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Median trans–atlanto-occipital membrane microsurgical approach to the posterior cranial fossa without craniotomy

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Minimally invasive approaches are becoming increasingly popular and contributing to improving the results of the surgical treatment of a wide variety of intracranial pathologies. Fifteen patients with posterior cranial fossa tumors underwent microsurgery through the atlanto-occipital membrane without resection of any bone structures. Tumors were localized in the brainstem in 8 patients and in the fourth ventricle in 7 patients. According to preoperative MRI and CT scans, the distance between the posterior arch of the atlas and the opisthion ranged from 9.9 to 16.5 mm (median 13 mm). The surgery was performed with the patient in the prone position and the head flexed. The trajectory of the surgical approach was directed from the skin incision located above the C2 spinous process 3.5–4 cm rostral along the midline. Total tumor resection was performed in 10 patients, subtotal resection in 2 patients, partial resection in 1 patient, and open biopsy in 2 patients. Surgical complications occurred in only 1 patient (meningoencephalitis). This minimally invasive trans–atlanto-occipital membrane approach for posterior cranial fossa tumors provides adequate visualization of the caudal part of the fourth ventricle and brainstem when the anthropometric parameters of the patient are suitable.

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KEYWORDS minimally invasive approach; fourth ventricle tumor; posterior fossa; atlanto-occipital membrane; oncology; surgical technique

Improvements in surgical microscopy, microsurgical techniques, endoscopy, and diagnostic methods have made minimally invasive keyhole surgery increasingly popular.

We previously described the outcomes of 19 surgeries performed using a median suboccipital approach (MSA) via the cerebellomedullary fissure, a minimally invasive approach, in tumors of the fourth ventricle and brainstem.[1] Currently, more than 80 such operations have been performed. These surgeries were performed through a small, 4-cm incision in the soft tissue in the upper cervical region. Because the skin incision was shifted in the caudal direction, the location gave us the opportunity to create a trajectory of surgical access, which made it possible to fully visualize the entire fourth ventricle along its axis through the cerebellomedullary fissure. For such an approach, resection of the occipital bone directly at the foramen magnum with a diameter of no more than 12–15 mm was sufficient. The purpose of applying this type of approach in the fourth ventricle is that the need for dissection or significant traction of the cerebellum is eliminated, considering that manipulations in the narrow and anatomically complex tonsillouvular fissure are challenging, so the surgeon is able to approach the area of interest through the natural anatomical fissures of the brain at an ideal angle.

At the same time, we noted that it was common for the distance between the opisthion and the posterior arch of the atlas to reach 15–17 mm. This anatomical feature in some patients allowed us to surgically remove tumors of the brainstem and the fourth ventricle through the atlanto-occipital membrane (AOM) without resection of any bone structures.

Methods

For the trans-AOM approach (TAOMA), we selected patients who met the following criteria: 1) The distance between the opisthion and posterior arch of C1 on sagittal

ABBREVIATIONS AOM = atlanto-occipital membrane; MSA = median suboccipital approach; TAOMA = trans-AOM approach; VAS = visual analog scale.
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MRI and CT scans was at least 10–12 mm. 2) No pathologies of the skull base or cervical vertebrae were observed. 3) No excessive fatty tissue was present in the suboccipital region, and the head could be freely flexed. 4) The tumor was located in the caudal portion of the fourth ventricle, dorsal medulla, or pons.

In all other cases, we refused to use the TAOMA, including large, highly vascularized tumors (e.g., hemangioblastoma) and in patients with signs of significant tumor expansion in the rostral or dorsal direction (i.e., into the cerebellar vermis).

TAOMA was performed in 15 patients (Table 1). The tumor was located in the brainstem in 8 patients and the fourth ventricle in 7 patients. In all but 2 patients (cases 2 and 9), the tumor was located completely intracranially, without extension beyond the McRae line. In the remaining 2 patients, only an insignificant portion of the tumor descended below this line (up to 3–4 mm). Hydrocephalus was present in only 3 patients (cases 1, 6, and 8). None of the patients underwent a CSF diverting procedure before or after surgery.

All operations were performed by the first author (D.P.) at Burdenko Neurosurgery Center from February 2021 to March 2022. The proposed surgical technique was approved by the ethics committee of the Neurosurgery Center. All patients signed consent forms.

Based on MRI and helical CT scans, the distance between the posterior arch of the atlas and opisthion ranged from 9.9 to 16.5 mm (median 13 mm). This distance increased from 0 to 7.7 mm (median 3 mm) following head flexion and soft-tissue dissection (intraoperative measurement).

All patients underwent the operation satisfactorily. To evaluate the tumor resection volume, all patients underwent contrast-enhanced MRI from 12 days to 2 months after surgery. The visual analog scale (VAS) was used to evaluate the patient's pain in the surgical wound area.

Surgical Technique

Standard microsurgical instruments and a Caspar counter retractor (Aesculap) were used in all procedures. All operations were performed, without brain retractors, under an OPMI Pentero operating microscope with an original Mari device (Tolikety Co., Ltd.)[2] from the time of the skin incision to suturing of the dura and the deep layers of the muscles.

After induction of general anesthesia, the patient was placed prone. The head was flexed to a distance of 2–3 cm between the chin and sternum and was fixed by the Mayfield fixation system. The patient's head was positioned strictly on the midline relative to the body axis, without any rotation (Fig. 1A–C).

The most protruding part of the spinous process of C2 was determined by palpation. The skin incision was started 10 mm caudal from this point in the rostral direction, strictly along the midline, and was created with a length of approximately 3.5–4 cm (Fig. 1 and Video 1).

VIDEO 1. Case 10. Video clip demonstrating the removal of a tumor of the fourth ventricle via a median TAOMA. © David Pitskhelauri, published with permission. Click here to view.

Subsequently, soft tissues were dissected along the nuchal ligament toward the posterior ridge of the foramen magnum at a low angle, as shown in Fig. 2C.

The superficial soft-tissue layers were dissected, and the ligamentum nuchae was further dissected between the neck muscles. From this stage, the Jansen retractor was replaced by the Caspar counter retractor, and after these muscles were separated, the rectus capitis posterior minor and major muscles were partially dissected from the posterior arch of the atlas at approximately 1 cm using monopolar cautery. After the posterior AOM was dissected along the midline, the flaps were separated from the dura. The posterior ridge of the foramen magnum was also symmetrically skeletonized (width 15–20 mm) (Fig. 1D).

The dura mater was then opened with a semioval or Y-shaped incision. The arachnoid membrane was sharply opened along the midline, and the CSF was aspirated from the cisterna magna.

The cerebellar tonsils were retracted with a suction tube on one side and with microforceps or scissors on the other side. The arachnoid trabeculae were transected in the area of the foramen of Magendie, and the caudal part of the fourth ventricle and the rhomboid fossa were opened (Fig. 1E).

If necessary, the dissection can be continued laterally, exposing the tonsillomedullary fissure to the lateral apertures of the fourth ventricle (Fig. 3). Depending on the relative position of the opisthion and the dorsal medulla, this approach allows visualization of not only the caudal part of the fourth ventricle and the rhomboid fossa below the facial colliculus (Fig. 1E) but also the inferior cerebellar peduncles and structures of the lateral cerebellomedullary cistern by tilting the Caspar retractor to the opposite side (Figs. 1F and 2D). Moreover, in some cases, the cerebral aqueduct was clearly visualized (Fig. 4 and Video 1).

After the necessary manipulations were completed within the intracranial space, the dura mater was sutured in a continuous fashion. Defects on the dura were often sealed with sealing material and fibrin glue. Then, the 4–5 layers of soft tissue were sutured separately.

During the incision of the soft tissue and dura mater and during manipulation in the area of the foramen of Magendie and obex, the surgeon was positioned in front of the patient's head (Fig. 1C, white arrow). As the manipulation shifted rostrally to the fourth ventricle and the rhomboid fossa, the surgeon changed his position to the side of the patient's head (Fig. 1C, shaded arrow).

Results

All the patients' surgeries were successful (Table 1). The duration of the surgery from skin incision to suturing ranged from 45 to 165 minutes (median 95 minutes). Total and gross-total tumor excision was achieved in 10 patients (66.7%). Open biopsy was performed in 2 patients with diffuse glioma of the brainstem, and partial removal of lymphoma of the dorsal part of the pons was performed in 1 patient. Subtotal resection was performed in the other 2 patients. Complications after surgery were recorded in

TABLE 1. Clinical data of 15 patients operated through the AOM

Case No.	Age (yrs), Sex	FU Duration (mos)	Tumor Location	Tumor Vol (cm³)	Histology	Skin-Opisthion Distance*	Posterior AO Distance (mm)			Op Duration (mins)§	EOR	Onset or Worsening of Sx	Cerebellar Signs (immediately postop/1–3 mos postop)	Op Complication	KPS Score (preop/immediately postop/1–3 mos postop)	VAS Score (short term/long term)¶
							Preop†	Intraop‡	Difference							
1	34, F	12	Medulla & middle cerebellar peduncle	1.54	Astrocytoma grade II	35.1	12	17	5	95	STR	Swallowing disturbance, nasogastric tube for 3 wks, lt hemihypesthesia	↔/↔	None	70/60/70	2/1
2	39, F	8	4th ventricle	32.14	Anaplastic ependymoma	36.5	11.3	19	7.7	155	GTR	Swallowing disturbance, nasogastric tube, tracheostomy	↓/↑	None	70/50/70	3/1
3	54, M	11	Pons	0.85	B-cell lymphoma	47.5	15.9	16	0.1	110	Partial	Mild skew deviation	↔/↔	None	70/70/70	2/1
4	25, M	10	Middle cerebellar peduncle lateral recess of 4th ventricle	5.21**	Pilocytic astrocytoma	49.7	13	15	2	145	STR	Mild dysphonia	↓/↑	None	80/70/100	0/0
5	36, M	10	Medulla	1.44	Astrocytoma grade I–II	45.1	13	13	0	45	Open biopsy	Numbness on rt half of body	↔/↔	None	80/80/100	0/0
6	67, M	9	4th ventricle	3.86	Subependymoma grade I	41.8	10.2	NA	NA	165	GTR	CN VI deficit	↓/↑	None	70/70/80	0/0
7	42, M	9	Medulla	0.45**	Hemangioblastoma	46.2	12.5	15	2.5	90	Total	None	↑/↑	None	80/80/100	0/0
8	20, F	7	4th ventricle	24.9	Medulloblastoma	28.5	13.7	17	3.3	135	GTR	Transient oculomotor disturbance	↓/↑	None	90/80/100	1/0
9	36, M	5	Medulla	4.45	Hemangioblastoma	48.7	15	18	3	130	Total	None	↔/↔	Meningoencephalitis	80/80/100	0/0
10	39, F	4	4th ventricle	0.95	Choroid plexus papilloma	37.7	12.9	17	4.1	60	Total	None	↑/↑	None	90/90/90	1/0
11	34, M	2	4th ventricle	0.44	Subependymoma grade I	37.9	13.0	NA	NA	60	Total	None	↔/↔	None	90/90/90	1/0
12	54, M	2	Pons	2.98	Cavernous malformation	38.0	16.5	17	0.5	65	Total	Increased motor disturbances in rt upper limb	↔/↔	None	60/60/70	1/0

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Case No.	Age (yrs), Sex	FU Duration (mos)	Tumor Location	Tumor Vol (cm³)	Histology	Skin-Opisthion Distance*	Posterior AO Distance (mm)			Op Duration (mins)§	EOR	Onset or Worsening of Sx	Cerebellar Signs (immediately postop/1–3 mos postop)	Op Complication	KPS Score (preop/immediately postop/1–3 mos postop)	VAS Score (short term/long term)¶
							Preop†	Intraop‡	Difference							
13	36, M	2	4th ventricle	0.48	Choroid plexus papilloma	46.1	13.4	15	1.6	75	Total	None	↔/↔	None	90/90/90	0/0
14	19, F	2	Pons, rt upper cerebellar peduncle	0.88	Astrocytoma grade I–II	23.1	15.9	20	4.1	70	Open biopsy	Spontaneous nystagmus	↔/↔	None	90/90/90	0/0
15	38, F	2	4th ventricle	13.44	Ependymoma grade II	31.0	9.9	15	5.1	95	Total	Oculomotor disturbance	↓/↔	None	80/70/80	2/0
Median	36	7		1.54		38	13	17	3	95					80/80/90	

AO = atlanto-occipital; CN = cranial nerve; EOR = extent of resection; FU = follow-up; GTR = gross-total resection; KPS = Karnofsky Performance Scale; NA = not available; STR = subtotal resection; Sx = symptoms; ↔ = unchanged compared with preoperative status; ↑ = improved compared with preoperative status; ↓ = deteriorated compared with preoperative status.

* Distance between skin and opisthion along a line perpendicular to the skin.

† Measured on MRI and helical CT scans.

‡ Measured using a sterile microruler.

§ Skin to skin.

¶ VAS score for pain in the surgical wound area.

** Volume of the solid part of the tumor, without the cystic component.

only 1 patient (case 9). The patient developed meningoencephalitis, which was successfully treated with intravenous antibiotic therapy. The surgical wound healed in all patients, with no complications. A pseudomeningocele (8.9 cm^3 and 14.7 cm^3) was observed in 2 patients, which resolved 2 months after the surgery. No CSF leakage was observed immediately after the surgery or during the follow-up period. Immediately after the operation, only 1 patient (6.7%) had pain in the neck area, with a VAS score of 3, and pain was barely noticeable (46.7% of patients) or completely absent (46.7% of patients) in the remaining 14 patients (Table 1).

The follow-up duration ranged from 2 to 12 months (median 7 months). Radiation therapy was performed in 5 patients, and radiation therapy combined with chemotherapy was performed in 3 of these patients. There were no signs of tumor recurrence in any of the patients at the last examination. One patient (case 2) died 4 months after discharge from the hospital of pneumonia caused by COVID-19.

Discussion

The telovelar approach to the fourth ventricle, as well as the previously proposed transvermian approach, is associated with the risk of developing posterior fossa syndrome in the form of mutism and cerebellar ataxia.[3–5] Reasons for the development of this kind of complication include dissection of the vermis, circulatory disorders in the dentate nuclei due to manipulation of the posterior inferior cerebellar artery branches located in the tonsillouvular fissure, and direct traction injury.[4,6,7] To reduce such risks, several types of minimally invasive approaches to the fourth ventricle, including endoscopic approaches, have been proposed.[8–14]

Our proposed technique differs from these approaches as well as from traditional ones. This type of surgery, which is performed along a "low-angle" trajectory through a limited working space, has become possible because of the Mari device, which provides hands-free control of the operating microscope in 6 degrees of freedom repositioning.[2] It is worth mentioning that we have successfully performed the operation in approximately 1000 patients (unpublished data) using the so-called burr hole technique,[1] in which manipulations are performed through a burr hole, with a diameter of 14 mm, to remove intracranial tumors from almost any location.

A low-angle trajectory is a cornerstone for a successful approach to the fourth ventricle through the AOM and foramen magnum. The approach should be directed in such a way that the field of view through the microscope is parallel to the rhomboid fossa plane (Fig. 2C). This is achieved by significant shifting of the skin incision in the caudal direction to be above the C2 spinous process. There is no need to extend the soft-tissue incision toward the inion; thus, the incision length can be limited to 3.5–4 cm.

There is almost no traction of the cerebellum due to the trajectory of the approach along the ridge of the foramen magnum, which serves as a limiting point for the microsurgical instruments and prevents the exertion of pressure on the cerebellum. It is worth noting that cerebellar neurological deficits that occurred in some of our patients after surgery were temporary and were completely relieved or returned to the preoperative level in all patients soon after discharge; additionally, mutism was not noted in any case.

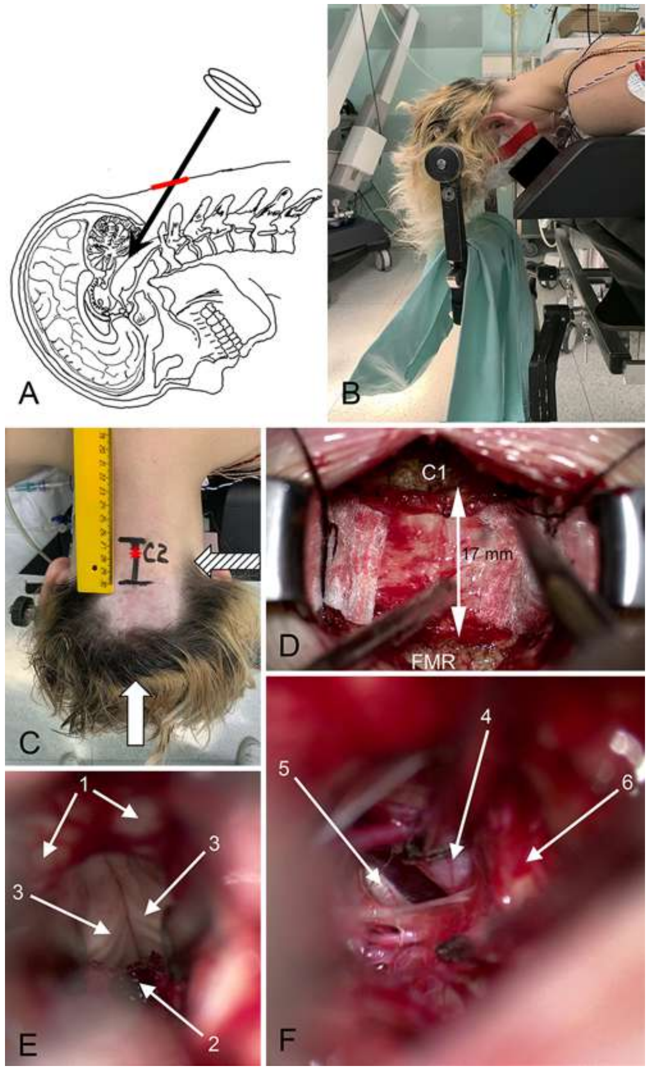

FIG. 1. Case 1. Median approach to the rhomboid fossa through the AOM. **A:** Schematic representation of the approach through the AOM. **B and C:** Patient positioning on the operating table (B) and marked area of the skin incision and localization of the C2 spinous process (*red asterisk*, C). Position of the surgeon relative to the patient's head during approach from skin incision to the dura opening (C, *white arrow*) and during manipulation in the intracranial cavity (C, *shaded arrow*). **D–F:** Intraoperative photographs of the approach. Soft-tissue incision and exposure of the dura mater at the craniovertebral junction (D). The Caspar retractor is used to provide retraction of all soft-tissue layers; the AOM is partially mobilized, and the edges of the atlas (C1) and foramen magnum ridge (FMR) are exposed. The cerebellar tonsils are retracted, and the fourth ventricle is opened (E). View of the operating field lateral to the right edge of the medulla oblongata (F). 1, gracile tubercles, 2, choroidal plexus of the fourth ventricle; 3, striae medullaris; 4, right vertebral artery; 5, cranial nerve XII; 6, lateral surface of the medulla oblongata. Figure is available in color online only.

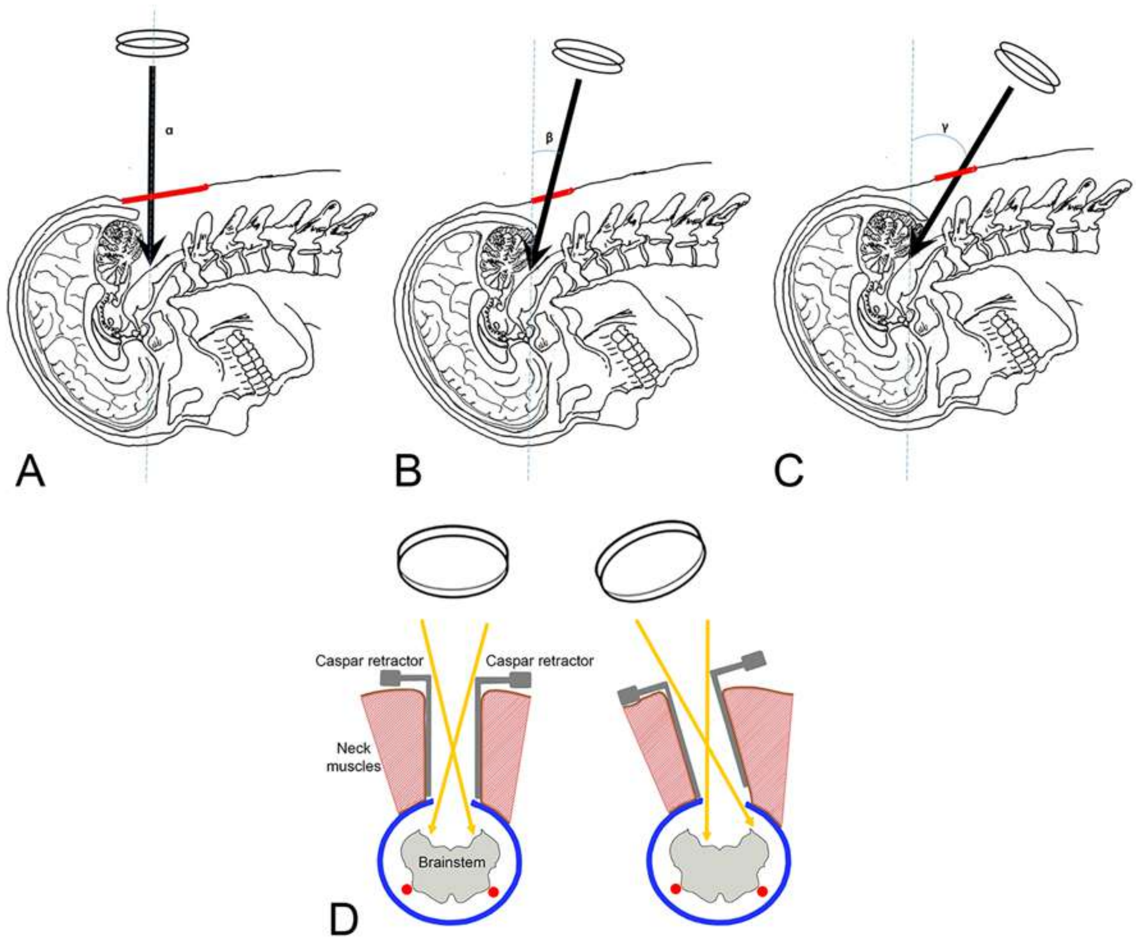

FIG. 2. Changing the angle of approach to the target through the cerebellomedullary fissure depending on the size of the craniotomy. **A:** Conventional craniotomy (3 × 4 cm). **B:** Minimally invasive craniotomy (1.5 cm). **C:** Approach without craniotomy (through the AOM). **D:** Changing the angle of approach on the horizontal plane by tilting the Caspar to the opposite side of the surgical target. Figure is available in color online only.

It is important to note that choosing not to perform a craniotomy is not the goal but rather the result of using such a trajectory of surgical access when the anatomical structure of the craniovertebral junction is suitable, and there is no need for the resection of bone structures.

Most importantly, this kind of approach provides adequate visualization of the caudal part of the floor of the fourth ventricle and its lateral apertures and, in some cases, allows manipulation in the rostral part of the fourth ventricle as far as the cerebral aqueduct. Moreover, viewing the area of interest at a horizontal angle is not limited to the rhomboid fossa and medulla oblongata. If it is necessary to examine the lateral recess of the fourth ventricle or the paramedullary region, it is sufficient to tilt the Caspar retractor in the opposite direction from the area of interest (Fig. 2D), which makes it possible to visualize these structures at the desired angle.

In addition to the main advantage of the TAOMA, we note that minimizing the risk of trauma is a noteworthy positive aspect of the approach, when compared with classic approaches, because the length of the incision is reduced by 2–3 times in the location where the soft tissues of the head reach their maximum thickness in the soft tissues of the suboccipital region. Apparently, this difference leads to a decrease in postoperative pain symptoms.

The positive aspects of the described access include the fact that resection of bone structures, including the arch of the atlas, is not needed.

Another problem a surgeon may encounter through the traditional MSA to the fourth ventricle is enlarged marginal and occipital sinuses. In cases of hypoplasia of the transverse sinuses, the occipital sinus is the main route of venous outflow.[15] In such cases, occipital sinus transection is accompanied by profuse venous bleeding, and ligation can potentially lead to severe venous circulatory disturbances in the posterior cranial fossa and intracranial hypertension.[16] Approaching through the AOM eliminates this complication.

According to Ferguson et al., another problem in approaching a tumor in the superior half of the fourth ventricle may be the required vertical angle, which can be quite extreme in the case of a steep tentorium and may be difficult to achieve with a telovelar approach, resulting in a potentially awkward working angle.[4] In such cases, it

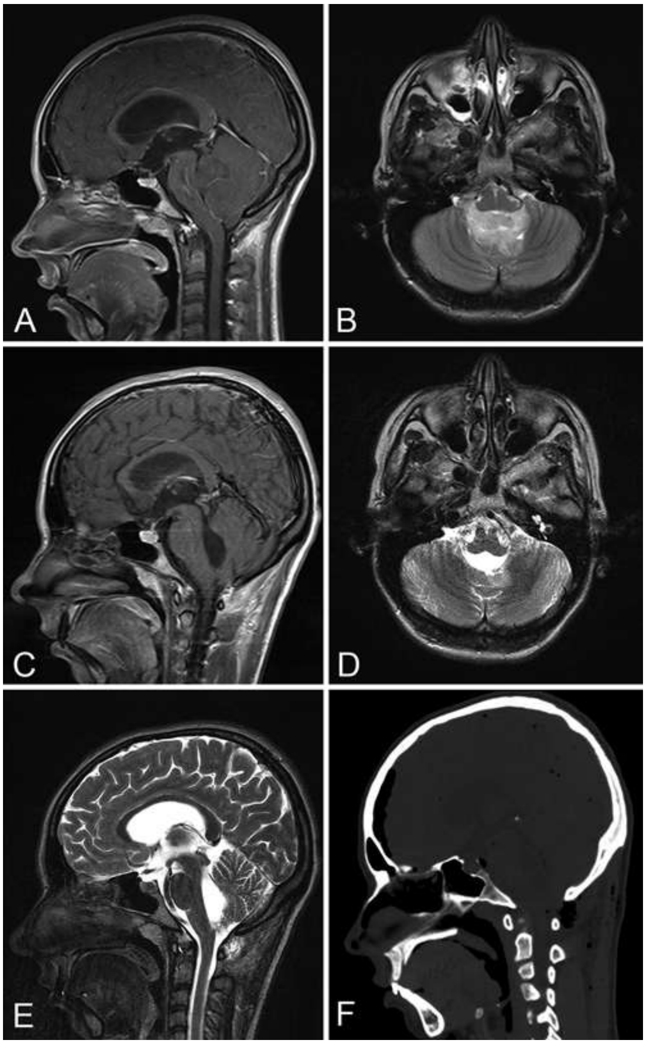

FIG. 3. Case 8. Resection of medulloblastoma of the fourth ventricle through the AOM. **A and B:** Sagittal T1-weighted (A) and axial T2-weighted (B) MR images revealing a large tumor completely obliterating the fourth ventricle and expanding toward the lateral recess, with poor contrast enhancement. **C–E:** Sagittal contrast-enhanced T1 and T2 MR images at 2 months postoperatively on sagittal (C and E) and axial (D) planes revealing gross-total tumor removal. **F:** Postoperative CT scan of the midsagittal skull reconstruction demonstrating the absence of craniectomy.

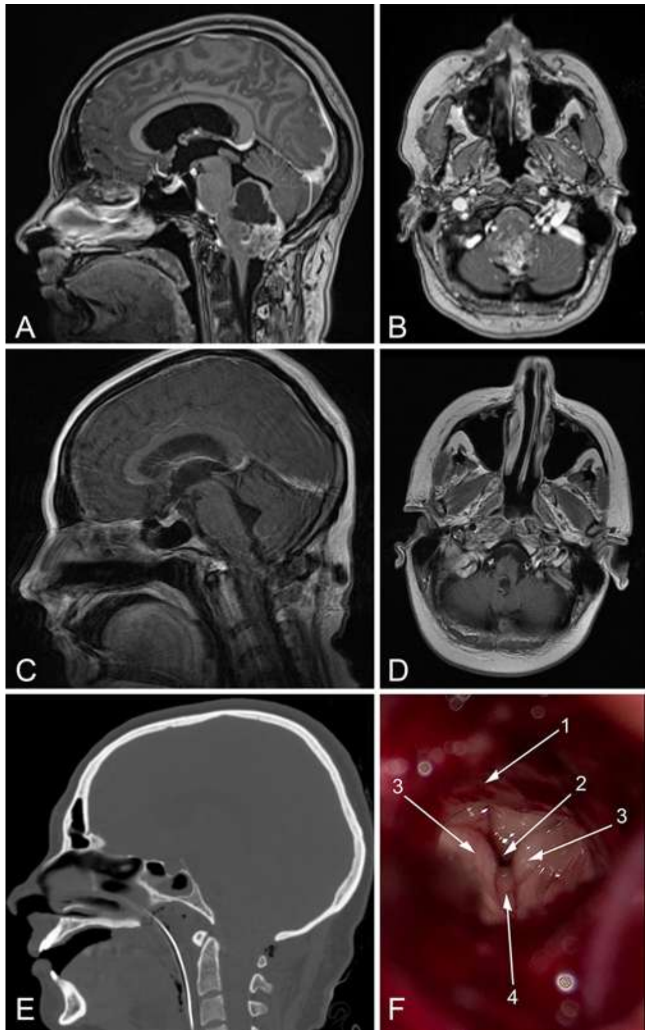

FIG. 4. Case 2. Resection of anaplastic ependymoma of the fourth ventricle through the AOM. **A and B:** Preoperative contrast-enhanced sagittal T1-weighted (A) and axial (B) MR images showing a large tumor of the fourth ventricle with extensive invasion into the brainstem. **C and D:** Contrast-enhanced sagittal T1-weighted (C) and axial (D) MR images obtained on day 12 after surgery, showing no tumor remnants. **E:** Sagittal CT reconstruction after surgery. **F:** Intraoperative photograph after gross-total tumor resection (F). 1, tumor-infiltrated rhomboid fossa; 2, caudal part of the cerebral aqueduct; 3, superior cerebellar peduncles; 4, superior velum medullare. Figure is available in color online only.

is apparently possible to successfully apply the TAOMA; thus, dissection of the cerebellar vermis, and all its negative consequences, can be avoided. The last advantage is that it seems that the proposed approach helps to reduce the operation time (Table 1).

Suturing the dura mater is one of the most difficult stages of the operation. Nevertheless, in our observations, we achieved sufficient hermetic suturing of the membrane, sometimes with the use of fibrin glue (6 cases). Postoperative MRI revealed pseudomeningocele in only 2 patients, and there was no wound liquorrhea in any of the cases. It is interesting to note that in our previously described observations, when traditional osteoplastic craniotomy was performed for MSA, the frequency of wound liquorrhea ranged from 2.6% to 25%.[17]

Disadvantages

Our experience with the TAOMA gives us an opportunity to discuss its disadvantages in comparison with the conventional MSA as well. 1) The operation can be performed in only a small group of patients. 2) There is limited maneuverability. 3) There is limited visualization of the rostral fourth ventricle in some cases. 4) There is difficulty in suturing the dura mater. 5) A high level of surgical training is required.

At the same time, it should be noted that if problems arise during the operation using TAOMA due to the above factors, the situation can be easily corrected by a small resection of the occipital bone. We have not encountered such problems thus far.

Conclusions

This minimally invasive approach to posterior cranial fossa tumors through the AOM provides adequate visualization of the caudal part of the fourth ventricle and brainstem when anthropometric parameters of the patient are suitable. These parameters include a distance of 10 mm or more between the posterior arch of the atlas and the opisthion and the possibility of a sufficient degree of head flexion.

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Disclosures

Dr. Pitskhelauri is the inventor of the Mari device and has ownership in Tolikety Co., Ltd., the company that manufactures the Mari device.

Author Contributions

Conception and design: Pitskhelauri. Acquisition of data: Sufianov, Pronin. Analysis and interpretation of data: Sufianov, Pitskhelauri. Drafting the article: Pitskhelauri. Critically revising the article: Pitskhelauri, Konovalov, Pronin, Sanikidze. Reviewed submitted version of manuscript: Sufianov, Pitskhelauri, Konovalov, Sanikidze. Administrative/technical/material support: Sufianov, Pitskhelauri, Sanikidze. Study supervision: Pitskhelauri.

Supplemental Information

Videos

Video 1. https://vimeo.com/715625596.

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