Ventricular Meningiomas: Surgical Strategies and a New Finding That Suggest an Origin From the Choroid Plexus Epithelium

Abuzer Güngör[1], Ayça Ersen Danyeli[2], Ahmet Akbaş[3], Murat Şakir Ekşi[1], Mustafa Güdük[1], Koray Özduman[1], M. Necmettin Pamir[1]

BACKGROUND: **The aim of this study is to share our experiences on a series of 21 patients with intraventricular meningiomas (IVMs). Histopathologic examinations are reviewed in detail and the cell of origin of IVMs is discussed.**

METHODS: **We retrospectively reviewed 1372 patients with intracranial meningioma who were surgically treated between September 1986 and July 2018. From this cohort, 21 patients with IVM were identified. The clinical, radiologic, surgical, and follow-up records were analyzed. The archival pathologic specimens were reviewed. Tissue microarray blocks were performed from the formalin-fixed, paraffin-embedded samples of all IVM cases, 2 choroid plexus tissue adjacent to the tumors, and 10 extraventricular fibrous meningioma cases selected as control randomly. Immunohistochemical staining with the antibodies S-100, SOX10, NGFR, and OTX2 was performed according to the protocols indicated by the manufacturers.**

RESULTS: **Surgical complications included hemiparesis in 1 patient (5%), postoperative seizure in 1 patient (5%), sensorial aphasia in 1 patient (5%), and preexisting headache in 1 patient (5%). Seventeen (81%) of the IVMs had grade I pathology and 4 (19%) had grade II pathology. The immunoprofile of IVMs is identical to the immunoprofile of normal choroid plexus epithelium.**

CONCLUSIONS: **Transcortical approaches using intraoperative ultrasonography and intraoperative monitoring with avoidance of eloquent cortical areas can achieve good outcomes. Resection of the choroidal attachments should be attempted. Our results indicate that IVMs do not show arachnoid cap cell phenotype and the findings support that IVMs originate from the choroid plexus epithelium or the progenitors of the choroid plexus epithelium.**

INTRODUCTION

Intraventricular meningiomas (IVMs) are extremely rare tumors constituting 1%–5% of all intracranial meningiomas and 13%–30% of all intraventricular tumors; they have attracted the attention of neurosurgeons over the last decades.[1-10] Most IVMs arise from the lateral ventricle (80%), followed by the third ventricle (15%) and the fourth ventricle (5%).[1,4,5] Most lateral ventricular meningiomas are located in the trigone (atrium).[1,4,5] Intracranial meningiomas are claimed to originate from arachnoid cap cells.[11] However, the cell of origin for IVMs has not been investigated in detail.

Surgical resection is the treatment of choice in patients with IVMs, because IVMs are usually benign and bulky at the time of diagnosis.[1,4,5] Despite the advanced surgical techniques, the deep location of IVMs and their closeness to the white matter tracts, neural and vascular structures, and eloquent cortical areas make IVM surgery still challenging.[12-17]

The aim of this study is to share our experiences of a series of 21 adult patients with trigone ventricular meningiomas who underwent surgical resection over a 32-year period. Histopathologic

Key words
- Choroid plexus
- Intraventricular meningioma
- Origin
- OTX2
- Trigone
- Ventricular surgery

Abbreviations and Acronyms
CSF: Cerebrospinal fluid
CT: Computed tomography
EI: Edema index
IVM: Intraventricular meningioma
MRI: Magnetic resonance imaging
USG: Ultrasonography
WHO: World Health Organization

From the Departments of [1]Neurosurgery and [2]Pathology, Acıbadem Mehmet Ali Aydınlar University, School of Medicine, Istanbul; and [3]Department of Neurosurgery, Health Sciences University, Bakirkoy Research & Training, Hospital for Psychiatry, Neurology, and Neurosurgery, Istanbul, Turkey

To whom correspondence should be addressed Abuzer Güngör, M.D. [E-mail: abuzergungor@gmail.com]

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findings are reviewed in detail and the cell of origin for IVMs is discussed.

METHODS

Patient Population

We retrospectively reviewed 1372 adult patients with intracranial meningiomas who were surgically treated by the senior author (M.N.P.) at Marmara University and Acıbadem University between September 1986 and July 2018. From this cohort, 21 patients with IVMs were identified, constituting 1.5% of all intracranial meningiomas. The clinical, radiologic, surgical, pathologic, and follow-up records were analyzed.

Preoperative Imaging

All patients before the era of magnetic resonance imaging (MRI) had preoperative computed tomography (CT) scans, whereas the patients who have been admitted since 1992 have had MRI. Tumor location, size, and contrast enhancement pattern, accompanied hydrocephalus, peritumoral edema, and tumoral calcification patterns were identified using CT and/or MRI. The tumor size was defined as the maximum diameter in any plane. Peritumoral edema was classified with the edema index (EI).[18] EI was calculated as the ratio of edema thickness from the tumor to the tumor diameter. Preoperative functional MRI and magnetic resonance tractography were obtained in 5 patients to identify the related important cortical areas and white matter tracts.

Surgical Procedures

Surgical approach, tumor blood supply, intraoperative blood loss, and intraoperative surgical complications were reviewed from operation notes. The surgical approach for each patient was chosen according to the tumor location and size, thickness of the brain from the tumor to the cortical surface, hemispheric dominance, and relation of the tumor with the eloquent cortical areas. The surgical approaches were as follows: posterior interhemispheric transcallosal approach in 2 patients with small tumors located medially in the atrium of the lateral ventricle (9%); parietal transcortical approach in 1 patient (5%) with a tumor superiorly located within the atrium extending the parietal region; posterior interhemispheric precuneal approach in 1 patient (5%) with a tumor located medially in the atrium of the lateral ventricle who already had an occipital falx meningioma in the same side; and temporal transcortical approach in the remaining 17 patients (81%). Intraoperative ultrasonography (USG) was performed to localize ventricles and tumors. Grossly, the tumors were attached to the choroid plexus in all cases. Attachment site and feeding arteries were found and coagulated in all patients. The ventricular ependymal and cortical defects were closed with hemostatic material (Surgicel [Surgicel Nu-Knit, Ethicon, Somerville, New Jersey, USA]). Prophylactic antibiotics and antiepileptics were used in all patients. Prophylactic antibiotics were used routinely for 3 days starting from 30 minutes before surgery (cefuroxime 1000 mg per day). Routine antiepileptic treatment was used in all patients (phenytoin 300 mg/day or levetiracetam 1000 mg/day). External ventricular drainage or lumbar drainage was not used in any case.

Steps of the Temporal Transcortical Approach

The temporal transcortical approach was performed in 17 tumors (81%) located in the atrium of the lateral ventricle. This approach allows us to reach directly inferior and anterior parts of the atrium of the lateral ventricle. It has been chosen for tumors located laterally with lateral and temporal extension. After the lateral decubitus position was obtained, the posterior temporal region was positioned at the top. After a U-shaped incision, a temporal craniotomy was performed, and dura was opened (**Figure 1A**). The location of the atrium and the tumor was found by using USG imaging (**Figure 1B** and **C**). A horizontal cortical incision was made at the thinnest cortical layer to the tumor (**Figure 1D**). After tumor was observed, retractors were placed (**Figure 1E**). Because of the size of the tumor and compression by the tumor, the ependymal layer of the ventricle was found to be damaged in 8 of the 17 cases. In 2 tumors, feeding arteries could be found and coagulated before debulking of the tumor (**Figure 1F** and **G**). In 15 cases, feeding arteries could be coagulated and cut after debulking of the tumor (**Figure 1G**). Before total removal, choroidal attachments were also coagulated and cut (**Figure 1G**). Continuous ventricular irrigation was used to avoid intraventricular blood (**Figure 1H**). Also, USG imaging was used to detect the extent of resection and intraventricular hematoma if present. Before dural closure, ventricular ependymal and cortical defects were closed with hemostatic material (Surgicel) (**Figure 1I**). Intraoperative neuromonitoring was used in 15 of these cases.

Histopathologic Evaluation

The archival pathologic specimens were reviewed by a neuropathologist (A.E.D.). The subtype analysis and grading based on the World Health Organization (WHO) 2016 classification were documented.[19] Sections were prepared from the formalin-fixed, paraffin-embedded samples of all IVM cases; 10 patients with normal choroid plexus tissue and 10 with extraventricular fibrous meningioma were selected as control, randomly. Immunohistochemical staining with the antibodies S-100, SOX-10, NGFR, and OTX-2 was performed according to the protocols indicated by the manufacturers (**Table 1**). The staining patterns were evaluated by the same neuropathologist (A.E.D.).

Postoperative Imaging and Follow-Up

All patients had CT scans within 2 hours after surgery. To define the extent of resection and any possible complications, CT scans with/without contrast enhancement were obtained 24 hours after surgery before 1992, whereas MRI with contrast enhancement has been obtained since 1992. Gross total resection was defined as no tumoral tissue in postoperative CTs or MRIs. Patients attended their first postoperative CT (before 1992) or MRI (after 1992) follow-ups 4 months after surgery. Patients with WHO grade II tumors were followed up biannually (every 6 months), whereas those with WHO grade I tumors were followed up annually (every year). Patients with no recurrence within their first 5 years were followed up every 2 years.

RESULTS

Study Population and Pr-Operative Findings

Sixteen patients were female (76%) and 5 were male (24%). The female/male ratio was 3.2:1. Median age was 43 years

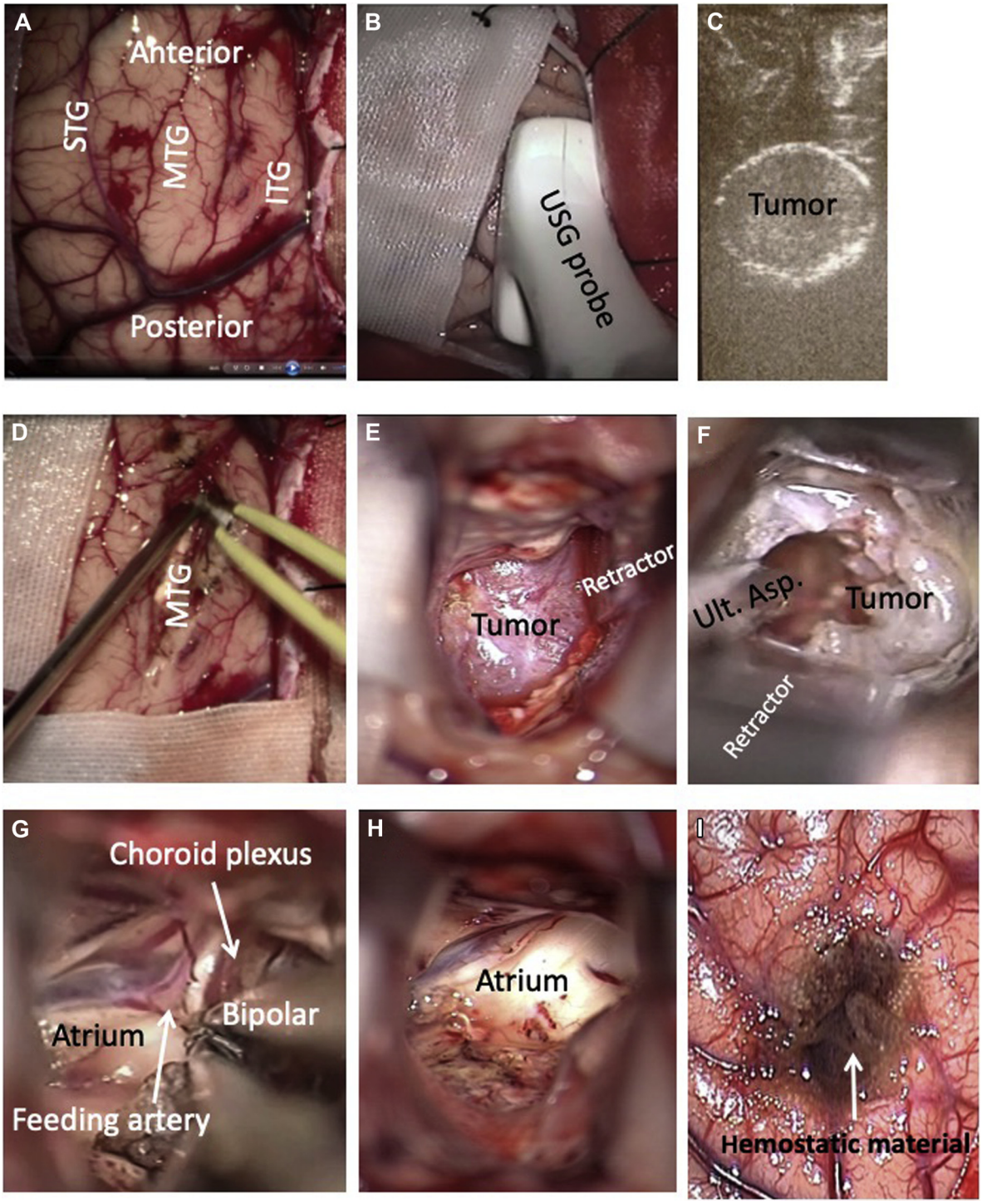

Figure 1. Intraoperative images of a patient with a right atrial meningioma operated on via a transtemporal approach. (**A**) After a right temporal craniotomy dura is opened, the posterior part of the temporal lobe is observed. (**B**) Intraoperative ultrasonography is used to show the shortest trajectory to the atrium and the tumor. (**C**) Intraoperative ultrasonography imaging shows the tumor and the shortest trajectory to the tumor. (**D**) A 2-cm linear incision parallel to the temporal base is made after coagulation of the cortex. (**E**) The tumor is exposed. (**F**) The tumor is debulked with an ultrasonic aspirator. (**G**) After debulking of the tumor, the feeding artery and choroidal attachments are coagulated and cut. (**H**) Continuous ventricular irrigation is performed after removal of the tumor and choroidal attachments. (**I**) The ependymal and cortical defects are closed with hemostatic material (Surgicel). ITG, inferior temporal gyrus; MTG, medial temporal gyrus; STG, superior temporal gyrus; Ult. Asp., ultrasonic aspirator; USG, ultrasonography.

Table 1. List of Immunohistochemical Stains and Staining Results Along with Staining Procedural Data

Immunohistochemical Stains	Manufacturer and Clone	Dilution	Number of Intraventricular Meningioma Cases with Positive Staining (N = 21)	Number of Intraventricular Meningioma Cases with Negative Staining (N = 21)	Number of Extraventricular Meningioma Cases with Positive Staining (N = 10)	Number of Extraventricular Meningioma Cases with Negative Staining (N = 10)	Staining Results of Normal Choroid Plexus Tissue (N = 10)
SOX-10	Biocare BC34	1:100	0	21	6	4	Negative
NGFR	Cell marque MRQ-21	Prediluted	21	0	8	2	Positive
S-100	ScyTek QBEND/10	Prediluted	21	0	10	0	Positive
OTX-2	ThermoFisher 1H12C4B5	1:200	21	0	0	10	Positive

(range, 18–65 years). The duration of symptoms ranged from a few days to 36 months. The most common symptom was headache (76%, n = 16), whereas 10% had seizures (n = 2), 10% had visual complaints (n = 2), 10% had vomiting (n = 2), 10% had vertigo (n = 2), and 5% had dysesthesia (n = 1). Ten percent of patients (n = 2) were asymptomatic. Patient population and preoperative findings are summarized in Table 2. The mean Karnofsky Performance Status of the patients preoperatively was 98.6 (Table 2).

Radiologic Findings

In our study, all the lateral ventricle meningiomas were in the trigone of the lateral ventricle. We observed that 62% of the lateral ventricle meningiomas were located within the right lateral ventricle, whereas 38% were located within the left lateral ventricle. The mean maximal tumor diameter was 4 cm (range, 2–7.2 cm). Contrast enhancement was detected in all tumors; homogeneous in 81% (n = 17) and heterogeneous in 19% (n = 4) of the patients (Figure 2). Ventricular entrapment was detected in 19% (n = 4) of patients. In this study, 42% (n = 9) of patients had tumoral calcification and 52% (n = 11) had peritumoral edema. Five patients had mild edema (EI ≤0.1), 4 patients had moderate edema (EI 0.1–1.0), and 2 patients had severe edema (EI ≥2) (Table 2). Multiple meningiomas were seen in only 1 patient, who had an additional falcian meningioma.

Histopathologic Results

Seventeen (81%) of the trigonal meningiomas had grade I pathology and 4 (19%) had grade II pathology. The fibrous subtype and transitional subtype with a fibrous component were most common (66% and 29%, respectively). Only 1 of the meningiomas was meningothelial (5%). The histopathologic results are summarized in Table 3.

The epithelium of all normal choroid plexus tissue showed strongly positive nuclear and cytoplasmic staining with S-100, and specific nuclear staining with SOX-10 (Figure 3). All patients in our IVM series were S-100 positive (Figures 4 and 5) and none showed positive immunostaining with SOX-10 antibody. All IVM tumors, regardless of the histologic subtype, showed positive immunoreaction with NGF antibody (Table 1).

OTX-2 stained mainly the fibrous subtype (Figures 4 and 5) or the fibrous component in the transitional subtype and the staining pattern was similar to the normal choroid plexus epithelium adjacent to the tumor (Figure 4). Six of the control patients with extraventricular meningioma were positive with SOX-10, 8 were positive with NGFR, all were positive with S-100, and none was positive with OTX2 (Figure 6, Table 1).

Surgical Outcomes

All patients underwent gross total resection, confirmed by using postoperative CT or MRI. The mean duration of follow-up was 48 months (range, 3–108 months). No recurrence was observed during the follow-up period. The mean preoperative, early, and late postoperative Karnosfky Performance Status of the patients is similar, at 98.6, 97.0, and 99.0, respectively. Three patients (15%) required blood transfusion during surgery (Table 3).

Table 2. Preoperative Clinical and Radiologic Findings

						Magnetic Resonance Imaging					
Case Number	Age (years)	Sex	Site	Presentation Symptoms	Preoperative Karnosfky Performance Status	Size of the Tumor (Largest Diameter Accested on Magnetic Resonance İmaging, mm)	Contrast	Calcification	Hydrocephalus	Edema	Shift (mm)
1	18	F	RLV	Headache	100	72	Heterogeneous	+	+	Mild	10
2	65	F	LLV	Headache	100	42	Homogeneous	+	–	–	5
3	55	F	LLV	Headache, vertigo	100	53	Homogeneous	+	–	Mild	–
4	24	F	LLV	Headache, vomiting	100	60	Homogeneous	–	–		–
5	55	F	RLV	İncidental	100	22	Homogeneous	–	–	–	–
6	19	M	RLV	Headache	90	40	Homogeneous	–	–	Mild	–
7	41	F	LLV	Headache, seizure	100	50	Heterogeneous	+	–	Severe	10
8	46	M	LLV	Headache, vertigo	100	20	Heterogeneous	+	+	Moderate	7
9	55	F	LLV	Headache	100	46	Homogeneous	–	–	–	–
10	25	F	LLV	İncidental	100	35	Homogeneous	–	–	–	–
11	64	M	RLV	Headache	100	40	Homogeneous	–	–	Mild	5
12	50	F	RLV	Dysesthesia	100	60	Heterogeneous	+	+	Severe	12
13	43	F	RLV	Headache	100	30	Homogeneous	–	–	–	–
14	56	M	LLV	Seizure	100	25	Homogeneous	+	–	Moderate	10
15	32	M	RLV	Headache, vomiting	90	70	Homogeneous	–	+	Mild	17
16	23	F	RLV	Headache	100	60	Homogeneous	–	–	Moderate	12
17	27	F	RLV	Visual symptoms	100	25	Homogeneous	–	–	–	–
18	58	F	RLV	Headache,	100	20	Homogeneous	–	–	–	–
19	42	F	RLV	Headache	90	45	Homogeneous	+	–	–	5
20	24	F	RLV	Headache	100	25	Homogeneous	–	–	–	–
21	60	F	RLV	Headache, visual symptoms	100	55	Homogeneous	+	–	Moderate	15

F, Female; RLV, right lateral ventricle; LLV, left lateral ventricle; M, male.

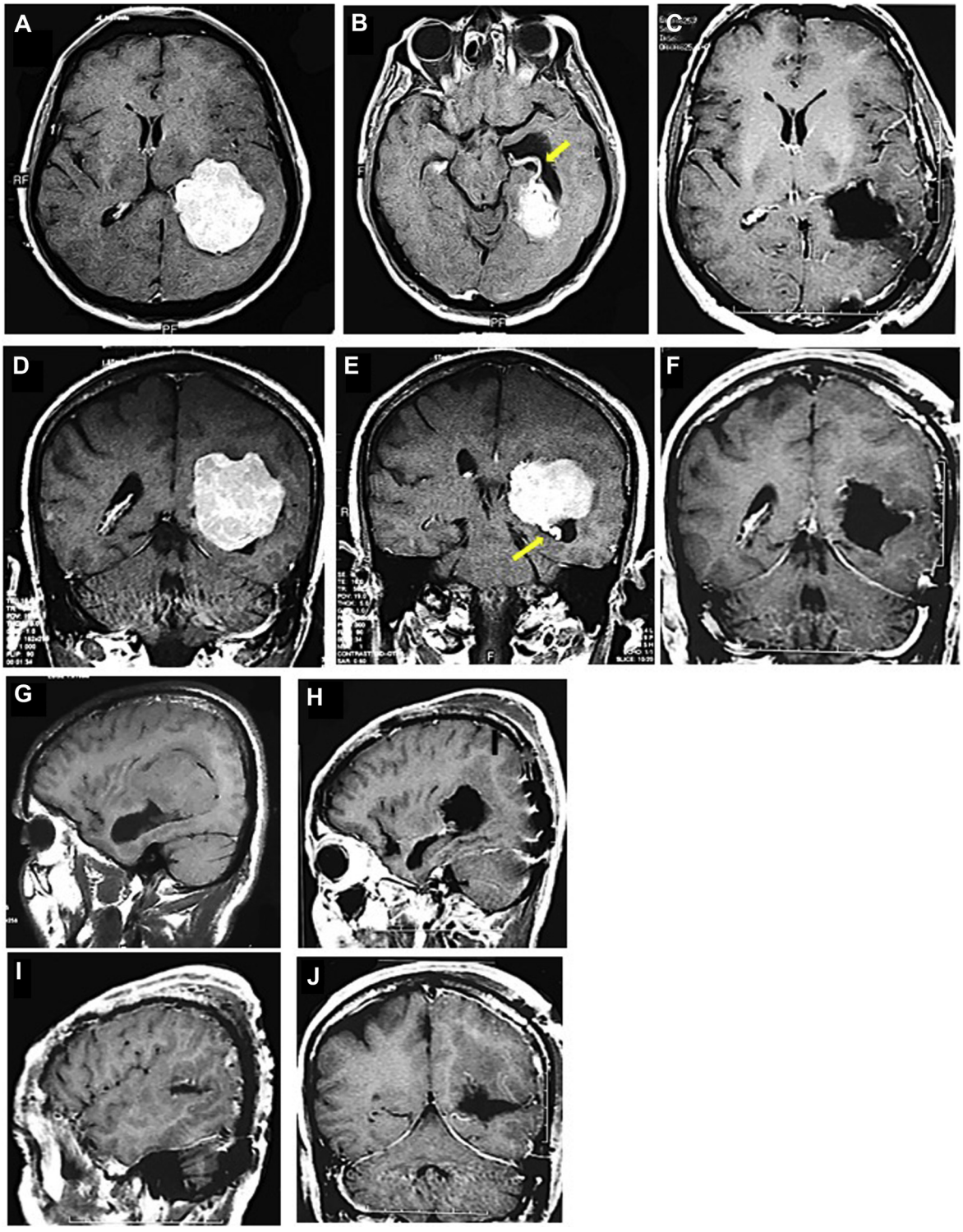

Figure 2. Pre operative and postoperative magnetic resonance imaging (MRI) of a patient with left atrial meningioma. (**A**) Preoperative axial and (**D**) coronal T1-weighted MRI with contrast and (**G**) sagittal T1-weighted MRI without contrast showing the left atrial mass with homogeneous contrast enhancement. (**B**) Axial and (**D**) coronal T1-weighted MRI with contrast showing the choroidal tail of the mass, which is a pathognomonic view for IVMs (*yellow arrow*). (**C**) Postoperative axial, (**F**) coronal, and (**H**) sagittal T1-weighted MRI with contrast showing the total removal of the intraventricular mass via a transtemporal transcortical approach. (**I**) Sagittal and (**J**) coronal T1-weighted MRI with contrast showing the surgical entry point as the posterior part of the middle temporal gyrus and surgical trajectory.

Table 3. Surgical Outcome of the Intraventricular Meningioma Cases

Case Number	Histopathologic Subtype of Meningioma	Histologic Degree	Surgical Approach	Karnosfky Performance Status Before Leaving Hospital	Postoperative Outcome (Early Complications)	Follow-Up Period (months)	Long-Term Follow-Up	Long-Term Karnosfky Performance Status
1	Fibrous	I	TT	100	Subdural CSF collection	3	Subdural CSF collection	100
2	Transitional	II	TT	100	—	6	—	100
3	Fibrous	I	TT	100	Headache	12	—	100
4	Fibrous	I	TT	100	Wernicke aphasia	36	—	100
5	Meningothelial	I	TT	100	—	24	—	100
6	Fibrous	I	TT	90	Subdural CSF collection	48	—	90
7	Fibrous	I	TT	100	—	48	—	100
8	Transitional	I	PIT	100	—	12	—	100
9	Fibrous	I	TT	100	—	36	—	100
10	Fibrous	II	TT	100	—	60	—	100
11	Fibrous	I	PT	70	Hemiparesis, seizure	24	Use antiepileptic medicine (EEG discharge continues)	100
12	Fibrous	II	TT	100	—	48	—	100
13	Transitional	I	TT	100	—	36	—	100
14	Transitional	I	TT	100	—	108	Use antiepleptic medicine (EEG discharge continues)	100
15	Fibrous	II	TT	100	—	60	—	100
16	Transitional	I	TT	100	—	72	—	100
17	Fibrous	I	PIT	100	—	60	—	100
18	Fibrous	I	TT	100	—	48	—	100
19	Transitional	I	PIPT	80	—	48	—	90
20	Fibrous	I	TT	100	—	60	—	100
21	Fibrous	I	TT	100	—	72	—	100

TT, temporal transcortical; CSF, cerebrospinal fluid; PIT, posterior interhemispheric transcallosal; PT, parietal transcortical; EEG, electroencephalography; PIPT, posterior interhemispheric precuneal transcortical.

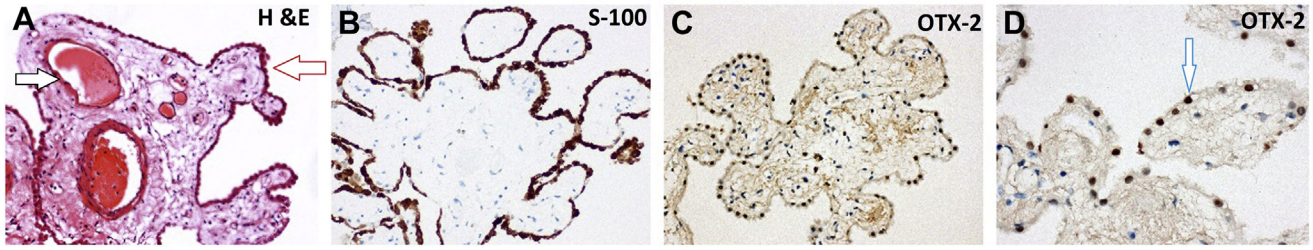

Figure 3. Normal choroid plexus tissue. (**A**) Hematoxylin-eosin (H & E) stain showing the normal histology of the choroid plexus. Black arrow shows the normal blood vessels in the stroma. Note the hypocellular stroma. The normal epithelium is readily seen (*red arrow*). (**B**) S-100 immunomarker stains the normal epithelium by both nuclear and cytoplasmic pattern. (**C**) The choroid plexus epithelium is positive with OTX-2. (**D**) OTX-2 stains the normal choroid plexus by nuclear pattern (*blue arrow*).

Surgical Complications

Surgical complications included hemiparesis in 1 patient (5%) operated on via the parietal transcortical approach (5%), sensorial aphasia in 1 patient operated on via the temporal transcortical approach (5%), and preexisting headache in 1 patient operated on via the temporal transcortical approach (5%). The sensorial aphasia completely resolved within 1 week after surgery. The hemiparesis completely resolved within 1 month after surgery (Table 4). In addition, in 1 patient operated on via the parietal transcortical approach (0.5%), postoperative seizures developed and were controlled with anticonvulsant therapy (levetiracetam 2000 mg per day). In 2 patients (10%), postoperative subdural cerebrospinal fluid (CSF) collection was observed. None required an additional operation. Operative mortality was 0% in our series and no mortality has been observed related to the disease during the follow-up period. None of the patients reported additional visual disturbance in the postoperative period (Table 3).

DISCUSSION

The intraventricular space is an infrequent location for meningiomas compared with other locations, accounting for only 0.5%–5% of all meningiomas.[1,9,20] Also, in our series, an intraventricular location was extremely rare, constituting 1.5% of all adult intracranial meningiomas operated on in the same period in our department. Within the ventricle, approximately 80% of the tumors were located in the lateral ventricle, with most in the trigone of the lateral ventricle.[1,4] In our series, the location of the all IVMs was the trigone. Within the last 32 years, there have been no third or fourth ventricular meningiomas in our series.

A recent extensive review of IVMs by Pereira et al.[1] (681 patients from 98 articles), informed us about the natural history of this disease. In that review, a female dominancy was reported, with a female/male ratio of 1.47:1. In our series, this ratio is higher, at 3.2:1, with a female dominancy consistent with the literature. Intracranial meningiomas have a peak incidence around the sixth decade, whereas IVMs have a peak incidence in the fourth decade.[1,4] In our series, the mean presenting age was 43 years, which is compatible with the literature. Our series showed right-sided predominance (62%), whereas the current literature showed left-sided predominance.[14,21,22]

Preoperative noninvasive differential diagnosis of IVMs compared with other diseases is important because of their benign nature and association with a good prognosis after total removal.[23-25] The common appearance of the IVMs is similar to that of other locations, with intensive contrast enhancement and a sharply demarcated round or lobulated mass.[5,20] The lack of dural attachment is also a distinguishing feature of IVMs.[20] In our series, the findings are consistent with the previous literature of tumors commonly having contrast enhancement (homogeneous in 81% and heterogeneous in 19% of all tumors) (Figure 2A, B,

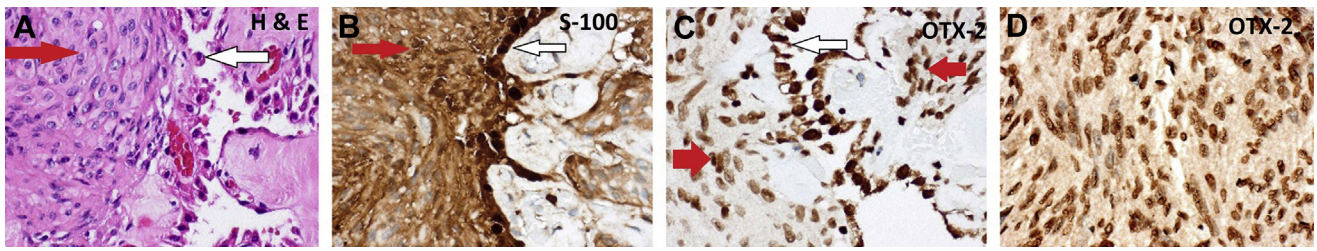

Figure 4. An intraventricular meningioma. (**A**) The meningioma transition from the normal choroid plexus epithelium is shown by hematoxylin-eosin (H & E). (**B**) Both the tumor cells (*red arrow*) and the normal epithelium (*black arrow*) are stained by S-100 antibody. (**C**) Both the tumor cells (*red arrow*) and the normal epithelium are stained by OTX-2 antibody. (**D**) The nuclear staining of the tumor cells by OTX-2 is shown.

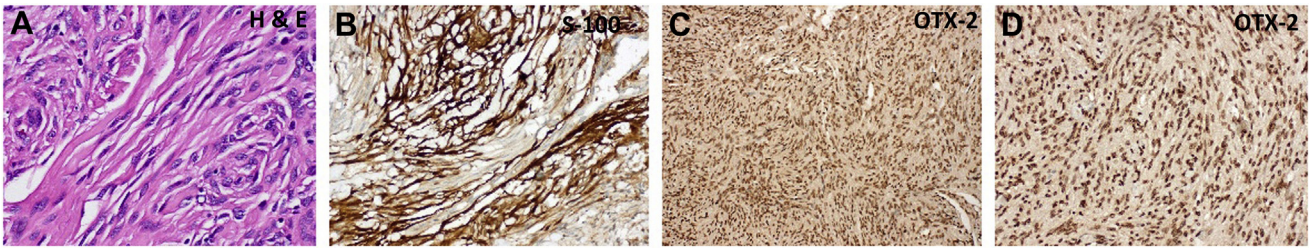

Figure 5. An intraventricular fibrous meningioma. (**A**) The fibrous pattern of the tumor is appreciated on hematoxylin-eosin (H & E). (**B**) The tumor strongly expresses S-100. (**C**, **D**) The tumor cells are OTX-2 positive.

D, E and G). Cystic changes and hematomas can also be seen in IVMs, although we did not observe any in our series.[26,27] We observed that the choroidal tail, which is the attachment of the choroid plexus to the tumor, is a pathognomonic for IVMs. The choroid plexus was visible and had a tortuous shape along the tumor borders in all cases (Figure 2B–E). The mean tumor diameter of the IVMs is larger than the other meningiomas probably because of the wide space of the ventricular region.[1,13,14,20,28] In our series, the mean maximum diameter was 4 cm (range, 2–7.2 cm) and this finding is compatible with the literature.

According to the literature, in approximately 5% of all IVMs, gross total resection could not be achieved.[1] Zhang et al.[29] reported the reason for subtotal resection in 14% of their ventricular tumors as the adhering veins near the thalamus. Also, Yonzhi et al.[6] reported their subtotal resection rate as 4 (3.3%) in 121 IVMs because of the extremely hard texture of the tumor and strong attachment to vessels. In our series, all patients underwent gross total resection without vascular complications (Figure 2C, F and H). One of the main reasons for our high rate of gross total resection is using a temporal transcortical approach, which can immediately and conveniently reach the tumor and also identify the feeding arteries with a wide exposure. The second reason is the use of an ultrasonic aspirator, which can help remove tumors even when they have a hard consistency. Our strategy in the total removal of tumor includes removal of the attachments of the adjacent choroidal plexus. We suggest that total removal in IVM surgery must include removal of the choroid plexus attached to the tumor to avoid recurrence (Figure 7A–C). Also, we used intraoperative USG to control the surgical site and the ventricle after total removal to detect any complications such as hematomas.

The mortality among patients in the literature is 4% (25/625 patients).[1] Eleven (44%) of these deaths occurred in the first 30 days after surgery. The main cause of death in the first month among IVMs was postoperative hematoma. The significant cause of death in the late postoperative period was recurrence of the tumor.[1] In our series, no mortality, no postoperative hematoma, and no recurrence were seen. This situation can be explained because our surgical procedure includes continuing irrigation to remove blood from the surgical area and because we obtain total removal of the tumor with choroidal attachments.

A recent study from Wang et al.[6] reported postoperative meningitis in 19.8% (1.7% CSF bacteria culture positive and 18.1% CSF bacteria culture negative) of their large series of 121 trigone meningiomas. We believe that the higher percentage of postoperative meningitis is related to their use of extraventricular drainage in their series.[6] Also, Kourbeti et al.[30] reported that using an extraventricular drainage system is the major risk factor for postoperative meningitis in their series of 453 postcraniotomy patients. We did not experience any postoperative meningitis. Not using an extraventricular drainage tube is one of the reasons for our meningitis-free series. Prophylactic antibiotic therapy may be the other reason.

Wang et al.[6] reported postoperative entrapped temporal horn in 23 (19%) of their 121 patients and 12 of these 23 patients required operation after ineffective nonsurgical therapies. According to these investigators, young age, a long clinical history,

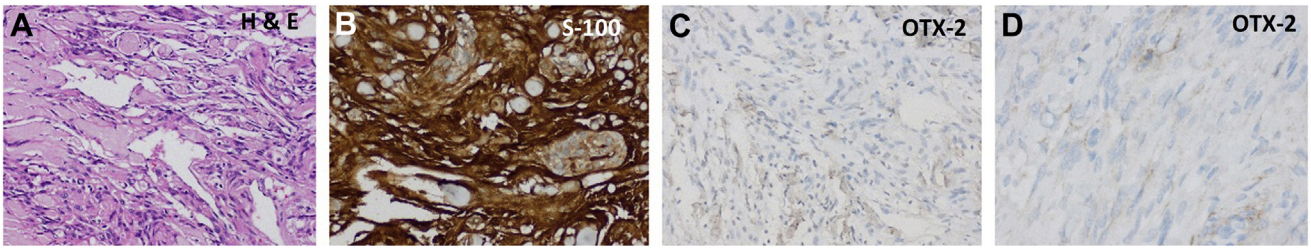

Figure 6. An extraventricular fibrous meningioma. (**A**) The fibrous pattern by spindled cells on hematoxylin-eosin (H & E). (**B**) The tumor is S-100 positive. (**C**, **D**) The tumor does not show any specific nuclear staining by OTX-2 antibody.

Table 4. Preoperative and Postoperative Symptoms

Symptoms	Total (%)	New	Improved (%)
Headache	16	1	15
Vomiting	2	—	2
Seizures	2	1	3
Vertigo	2	—	2
Visual Complaints	2	—	—
Dysesthesia	1	—	1
Hemiparesis	—	1	1
Aphasia	—	1	1
No symptom	2	—	—

development of postoperative meningitis, and long duration of ventricular drainage are associated with development of postoperative entrapped temporal horn.[6] In our series, we did not observe any postoperative temporal horn entrapment. This finding can be explained by the lack of risk factors for this entity described by Wang et al. such as use of extraventricular drainage and postoperative meningitis. Nanda et al.[5] reported requirement of ventriculoperitoneal shunt replacement in 28% of their patients preoperatively and in 21% postoperatively. Grurijicic et al.[4] reported use of lumbar drain during surgery to reduce intracranial pressure while debulking the tumor. These investigators reported no postoperative ventriculoperitoneal shunt requirement, even although 12 of 42 patients showed hydrocephalus at admission.[4] Based on our experience, we did not observe any patient with acute hydrocephalus at the first admission before operation, so we adopted a wait-and-see policy after operation after resection of IVMs. None of the patients required CSF diversion surgery.

Tanaka et al.[31] reported postoperative subdural fluid collection in 39% of patients in their series including ventricular and paraventricular tumors. Of the patients, 11% required surgical treatment because of positive clinical signs and symptoms. We observed subdural CSF collection in 2 patients (10%) and none required surgical treatment, although one patient's symptoms persisted (Table 3). Jung et al.[32] advocated that the use of fibrin glue to close defects can prevent postoperative subdural CSF collection. We used only hemostatic material (Surgicel) to close ventricular ependymal and cortical defects. According to our results, this method can be used to prevent postoperative subdural CSF collection.

Pereira et al.[1] reported a 2.6% recurrence rate in their extensive literature review. The recurrence rate in IVMs is lower compared with other meningiomas. This situation can be explained by higher GTR rates. However, recurrence of IVM may have been underestimated because of a lack of series with long-term follow-up. High recurrence rates of up to 28% have been reported in the literature.[5] There was no recurrence in our series with a mean follow-up of 48 months. We believe that our recurrence-free series may be linked to our surgical strategy, which includes the removal of choroidal attachments of the tumor, in addition to total removal of the tumor.

Selection of Surgical Approach

Surgical treatment of trigone lateral ventricular lesions still poses a challenge in neurosurgical practice because of its intensive relationship with white matter tracts settling deep in the brain. Over the years, several approaches have been described to reach ventricular lesions by preserving the white matter tracts intact.

According to our results, IVMs can be resected totally with lower low morbidity, mortality, and recurrence rates. Tew et al.[33] stated that "the best approach is the shortest distance to the lesion with a perpendicular field of view that requires minimal retraction of the brain and avoids trajectory through important structures."[33] Our strategy is the same as that of Tew et al.[33] by using intraoperative USG, which provides us with an opportunity to find the shortest trajectory to the IVMs. The closest trajectory to the tumor was used to prevent greater cortical damage. Intraoperative USG was used to determine not only the thinnest cortical mantle to the ventricle but also the exact tumor location and the vascular supply of the tumor.

Although most investigators recommend a parietal transcortical approach, our tendency in approaching IVMs has evolved to a temporal transcortical approach because of the possible complications of a parietal transcortical approach (e.g., hemiparesis in 1 patient).[1-5,34-36] With the parietal transcortical approach, it is difficult to find the vascular supply before tumor removal and, therefore, it causes risk of hemiparesis as a result of damage to the primary motor area after retraction. In our series, temporary hemiparesis and new-onset seizure were observed postoperatively in 1 patient (5%) who was operated on via a transparietal approach. In the transtemporal approach, a cortical incision through the posterior part of the middle temporal sulcus was used in 17 patients (81%) with tumor in the atrium of the lateral ventricle with extensions to the temporal horn or lateral ventricular wall (Figure 2A–J). This approach allows earlier visualization of the feeding arteries of the tumor and attachments of the tumor to the choroid plexus compared with a parietal transcortical approach. Although this approach has a short trajectory and quick access, its use has been limited because of the high risk of visual and language disconnection syndromes.[5,22] Kim et al.[2] reported 50% of their patients as having postoperative visual field deficits via the trans–middle temporal gyrus approach. Also, these investigators reported 75% visual field preservation in patients who underwent surgery via a modified trans–middle temporal gyrus approach.[2] A modified trans–middle temporal gyrus approach was introduced by Choi et al.[37] to preserve optic radiation. In this approach, the posterior part of the superior temporal sulcus was used as the entry point. Choi et al.[37] showed visual preservation in 3 of 3 patients with trigonal meningiomas with this modification. Also, the horizontal incision that we used parallel to the optic fibers can prevent visual deficits.[37] Sizdahkani et al.[38] suggested using preoperative diffusion tensor imaging and fiber tracking to assist surgical approach planning. Five of our patients underwent magnetic resonance tractography and functional MRI preoperatively to determine eloquent areas and white mater tracts such as the corticospinal tract and optic radiation. We modified our trajectory as the shortest trajectory to the lesion the furthest away from these white matter tracts. Although the patients did not undergo detailed visual assessment, none had new visual complaints or visual deficits based on our rough visual tests

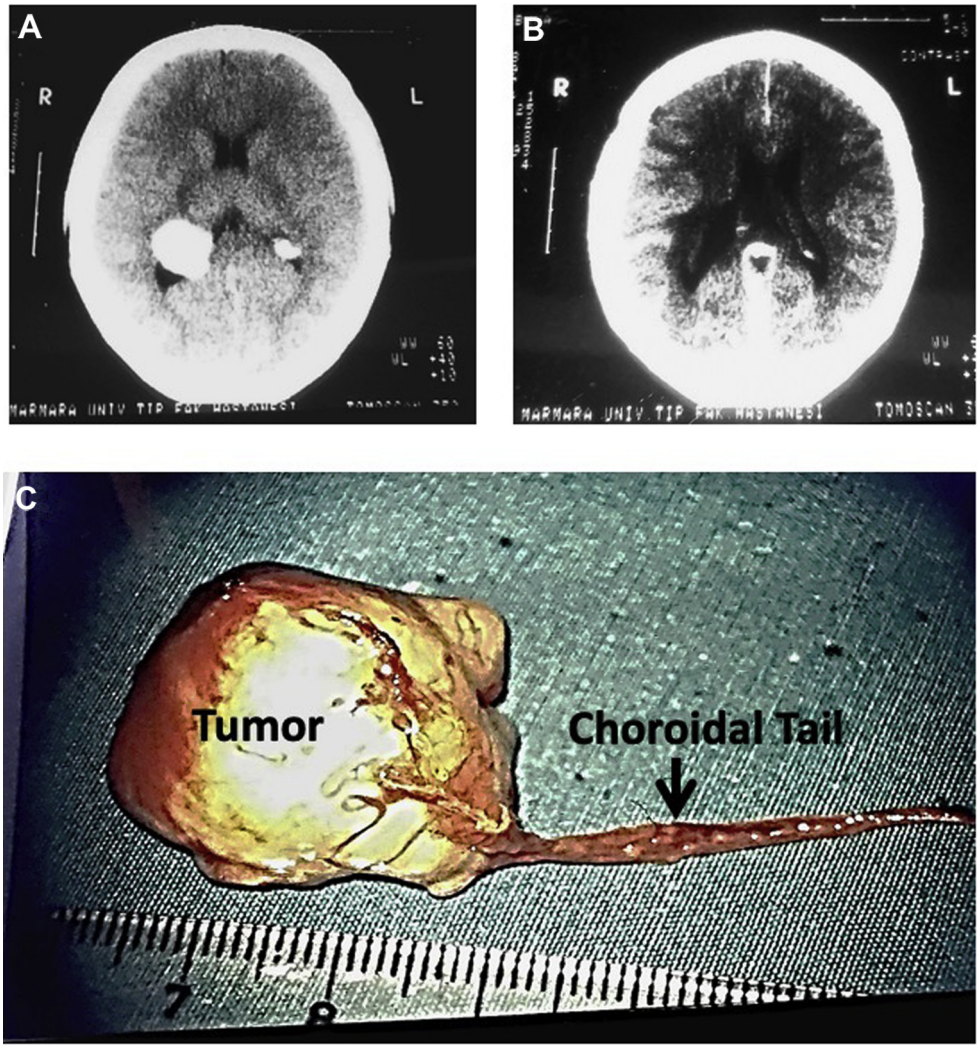

Figure 7. Preoperative and postoperative computed tomography (CT) and gross pathologic specimen of a patient with right atrial meningioma (**A**) Preoperative axial CT with contrast showing right atrial mass with homogeneous contrast enhancement. (**B**) Postoperative CT with contrast showing total en bloc removal of the tumor. (**C**) The tumor is totally removed with its choroidal attachments (choroidal tail). L, left; R, right.

performed postoperatively. This situation can be explained not by visual preservation in all patients but by underestimation of unrecognizable visual field defect in patients with injury of the posterior part of the optic fibers, underlying the posterior part of the superior temporal gyrus and middle and superior occipital gyrus.[17,39]

In our series, temporary sensorial aphasia was observed in only 1 patient, who was operated on via a transtemporal approach. Although this approach is not recommended in the dominant hemisphere because of the language centers, we did not observe any language disorder in our series except for that 1 patient.[5] One of the main advantages of the transtemporal approach is to permit detection and removal of the choroidal attachment in addition to early coagulation of the feeding artery.

The posterior interhemispheric transcallosal approach is used to reach lesions that extend superiorly from the atrium of the lateral ventricle or the splenium of the corpus callosum. This approach allows a direct route to the trigone of the lateral ventricle through the splenium of the corpus callosum and can be used for small tumors in the trigone of the lateral ventricle. We used this approach in 2 (10%) medially located small tumors. Although the risk of postoperative seizure, speech disturbance, and visual field deficits is lower by this approach compared with a transcortical approach, this approach is not convenient for large or laterally

located tumors because of the narrow exposure to the trigone of the lateral ventricle.

The posterior interhemispheric precuneal approach allows access of the medial part of the trigone of the lateral ventricle similar to the posterior interhemispheric approach. This approach has the advantage of gaining more exposure and disadvantages of cortical damage compared with a transcallosal approach.[17] We used this approach in only 1 patient who had a simultaneous occipital falcian meniningioma. This approach was chosen instead of the transcallosal approach because of the large size of the ventricular tumor.

Histopathologic Findings

It has been widely accepted for more than a hundred years that intracranial meningiomas arise from arachnoid cap cells covering the arachnoid villi or arachnoid granulations.[40-42] These arachnoid cells are part of the leptomeningeal layer, which has different embryologic origins in different sites of the neuraxis and a different anatomic localization. The progenitor leptomeningeal cells in the skull base have a mesodermal origin; the progenitor leptomeningeal cells in the telencephalon arise from the neural crest, which partly stands in front of the neuroectodermal layer (the neural tube).[43] Therefore, meningiomas that are accepted to originate from the arachnoid cells are supposed to have different embryonic origins as well. IVMs are accepted in the literature to originate from the arachnoid cap cells in the stroma of the choroid plexus, without any hard evidence.[11] However, this claim has never been questioned. Embryologically, each of the ventricles arises from a different embryonic segment or origin (e.g., the lateral ventricle, which is the only site of tumor origin in our series, arises from the telencephalon).[44] If the IVMs arose from the arachnoid cap cells and the ventricles originated from the telencephalon, then, IVMs would have similar immunophenotypic features to convexity meningiomas, which also arise from the telencephalon, and they would both express neural crest markers because the leptomeningial progenitor cells of the telencephalon are derived from the neural crest. However, none of our cases of IVM showed immunoreactivity with the well-known neural crest marker SOX-10.[45] When we reviewed the histology of 10 samples of normal choroid plexus tissue from our archive, there were no arachnoid cap cells in the stroma of the choroid plexus.

Mortazi et al.[46] comprehensively reviewed the literature regarding the histology of the choroid plexus and did not report any arachnoid cap cells as part of normal choroid plexus histology. Because there are no arachnoid cap cells in the choroid plexus, we questioned a possible cell of origin for IVMs other than arachnoid cap cells. In our series, all of the meningiomas showed strong immunostaining with S-100, a well-known neuroectodermal marker. In addition, all our IVMs also showed immunopositivity with NGFR, a transcription factor indicating neuroectodermal origin (neural tube).[47] These results supported a possible neuroectodermal (neural tube) origin for IVMs. The only neuroectoderm (neural tube)–derived component in the choroid plexus is the specialized choroid plexus epithelium. There are only 2 types of neuroectoderm-derived epithelium in the body: one is retinal pigment epithelium and the other is choroid plexus epithelium.[44,48] Choroid plexus epithelium is not an ordinary epithelium; it consists of modified ependymal cells. Recent studies have shown that among choroid plexus epithelium cells, there are also progenitors that give rise to different cells such as neuronal and glial lineage cells.[49,50] We hypothesized that the choroid plexus epithelium or the progenitors in the choroid plexus epithelium are the possible cell of origin for IVM. So, for the present study, we chose an immunohistochemical marker OTX-2, which is a transcription factor that has a central role in the development of the choroid plexus epithelium.[51] We first showed the positive immunoreactivity with OTX- 2 in 10 samples of normal choroid plexus epithelium. Then, we performed the stain in our case series and all our IVMs showed strong immunoreactivity with OTX-2. Most of our IVMs were either a fibrous type or a transitional type with a fibrous component. Therefore, we performed this stain also to randomly select 10 fibrous meningiomas located extraventricularly but none of the extraventricular meningiomas showed OTX-2 positivity.

IVMs immunohistochemically are negative with the neural crest marker SOX-10, positive with neuroectodermal markers S-100 and NGFR, and also positive with OTX-2, a transcription factor responsible for the development of the choroid plexus. This immunoprofile (SOX-10 negative, S-100 positive, NGFR positive, OTX-2 positive) of IVM is identical to the immunoprofile of normal choroid plexus epithelium. These results indicate that IVMs do not show an arachnoid cap cell phenotype and the findings support the theory that the IVMs originate from the choroid plexus epithelium or the progenitors of the choroid plexus epithelium.

Limitations

This is a retrospective study and includes only an adult population and no detailed visual and cognitive assessment was performed in the preoperative and postoperative period. Our series has not included pediatric patients since establishment of our pediatric neurosurgery department in 1986.

CONCLUSIONS

Surgery is curative and the first choice for treatment of ventricular meningiomas because of their benign nature. The approach must be chosen depending on the tumor location within the ventricle, tumor size, and thickness of cortical tissue to the tumor. Transcortical approaches using intraoperative USG and intraoperative monitoring with avoidance of eloquent cortical areas can achieve good outcomes. The routine use of extraventricular or lumbar drainage systems should be reconsidered in neurosurgical practice to avoid postoperative meningitis and entrapped temporal horn. Closing the ventricular ependymal and cortical defects with hemostatic material can prevent postoperative subdural CSF collection. To achieve long-term recurrence-free status, resection of the choroidal attachments should be attempted, similar to the dural attachments in extraventricular meningiomas. This similarity is probably because IVMs originate from the choroid plexus epithelium, as shown in our study.

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