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The Extreme Anterior Interhemispheric Transcallosal Approach for Pure Aqueduct Tumors: An Anatomical Study

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ABSTRACT

AIM: To show the normal anatomy of the cerebral aqueduct, and the feasibility of the extreme anterior interhemispheric transcallosal approach to remove tumors within the aqueduct.

MATERIAL and METHODS: This human cadaveric brain research was composed of ten formalin-fixed human brains and one injected head. The dissection was performed under an operative microscope with 6x to 40x magnification. The cerebral aqueduct anatomy was delineated along with the relationship to nearby structures in the extreme anterior interhemispheric transcallosal approach.

RESULTS: We described the anatomy of the cerebral aqueduct within the brain and showed that, with the proper angle for the extreme anterior interhemispheric transcallosal approach, lesions in the cerebral aqueduct can be reached in a single session without damaging periventricular structures.

CONCLUSION: The extreme anterior interhemispheric transcallosal approach provides a direct corridor to the cerebral aqueduct and, thus, is feasible for resecting pure aqueduct tumors in an already dilated intraventricular foramen.

KEYWORDS: Cerebral aqueduct, Fiber dissection, Microsurgical anatomy, Transcallosal approach

INTRODUCTION

Pure aqueduct tumors (PATs) are a rare entity within the ventricular system, in which the tumor arises directly from the cerebral aqueduct and not from nearby structures (23). As the cerebral aqueduct is located within the midbrain, the risk of damaging nearby structures during surgery is high.

Patients with PATs are usually asymptomatic when the tumor is small, but when the lesion is large enough to obstruct the normal flow of cerebrospinal fluid (CSF) through the aqueduct, symptoms of hydrocephalus become evident (15). How the tumor grows in the aqueduct is not fully understood, but these tumors are believed to originate from undifferentiated cells in the subependymal layer (10).

The cerebral aqueduct, located deep within the brain, is surrounded by important structures prone to damage (2). Thus, methods chosen to approach the aqueduct must preserve the nearby white and gray matter. The endoscope is widely used for hydrocephalus and tumor biopsy procedures. Additionally, the flexible endoscope provides some advantages such as

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a better angle for visualizing a lesion, but its use is not free from damage to neighboring brain structures. Some studies of endoscopic techniques have reported complications, such as ventriculitis and recurrence in other parts of the ventricular system (18).

On the other hand, when correctly used, microscopic approaches through the corpus callosum to resect aqueduct tumors – such as the extreme anterior interhemispheric transcallosal (eAIT) approach -- do not present a great risk of cortical, vascular or white matter injury other than a small lesion in the corpus callosum (6).

This study describes the anatomy of the aqueduct and the use of the eAIT approach for pure aqueduct tumors to directly access the lesion within this structure, without damaging surrounding areas.

MATERIAL and METHODS

The anatomy of the aqueduct and the eAIT approach were studied in 10 formalin-fixed human brains and one injected head. Specimens were rinsed for several hours with water to remove the formalin, then frozen for 14 days at -12 degrees Celsius. During this process, the water formed ice crystals that separate the fibers, which is not possible when the brain is infused with formalin. The freezing process allowed us to identify and study the subcortical white matter tracts under an operating microscope (magnification from 6x to 40x). Later, the specimens were thawed under running water for several hours. The changes that occurred during the freezing process remained after thawing; thus, white matter structures could be easily observed.

Before beginning the eAIT approach, we used fiber dissection to better expose the structures around the surgical corridor. After removing the cortex, all the white matter tracts were studied in a stepwise manner. This technique was described in 1935 by Klingler (12,13). but has been more widely used after Türe, et al., revitalized it more than 40 years later with the use of an operative microscope (25,26).

To begin the eAIT approach, a superior-to-inferior dissection of the cortex and white matter tracts was done in the hemispheres, leaving important landmarks to use for orientation during surgery.

An endoscope (Aesculap Full HD 0°, Pennsylvania, USA) was used in some of the specimens and in the injected head to reveal the entire surgical corridor and the relationship of the approach to periventricular structures.

RESULTS

The eAIT approach to resect lesions located within the cerebral aqueduct is described herein. It is a combined approach, in which the endoscope is mainly used to identify the aqueduct before and after tumor resection. Thus, most of the approach is done under the microscope. The cerebral aqueduct is a ventricular structure located deep in the brain, and lesions within it are difficult to resect. Thus, the eAIT approach takes advantage of the dilated interventricular foramen (IVF) caused by hydrocephalus, allowing full resection of the lesion in the aqueduct.

The cerebral aqueduct is a narrow structure located in the floor of the third ventricle that facilitates the correct flow of cerebrospinal fluid from the third into the fourth ventricle. The aqueduct is located in the midbrain and can be divided into three portions: superior, medial, and inferior. The superior portion is where an aqueduct tumor can produce obstructive hydrocephalus when it is large enough. The superior portion is in close relationship superiorly and posteriorly with the pineal gland and the posterior commissure, and anteriorly with the interthalamic adhesion (IThA).

The middle portion of the aqueduct is in relationship posteriorly with the superior and inferior colliculi, and anteriorly with the cerebral peduncle. Finally, the inferior portion of the aqueduct opens directly into the fourth ventricle. The eAIT approach reaches a PATs through a direct angle to the tumor, using the increased diameter of the ventricles as a natural corridor for resection (Figure 1).

Brain dissection was carried out in a stepwise manner, from superior to inferior. Before beginning dissection, the topography of the gyri and sulci were carefully studied. Once the vessels on the superior and medial surfaces of the whole brain were removed, sparing the pericallosal arteries, the location of the callosotomy was chosen (Figure 2A). Then,

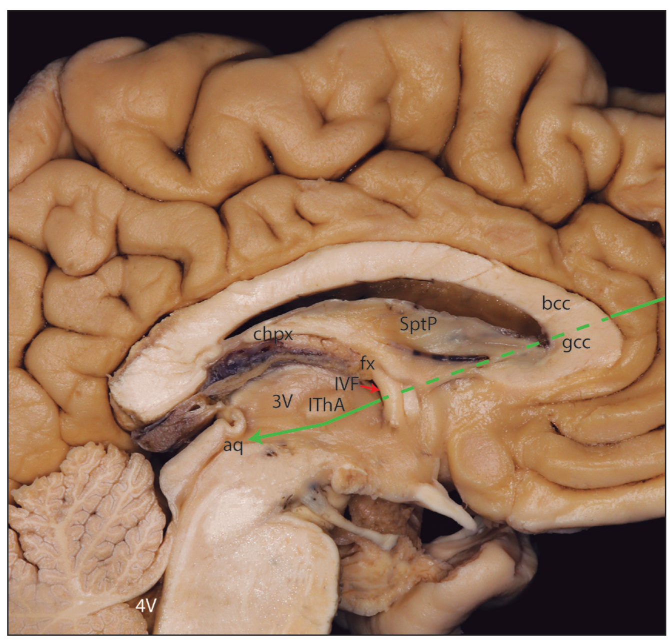

Figure 1: Normal anatomy of the left hemisphere (medial view). The aqueduct is located between the third and fourth ventricle. The most superior aspect of the aqueduct can be approached directly from the third ventricle, which is separated from the lateral ventricle through the interventricular foramen. The green arrow is showing the trajectory used in the eAIT approach. **3V:** third ventricle; **4V:** fourth ventricle; **aq:** aqueduct; **bcc:** body of the corpus callosum; **chpx:** choroid plexus; **SptP:** septum pellucidum; **fx:** fornix; **gcc:** genu of the corpus callosum; **IThA:** Inter thalamic adhesion; **IVF:** interventricular foramen.

the entire brain was dissected to identify the periventricular structures seen during the eAIT approach. Usually, the eAIT approach cannot be done in a brain without hydrocephalus because the IVF is too narrow to pass an endoscope or aspirator (Figure 2B).

The angle formed between the aqueduct and the IVF protects periventricular structures prone to damage during the resection of PATs through other methods. The IVF can be found easily in the frontal horn of the lateral ventricle, taking the fornix and choroid plexus as landmarks. When the IVF is dilated by hydrocephalus, the structures in the third ventricle can be seen in the surgical corridor. The first landmark in the third ventricle is the IThA (Figure 2C), which is not an obstacle to the surgical corridor. In fact, the endoscope and aspiration can be placed under the IThA in order to approach the aqueduct and safely remove the PATs (Figure 2D). (In the specimen shown in Figure 2C and 2D, the third ventricle was opened for didactic reasons.) To avoid confusion during surgery, the surgeon should also be aware of the possibility of a double IThA (1).

In the injected head, a frontal incision was made 2 cm posterior to the hairline; then, an extreme anterior craniotomy was done (adapted according to magnetic resonance venography images) anterior to the coronal suture so that the angle between the body and the genu of the corpus callosum could be approached (Figure 3A). After the craniotomy, the interhemispheric fissure was dissected to release CSF (Figure 3B), and the exact point for the callosotomy was chosen between

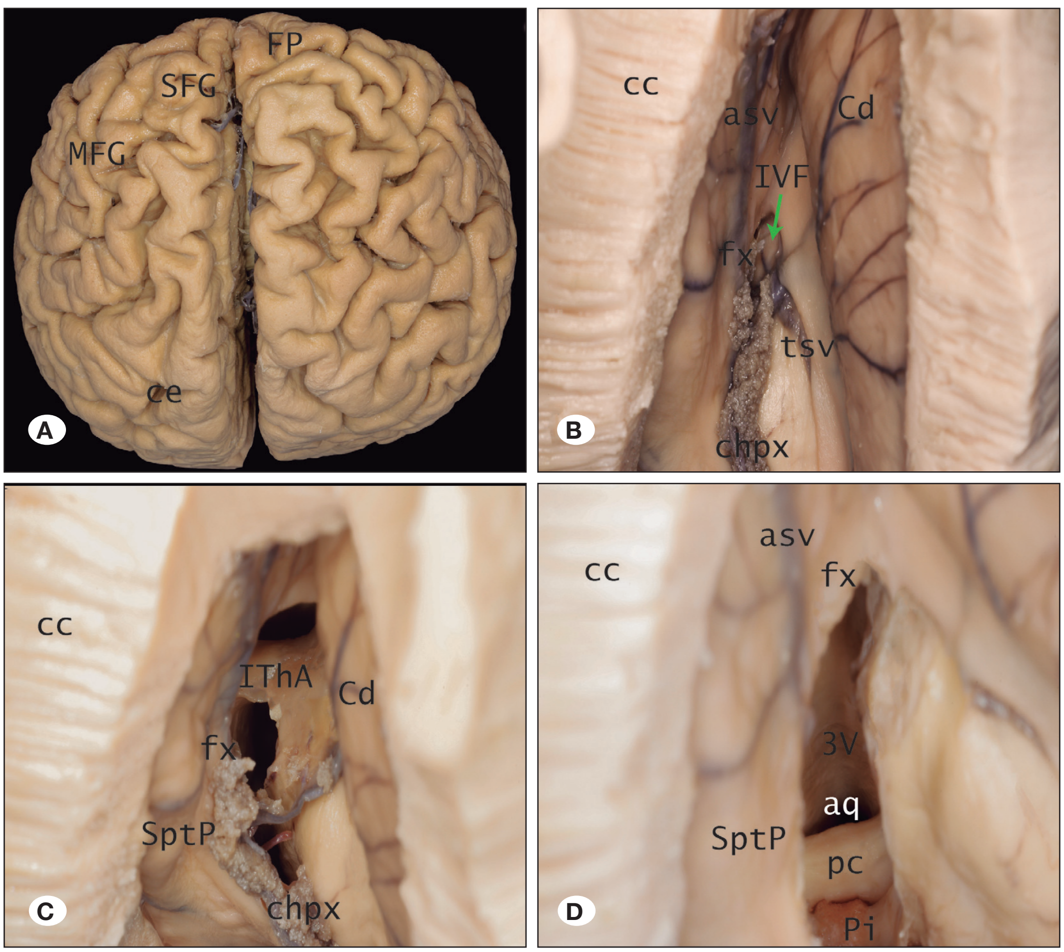

Figure 2: Periventricular anatomy related to the eAIT approach. **A)** Whole brain in surgical position, this extreme anterior view shows the place in which the genu and the body of the corpus callosum are joining together, thus it will be the place for the callosotomy. **B)** After dissecting most of the hemispheres we can see the relationship of the intraventricular structures; with the septum pellucidum untouched we can see the anatomy of the frontal horn of the lateral ventricle, with an external wall formed by the ependyma covering the caudate, a medial wall formed by the septum pellucidum, an inferior wall with the thalamus and the fornix, and a superior wall formed by the corpus callosoum. **C)** The interventricular foramen was open after which the presence of the interthalamic adhesion is evident. **D)** After removing the interthalamic adhesion the third ventricle is better observed. The third ventricle is formed laterally by the thalamus, superiorly by the fornix and inferiorly by the mesencephalon. In its posterior part the third ventricle continues with the aqueduct, formed mainly by the posterior commissure. **3V:** third ventricle; **aq:** aqueduct; **asv:** anterior septal vein; **cc:** corpus callosum; **Cd:** caudate nucleus; **ce:** central sulcus; **chpx:** choroid plexus; **FP:** frontal pole; **fx:** fornix; IThA**:** inter thalamic adhesion; **IVF:** interventricular foramen; **MFG:** medial frontal gyrus; **pc:** posterior commissure; **Pi:** pineal gland; **SFG:** superior frontal gyrus; **SptP:** septum pellucidum; **tsv:** talamo striate vein.

the pericallosal arteries by using ultrasound with a cottonoid marker (Figure 3C). After CSF was released from the lateral ventricle, the endoscope was used to verify the position of the PAT. The endoscope was passed through the callosotomy into the lateral ventricle, where the fornix and choroid plexus were used to identify the position of the IVF (Figure 4A). The endoscope was easily passed within the dilated ventricular system through the IVF to the third ventricle, in which the IThA could be identified between both thalami (Figure 4B). The endoscope was moved further below the IThA without any risk to this structure, and the aqueduct was directly seen (Figure 4C,D). Then, the endoscope was removed and, with the microscope and aspiration, the tumor could be removed without damaging any structures. Finally, the endoscope was reinserted to verify complete resection of the tumor (6,20). In a video taken through an operative endoscope in a whole head, the entire operative corridor is shown (Video 1).

DISCUSSION

Pure aqueduct tumors are lesions located specifically in the cerebral aqueduct, and their description in the literature is rare (16). Although the number of cases diagnosed has increased lately, the etiology continues to be unknown.

The normal ventricular system in the human brain is formed by three layers: 1) ependymal cells, 2) glial fibers, and 3) the subependymal cell plate (dense lamina of the glial nuclei) (4). Like other structures within the ventricular system, the cerebral aqueduct is lined by a single layer of ependymal cells. The subependymal layer contains undifferentiated cells with proliferative activity. This layer is believed to be the source of aqueduct tumors (8).

The symptoms in patients with PATs, such as headache and disturbed gait and cognition, are related to non-communicating hydrocephalus (7). These symptoms go unnoticed until the tumor obstructs most of the aqueduct, and they can be tolerated for years (21,22). Consequently, PATs present symptoms only when the obstruction restricts the normal flow of CSF, and intervention is needed to prevent death.

In the past, the diagnosis of aqueduct stenosis was made only in post mortem studies, or with common symptoms of an acute onset of headache, hydrocephalus, or death (20,22). In addition, most early cases were reported by pathologists, who found stenosis of the cerebral aqueduct as a cause of death (7, 27). Now, with the use of magnetic resonance imaging (MRI), it is easier to identify the presence of a mass in the aqueduct, and cases of PATs are not found only in post mortem studies.

The differential diagnosis of PATs is among all lesions that cause symptoms related to hydrocephalus, especially those with increased diameter in the lateral and third ventricles (20). But lesions located in the periaqueductal area and gliomas of the tectum can have similar MRI findings as with PATs (20, 22,24). In the same manner, problems that can mimic PATs include infections, vascular lesions, and blood clots (16). Thus, a high index of suspicion is necessary to accurately diagnose this lesion and avoid unnecessary procedures.

Additionally, there are reports of patients with neurofibromatosis and aqueduct stenosis produced by a mass lesion (9,10). Accordingly, patients with neurofibromatosis and symptoms of increased intracranial pressure should be evaluated for the patency of the cerebral aqueduct. In the same manner, patients with cerebral aqueduct tumors should be evaluated for the presence of neurofibromatosis.

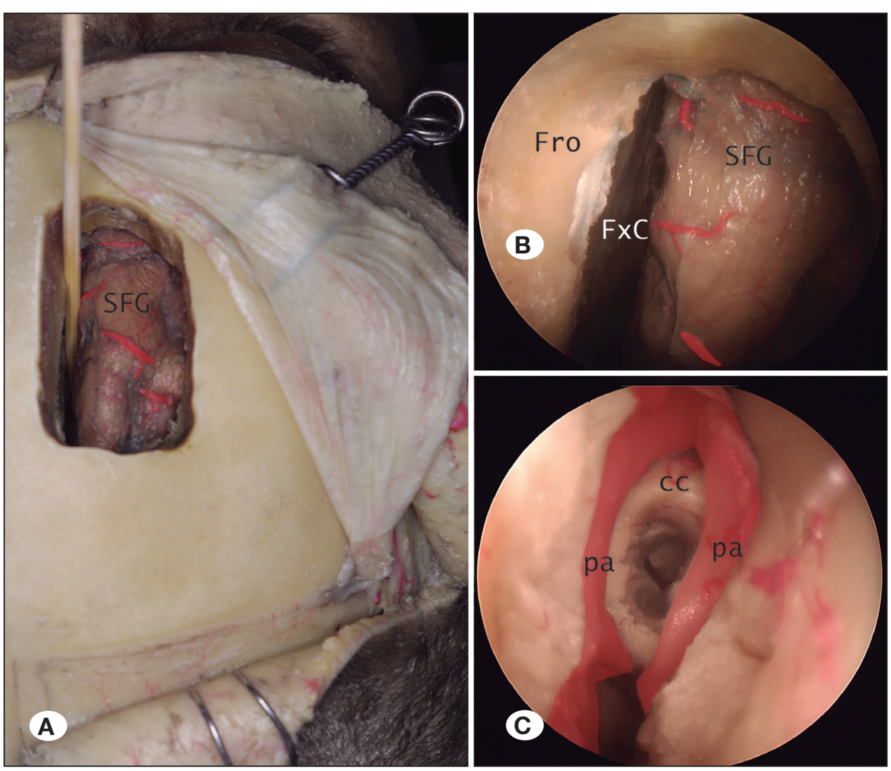

Figure 3: Cadaveric head used for the eAIT approach. **A)** Extreme anterior craniotomy showing the angle in which we are going to get in between the genu and body of the corpus callosum. Under the microscope the dissection of the interhemispheric fissure is made, and with the use of a cottonoid, the callosotomy is made.
B) Endoscopic view, before entering to the interhemispheric fissure. **C)** Endoscopic view of the callosotomy made between booth pericallosal arteries.

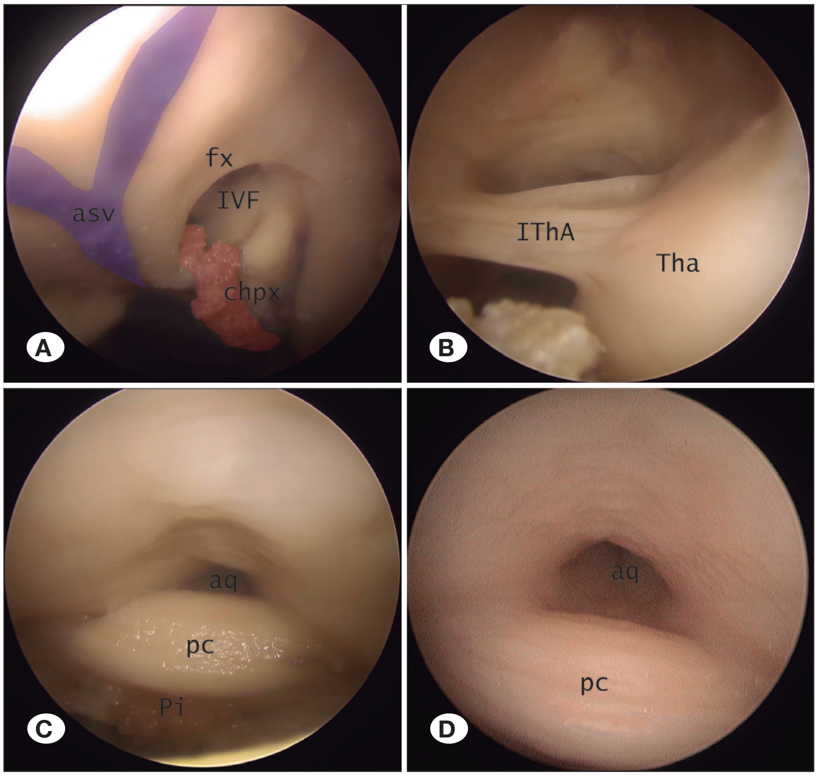

Figure 4: Endoscopic view of the surgical corridor in eAIT approach; **A)** after passing the callosotomy -when the lateral ventricle has hydrocephalus, the interventricular foramen (IVF) is already dilated. **B)** After entering the IVF, the interthalamic adhesion (IThA) can be observed within the third ventricle (3V). **C)** The endoscope is moved under the IThA, without any damage to this or other structures. **D)** The aqueduct is observed directly under the endoscopic exploration. **aq:** aqueduct; **asv:** anterior septal vein; **chpx:** choroid plexus; **fx:** fornix; **IThA:** interthalamic adhesion; **IVF:** interventricular foramen; **pc:** posterior commissure; **Pi:** pineal gland; **Tha:** thalamus.

The deep location of PATs makes the endoscope a precise tool because it is less invasive and it causes less damage to the periventricular structures (11,24). Even though the use of an endoscope is considered ideal, bleeding from the tumor can be a common complication (18). Nevertheless, constant irrigation should resolve this problem.

The endoscope is ideal for resecting pure aqueduct tumors because the CSF obstruction dilates the ventricular structures, allowing easier maneuvering inside the ventricular system (17). Thus, the use of the endoscope allows the treatment of hydrocephalus without difficulty.

Even though the endoscope improves visualization during surgery, there is a risk of damaging periventricular structures when the IVF is not dilated or the surgeon tries to simultaneously see structures in different locations with a different angle (11), for example, the tuber cinereum and aqueduct in the same session. On the other hand, the use of a flexible endoscope seems to resolve the latter problem. A flexible endoscope is easy to manipulate, has a larger range of movement inside the ventricular system, and increases the vision field, so, in theory, it can be used to identify and resect the PAT in the same session (17,18). Still, even though a flexible endoscope is used to carry out an ETV and a biopsy of the tumor at the same time, it is not widely used for total resection of aqueduct tumors (3,5).

There is no consensus on the treatment of PATs. Some authors define the treatment in relation to the histological characteristics of the tumor; for others, the application of a CSF shunt, biopsy, surgical resection, and ETV is the best approach for these lesions (7,15,23). Thus, all authors intend to diminish the intracranial pressure that, if left untreated, can lead to death.

Some studies define ETV as the best surgical option for treating PATs (14), but because it does not resect the mass lesion and therefore remove the cause of the hydrocephalus, it cannot be considered adequate treatment. In addition, the third ventricle cannot be reached without manipulating the periventricular structures when there is no hydrocephalus (25).

Pure aqueduct tumors are deep lesions, difficult to reach with the conventional use of an endoscope or microscope (5). Even though most of these masses have a benign evolution, their treatment must be adequate to prevent unnecessary complications related to hydrocephalus. Most PATs are treated symptomatically through ETV, biopsy, and follow up (23). But when using the endoscope only, there are no proper instruments for dissecting the lesion, and visualization in the operative corridor is not optimum.

Nowadays, the treatment for patients with PATs differs according to the surgeon. For example, the tumor can be partially removed using only the endoscope, but transient Parinaud syndrome has been reported, after which it was necessary to do a standard ETV (3,11,24). In other cases that used the flexible endoscope, the ETV and tumor resection could be done simultaneously, but some complications, such as ventriculitis and tumor recurrence, have been reported (18). Other reports describe using an ETV for symptomatic patients with a rigid endoscope and, in some, a biopsy with a flexible endoscope. However, in the few patients in which a resection was done, diplopia and upper midbrain injuries were observed (16).

In intraventricular surgeries, IVF does not allow free movement from the lateral to the third ventricle, and the instruments used for endoscopic or microscopic neurosurgery lack mobility. In addition, the endoscopic approach allows only an ETV and, when using a flexible endoscope, biopsy as well, but total resection using an endoscope is not reported widely. Thus, in the approach described here, all the strengths of the endoscope are used, and the microscope is also used to remove the entire tumor in a single approach. Moreover, in the eAIT approach, is not necessary to make an ETV or any other derivation procedure because gross total resection is achieved.

The eAIT approach uses an extreme anterior craniotomy, so surgeons can reach the angle between the genu and the body of the corpus callosum. This approach allows us to reach the superior portion of the cerebral aqueduct through the already dilated IVF. After dissection in the interhemispheric fissure, the brain relaxes and allows us to make a callosotomy between the pericallosal arteries using a cottonoid and ultrasound as a guide. The patient is positioned with a trunk elevation of 15 degrees and the head parallel to the floor. A small hole is opened parallel to callosal fibers with bipolar forceps without any thermocoagulation or incision. This approach is crucial not to damage any callosal fibers. Generally, just after the surgery 5-7 mm opening is visible on MRI, which will even become smaller at later follow-up images. We expect no neurological deficit with this surgical technique. The endoscope is used to directly see the third ventricle and the mass. Then, the lesion is removed totally under the microscope. Finally, the patent aqueduct can be confirmed by using the endoscope a second time (6,19). In patients with a PAT, the IVF is widely dilated (see Video 1), and movement from the lateral to third ventricles down to the aqueduct is feasible and does not present any risk to the periventricular structures.

CONCLUSION

In microscopic neurosurgery, the main goal is to carry out surgery with minimal damage to the brain structures. For us, the eAIT approach is the best technique for PATs resection because the surgeon can use a natural corridor, with little damage to the corpus callosum, for direct access to the aqueduct. In addition, the periventricular structures are not at risk during the eAIT approach.

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AUTHORSHIP CONTRIBUTION

Study conception and design: AG, UT
Data collection: APMG, PKB, EOY
Analysis and interpretation of results: APMG, PKB, EOY, AG, UT
Draft manuscript preparation: APMG, PKB
Critical revision of the article: AG, UT
All authors (APMG, PKB, EOY, AG, UT) reviewed the results and approved the final version of the manuscript.

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