Small Extended Bifrontal Approach for Midline Anterior Skull Base Meningiomas: Our Experience with 54 Consecutive Patients

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■ OBJECTIVE: **To describe the technique of a small extended bifrontal approach and review the clinical outcome of patients with midline anterior skull base (MASB) meningiomas treated using this technique.**

■ METHODS: **The small extended bifrontal craniotomy extends inferiorly to the nasofrontal suture without entering the orbit, superiorly 3 cm above the supraorbital rim, and laterally 3 cm to the midline on both sides. A review of a prospectively acquired database was performed of 54 consecutive patients with MASB meningiomas who underwent this craniotomy.**

■ RESULTS: **Twenty-nine patients with olfactory groove meningiomas, 2 with planum sphenoidale meningiomas (PSMs), and 23 with tuberculum sellae meningiomas (TSMs) were treated using this technique. Gross total resection was achieved in all patients. Of 29 patients with olfactory groove meningiomas, 12 (41.4%) had normal olfaction at presentation and 8 had preservation of olfaction postoperatively. Of 25 patients with TSMs/PSMs, 23 (92.0%) had preoperative visual impairment, with 13 showing improved vision (56.5%), 8 unchanging (34.8%), and 2 deteriorating (8.7%) after surgery. The most common complications were anosmia and hyposmia, which occurred in 5 patients (20.0%) and 3 patients (12.0%) with TSMs/PSMs, respectively. No mortality was reported. There was no recurrence in all patients after a mean follow-up of 39.5 months (range, 16—64 months).**

■ CONCLUSIONS: **The small extended bifrontal approach is a safe and effective technique for resection of MASB meningiomas, which provides adequate surgical exposure with less approach-related morbidity. It is an excellent alternative for surgeons who favor the bifrontal approach and its extended variations.**

INTRODUCTION

Midline anterior skull base (MASB) meningiomas represent 12%—20% of all intracranial meningiomas. They are separated into the more ventral olfactory groove meningiomas (OGMs), and the more dorsal planum sphenoidale meningiomas (PSMs) and tuberculum sellae meningiomas (TSMs), according to the site of attachment. OGMs arise over the cribriform plate and frontosphenoid suture, PSMs arise from the planum sphenoidale, and TSMs arise from the tuberculum sellae, chiasmatic sulcus, limbus sphenoidale, and diaphragm sellae. The large size of many of these tumors at the time of diagnosis, as well as the intimate relationship with the vital neurovascular structures, often make their resection challenging.

Many different approaches, including the unilateral subfrontal, bifrontal, pterional, frontolateral, supraorbital keyhole, and endoscopic endonasal approaches, have been described for resection of MASB meningiomas.[1,2] Among these approaches, the bifrontal approach (Figure 1A) is often recommended for large tumors because it can provide a wide surgical exposure and multiple axes for dissection,[4,5] but postoperative complications

Key words
- Anterior skull base
- Olfactory groove meningioma
- Planum sphenoidale meningioma
- Surgical approach
- Tuberculum sellae meningioma

Abbreviations and Acronyms
ACA: Anterior cerebral artery
CSF: Cerebrospinal fluid
CT: Computed tomography
KPS: Karnofsky Performance Status
MASB: Midline anterior skull base
MRI: Magnetic resonance imaging
OGM: Olfactory groove meningioma
PSM: Planum sphenoidale meningioma
TSM: Tuberculum sellae meningioma
WHO: World Health Organization

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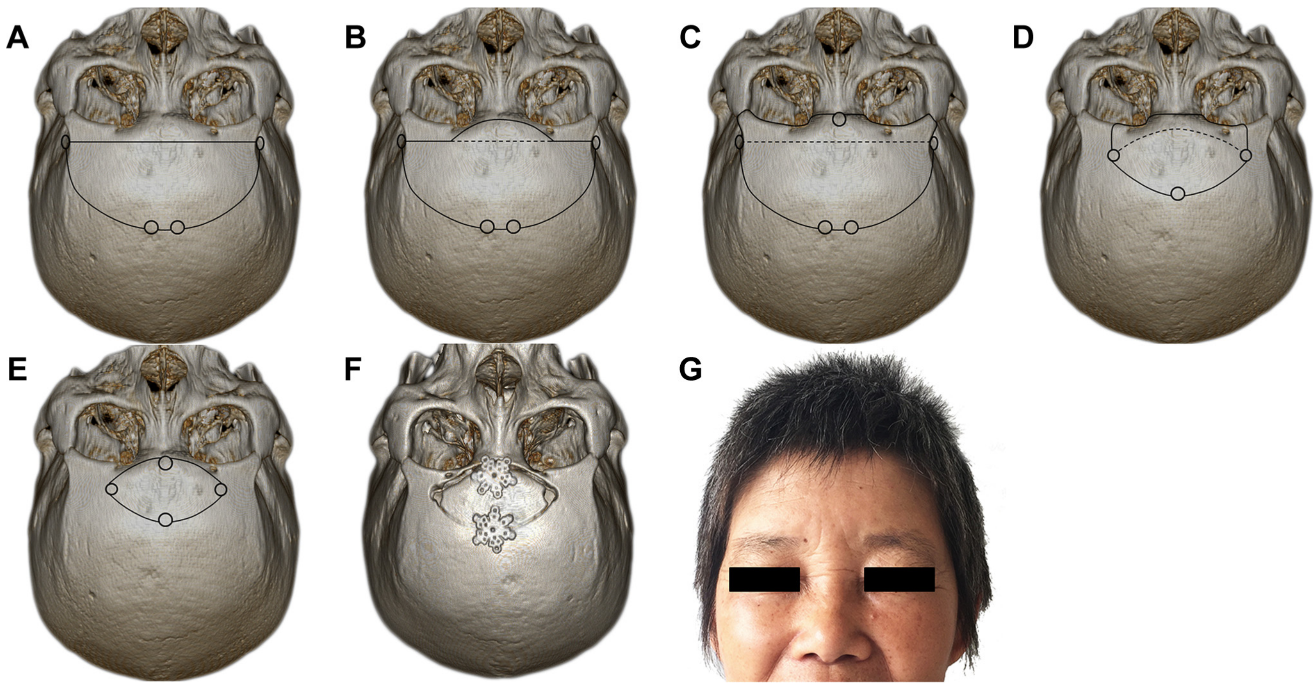

Figure 1. Anterior views of the bifrontal craniotomy and its extended variations. (**A**) Bifrontal craniotomy. (**B**) Bifrontal craniotomy with median fronto-orbital osteotomy without entering the orbit in a 1-piece or 2-piece (*dashed line*) fashion. (**C**) Bifrontal craniotomy with entire fronto-orbital osteotomy in a 1-piece or 2-piece (*dashed line*) fashion. (**D**) Small bifrontal craniotomy with median fronto-orbital osteotomy in a 1-piece or 2-piece (*dashed line*) fashion.[3] (**E**) Small extended bifrontal craniotomy. (**F**) Postoperative computed tomography with three-dimensional reconstruction showing the final result of the small extended bifrontal craniotomy, after securing the bone with titanium burr-hole covers. (**G**) An elderly patient with normal forehead contour 2 years after the operation.

because of excessive retraction persist.[6-9] To reduce the brain retraction, the extended variations of bifrontal approach (Figure 1B–D) have also been applied to these tumors in recent decades.[8-17] However, they are always related to a large and time-consuming craniotomy, potentially increasing surgical morbidity not related to the lesion itself. To minimize the morbidity, we have developed a small extended bifrontal approach, which is simple and fast for approaching extrinsic and intradural lesions of MASB. In this work, we describe in detail the technique of the small extended bifrontal approach and review the clinical outcome of 54 consecutive patients with MASB meningiomas treated using this technique.

METHODS

Patients

We reviewed a prospectively acquired database of 54 consecutive patients with MASB meningiomas who underwent surgery by the senior author (P.Z.) at the Department of Neurosurgery of Huashan Hospital between July 2013 and June 2017. Patients with anterior skull base meningiomas located on one side, as well as recurrent cases, were excluded from this work. All patients included underwent surgery through the small extended bifrontal approach. Informed consent was provided from each patient, and approval from our institutional review board was obtained.

A careful review of the clinical, radiologic, and surgical records was performed. The clinical conditions of patients were expressed by the Karnofsky Performance Status (KPS). All patients underwent olfactory and visual function assessments before and after surgery and during follow-up. Each was tested while blinded with 5 common odors: alcohol, perfume, vinegar, orange juice, and coffee. Subjective olfactory outcome was classified into anosmic, hyposmic, or normal. Visual acuity and visual field were tested and analyzed using the visual impairment score described in the German Ophthalmological Society guidelines.[6,18] Using the visual impairment score, visual outcome was classified as improved (lower score after surgery), unchanged (unchanged after surgery), or deteriorated (higher score after surgery). All patients underwent computed tomography (CT) and magnetic resonance imaging (MRI) scans of the brain, and CT angiography before surgery. The preoperative images were evaluated for tumor location, size, possible calcification, signs of peritumoral brain edema, the lion's mane sign[16] (which is characterized as peritumoral fingerlike hyperintensities extending into the bilateral frontal white matter and into at least three eighths of the total length of the external and/or extreme capsules on T2-weighted MRI), hyperostosis, paranasal sinus extension, and involvement of anterior cerebral arteries (ACAs), internal carotid arteries, optic nerves, optic chiasm, and pituitary stalk.

Radiotherapy was performed 1 month after surgery for non-benign meningiomas (2016 World Health Organization [WHO] classification[19] grades II and III). The extent of tumor resection was based on intraoperative assessment and contrast-enhanced MRI performed 3 months after surgery. All patients were periodically followed up at the outpatient clinic, first at 3 months after surgery, and then at 1-year to 2-year intervals. The follow-up MRI was performed annually for the first 2 years and after that every 2 years. Patients with nonbenign meningiomas had a clinical examination and MRI follow-up once a year.

Surgical Technique

After general anesthesia, a lumbar drain is put to drain cerebrospinal fluid (CSF) and relax the brain if needed. The patient is then positioned supine. The trunk is elevated 15° to facilitate venous drainage. The neck is slightly extended. The head is then placed in a neutral position and fixed in a 3-pin Mayfield head holder.

A limited bicoronal incision is placed 1 cm behind the hairline and extending to 3 cm above the zygomatic arches bilaterally. The scalp flap is elevated, leaving the subgaleal areolar tissue with the pericranium. The subgaleal dissection continues to the nasion in the midline and about 1 cm to the supraorbital rim bilaterally and stops once the superficial fat pads over the temporalis muscles are identified bilaterally. A thick pedicled pericranial flap that covers the designed bone flap is incised and dissected forward and reflected over the scalp flap. The supraorbital rims are exposed and the supraorbital neurovascular bundles are preserved. More traction is needed in the midline to expose the nasofrontal suture. There is no need to expose the frontozygomatic processes bilaterally.

The craniotomy is performed with 2 burr holes placed straddling the superior sagittal sinus, one 3 cm above the supraorbital rim and the other close to the nasofrontal suture and passing through the anterior and posterior walls of the frontal sinus. Two additional small holes are placed about 1 cm superolateral to the supraorbital foramen bilaterally to prevent dural laceration. After blunt dissection of the dura from the inner surface of the skull bone, a high-speed craniotome is used to create a fusiform bone flap (**Figure 1E**). If complete cutting across the frontal sinus is not possible, the outer table is cut separately, and the inner table is then broken as the bone flap is elevated. The crista galli is resected. The frontal sinus is entered in all but 1 patient. The mucosa is removed from the free flap and the lateral recesses of a giant sinus to prevent mucocele formation, and the mucosa within the sinus is resected to the frontonasal orifices. The posterior wall of the sinus and the intersinus septa are removed with a high-speed drill. All walls of the sinus are sterilized using gauze soaked in 10% povidone-iodine. The sinus is then packed with gentamicin-soaked gelfoam and sealed with a layer of bone wax. Dural tack-up sutures are performed.

The dura is opened bilaterally in a curved fashion about 1 cm above the orbit and fixed downward with stitches. The superior saggital sinus is ligated and divided at the cecal foramen; coagulation of draining veins from both frontal poles should be avoided if possible. The falx is cut at its lowest limit.

After completion of hemostasis, the dura is closed in a watertight fashion. The pedicled pericranial flap is laid over the frontal sinus and sutured to the dura in the anterior skull base. The bone flap is replaced and secured with 2 titanium burr-hole covers (**Figure 1F**). For cosmetic reasons, the bone flap is in close contact to the upper margin of the craniotomy, the lower craniotomy defect is passed through by the thick pericranial flap and hides just behind the eyebrows, and the holes on both sides are filled with a mixture of bone dust and bone wax to avoid a visible indentation in the forehead after scar formation. The skin is closed in 2 layers. No suction drain is necessary and the lumbar drain is removed at the end of the surgery.

Techniques Applied to OGMs

When the dura is opened, approximately 30–50 mL of CSF is slowly drained to make the brain relax. If the tumor attaches to the falx, the falx is cut around the area of attachment of the tumor to incorporate a free edge. The relaxed frontal poles are dissected free of the tumor under the microscope and then held with self-retaining retractors. For small- to medium-sized tumors, the olfactory tracts could be identified laterally to the tumor and should be anatomically preserved if possible. The capsule of the tumor is coagulated to shrink the lesion. Initial debulking of the tumor is performed to expose the skull base to interrupt the vascular supply. Extensive internal decompression allows the surrounding neurovascular structures to be identified and separated from the tumor capsule. If the ACAs and their respective branches adhere to the tumor, careful sharp dissection is required to free them from the tumor. The dural attachment is excised. The hyperostotic bone should be removed by a high-speed diamond drill until normal bone is identified, with care taken to avoid entering the ethmoid sinus. A graft of pericranial tissue is anchored on the area of dural defect using fibrin glue.

Techniques Applied to TSMs/PSMs

After durotomy, the first step should be the removal of sufficient CSF by opening the olfactory and basal interhemispheric cisterns. The frontal poles are gently retracted from the anterior fossa using 2 self-retaining retractors, which are adjusted stepwise. The arachnoid membrane and small blood vessels are carefully dissected. After exposure of olfactory bulbs, the olfactory tracts are sharply dissected within the arachnoidal plane all the way to the olfactory trigone. Traction should not be applied to the olfactory tracts during surgery. The olfactory tracts are intermittently moistened with normal saline. The interhemispheric cistern is dissected from the basal side, and the degree of dissection is related to the superior extent of the tumor. The tumor is exposed during this step and care should be taken to preserve the arachnoidal planes whenever possible. Tumor feeders are coagulated and severed on the basal aspect of the tumor in the midline. After sufficient debulking of the tumor, the compromised optic nerves are identified. By tracing the arachnoidal plane, the tumor is meticulously stripped from the flattened or engulfed nerve. Small tumor extensions into the optic canal are teased out. The internal carotid artery, ophthalmic artery, optic chiasm, and ACA complex are dissected free from the tumor. To preserve any remaining vision, the vascular supply to the optic nerves and chiasm should be maintained. Tumor resection is completed to the posterior direction when the pituitary stalk becomes visible and is preserved. The dural attachment is thoroughly coagulated with bipolar cautery. Unroofing of the optic canal and drilling of the tuberculum sellae are not performed.

Table 1. Clinical and Radiologic Features

	Olfactory Groove Meningiomas	Planum Sphenoidale Meningiomas	Tuberculum Sellae Meningiomas	Total
Number of patients	29	2	23	54
Male	11 (37.9)	1 (50.0)	6 (26.1)	18 (33.3)
Female	18 (62.1)	1 (50.0)	17 (73.9)	36 (66.7)
Age (years), mean (range)	54.9 (38–73)	40.0 (37–42)	52.2 (34–65)	53.2 (34–73)
Karnofsky Performance Status, median (range)	80 (40–100)	85 (80–90)	80 (40–100)	80 (40–100)
Anosmia/hyposmia	17 (58.6)	0 (0.0)	0 (0.0)	17 (31.5)
Mental disturbance	15 (51.7)	0 (0.0)	0 (0.0)	15 (27.8)
Visual impairment	6 (20.7)	1 (50.0)	22 (95.7)	29 (53.7)
Headache	10 (34.5)	1 (50.0)	6 (26.1)	17 (31.5)
Seizures	4 (13.8)	0 (0.0)	0 (0.0)	4 (7.4)
Incidental	5 (17.2)	0 (0.0)	3 (13.0)	8 (14.8)
Size (mm), mean (range)	43.1 (23–69)	30.0 (22–38)	30.6 (21–42)	37.3 (21–69)
Calcification	6 (20.7)	1 (50.0)	2 (8.7)	9 (16.7)
Peritumoral brain edema	23 (79.3)	0 (0.0)	1 (4.3)	24 (44.4)
Hyperostosis	13 (44.8)	0 (0.0)	1 (4.3)	14 (25.9)
Paranasal sinus extension	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

Values are number (%) except where indicated otherwise.

RESULTS

Clinical Features

This work included 29 patients with OGMs, 2 with PSMs, and 23 with TSMs. The clinical features are presented in Table 1. The mean age at surgery was 53.2 years (range, 34–73 years) and the female/male ratio was 2:1. The median preoperative KPS was 80 (range, 40–100). The symptoms of patients with OGMs were anosmia/hyponosmia (58.6%), mental disturbance (51.7%), headache (34.5%), visual impairment (20.7%), and seizures (13.8%), whereas those with TSMs/PSMs included visual impairment (92.0%) and headache (28.0%).

Radiologic Features

The radiologic features are presented in Table 1. Seventeen OGMs (58.6%) were larger than 4 cm in diameter and 12 TSMs/PSMs (48.0%) were larger than 3 cm. Calcification occurred in 6 OGMs (20.7%) and 3 TSMs/PSMs (12.0%). Peritumoral brain edema occurred in 23 OGMs (79.3%) and 1 TSM/PSM (4.0%). The lion's mane sign occurred in 11 OGMs (37.9%). Hyperostosis occurred in 13 OGMs (44.8%) and 1 TSM/PSM (4.0%). No paranasal sinus extension was observed.

Surgery

The mean operating time was 305 minutes (range, 210–450 minutes) and the mean estimated blood loss was 308 mL (range, 100–800 mL). Gross total resection (Simpson grade 1 or 2) was achieved in all patients. Bilateral olfactory tracts were anatomically preserved in 20 patients (80.0%) with TSMs/PSMs, and the unilateral olfactory tract was anatomically preserved in 11 patients (37.9%) with OGMs and 4 (16.0%) with TSMs/PSMs. Bilateral olfactory tracts could not be preserved in 18 patients with OGMs (62.1%) and 1 (4.0%) with TSM/PSM (Table 2).

Histology

According to the 2016 WHO classification,[19] 26 OGMs (89.7%) were grade I (26 meningothelial), and 3 OGMs (10.3%) were grade II (3 atypical); 25 TSMs/PSMs (100%) were grade I (21 meningothelial, 2 fibrous, 1 transitional, and 1 secretory). There were no grade III tumors.

Outcome

The mean follow-up at the time of data collection was 39.5 months (range, 16–64 months). No deaths occurred during follow-up and no recurrence has been noted. The median follow-up KPS was 90 (range, 50–100). Cosmetic results were perfect, with normal forehead contour in all patients (Figure 1G). The outcomes of postoperative olfactory and visual function at the last outpatient follow-up are presented in Tables 2 and 3, respectively.

Twelve patients (12/29) with OGMs had normal olfaction at presentation, 8 of whom (8/12) had preservation of olfaction (6/12 normal and 2/12 hyposmic) postoperatively, with tumor sizes <4 cm in 7 patients and >4 cm in 1 patient. These 8 patients had only

Table 2. Subjective Olfactory Outcome in Relation to Intraoperative Findings of the Olfactory Tracts

	Intraoperative Findings of the Olfactory Tracts								
	Olfactory Groove Meningiomas			Planum Sphenoidale Meningiomas			Tuberculum Sellae Meningiomas		
Subjective Olfactory Outcome	Bilateral Preserved	Unilateral Preserved	Bilateral Damaged	Bilateral Preserved	Unilateral Preserved	Bilateral Damaged	Bilateral Preserved	Unilateral Preserved	Bilateral Damaged
Normal	0	6	0	1	1	0	13	2	0
Hyposmic	0	2	0	0	0	0	3	0	0
Anosmic	0	3	18	0	0	0	3	1	1
Total	0	11	18	1	1	0	19	3	1

unilateral attachment of the tumor to the olfactory tract. The remaining patients (21/29) with OGMs lost their sense of smell because of tumor infiltration and tumor removal. All patients with TSMs/PSMs had normal olfaction at presentation, whereas postoperatively, 17 of 25 had normal olfaction, 3 were hyposmic, and 5 anosmic (Table 2).

Six patients (20.7%) with OGMs had preoperative visual impairment, 5 of them showing improved vision and 1 deteriorating after surgery. Twenty-three patients (92.0%) with TSMs/PSMs had preoperative visual impairment, with 13 showing improved vision (56.5%), 8 unchanging (34.8%), and 2 deteriorating (8.7%) after surgery. The remaining patients had no visual problems (Table 3).

Fifteen patients (51.7%) with OGMs had preoperative mental disturbance, with 4 developing a temporary frontal lobe syndrome after surgery, and all showing improvement in their mental status within 1 month. The remaining patients had no mental problems.

The most common complications were anosmia and hyposmia, which occurred in 5 patients (20.0%) and 3 (12.0%) with TSMs/PSMs, respectively. Temporary frontal lobe syndrome occurred in 4 patients with OGMs (13.8%), manifested as a difficulty in inhibiting excitement that disappeared within 2 weeks. Temporary diabetes insipidus occurred in 3 patients with TSMs (13.0%) and was well controlled with desmopressin acetate. Two patients developed postoperative meningitis (3.4%) and were cured by medical treatment. One patient developed postoperative epilepsy (1.7%). There was no CSF leakage or mucocele formation related to frontal sinus opening, and no brain edema or venous infarction related to superior saggital sinus sectioning. There was no instance of perioperative mortality.

Illustrative Cases

Case 16: OGM. A 62-year-old man presented to the emergency department after a major seizure. CT and MRI of the brain showed a 6.9 × 5.6 × 4.3 cm partially calcified OGM with the lion's mane sign (Figure 2A and B). He recalled more than 1 year of loss of smell, blurry vision, and lack of interest in his normal activities. On examination, he had anosmia and bilateral papilledema. Surgery was performed through the small extended bifrontal approach, and Simpson grade 1 resection of the tumor was achieved (Figure 2C–F). The disease was a WHO grade I meningioma. After surgery, he had a temporary frontal lobe syndrome. His mental status and vision improved significantly within 1 month.

Case 31: TSM. A 46-year-old woman presented with a 6-month progressive deterioration of vision, especially in the right eye. Physical examination showed bitemporal hemianopia; visual acuity was 1.0 in her left eye and 0.4 in her right eye. CT and MRI of the brain showed a 3.1 × 3.6 × 2.6 cm TSM (Figure 3A and B). The patient underwent surgery through the small extended bifrontal approach, and Simpson grade 2 resection of the tumor was achieved (Figure 3C–F). Histologic examination showed a WHO grade I meningioma. After surgery, temporary diabetes insipidus developed and was well controlled with desmopressin acetate, and her vision improved.

DISCUSSION

Historical Development

The extensive subfrontal approach (Figure 1C) has been used for a variety of lesions involving the skull base in our department since

Table 3. Visual Outcome of Patients with Preoperative Visual Impairment

Visual Outcome	Olfactory Groove Meningiomas	Planum Sphenoidale Meningiomas	Tuberculum Sellae Meningiomas
Improved	5	1	12
Unchanged	0	0	8
Deteriorated	1	0	2
Total	6	1	22

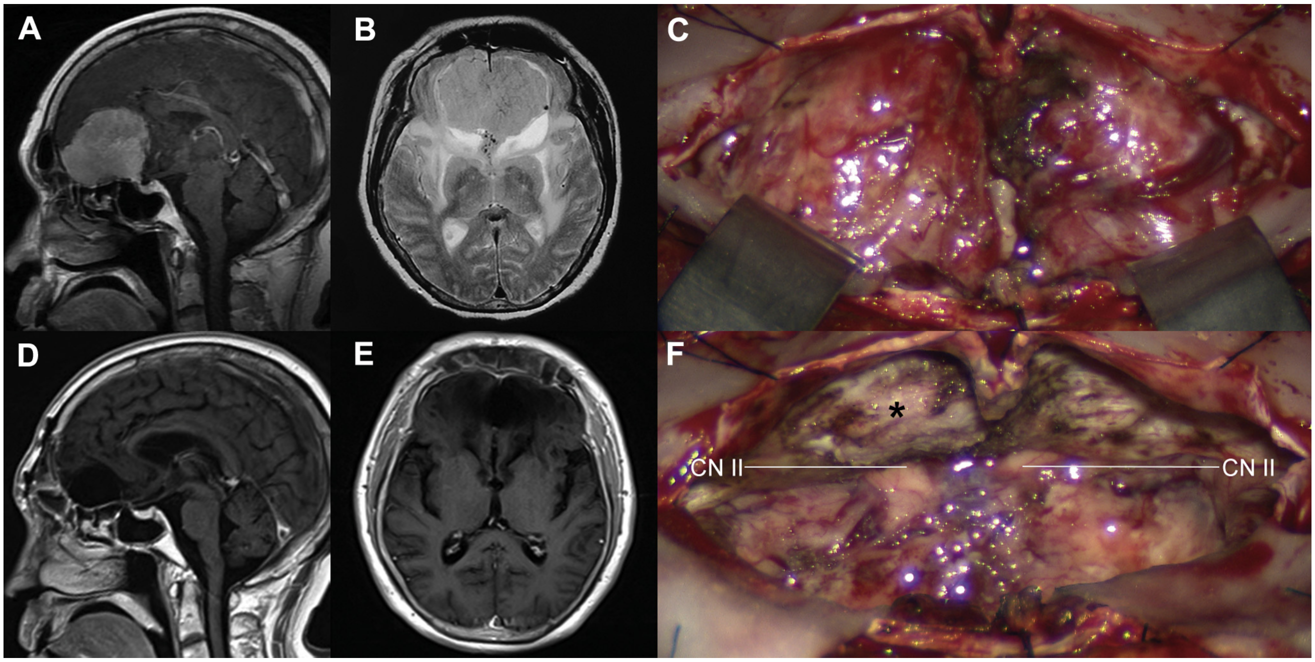

Figure 2. Case 16. Preoperative sagittal postcontrast T1-weighted (**A**) and axial T2-weighted (**B**) magnetic resonance images showing a giant olfactory groove meningioma with the lion's mane sign. (**C**) Intraoperative photographs showing surgical exposure. Postoperative sagittal (**D**) and axial (**E**) postcontrast T1-weighted magnetic resonance images obtained 2 years later showing no recurrent tumor. (**F**) Intraoperative final view after tumor removal. The dural attachment was excised, the hyperostotic bone was drilled (*), and bilateral optic nerves (CN II) were well preserved.

1983.[20] It is an extended modification of the transbasal approach described by Derome in 1972[21] and consists of a level I transbasal approach in the Feiz-Erfan classification scheme.[22] Over the years with experience, we noted that bifrontal craniotomy extended inferiorly to the nasofrontal suture[23] (Figure 1B) was sufficient for extrinsic and intradural lesions of MASB, and the bifrontal craniotomy was too large. This observation subsequently led to the development and use of the small extended bifrontal approach.

Our Modification

First, the small extended bifrontal approach extends inferiorly to the supraorbital rim and the nasofrontal suture, as low as the level of MASB. The inferior margin of the craniotomy is an inverted V shape, following the contour of MASB in the coronal orientation, so there is no impediment from bone overhang to approach MASB.[17] An osteotomy more laterally entering the orbit would therefore be of limited additional benefit. In more recent years, similar modification in a 2-piece fashion was introduced to treat MASB meningiomas. Patel et al.[24] reported a bicoronal frontobasal approach involving a limited midline orbital bar osteotomy for resection of OGMs. Safaee et al.[25] described a 2-piece bifrontal craniotomy and added a tailored supraorbital osteotomy for resection of TSMs. We agree with Patel et al. that a small separate fronto-orbital bone flap may have more chance of resorption or infection when adjuvant radiotherapy is applied to nonbenign meningiomas (WHO grades II and III). Therefore, such a modification is better in a 1-piece fashion.

Second, the small extended bifrontal approach reduces the size of bifrontal craniotomy. The superior extent is limited to 3 cm above the supraorbital rim, and the lateral extents are limited to 3 cm lateral to the midline on both sides. For large tumors, the superior and lateral parts do not need to be exposed at the initial stage of exposure, and they are gradually brought toward the MASB as the debulking progresses. The large bifrontal craniotomy is beneficial to open the sylvian fissure for brain relaxation. This procedure can be replaced by opening the olfactory and basal interhemispheric cisterns for TSMs/PSMs or lumbar drainage for OGMs. In the literature, several more limited craniotomies can be seen in the transfrontal sinus subcranial approach[26,27] and the transglabellar approach.[28,29] These procedures used the technique of frontal sinus osteotomy with an oscillating saw. They are dictated by the anatomy of the frontal sinus and their surgical indications are confined to OGMs and PSMs. The small extended bifrontal approach is not dictated by the sinus, and its surgical indications can be extended to sellar lesions when the basal interhemispheric technique is used.[30]

Advantages

The small extended bifrontal approach retains the inveterate advantages of the extended bifrontal approach for MASB meningiomas: 1) additional basal exposure, which reduces the brain retraction and avoids partial frontal lobectomy to uncap the tumor;

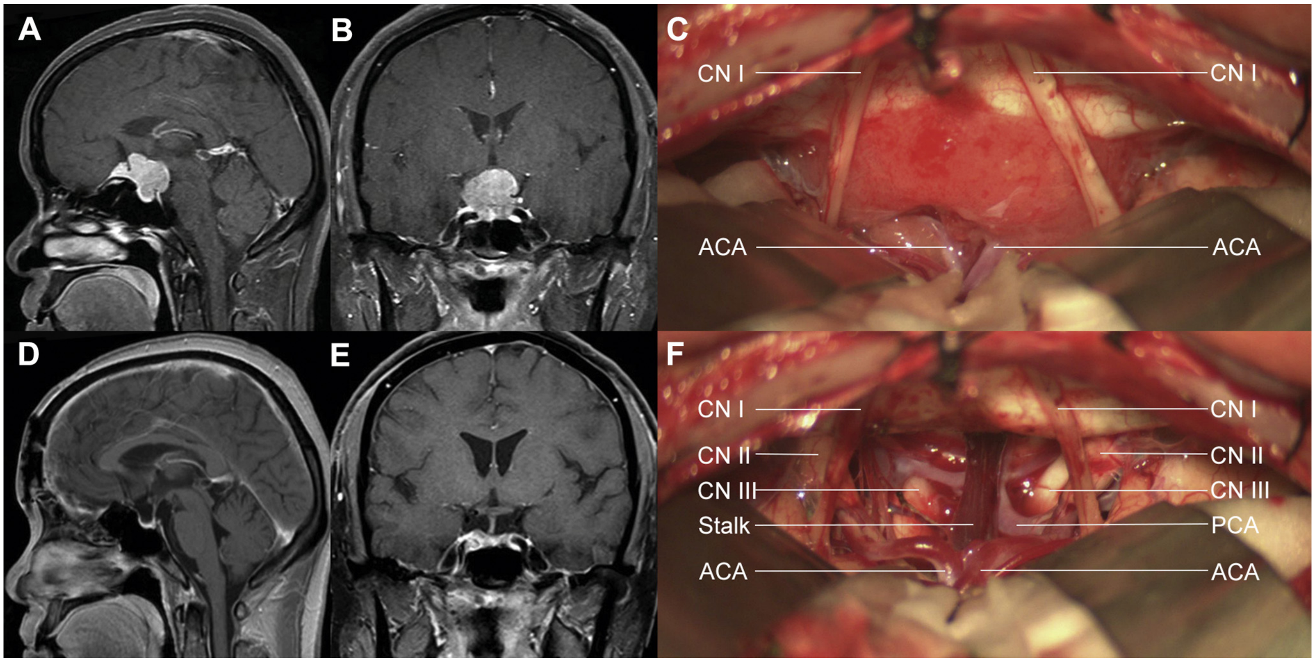

Figure 3. Case 31. Preoperative sagittal (**A**) and coronal (**B**) postcontrast T1-weighted magnetic resonance images showing a tuberculum sellae meningioma. (**C**) Intraoperative photographs showing surgical exposure. Postoperative sagittal (**D**) and coronal (**E**) postcontrast T1-weighted magnetic resonance images showing gross total resection of the tumor at the 3-month follow-up. (**F**) Intraoperative final view after tumor removal. ACA, anterior cerebral artery; CN I, olfactory nerve; CN II, optic nerve; CN III, oculomotor nerve; PCA, posterior cerebral artery; Stalk, pituitary stalk.

2) direct access to the MASB; 3) easier anatomic orientation; 4) early interruption of the vascular supply; 5) multiple axes for dissection; and 6) good visualization of the inferomedial aspects of both optic nerves at their entrance into the canal, the most common site of TSM origin.[1,2,4,5] Furthermore, the small extended bifrontal approach represents the key characteristic for entering MASB. It has a limited bicoronal incision, no manipulation of the temporal fat pads and muscles, and no orbital dissection. It involves a small bifrontal craniotomy with less brain exposure, which further limits the extent of brain retraction and reduces the risk of brain injury.[31] It is simple and fast, with an improved cosmetic result.

Disadvantages

The disadvantages of the small extended bifrontal approach still persist: 1) opening of the frontal sinus; 2) sectioning of the superior sagittal sinus; 3) risk of olfactory nerve damage; and 4) late visualization of the vital neurovascular structures. To reduce the complications, we used the following precautions: 1) the frontal sinus was meticulously demucosalized, cranialized, sterilized, and closed; because bone wax is nonabsorbable, it should be used as little as possible. Instead of packing the frontal sinus directly with bone wax, we emphasized the sterile environment and designed the bone wax as a cover, which can eliminate CSF leakage and reduce complications associated with bone wax; 2) the superior sagittal sinus was divided at the cecal foramen and the cortical bridging veins were maintained to the sinus above the incision; 3) the lumbar drain was not opened for TSMs/PSMs if possible, and a copious amount of CSF was left in the olfactory cistern to facilitate arachnoidal dissection, which helped to maintain the anatomic integrity and vascular supply of the olfactory tracts, whereas the basal interhemispheric cistern was opened to expose the tumor, which reduced the frontal lobe retraction in a posterior direction and prevented the olfactory nerves from being pulled out, and the olfactory tracts were intermittently moistened with normal saline; and 4) the posterior arachnoidal membranes were traced, which created a plane between the tumor and the vital neurovascular structures. In our series, there was no CSF leakage or mucocele formation related to frontal sinus opening and no brain edema or venous infarction related to superior saggital sinus sectioning. Olfactory dysfunction was still a risk and functional damage to the olfactory nerve was explained by attachment between the olfactory tract and the tumor, retraction forces, dryness, or interruption of its vascular supply.[32,33]

Comparison with Other Extended Variations

In recent decades, the extended variations of bifrontal approach have been applied to MASB meningiomas. Compared with the bifrontal approach, they were always associated with a lower risk of life-threatening complications (including retraction-related brain swelling, bleeding, and ischemia) and they allowed a greater percentage of Simpson grade 1 and 2 resection. Our surgical results were similar to those reported in the literature (Table 4).[8,9,11,13-17] In our series, the small extended bifrontal approach provided adequate

Table 4. Microsurgical Series of Midline Anterior Skull Base Meningiomas Treated Through the Extended Variations of Bifrontal Approach

Reference	Diagnosis and Number of Cases	Simpson Grade 1 and 2 (%)	Life-Threatening Complications (%)	Mortality (%)	Recurrence (%)	Mean Follow-Up (Months)
Arai et al., 2000[11]	TSMs, 21	100	0	0	4.8	36
Hentschel and DeMonte, 2003[13]	OGMs, 13	85	0	0	0	24
Spektor et al., 2005[8]	OGMs, 12	100	0	0	0	70.8
Chi et al., 2006[14]	OGMs, 10 TSMs/PSMs, 31	80	0	0	0	NA
Terasaka et al., 2011[15]	TSMs, 9	100	0	0	0	25.2
Li et al., 2014[16]	OGMs, 9	100	11.1	0	0	NA
Pallini et al., 2015[9]	OGMs, 22	100	9.1	0	NA	103.4
Liu et al., 2018[17]	OGMs, 15	80	0	0	NA	14.5
Present series	OGMs, 29 TSMs/PSMs, 25	100	0	0	0	39.5

OGM, olfactory groove meningioma; PSM, planum sphenoidale meningioma; TSM, tuberculum sellae meningioma; NA, not available.

surgical exposure for resection of MASB meningiomas of all sizes, without compromising any intradural procedure, including excising the dural attachment and drilling the hyperostotic bone. The small extended bifrontal approach can also permit unroofing of the optic canal when necessary. The lion's mane sign, representing extreme peritumoral brain edema, was suggested as a predictor of increased severity of postoperative morbidity.[16] All 11 of our patients with this sign had a dramatic recovery, and none required >1 night in an intensive care unit. Because the small extended bifrontal approach had limited brain exposure and retraction, surgical traumatization was reduced and postoperative recovery was accelerated.[31]

Choice of Surgical Approach

The different approaches for MASB meningiomas exist with individual advantages and disadvantages, which have been discussed in many studies.[1,2] The choice is often based on the surgeon's preference and the size of the tumor. The bifrontal approach and its extended variations are often recommended for large tumors.[4,5] For small to medium-sized tumors, the trend is to adopt other approaches, such as the frontolateral, supraorbital keyhole, or endoscopic endonasal approaches.[17,31,34,35] For surgeons who favor the bifrontal approach and its extended variations, the modifications presented in this work are worth considering.

Limitations

Although this work is limited by a single-surgeon series, the short duration of follow-up, selection biases, and no controls, it shows that the small extended bifrontal approach is a safe and effective technique for resection of MASB meningiomas. The limitation of this approach is that surgical freedom of extradural operation is compromised by the relatively small opening. To close the dural defect of MASB by suturing a graft to the dura along the planum sphenoidale is more painstaking. For MASB meningiomas with paranasal sinus extension, the small extended bifrontal approach is better substituted by the extended bifrontal approach or supplemented by the endoscopic endonasal approach.[17]

CONCLUSIONS

The small extended bifrontal approach is a safe and effective technique for resection of MASB meningiomas, which retains the inveterate advantages of the extended bifrontal approach, providing adequate surgical exposure with low morbidity and no mortality. Surgical results with this simple and fast approach are similar to those obtained with large and time-consuming approaches. Based on our experience, we recommend this technique for the removal of large MASB meningiomas without paranasal sinus extension.

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