projections. Although we were able to identify the plane of localization of the TR together with the column of fornix and the anterior commissure in all the MRI performed, in 10 cases the triangular opening of the recess could not be visualized. This difference with the dissection study (in which, even the smallest TR opening could be visualized) is likely because of an intrinsic limit of the methodology itself.

Based on the radiologic findings, we were able to identify 3 different types of TR. The classification system proposed considers 2 parameters: the dimension of the recess and the dimension of the ventricular system. In fact, as we noted in the conduction of our study, there is an evident correspondence between ventriculomegaly and larger dimensions of the TR.

The first type of TR is the one characterized by a wide and clearly visible opening in patients with ventriculomegaly. On average, the biggest recesses were detected in patients with a dilatated ventricular system.

The second type include those patients in whom the opening of the recess could be visualized despite the normal dimension of the ventricular system. In these cases, the average dimensions of the recess were smaller than those observed in the first type.

The third type, which we called "closed" or "blind" recess, is constituted by those cases in which the opening of the recess could not be visualized on MRI. As mentioned earlier, we believe that this condition does not reflect a real absence of the recess, but indeed we believe that it is the consequence of an intrinsic limit of the MRI that is not able to detect the smallest recesses.

## Clinical Implications in CC Surgery

The growth pattern of CC within the third ventricular cavity is influenced by the anatomic organization of neural structures constituting the boundaries of the third ventricle itself.[14]

Depending on the modalities by which these neural structures relate each other in the third ventricular space, some areas of the third ventricular walls may be constituted only by a thin ependymal layer resulting virtually empty. These neural voids areas represent natural corridors through which CC may develop.[14]

Conversely, regions of the third ventricle characterized by minimal distance between neural structures may prevent the lesions from growing through limited spaces inducing alternative growth patterns.[14]

It has been previously demonstrated how the void area between the crura of fornix, just behind the psalterium, represent a common site of growth of CC.[14]

In our study, we analyzed how the distance between the columns of fornix, and consequently the dimension of the TR, could influence the development of CC localized in correspondence of the most rostral portion of the third ventricle, and the choice of the surgical route chosen to obtain a complete removal of the lesion respecting the anatomo-functional integrity of the fornix.

In case of particularly divergent columns of fornix (type A TR), CC may exploit the intercolumnar space to grow rostrally. In contrast, in those cases in which this distance is not so wide, cysts are forced to find alternative routes of development.

By carefully analyzing the preoperative MRI of 30 CCs localized at the rostral portion of the third ventricle and operated at our institute, we were able to identify 3 main growth patterns.

The first growth pattern is the most commonly observed in clinical practice. In this type, the cyst is localized at the foramen of Monro and grows within the boundaries of the third ventricle, below and behind the fornix. With every likelihood, this growth pattern is encountered in those cases in which the distance between the column of fornix is minimal and not enough to allow the development of the cyst (TR type B, C).

In these cases, as shown in the first illustrative case, a classic ipsilateral interhemispheric transcallosal transforaminal approach represents the best surgical strategy.[6,7,55]

The second growth pattern is characterized by the rostral development of the lesion between the column of fornix. This pattern is encountered in those patients in whom the distance between the column of fornix is elevated (TR type A).

The second illustrative case is explicative. In this patient, the cyst grew ventrally, displacing the rostrum of the corpus callosum anterosuperiorly and the third ventricle anterior wall rostrally. In these cases, given the enlargement of the distance between the laterally displaced columns of fornix, 2 possible surgical routes can be chosen. The first is a classic interhemispheric subcallosal trans-lamina terminalis approach.[56,57] The second is an interhemispheric, transcallosal, trans-rostral approach.[58]

In both the approaches, the working area is localized between the columns of fornix. This aspect is of pivotal importance because it allows to perform most of the procedure with minimal manipulation of the columns of fornix that were encountered only in the final stages of surgery after significant decompression of the lesion.

The subcallosal trans-lamina terminalis approach allows a direct and straightforward route to the intercolumnar space and does not require incision of the corpus callosum. Disadvantages of this approach are represented by the elevated risk of frontal sinus violation, retraction of the frontal lobes, olfactory nerve injury, and difficult identification of the cleavage plane between the lesion and the adjacent neurovascular structures.[56,57]

In the case presented the remarkable dimensions prompted us to prefer the transcallosal transrostral route. Even if this approach is characterized by a longer surgical trajectory, and by the necessity to incise the corpus callosum, the transrostral trajectory allows the early visualization of the posterior pole of the lesion and the clear identification of the dissection plane between the cyst, the ventricular wall, and the delicate subependymal venous system.[58]

The third growth modality is characterized by a cranial development of the cyst, above the plane of the third ventricular roof, behind the anterior wall. This growth pattern occurs in those cases in which the intercolumnar window is not wide enough to allow the rostral development of the cyst, but, at the same time, the existence of an even limited distance between the 2 fornices allows the cyst to grow upward displacing cranially 1 of the 2 fornices. The physiopathology underlying this modality of development is confirmed by the preoperative MRI of the Illustrative case number 3. On sagittal projections, it can be observed how the cyst had displaced the left fornix cranially sparing the right one.

In this case, we decided to perform a right transcallosal transseptal pellucidum approach. The choice of this route is supported by 2 considerations.[59-61]

The first consideration is that the contralateral trajectory ensures a better angle of view of the ventricular cavity of the opposite side. The second consideration is specific for the Illustrative case number 2. By performing a contralateral right to left transcallosal approach, we have been able to expose through a direct trajectory the portion of the lesion localized below the cranially displaced fornix. In this way, we were able to remove a significant portion of the lesion reducing the risk of traumatic manipulation of the fornix. In fact, once the cyst had been decompressed, the cleavage plane between the fornix and the cyst wall was easily identified and the removal of the lesion was completed atraumatically.[59-61]

All the patients treated in this series did not experience any typology of permanent neuropsychological deficit in the postoperative course. This aspect confirms the validity of our classification system and its clinical applicability.

## CONCLUSIONS

The TR, also known as vulva cerebri, is a triangular area delimited by the divergent columns of fornix and the anterior commissure. The dimensions of this area vary significantly among different individuals as demonstrated by our study. The interindividual variability of the fornix, anterior commissure, and TR conformation are of pivotal importance in neurosurgical practice. In fact, this heterogeneity not only influence the growth pattern of CC within the ventricular cavity, but it also determines the surgical strategy for their correct and atraumatic removal.

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