Surgical treatment of falcotentorial meningiomas: a retrospective review of a single-institution experience

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OBJECTIVE Meningiomas at the falcotentorial junction represent a rare subgroup of complex meningiomas. Debate remains regarding the appropriate treatment strategy for and optimal surgical approach to these tumors, and surgical outcomes have not been well described in the literature. The authors reviewed their single-institution experience in the management, approach selection, and outcomes for patients with falcotentorial meningiomas.

METHODS From the medical records, the authors identified all patients with falcotentorial meningiomas treated with resection at the Barrow Neurological Institute between January 2007 and October 2017. Perioperative clinical, surgical, and radiographic data were retrospectively collected. For patients who underwent the supracerebellar infratentorial approach, the tentorial angle was defined as the angle between the line joining the nasion with the tuberculum sellae and the tentorium in the midsagittal plane.

RESULTS Falcotentorial meningiomas occurred in 0.97% (14/1441) of the patients with meningiomas. Most of the patients (13/14) were female, and the mean patient age was 59.8 ± 11.3 years. Of 17 total surgeries (20 procedures), 11 were single-stage primary surgeries, 3 were two-stage primary surgeries (6 procedures), 2 were reoperations for recurrence, and 1 was a reoperation after surgery had been aborted because of brain edema. Hydrocephalus was present in 5 of 17 cases, 4 of which required additional treatment. Various approaches were used, including the supracerebellar infratentorial (4/17), occipital transtentorial/transfalcal (4/17), anterior interhemispheric transsphenoidal (3/17), parietal transventricular (1/17), torcular (2/17), and staged supracerebellar infratentorial and occipital transtentorial/transfalcal (3/17) approaches. Of the 17 surgeries, 9 resulted in Simpson grade IV resection, and 3, 1, and 4 surgeries resulted in Simpson grades III, II, and I resection, respectively. The tentorial angle in cases with Simpson grade I resection was significantly smaller than in those with an unfavorable resection grade ($43.3^\circ \pm 4.67^\circ$ vs $54.0^\circ \pm 3.67^\circ$, $p = 0.04$). Complications occurred in 10 of 22 approaches (17 surgeries) and included visual field defects (6 cases, 2 permanent and 4 transient), hemiparesis (2 cases), hemidysesthesia (1 case), and cerebellar hematoma (1 case).

CONCLUSIONS Falcotentorial meningiomas are challenging lesions. A steep tentorial angle is an unfavorable preoperative radiographic factor for achieving maximal resection with the supracerebellar infratentorial approach. Collectively, the study findings show that versatility is required to treat patients with falcotentorial meningiomas and that treatment goals and surgical approach must be individualized to obtain optimal surgical results.

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KEYWORDS falcotentorial; meningioma; surgery; oncology

FALCOTENTORIAL meningiomas are rare, composing 0.3%–1.1% of all intracranial meningiomas.^{10,18,20,25} The term “falcotentorial” describes meningiomas located at the anterior of the junction between the falx and tentorium,^{3,7} whereas meningiomas located at the posterior part of the junction (closer to the torcula) are

“peritorcular” meningiomas and require separate consideration.^{3,7} Meningiomas of the velum interpositum are another distinct subtype of meningioma located in this area, originating from the double-layered pia of the velum interpositum.⁴ In many cases, the similar location and growth pattern of falcotentorial and velum interpositum

ABBREVIATIONS EVD = external ventricular drain; mRS = modified Rankin Scale; VFD = visual field defect.

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meningiomas do not allow definitive preoperative differentiation between them.^{16,18} “Pineal region” meningiomas are falcotentorial meningiomas that occupy and compress the pineal region; these pineal meningiomas also include velum interpositum meningiomas, according to some researchers.^{13,19,30}

Resecting meningiomas located at the anterior portion of the falcotentorial junction is challenging because of their deep location and proximity to critical structures, such as the pineal gland, tectum, and veins of the galenic group.¹⁷ The occipital transtentorial/transfalcine and supracerebellar infratentorial approaches are usually chosen, but the rate of complications related to the approach itself remains high.^{2,3,25}

In this study, we retrospectively assessed the treatment strategy, surgical approach selection, and postoperative outcomes for patients with falcotentorial meningiomas treated at a single institution.

Methods

The study was performed with approval from St. Joseph’s Hospital and Medical Center Institutional Review Board for Human Research, Phoenix, Arizona. The STROBE guidelines for observational cohort studies were followed.

We retrospectively reviewed the medical charts of all patients with meningiomas treated between January 2007 and October 2017 at a single institution (Barrow Neurological Institute, Phoenix, Arizona) and selected all patients with falcotentorial meningiomas, including lesions at the anterior portion of the falcotentorial junction with or without invasion into the pineal region. Preoperative MRI studies were reviewed, and the following variables were recorded and analyzed: Bassiouni type,² Asari type,¹ tumor diameter, tumor base attachment, displacement and patency of veins of the galenic group, and presence of hydrocephalus. We also reviewed surgical factors, such as approach selection, position selection, and complications. Simpson resection grades²⁹ were assigned by an independent neurosurgeon (X.Z.) who reviewed all postoperative MRI as well as the intraoperative observations recorded in operation notes. Presenting symptoms, histopathology, any postoperative radiotherapy, recurrence, preoperative modified Rankin Scale (mRS) score,²⁶ mRS score at the 3-month follow-up, and follow-up duration were assessed. Because patients undergoing multiple surgeries were included in the analysis, follow-up duration, radiotherapy, and recurrence were reported per patient, while the rest of the variables were reported per surgery or approach (for complications).

Additionally, for patients who underwent the supracerebellar infratentorial approach, we measured the tentorial angle on preoperative MRI. The tentorial angle was measured between the line joining the nasion with the tuberculum sellae and the tentorium in the midsagittal plane.¹¹

Statistical analysis was performed using PASW Statistics 18.0.0 (SPSS Inc.). We used the independent t-test for all comparisons of numerical variables, and the results are presented as the mean $\pm$ standard deviation (range). A *p* value < 0.05 was set as the threshold of significance.

Results

General Patient Characteristics

Patients with falcotentorial meningiomas composed 0.97% (14/1441) of all patients with meningiomas treated at our institution (January 2007–October 2017). Fourteen patients underwent 17 surgeries to treat falcotentorial meningiomas, including 11 single-stage primary surgeries and 3 two-stage primary surgeries (6 procedures); an additional 3 secondary surgeries were reported (2 reoperations for recurrence and 1 reoperation after surgery was aborted because of brain edema) for a total of 20 procedures. The mortality rate was 7.14% (1 of 14 patients died). Clinical characteristics for all patients are summarized in Tables 1 and 2. Most patients (13/14) were women, and the mean patient age at surgery was 59.8 ± 11.3 years (range 31–77 years). Preoperative imaging for 1 patient (case 11) was lost, and the tumor diameter was the only information acquired from the operation notes.

Presenting Symptoms

Headache was the most common preoperative symptom (8/14; Table 1). Two patients (cases 1 and 7) presented with memory deficits caused by obstructive hydrocephalus. Tumor-related visual field defects (VFDs) were present in 2 patients. Other symptoms included extremity weakness, personality changes, imbalance, dizziness, and seizure. One patient (case 3) was admitted with asymptomatic recurrent growth noted on MRI 17 years after the index surgery, which had been performed at another institute.

Two patients underwent multiple surgeries. The patient in case 5, whose primary surgery had been aborted, was admitted for secondary surgery without new neurological symptoms. In the patient in case 14, 2 years after the first surgery, a second surgery was performed for tumor recurrence with newly developed imbalance. Unfortunately, this patient developed postoperative complications after the second surgery and presented again with continuing tumor growth and symptoms of hydrocephalus 1 year after the second surgery.

Preoperative Imaging

Preoperative MRI studies were available for review for all surgeries except one (16/17; Table 2). In the case missing MRI, available data were extracted from chart records. According to the radiological classification of Bassiouni, 9/16 tumors were type II, 4/16 were type III, 2/16 were type IV, and only 1/16 was type I. According to the Asari classification, 9/16 were the inferior type, 4/16 the superior, 2/16 the anterior, and 1/16 the posterior.

Only 2/16 preoperative MRI studies (cases 3 and 4) showed no vein displacement by the tumors. In the 14 cases with vein displacement, tumor type appeared to be associated with the direction of vein displacement. For meningiomas originating from a unilateral tentorium (Bassiouni type III) or falx (Bassiouni type IV), the veins of the galenic group were usually displaced contralaterally (4/6). For meningiomas that originated from the midline (between the two leaflets of falx [Bassiouni type I] or based on bilateral tentorium [Bassiouni type II]), the veins were displaced superiorly or inferiorly (10/10).

TABLE 1. Clinical characteristics of 14 patients who underwent 17 operations for the removal of falcotentorial meningiomas

Case No.	Op No.	Age (yrs), Sex	Presenting Symptoms	Preop mRS Score	Hydrocephalus Management & Outcome	Simpson Resection Grade	Surgical Complications	Postop mRS Score	WHO Grade	RS	FU (mos)	Recurrence
1	1	69, F	Memory issues	1	Resolved	III	Permanent VFD, balance difficulties	2	I	Yes	39	No
2	1	41, F	HA, blurry vision, lt-sided weakness	1	EVD prior to op, received VPS subsequently	IV	Transient VFD	1	I	Yes	36	No
3	2	63, F	None, recurrence from op 17 yrs earlier	1	NA	IV	None	1	I	No*	2	No
4	1	31, F	HA	1	NA	I	None	0	II	No†	42	No
5	1	65, F	HA	1	NA	IV	Transient VFD	1	I	Yes	36	Op aborted
	2	67, F	HA	1	NA	III	None	1	II	Yes	36	No
6	1	60, F	HA	1	NA	I	None	0	I	No	24	No
7	1	59, F	Memory issues, vision loss	1	ETV prior to op	I	None	1	I	No	24	No
8	1	60, F	HA	1	NA	IV	Permanent rt-sided numbness	1	I	No	32	No
9	1	72, F	Incidental	0	EVD prior to op, resolved afterwards	IV	None	0	I	No	24	No
10	1	60, F	HA	1	NA	I	Transient VFD	1	I	No	12	No
11	1	59, M	Personality difficulties, imbalance	2	NA	IV	Transient lt-sided weakness	1	I	Yes	72	No
12	1	77, F	Dizziness	1	NA	III	Cerebellar hematoma, hydrocephalus (decompression op performed)	5	I	No	24	No
13	1	45, F	Seizure, HA	2	NA	II	Permanent VFD	1	I	No	3	No
14	1	61, F	HA	1	NA	IV	Transient VFD	1	II	No*	36	Yes
	2	63, F	Imbalance	2	NA	IV	Permanent weakness of lower extremities, dysarthria	4	II	No*	36	Yes
	3	64, F	Imbalance, confusion	3	EVD prior to op, patient died before VPS	IV	No	6	II	No*	36	Yes

ETV = endoscopic third ventriculostomy; FU = follow-up; HA = headache; NA = not applicable, no hydrocephalus; RS = radiosurgery; VPS = ventriculoperitoneal shunt.

* Radiosurgery was recommended in cases 3 and 14, but the patient in case 3 was lost to follow-up after moving to another state and the patient in case 14 refused the procedure because of financial issues.

† Not for the falcotentorial meningioma, but for the 2 meningiomas at other locations.

At presentation, the mean maximum tumor diameter was 3.8 ± 1.22 cm (range 2.8–6.1 cm) for the patients with no previous surgery. The recurrent tumors (cases 3 and 5 had single recurrences and case 14 had two recurrences) had maximum diameters of 1.6, 4.6, 5.1, and 4.5 cm, respectively. In case 5, whose first surgery was aborted, the tumor size increased from 4.1 to 4.6 cm within 2 years of observation. On available preoperative MRI, 16/16 galenic venous groups were patent, and all were confirmed to be so postoperatively. Among 5/17 surgeries, the patients had signs of hydrocephalus on preoperative MRI. Four of the patients were primary cases, and 1 patient developed hy-

drocephalus after a second surgery for a WHO grade II meningioma.

Three patients had additional meningiomas remote from the falcotentorial junction: case 4 had a 3-mm parasagittal meningioma and a 3-mm meningioma at the anterior skull base, case 9 had a 9-mm falcine meningioma, and case 10 had a 14-mm falcine meningioma.

Preoperative Management

Five patients presented with radiographic evidence of hydrocephalus; 4 received additional surgery prior to tumor removal, and 1 patient had resolution of the hydro-

TABLE 2. Radiological and surgical characteristics of 14 patients who underwent 17 operations for the removal of falcotentorial meningiomas

Case No.	Op No.	Bassiouni Type	Asari Type	Tumor Base Location	Max Tumor Diameter (cm)	Galenic Group Veins		Approach	EBL (mL)	New Op-Related Complications	Comments
						Displacement	Patency				
1	1	III	Superior	Lt tent	4.0	Contralaterally	Yes	Transventricular	300	Permanent VFD, balance difficulties	
2	1	I	Posterior	Bilat falx	6.1	Inferiorly	Yes	AIH	350	Transient VFD	
3	2	IV	Superior	Lt falx	1.6	No	Yes	OT/F	75	None	
4	1	III	Superior	Lt tent	3.3	No	Yes	Staged paramedian SC & OT/F	200/100	None	
5	1	II	Inferior	Bilat tent	4.1	Superiorly	Yes	Torcular (bilat SC & OT/F)	500	Transient VFD	Op aborted because of occipital lobe edema
2	2	II	Inferior	Bilat tent	4.6	Superiorly	Yes	Torcular (bilat SC & OT/F)	200	None	2nd op
6	1	II	Inferior	Bilat tent	2.8	Superiorly	Yes	Midline SC	600	None	
7	1	II	Anterior	Bilat tent	2.9	Inferiorly	Yes	Midline SC	300	None	
8	1	II	Anterior	Bilat tent	4.2	Rt superiorly	Yes	AIH	100	Permanent rt-sided numbness	
9	1	II	Inferior	Bilat tent	2.8	Superiorly	Yes	Paramedian SC	100	None	
10	1	III	Inferior	Lt tent	2.2	Contralaterally	Yes	Endoscopic OT/F	200	Transient VFD	Another parietal falicine meningioma removed through same craniotomy
11	1	NR	NR	NR	4.9	NR	NR	AIH	400	Transient lt-sided weakness	
12	1	III	Inferior	Lt tent	2.8	Contralaterally	Yes	Midline SC	1600	Cerebellar hematoma, hydrocephalus (decompression op performed)	
13	1	IV	Superior	Lt tent, lt falx	5.2	Contralaterally	Yes	OT/F	450	Permanent VFD	
14	1	II	Inferior	Rt tent	4.8	Superiorly	Yes	Staged lat SC & OT/F	500/500	Transient VFD	Tumor's feeding arteries embolized endovascularly before op
2	2	II	Inferior	Rt tent	5.1	Superiorly	Yes	Staged lat SC & OT/F	NR/500	Permanent weakness of lower extremities, dysarthria	
3	3	II	Inferior	Bilat tent	4.5	Superiorly	Yes	OT/F	500	None	Died 3 mos postop

AIH = anterior interhemispheric; EBL = estimated blood loss; max = maximum; NR = not reported; OT/F = occipital transtentorial/transfalicine; SC = supracerebellar; tent = tentorium.

cephalus postoperatively without additional treatment. Prior to surgery, 1 patient (case 7) underwent endoscopic third ventriculostomy that cured the hydrocephalus. Three patients (cases 2, 9, and 14) received an external ventricular drain (EVD). The EVD was successfully removed postoperatively in the patient in case 9, whereas the other 2 patients (case 2 and case 14 after her third surgery) had symptomatic hydrocephalus that would have mandated shunt placement. One patient (case 2) received a ventriculoperitoneal shunt; however, the other patient (case 14) died before she could receive treatment.

One surgery (1/17) was preceded by angiography with embolization of the tentorial arteries feeding the tumor (case 14).

Surgical Approaches and Resection Grades

Different approaches were used to access the falcotentorial meningiomas (Table 2): the midline or paramedian supracerebellar infratentorial approach (4/17), occipital transtentorial/transfalcine approach (4/17), anterior interhemispheric transsplenic approach (3/17), and parietal transventricular approach (1/17). A torcular craniotomy (combined supratentorial and infratentorial approach) was used twice in 1 patient (case 5); her first surgery had been aborted after partial tumor removal because of increasing brain edema. At that time, she was neurologically stable except for a transient VFD. She underwent surgery 2 years later using the same approach, and a Simpson grade III resection was achieved with an uneventful recovery. Three (18%) of the 17 surgeries were staged with the supracerebellar approach followed by the occipital transtentorial/transfalcine approach. The interval between stages was 1 week in 2 cases (1 planned and 1 not planned prior to the index surgery) and 3 months (planned) in 1 case. Among the 7 cases using the supracerebellar approach (pure or staged), 2 cases were performed with the patient in the sitting position, 2 with the patient in the park bench position, and 3 with the patient prone.

A Simpson grade IV resection was achieved in 9/17 surgeries; Simpson grade III, II, and I resections were achieved in 3/17, 1/17, and 4/17 surgeries, respectively.

Management of Multiple Meningiomas

Among the patients with multiple meningiomas (cases 4, 9, and 10), only 1 patient (case 10) underwent resection of the other meningioma in a single operation (Fig. 1). Surgical removal was not offered to the other 2 patients because of their stability and small tumor size.

Postoperative Complications

Postoperative complications occurred in 10/17 surgeries. Because most of the new postoperative deficits were related to the trajectory of a surgical approach, the complications were stratified based on the individual approach. For this reason, we accounted for staged and combined procedures that involved two approaches separately. Thus, 9 occipital transtentorial/transfalcine approaches, 9 supracerebellar infratentorial approaches, 3 anterior interhemispheric approaches, and 1 parietal transventricular approach were analyzed for complications (22 approaches, 17 surgeries; Table 3).

Four of 9 patients who underwent the occipital transtentorial/transfalcine approach developed VFDs (1 permanent, 3 transient). One patient developed permanent hemiparesis and dysarthria (case 14, after the second stage of the two-stage supracerebellar infratentorial and occipital transtentorial/transfalcine approaches).

One severe complication of cerebellar hematoma with secondary hydrocephalus occurred in case 12 after a midline supracerebellar infratentorial approach (Fig. 2). Surgical decompression was required after the index surgery, and the patient's quality of life was significantly affected (mRS score increased from 1 to 5). All other (8/9) supracerebellar infratentorial approaches had no complications.

One (case 2) of the 3 patients who had undergone the anterior interhemispheric approach developed a transient VFD, 1 (case 8) had permanent numbness, and 1 (case 11) developed transient hemiparesis.

The 1 patient undergoing a parietal transventricular approach developed permanent VFDs and imbalance postoperatively.

In summary, neurological morbidity was transient after 5 (29%) of 17 surgeries and permanent after 5 (29%) of 17 surgeries.

Histology

Pathology reports for 3 patients showed WHO grade II meningiomas, including 1 patient (case 5) in whom a WHO grade I meningioma transformed to grade II after 2 years. Eleven other patients had WHO grade I meningiomas, and no WHO grade III meningioma was reported.

Radiosurgery

Postoperative radiosurgery was recommended to 6 (43%) of the 14 patients. All such patients had Simpson grade III or IV resections, and 2 had WHO grade II meningiomas, including the patient in case 14 who declined radiosurgery because of financial issues. In 1 of the 3 patients with WHO grade II meningiomas, the decision was made not to perform radiosurgery because surgery had achieved a Simpson grade I resection. Three other patients with Simpson grade III or IV resection were not recommended for radiosurgery. One patient (case 12) developed severe complications, and radiosurgery was not considered a meaningful option. In the other 2 patients, the residual tumor volume was minimal, and these patients were followed up with periodic imaging studies. Overall, among the patients who underwent radiosurgery, no recurrence was reported, and the mean mRS score was 1.25 at the last follow-up.

Tentorial Angle

The relationship between resection rate and tentorial angle in each case using the supracerebellar infratentorial approach is outlined in Table 4. We found that patients with a steep tentorium tended to have unfavorable resection rates. Although 1 patient (case 4) with a steep tentorium had a Simpson grade I resection, this grade was possible only because of the staged procedures (Fig. 3). The first-stage supracerebellar infratentorial approach was insufficient, and some residual tumor was intentionally left at the superior posterior aspect of the resection cavity. The

FIG. 1. Case 10. A 60-year-old woman presented with a headache. Preoperative MRI revealed a falcotentorial meningioma based on the left tentorium and an additional smaller falcine meningioma on the left side. A left occipital transtentorial/transfalcal approach was used to exploit the natural corridor between the left occipital lobe and the falx. The second smaller falcine meningioma was resected afterward through the interhemispheric trajectory using the same craniotomy during the same operation. The patient had a transient VFD and demonstrated no recurrence on 12-month follow-up MRI. Preoperative T1-weighted MRI: a sagittal image with contrast enhancement (A) showed two lesions, a smaller falcine and a larger falcotentorial meningioma; an axial image (B) showed that the tumor displaced the tributaries of the vein of Galen (arrow) to the right; and a contrast-enhanced coronal image (C) showed the falcine tumor projecting to the left side. Intraoperative view (D) during the first-stage transtentorial/transfalcal approach shows exposure of the tumor (arrowhead) after the left tentorium was cut (arrow). Postoperative contrast-enhanced T1-weighted MRI: the coronal view (E) showed Simpson grade I resection with removal of the tumor base (cut tentorium, arrow), and patency of the galenic venous system is illustrated on the sagittal (F) image as a flow void (arrow). Figure is available in color online only.

mean tentorial angle in the other cases with a Simpson grade I resection (cases 6 and 7) was significantly smaller than in the cases with a worse resection rate (cases 9 and 12 and the first and second surgeries in case 14; $43.3^\circ \pm 4.67^\circ$ vs $54.0^\circ \pm 3.67^\circ$, respectively, $p = 0.04$).

Follow-Up and Outcomes

The mean patient follow-up was 29 ± 17.7 months (range 2–72 months). Postoperative complications worsened the quality of life with an increase of mRS scores after 4/17 surgeries. After 9/17 surgeries, the mRS score remained unchanged, and after 4/17 surgeries, the mRS score was improved. One death among the 14 patients (case 14) occurred 3 months after a third surgery (36 months after the first surgery). This patient had continuous growth of her tumor despite multiple staged resections, the second of which unfortunately resulted in complications that negatively affected her quality of life to a substantial degree.

Discussion

Falcotentorial meningiomas are technically challenging lesions for which the optimal treatment strategy and

approach selection are individualized. Resection of these tumors is complicated by their deep location and proximity to vulnerable anatomical structures, such as the pineal gland, tectum, veins of the galenic group, and medial posterior choroidal arteries.^{6,34} Meningiomas of a pure falcotentorial location are also rare, with the largest series of 15 cases reported by Qiu et al. in 2014.²³

Two classification systems have been proposed for falcotentorial meningiomas: one by Asari et al.¹ in 1995, which is based on tumor projection and classifies the tumors as anterior, superior, posterior, and inferior types; and the other by Bassiouni et al.² in 2008, which classifies tumors according to tumor base location and includes type I (between the 2 falx leaflets), type II (middle inferior tentorial surface), type III (unilateral tentorium), and type IV (unilateral falx or straight sinus). The Asari and Bassiouni classifications are detailed in Table 5.

Selected Approaches and Complications Observed

Multiple approaches were used in our case series, with the supracerebellar infratentorial approach and occipital transtentorial/transfalcal approach being the two most

TABLE 3. Complications stratified by the surgical approach used

Approach	Complication				
	VFD	Imbalance	Sensory Deficit	Motor Deficit	Hematoma
OT/F (n = 9)*	4/9 (3 transient, 1 permanent)			1/9 (permanent hemiparesis), 1/9 (dysarthria)	
SC infratentorial (n = 9)†					1/9
AIH (n = 3)	1/3 (transient)		1/3 (numbness, per- manent)	1/3 (transient hemiparesis)	
Transventricular (n = 1)	1/1 (permanent)	1/1			

n = number of cases.

* All occipital transtentorial/transfalcine approaches, including pure occipital, staged, or simultaneous combined with the supracerebellar approach.

† All supracerebellar infratentorial approaches, including pure medial, paramedian, staged, and simultaneous combined with the occipital approach.

common, as in previous studies.^{1,2,8,23} These approaches, as compared to a transcortical approach, take advantage of the natural corridors created by gravity-assisted brain retraction.

Occipital Transtentorial/Transfalcine Approach and Its Variant

The occipital transtentorial/transfalcine approach exploits the relative paucity of occipital bridging cortical veins and the natural path created by gravity-assisted re-

FIG. 2. Case 12. A 77-year-old woman presented with episodes of dizziness. Preoperative sagittal (A) and axial (B) MRI demonstrated an inferior-pointing falcotentorial meningioma. The lesion base was located on the inferior surface of the tentorium on both sides. The diameter was measured as 2.5 cm on the sagittal section. A midline supracerebellar infratentorial approach was planned. A prone position was selected instead of a sitting position because of the patient's history of patent foramen ovale. A lumbar drain was placed preoperatively to achieve brain relaxation. The cerebellum appeared edematous after tumor resection; therefore, the bone flap was left off. The patient presented with decreased mental status after the operation, with a Glasgow Coma Scale score of 5, and postoperative imaging demonstrated increasing hydrocephalus and swelling cerebellum. A posterior fossa decompression with resection of the infracted cerebellum was performed. The patient was confined to a wheelchair and had an mRS score of 5 at the 24-month follow-up. Postoperative axial CT (C) of the tumor resection cavity showed scattered sub-arachnoid hemorrhage. Postoperative axial (D) and sagittal (E) MRI demonstrated an edematous cerebellum. Axial CT (F) after posterior fossa decompression showed the large decompressive craniotomy.

TABLE 4. Summary on tentorial angle and Simpson grade for all falcotentorial meningiomas treated via a supracerebellar infratentorial approach

Case No.	Tentorial Angle	Simpson Grade
4	49.0°	I*
6	46.6°	I
7	40.0°	I
9	56.7°	IV
12	53.4°	III
14	56.8°	IV†

Case 5 was not included in this analysis as the patient's craniotomy was not a pure supracerebellar approach in a single operation.

* The patient in case 4 underwent staged surgery. The Simpson grade after the first supracerebellar infratentorial approach was IV, and Simpson grade I resection was achieved after the second occipital transtentorial approach.

† The patient in case 14 underwent multiple staged surgeries; the supracerebellar approach was used prior to the occipital approach for both surgeries, and the tentorial angle was the same in the two surgeries.

traction of the ipsilateral occipital lobe. Incision of the tentorium allows a direct route to the pineal region. The most common complication risk in the occipital transtentorial/transfalcine approach is a VFD, which is usually transient (only one such complication among 9 of these surgeries in our study).³³ The tentorial angle is also important, as a steeper tentorial angle was shown by Li et al.¹⁴ to have a higher risk of occipital lobe damage in this approach. Liu and Cohen¹⁵ used the posterior interhemispheric approach for a patient with a very steep tentorial angle whose occipital lobe was also low set. This approach can be interpreted as a variant of the occipital transtentorial/transfalcine approach when the tentorial alignment is extremely steep, as it provides a similar operative angle.

Goto et al.⁸ asserted that the occipital transtentorial approach resulted in better outcomes in falcotentorial meningiomas with superior extension than those with inferior extension. In our series, however, we were not able to discern a preference for an occipital transtentorial/transfalcine approach for any particular meningioma subtype or growth pattern. Such selection remains biased because of the low number of cases and the personal preference of the surgeon. A pooled multicenter analysis is required to pro-

FIG. 3. Case 4. A 31-year-old woman presented with headache and was found to have a falcotentorial meningioma. The lesion base was located on the left tentorium, and the tumor projected superiorly. A stage 1 supracerebellar infratentorial approach was performed first. The superior posterior portion of the tumor projecting into the occipital lobe was left for a second-stage surgery. A stage 2 ipsilateral occipital transtentorial/transfalcine approach was then used to remove the residual tumor. A Simpson grade I resection was achieved, and no complication was encountered postoperatively. The patient had no recurrence on the 42-month follow-up MRI. Preoperative sagittal (A) and axial (B) T1-weighted MRI with contrast enhancement demonstrated a left-sided falcotentorial meningioma projecting superiorly and laterally, while the tentorial angle (C) was measured as 49.0°. Sagittal MRI (D) after stage 1 surgery showed that superior and posterior portions of the tumor required a more upward approach angle (arrow), so a small residual lesion was intentionally left for a second-stage surgery. Sagittal (E) and coronal (F) contrast-enhanced T1-weighted MRI after the second-stage surgery via the occipital transtentorial/transfalcine approach showed a Simpson grade I resection.

vide a more definitive conclusion. At this stage, however, a tailored individualized approach selection, also incorporating the preference of the surgeon and the facility with a given approach, represents a reasonable option. For example, in case 10, the tumor originated from one side of the tentorium, and the major part of the tumor was infratentorial. In such a case, both a supracerebellar infratentorial approach and an occipital transtentorial/transfalcine approach are feasible. However, the presence of a second tumor and a bridging vein-free zone on the left side favored the occipital transtentorial/transfalcine approach, and both meningiomas were successfully resected through the same craniotomy. We believe that a tumor occupying the infratentorial space can also be accessed effectively through an occipital transtentorial/transfalcine approach by opening the tentorium.

Supracerebellar Approach

The supracerebellar approach uses the natural space between the superior surface of the cerebellum and tentorium; variants include midline, paramedial, lateral, and extreme-lateral approaches.³⁵ The midline supracerebellar approach necessitates the sacrifice of the occipital sinus along with the midline bridging veins, which could have caused venous congestion and resulted in the edema and hemorrhage in case 12.

The patient position was decided on the basis of multiple factors. The sitting position is unfavorable for patients with a congenital heart defect, such as a patent foramen ovale (case 12). An advantage of the sitting position is that it is associated with greater brain relaxation. Endoscopy is a valuable adjunctive visualization tool for deep and close inspection. The approach selection was made in part on the basis of the attending neurosurgeon's preference and in part on the basis of the needed exposure. Usually, larger craniotomies were performed with the patient prone if a more extensive exposure was anticipated.

We believe that not only the location and projection of the tumor but also the tentorial angle should influence approach selection. Despite the limited number of supracerebellar approach cases ($n = 6$; Table 4), we found that patients with Simpson grade I resection had a significantly smaller tentorial angle ($p = 0.04$) than the patients with other Simpson grades.

The patient in case 4 in our series underwent a supracerebellar infratentorial approach, and the superior posterior portion of the tumor, which invaded the occipital lobe, was inaccessible because it required a more upward approach angle. The decision was made to leave some residual tumor and approach the residual lesion through an occipital transtentorial/transfalcine approach in a second stage 1 week later. On the postsurgical film review, we concluded that the difficulties in reaching the distal part could have been predicted, leading to the option of a staged surgery at the beginning.

Several other studies have also suggested that an infratentorial approach to the supratentorial or pineal regions can be challenging in patients with a steep tentorium, and the occipital transtentorial/transfalcine approach should be favored in such cases.^{5,9,31}

TABLE 5. Descriptions of the Asari and Bassiouni classifications

Classification	Description
Asari*	
Superior type	Superior extension above cerebellar tentorium
Inferior type	Inferior extension between great vein of Galen and straight sinus
Anterior type	Anterior extension between inferior sagittal sinus and great vein of Galen
Posterior type	Posterior extension along straight sinus
Bassiouni†	
Type I	Origin: btwn leaflets of the falx above the junction of great vein of Galen with straight sinus Direction of growth: toward pineal region; displaces great vein of Galen and internal cerebral veins inferiorly
Type II	Origin: from underneath tentorium near the junction of vein of Galen with straight sinus Direction of growth: toward pineal region; pushes galenic venous system upward
Type III	Origin: from paramedian tentorial incisura; hence, it is lateralized; great vein of Galen lies medial to tumor
Type IV‡	Origin: from falcotentorial junction along straight sinus Direction of growth: toward pineal region; displaces galenic venous system contralaterally

* Based on tumor extension.

† Based on tumor origin and direction of growth.

‡ Corresponds to the posterior type in the Asari classification.

Anterior Interhemispheric Approach

The anterior interhemispheric approach was used as a single-stage primary surgery in 3 of our patients. Although the distance to the tumor in this approach is relatively long and requires longer instruments, it is thought that the trajectory minimizes the risk of sacrificing bridging veins and retraction on the visual cortex.³² Despite this, transient VFDs occurred in 1 of our patients, and hemiparesis or hemidysesthesia occurred in another 2, most likely caused by over-retraction, impingement of the bridging veins, or retraction injury to the functional cortex in the interhemispheric fissure.

Torcular Approach

The torcular approach was used twice in 1 patient (case 5, whose first operation was aborted after partial resection of tumor because of brain edema and whose second operation was performed 2 years later). This bilateral, combined supratentorial and infratentorial approach has been advocated by several studies^{24,37} for better exposure, although in one series, 100% of cases developed transient VFDs.²⁴

Parietal Transventricular Approach

The parietal transventricular approach was used in 1 patient (case 1) because the lesion grew superiorly and laterally with thinning of the medial wall of the left ventricle. The permanent VFD was predictable because the lateral

FIG. 4. Case 9. Preoperative coronal (A) and sagittal (B) T1-weighted MRI with contrast enhancement showed the galenic venous system was displaced superiorly (arrow). The postoperative coronal image (C) showed subtotal resection. Case 10. Preoperative coronal (D) and axial (E) T1-weighted MRI with contrast enhancement showed the galenic venous system was displaced contralaterally (arrow). A postoperative coronal image (F) showed that gross-total resection was achieved.

wall of the lateral ventricle, which contains the optic radiation, was transgressed. This approach is rarely reported in the literature, likely because of the fear of damage to the optic radiation.

Staging of Surgery

Staged surgery may be a reasonable option for the complete removal of complex falcotentorial meningiomas. In this strategy, each approach is used within the safe limits of the working angles. Rather than extending the existing approach and risking critical structures by over-retraction, the remaining parts of a tumor can be safely removed via a separate approach with a more favorable trajectory. Otani et al.²¹ demonstrated that a staged strategy was successful for the safe removal of large pineal region meningiomas ($n = 4$). In our series, 3 staged surgeries were performed in 2 patients (cases 4 and 14) with WHO grade II meningiomas with aggressive growth and adhesion to adjacent structures. The supracerebellar infratentorial approach was always used before the occipital transtentorial/transfalcine approach. The infratentorial space is naturally larger than the supratentorial space, especially in the presence of space-occupying lesions. With a first-stage supracerebellar infratentorial approach, the relatively large infratentorial space can be used when debulking the tumor, and more space and greater maneuverability are subsequently available for the second stage. The risks of unintentional injury

while removing remote tumor remnants via a single approach may outweigh the risks of a subsequent surgery.

Individualized Approach Selection

Although multiple approaches can be selected for falcotentorial meningiomas, an individualized approach selection for each patient should be preferred. Many factors, such as projection of the tumor, individual anatomy of bridging veins, dislocation of the galenic venous system, tentorial angle, and presence of a second tumor, play a role in approach selection.

In our series, cases 9 and 10 (Fig. 4) were almost identical on preoperative imaging. Both patients had 2 meningiomas at the same location, 1 falcotentorial and 1 falcine (Fig. 4A and 4D). As discussed above, the occipital transtentorial/transfalcine approach was selected for case 10, and both meningiomas were successfully removed through a single craniotomy. Unlike in case 10, whose galenic veins were displaced contralaterally (Bassiouni type III), the veins of case 9 were displaced superiorly (Bassiouni type II), and those veins could be jeopardized as they blocked surgical access through an occipital transtentorial/transfalcine approach. Case 9 also had a very steep tentorial angle, which was an unfavorable factor for a supracerebellar infratentorial approach. However, the supracerebellar infratentorial approach was still selected after balancing the risk of damage to the deep draining veins and the risk

of incomplete resection. In this case, we did not attempt to remove the second meningioma.

Hydrocephalus

Hydrocephalus due to aqueductal compression is another concern for patients with falcotentorial meningiomas. In a previous report, the preoperative treatment of hydrocephalus was not recommended as decompression of the aqueduct in the index surgery was expected to restore patency of the CSF pathways.²³ In our series, 4/5 patients with signs of hydrocephalus received additional treatment. Only 1 patient (case 1) did not receive additional treatment because the ventricle was opened during the transventricular approach. Preoperative management of hydrocephalus can ease brain retraction, facilitate tumor exposure, decrease brain edema, and provide CSF drainage if surgical removal of the tumor does not restore aqueductal CSF flow. Further studies are merited to determine whether a permanent shunt or temporary shunt should be used in cases in which the decompressive operation may relieve the hydrocephalus.

Adjunctive Radiosurgery

Adjunctive radiosurgery for meningioma can play an essential role in preventing tumor regrowth or controlling recurrence.^{12,22,36} In our series, radiosurgery was recommended to patients with high-grade pathology without Simpson grade I resections. Radiosurgery in patients with unfavorable Simpson grades can be withheld if the residual tumor is small and stable on serial postoperative imaging.

Preoperative Embolization

Reduced intraoperative blood loss, decreased operative duration, and decreased firmness of the tumor are all theoretical benefits of preoperative embolization, but definitive evidence regarding the effects of preoperative embolization on patient outcome is still lacking.^{27,28}

The most common arterial feeders of falcotentorial meningiomas are branches of the tentorial, posterior cerebral, or superior cerebellar arteries.^{1,10} Because the anatomy is such that the tumor's dural base can be accessed and coagulated, we used endovascular embolization infrequently in our series.

Limitations of the Study

The retrospective nature and limited number of cases are the main limitations of this study. In the supracerebellar infratentorial approach, a steep tentorial angle is an unfavorable factor. However, multiple factors can affect the Simpson grade and outcome, which can confound the results. Because of the low incidence of falcotentorial meningiomas, multicenter studies or meta-analyses are necessary to obtain results with a higher level of evidence.

Conclusions

Falcotentorial meningiomas presented in 0.97% (14/1441) of meningioma patients in our single-institution series. Our study shows that a steep tentorium angle is an unfavorable factor for a supracerebellar infratentorial ap-

proach, and we conclude that an occipital transtentorial/transfalcine approach should be considered for patients with a steep tentorium or when a falcotentorial meningioma extends superiorly. Staged surgery with multiple approaches appears to be a safe strategy for large, complex falcotentorial meningiomas. Overall, as in other series, surgical treatment was associated with a high rate of permanent complications (29%), mainly visual deficits and venous complications. The approach selection should be individualized for patients with falcotentorial meningiomas to achieve tumor growth control while avoiding approach-related complications.

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Conception and design: Nakaji, Zhao. Acquisition of data: Zhao, Przybylowski, Borba Moreira, Gandhi. Analysis and interpretation of data: Zhao, Belykh, Tayebi Meybodi, Cavallo, Valli. Drafting the article: Zhao. Critically revising the article: Nakaji, Zhao, Belykh, Przybylowski, Wicks. Reviewed submitted version of manuscript: Nakaji. Statistical analysis: Zhao, Cavallo. Administrative/technical/material support: Nakaji. Study supervision: Nakaji.

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