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Authors

Safae, Michael M
McDermott, Michael W
Benet, Arnau
[et al.](#)

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First Author: Michael M. Safaee
Corr. Author: Michael M. Safaee



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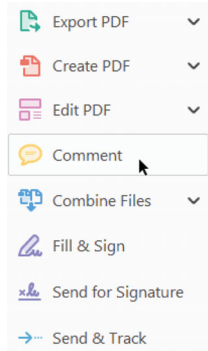
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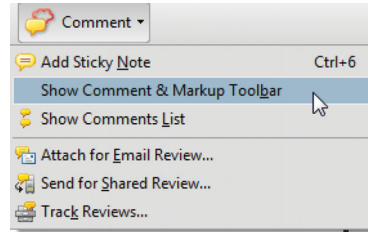


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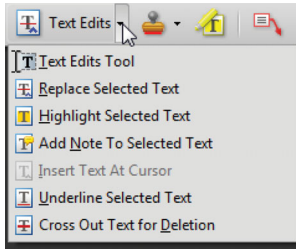


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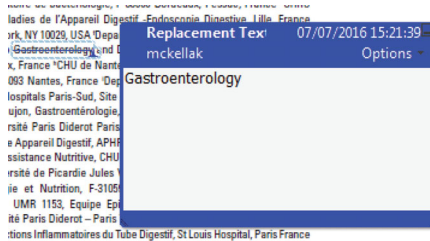
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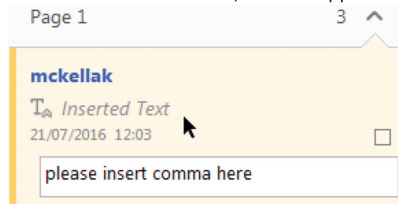


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Tailored Extended Bifrontal Craniotomy for Anterior Skull Base Tumors: Anatomic Description of a Modified Surgical Technique and Case Series

Michael M. Safaei, MD
Michael W. McDermott, MD
Arнау Benet, MD
Philip V. Theodosopoulos, MD

Department of Neurological Surgery, University of California, San Francisco

Correspondence:

Philip V. Theodosopoulos, MD,
 Department of Neurological Surgery,
 University of California,
 505 Parnassus Ave., Rm. M779,
 San Francisco, CA 94143.
 E-mail: philip.theodosopoulos@ucsf.edu

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BACKGROUND: Open transcranial approaches to the anterior skull base remain an integral component of current skull base practice. Evolution of these and other techniques has resulted in revisions of standard, tried-and-true methods in attempts to improve patient outcomes and cosmesis, while still providing the best combination of surgical exposure and ergonomics.

OBJECTIVE: To describe a modified approach for midline tumors of the anterior skull base.
METHODS: We describe the anatomy and techniques of a modified extended bifrontal craniotomy for anterior skull base tumors. Case examples and a postoperative 3-dimensional computed tomographic reconstruction of the craniotomy are provided.

RESULTS: The technique has been employed with success in 3 tuberculum sellae meningiomas where the anterior limit of the tumor is several centimeters back from the inner table of the frontal bone. The mean distance from the tumor to inner table was 2.8 cm (range 1.3-3.8 cm). Mean tumor dimensions were 3.0 cm (transverse), 3.5 cm (anterior-posterior), and 2.2 cm (craniocaudal). Average operative time was 557 min. No cases had new T2/fluid-attenuated inversion recovery magnetic resonance imaging signal of the inferior frontal lobe to indicate retraction injury.

CONCLUSION: The tailored extended bifrontal craniotomy for anterior skull base tumors provides adequate access to the anterior cranial fossa and has replaced our standard extended bifrontal approach. Keeping the osteotomy cut lines outside of the orbit reduces orbital swelling and mechanical disruption of conjugate eye movements in the early postoperative period, while allowing for minimal frontal lobe retraction and providing sufficient surgical exposure along the anterior skull base.

KEY WORDS: Supraorbital craniotomy, Bifrontal craniotomy, Anterior skull base tumor

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Tumors along the posterior aspect of the anterior fossa pose unique challenges due to their proximity to the optic apparatus, olfactory nerves, pituitary gland, and carotid artery and its branches. Tuberculum sellae meningiomas are particularly challenging given their relationship to the optic nerve and propensity to displace them laterally and superiorly.¹

When symptomatic, these lesions require treatment to prevent permanent symptoms especially when there is vision compromise.

ABBREVIATIONS: FLAIR, fluid-attenuated inversion recovery; MRI, magnetic resonance imaging

The ideal surgical approach should provide sufficient exposure of the lesion, its dural attachments, its vascular supply, and the involved osseous skull base, all while minimizing the need for brain retraction or undue manipulation of adjacent neurovascular structures. Contemporary approaches to this region include subfrontal (through bilateral or unilateral craniotomy), pterional, supraorbital, and endoscopic approaches including extended variations such as orbitozygomatic or bilateral orbital osteotomies.²⁻⁹ These adjunct osteotomies help serve one of the critical tenets of skull base surgery, which is to remove bone along the cranial base in order to limit the need for brain retraction and maximize safe surgical resection.¹⁰

For large midline anterior and select middle skull base lesions, the standard extended bifrontal craniotomy involves a supraorbital osteotomy over both orbits. Such an approach requires meticulous dissection of the periorbital, the supraorbital and supratrochlear nerves, and the bony insertion of the trochlea for the superior oblique muscle medially. Although rarely associated with permanent injury, such manipulation often contributes to orbital swelling and transient diplopia related to superior oblique dysfunction. In an effort to minimize the morbidity of this approach, we developed a tailored supraorbital osteotomy that limits the supraorbital bar osteotomy outside the orbital contents, yet provides adequate relevant surgical exposure. Here, we detail the anatomy and techniques related to this tailored approach and discuss important considerations for its use. We have used this technique as a modification of the extended bifrontal approach without compromise in exposure to several lesions along the anterior cranial fossa.

METHODS

Consecutive patients undergoing tailored extended bifrontal craniotomy were included in this study. Informed consent was provided from each patient and approval from the Committee of Human Research, our institutional review board, was obtained.

The Supraorbital Bar

The supraorbital bar of the frontal bone connects to the zygoma laterally and nasal bone inferiorly. The supraorbital notch—sometimes a foramen—is located at the transition between the first- and second-third of the supraorbital bar. The supraorbital notch contains the supraorbital neurovascular bundle as it transitions from the orbit into the forehead. The supraorbital notch serves as the lateral limit of the tailored orbital osteotomy bilaterally. Even when there is a true foramen, mobilization of the nerve is unnecessary, as the cut is made medial to the foramen.

More medially within the rim are the supratrochlear nerve, artery, and vein and then the tendinous insertion for the pulley of the superior oblique muscle. A small spine called the incisura frontalis may be present at the superomedial corner of the orbit at the site of the tendinous insertion. The frontonasal suture at the nasion is the junction of the frontal and nasal bones and serves as the landmark above which the midline osteotomy is made. Laterally, this suture is continuous with the frontomaxillary suture, which lays at the medial wall of the orbit. Dissection of the epidural space along the anterior fossa following the bifrontal craniotomy was the only necessary step to allow for enough exposure to complete the medial cuts in order to free the tailored supraorbital bar from the anterior skull base anterior to the crista galli.

Anatomy of the Anterior Cranial Fossa

The anterior cranial fossa is formed by the frontal, ethmoid, and sphenoid bones. Laterally, the anterior cranial fossa is a thin, flat, and rough surface that corresponds to the roof of the orbit, which is largely formed by the frontal bone and ends posteriorly at the lesser wing of the sphenoid bone (also known as the sphenoid ridge). At the midline, the anterior cranial fossa is largely shaped by the ethmoid and sphenoid bones. The ethmoid bone fuses to the roof of the orbit (frontal bone) laterally to form the medial wall of the orbit (Figure 1).

Anatomy of Osteomies for Tailored Supraorbital Approach

A coronal incision with subperiosteal dissection is used to elevate the anterior pedicle-based pericranial flap used for reconstruction. Laterally over the temporalis muscle, subgaleal dissection is used and an interfascial dissection may be added for additional release of the tension of the musculocutaneous flap. Subperiosteal dissection of the pericranium is continued down to, but not over, the supraorbital margin. The frontal bone above the nasofrontal suture can be exposed. To begin the bony exposure of the anterior cranial base, a 1-part, or our preferred 2-part, frontal craniotomy is performed to expose the frontal dura bilaterally and the superior sagittal sinus. A short segment of temporalis muscle is disinserted from the superior temporal line just below its junction with the frontozygomatic process on both sides. Beginning on the right side, a burr hole is made behind McCarty's key point to expose the dura over the frontal lobe. A second burr hole is made 1.5 cm lateral to the midline along the posterior edge of the preferred craniotomy. After the right side bone is removed, the midline and left frontal convexity dura can be dissected under direct vision reducing the chance of superior sagittal sinus injury.

Once both sides of the frontal bone are removed, the supraorbital notches are identified as the lateral limit of the supraorbital osteotomy. The epidural space is dissected over the roofs of the orbits back to the anterior limit of the crista galli. An oscillating saw or spiral cutting blade is used to make the cuts through the frontal bone medial to the supraorbital notch on both sides, staying medial to and outside the orbits towards the midline, and then virtually horizontally from anterior to posterior, above the nasofrontal suture along the midline. Working from the inner table side, cuts are made along the floor anterior to the crista galli from left and right in order to completely release the orbital osteotomy (Figure 2).

RESULTS

Patient demographics are summarized in Table. The mean distance to the anterior margin of the tumor from the inner table was 2.8 cm (range 1.3–3.8 cm). Mean tumor dimensions were 3.0 cm (transverse), 3.5 cm (anterior-posterior), and 2.2 cm (cranio-caudal). Average operative time was 557 min (range 467–619 min). No cases had new T2 signal of the inferior frontal lobe compared to preoperative magnetic resonance imaging (MRI) to indicate retraction injury. The tailored supraorbital osteotomy was successfully completed in 3 cases reported herein. The extradural exposure provided was deemed qualitatively adequate intraoperatively in all cases when compared to the traditional supraorbital bar osteotomy (Figure 3). With respect to olfaction, 2 patients had decreased or absent olfaction preoperatively and remained stable. One patient developed a new olfactory deficit.

Summary of Cases

Patient 1 was a 48-yr-old male who presented with 6 mo of progressive vision loss involving the left eye and was found to have a $3.3 \times 1.9 \times 3.8$ cm tuberculum sellae meningioma interdigitating the distal branches of the anterior cerebral artery with extension down both optic canals (Figure 4). Intraoperative findings were notable for a fibroblastic meningioma with extension down bilateral optic canals, worse on the left. Near total

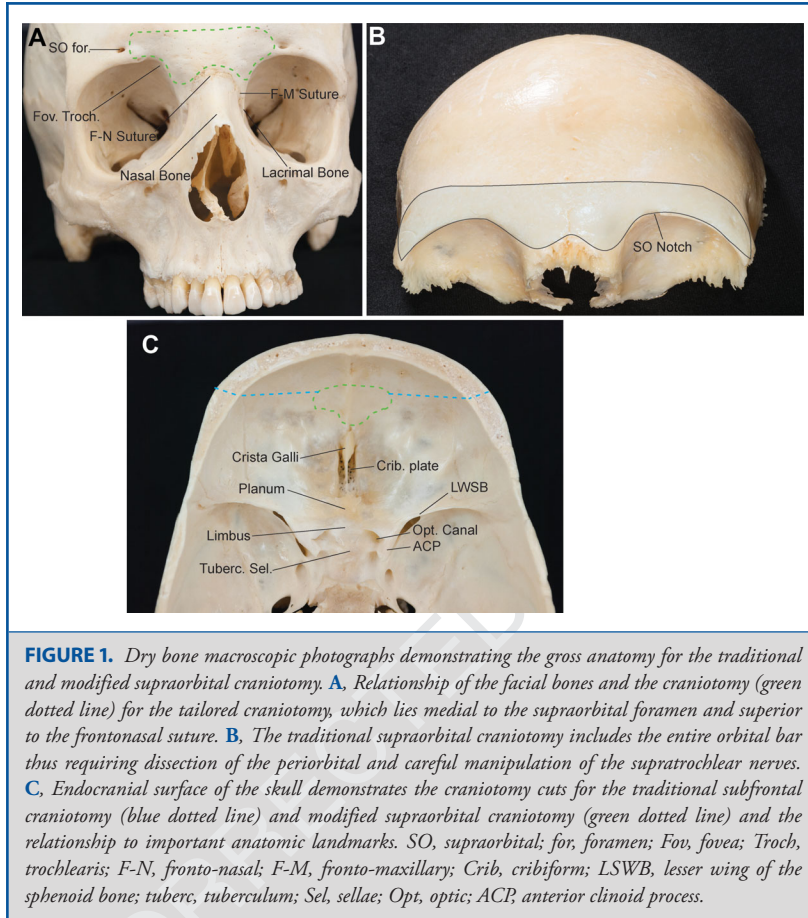


FIGURE 1. Dry bone macroscopic photographs demonstrating the gross anatomy for the traditional and modified supraorbital craniotomy. **A**, Relationship of the facial bones and the craniotomy (green dotted line) for the tailored craniotomy, which lies medial to the supraorbital foramen and superior to the frontonasal suture. **B**, The traditional supraorbital craniotomy includes the entire orbital bar thus requiring dissection of the periorbital and careful manipulation of the supratrochlear nerves. **C**, Endocranial surface of the skull demonstrates the craniotomy cuts for the traditional subfrontal craniotomy (blue dotted line) and modified supraorbital craniotomy (green dotted line) and the relationship to important anatomic landmarks. SO, supraorbital; for, foramen; Fov, fovea; Troch, trochlearis; F-N, fronto-nasal; F-M, fronto-maxillary; Crib, cribiform; LWSB, lesser wing of the sphenoid bone; tuberc, tuberculum; Sel, sellae; Opt, optic; ACP, anterior clinoid process.

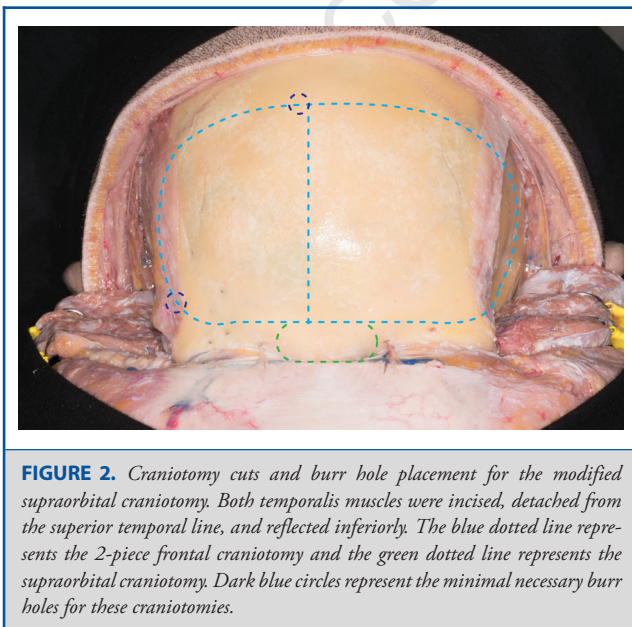


FIGURE 2. Craniotomy cuts and burr hole placement for the modified supraorbital craniotomy. Both temporalis muscles were incised, detached from the superior temporal line, and reflected inferiorly. The blue dotted line represents the 2-piece frontal craniotomy and the green dotted line represents the supraorbital craniotomy. Dark blue circles represent the minimal necessary burr holes for these craniotomies.

resection was achieved with residual tumor in the left optic canal. Postoperatively, he was noted to have decreased olfaction but was otherwise at his neurological baseline. At last follow-up, 4 mo after surgery, he reported improved visual acuity compared to his preoperative baseline and his residual tumor will be followed by serial imaging. Postoperative CT showed a good cosmetic result (Figure 5).

Patient 2 was a 39-yr-old female with several years of headaches and imaging demonstrating a 3.4 × 2.7 × 3.9 cm tuberculum sellae meningioma (Figure 6). She had no visual symptoms but absent olfaction and was taken to the operating room for resection of this lesion. Intraoperative findings were notable for a very fibrous and calcified lesion with no good plane along the capsule. The optic chiasm and the right A2 branch of the anterior cerebral artery was dissected off the back of the tumor as was the right recurrent artery of Heubner, which was embedded within tumor. A small amount of tumor was left along the diaphragma given the acute limbus sphenoidale angle. She had an uneventful recovery and was discharged at her neurological baseline. Pathology was consistent with grade I meningioma and MRI at 4-mo follow-up showed a small focus of residual tumor adjacent to the now fully descended optic chiasm with no change in her neurological exam.

TABLE. Xxxx

Age/Gender	Presenting symptoms	Tumor size	Distance to inner table
48 M	Vision loss in left eye	3.3 × 1.9 × 3.8 cm	3.2 cm
39 F	Headaches	3.4 × 2.7 × 3.9 cm	1.3 cm
59 F	Temporal hemianopsia	2.2 × 1.9 × 2.7 cm	3.8 cm

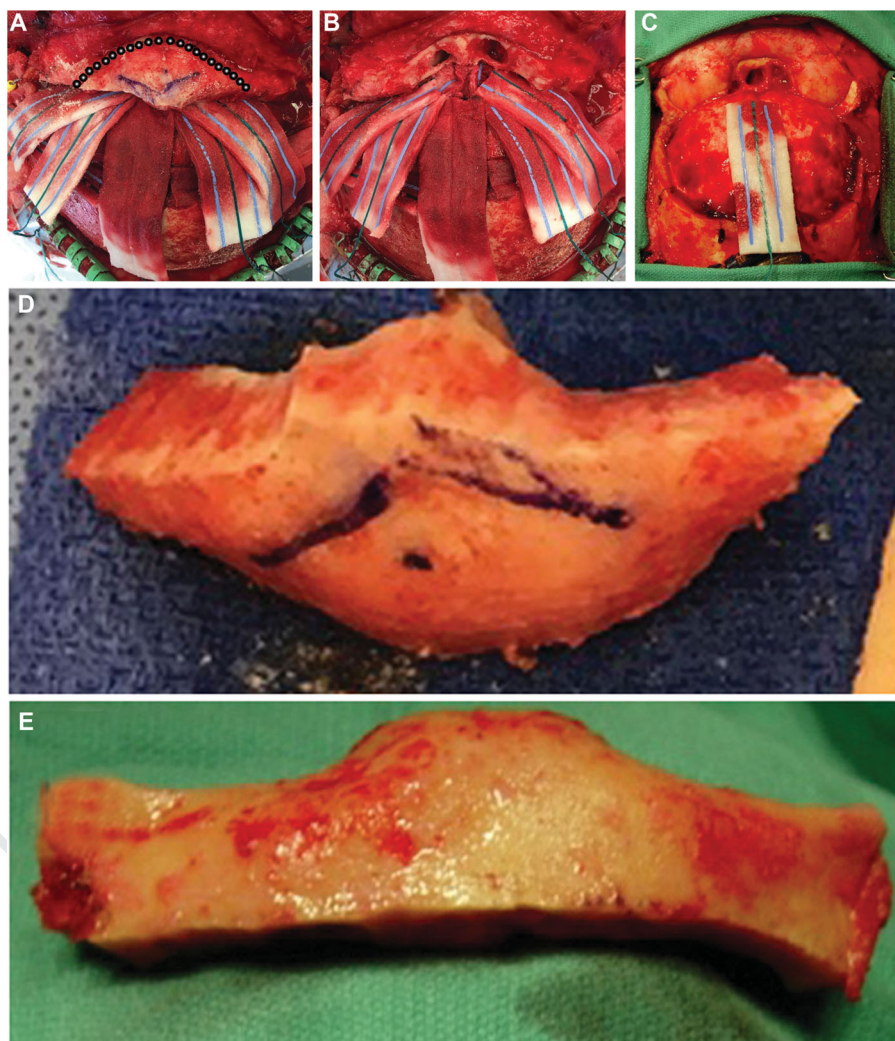


FIGURE 3. Demonstration of the tailored supraorbital osteotomy. **A**, The osteotomy cuts are placed medial to the supraorbital notches on both sides and stay outside the orbits (dotted line) bilaterally. **B** and **C**, The final exposure **B** provides similar access to the previously described approach **C**. **D** and **E**, The osteotomy **D** is seen in comparison to the traditional approach **E** which includes the orbital roof.

Patient 3 was a 59-yr-old woman who presented with headaches and mild temporal hemianopsia of the right eye. MRI revealed a 2.2 × 1.9 × 2.7 cm tuberculum sellae meningioma (Figure 7). Intraoperatively, the tumor appeared to have a good

plane with both internal carotid arteries and both optic nerves. Along the posterior base of the tumor on the diaphragma sellae, large perforating branches from both internal carotid arteries were seen encased within the tumor and coursing back towards the

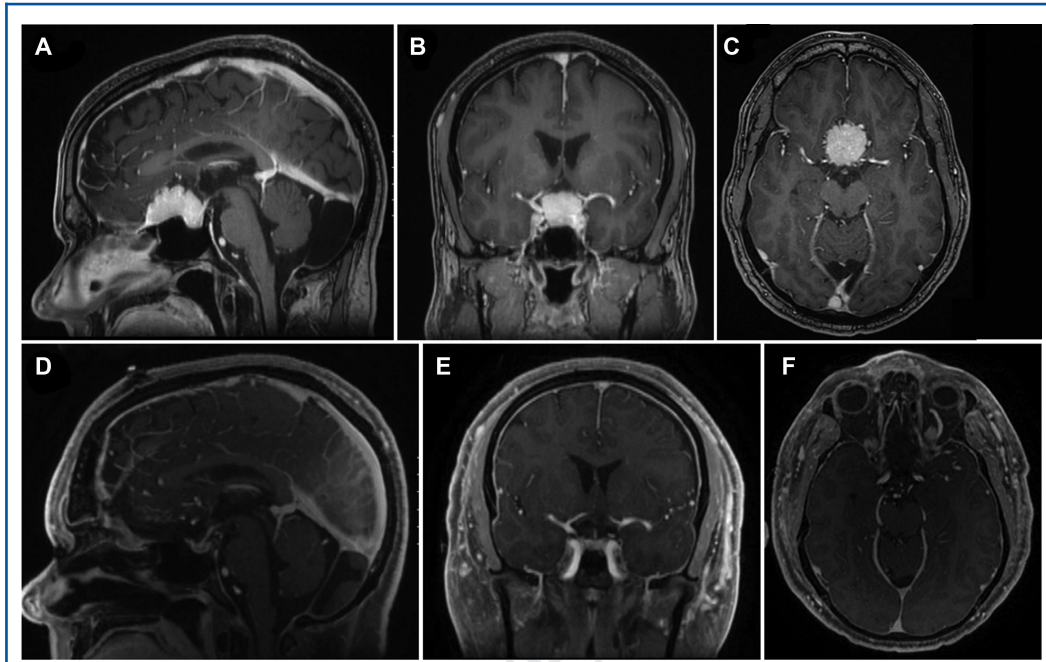


FIGURE 4. Patient 1 pre- and postoperative imaging. Preoperative MRI shows a $3.3 \times 1.9 \times 3.8$ cm tuberculum meningioma interdigitating the distal branches of the anterior cerebral artery with extension down both optic canals in the sagittal **A**, coronal **B**, and axial **C** planes. Postoperative MRI shows near total resection with trace residual tumor in the left optic canal in the sagittal **D**, coronal **E**, and axial **F** planes.

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FIGURE 5. Three-dimensional representation of tailored supraorbital osteotomy. Postoperative CT with 3-dimensional reconstruction demonstrating the tailored supraorbital osteotomy that avoids disruption of the periorbital and provides good cosmetic results.

chiasm. Those perforators could not be safely dissected away and a small piece of capsule was left in place to avoid vascular injury to the optic chiasm. She tolerated the procedure without complication and her neurological exam and olfactory function remained stable at last follow-up, with MRI at 7 mo showing a stable small residual tumor posterior to the tuberculum.

DISCUSSION

We present a modified surgical approach for tumors of the anterior skull base that allows for adequate exposure of midline lesions without the need for osteotomies into the orbit. All 3 patients presented in this manuscript had good outcomes with adequate exposure of tumor for achieving maximal safe resection. Our experience suggests that a tailored supraorbital osteotomy is adequate and sufficient for the resection of even large midline anterior skull base lesions.

An often-cited limitation of bifrontal approaches is the need for frontal lobe retraction to obtain an adequate trajectory of view, particularly superiorly and posteriorly, a limitation that can result in frontal lobe injury.¹¹⁻¹³ Some cite this as an advantage of endonasal approaches since they do not require brain retraction and therefore put the frontal lobe and olfactory nerves at less risk of injury.¹³ Chi et al¹⁰ assessed the extent of fluid-attenuated inversion recovery (FLAIR) and T2 signal within the inferior

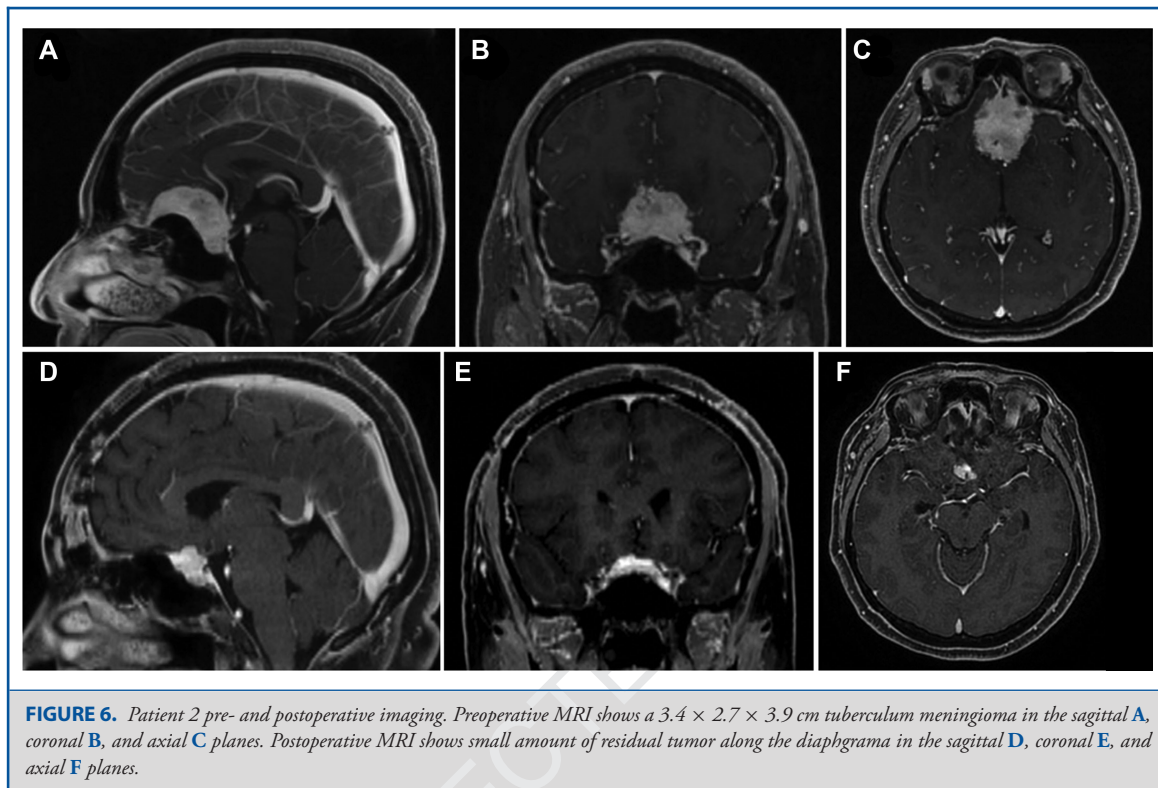


FIGURE 6. Patient 2 pre- and postoperative imaging. Preoperative MRI shows a $3.4 \times 2.7 \times 3.9$ cm tuberculoma meningioma in the sagittal **A**, coronal **B**, and axial **C** planes. Postoperative MRI shows small amount of residual tumor along the diaphragma in the sagittal **D**, coronal **E**, and axial **F** planes.

frontal lobes after resection of 45 anterior skull base tumors using the traditional extended bifrontal craniotomy. Over half were greater than 4 cm and Simpson grade 2 or 3 resections were achieved in 82% of patients. Retraction-related edema was grouped into 4 categories for analysis: A—no edema; B—edema restricted to gyrus rectus; C—edema beyond gyrus rectus, and; D—extensive bifrontal edema. The extent of edema was unchanged in 87.5% and 91% had postoperative scans classified as category A or B. The authors concluded that this approach was safe with limited retraction-associated injury. In our series of patients, no patient had any new T2/FLAIR signal abnormality to suggest retraction injury (Figure 8).

Although we have practiced for a long time the extended bifrontal approach for many anterior skull base tumors, especially large ones, we have come to appreciate that there is some morbidity associated with the performance of the orbital bar osteotomy. Dissection of the orbits and periorbita is required for the osteotomy beginning out laterally above the frontozygomatic suture and cutting across the roof of the orbit through the region of the nasofrontal suture in the midline. By necessity, the supraorbital and supratrochlear nerves as well as the tendinous insertion of the trochlea for the superior oblique muscle must be dissected in the subperiosteal plane. Orbital swelling postoperatively due to this dissection and/or disruption of the periorbita can limit ocular movements, usually temporarily. The resultant transient impairment of conjugate ocular movement can cause double

vision, which is limiting to the patient's function during the recovery phase. In our experience, this is especially pronounced while looking down and walking downstairs given the dissection around the tendinous insertion of the superior oblique muscles. With the tailored supraorbital osteotomy, the orbits do not need to be dissected as none of the cuts enter into the orbital space, alleviating the risk of any ocular dysfunction. Limiting the size of the orbital osteotomy has also not resulted, in our experience, in any decrease in the size of the surgical exposure. Although we do not have quantitative measures of the exposure with each approach, qualitatively we found no limitation in the surgical exposure in any of the 3 cases reported.

The rest of the risk profile of the tailored osteotomy is similar to the standard extended bifrontal approach, particularly with respect to the risk of cerebrospinal fluid leak and infection given the wide exposure into the frontal sinus. Rates of cerebrospinal fluid leak are generally cited at 8% to 10%^{12,14,15} with meningitis between 1% and 10%.^{16,17} Meticulous closure and use of vascularized pericranial graft to exclude the frontal and sphenoidal sinuses remain imperative steps to allow safe use of the surgical corridor presented.¹⁸⁻²⁰ In each case, the mucosa of the frontal sinus was removed across all areas and an antibiotic-soaked gelfoam sponge placed in the cavity during the case. Dura was opened in a linear fashion along the inferior margin of the osteotomy, approximately 1 fingerbreadth above the orbit, then closed primarily followed by a coat of tisseal. After tumor resection

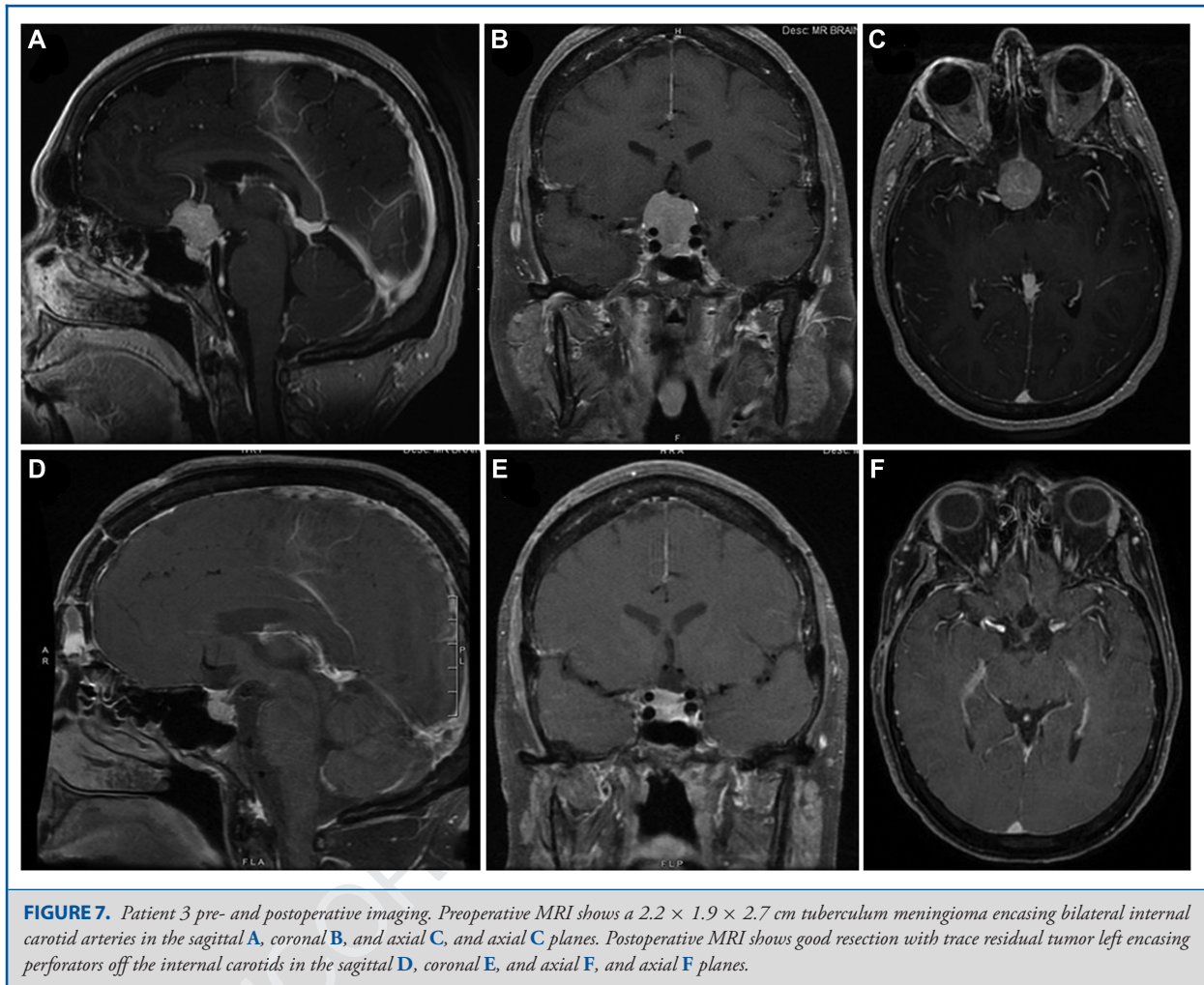
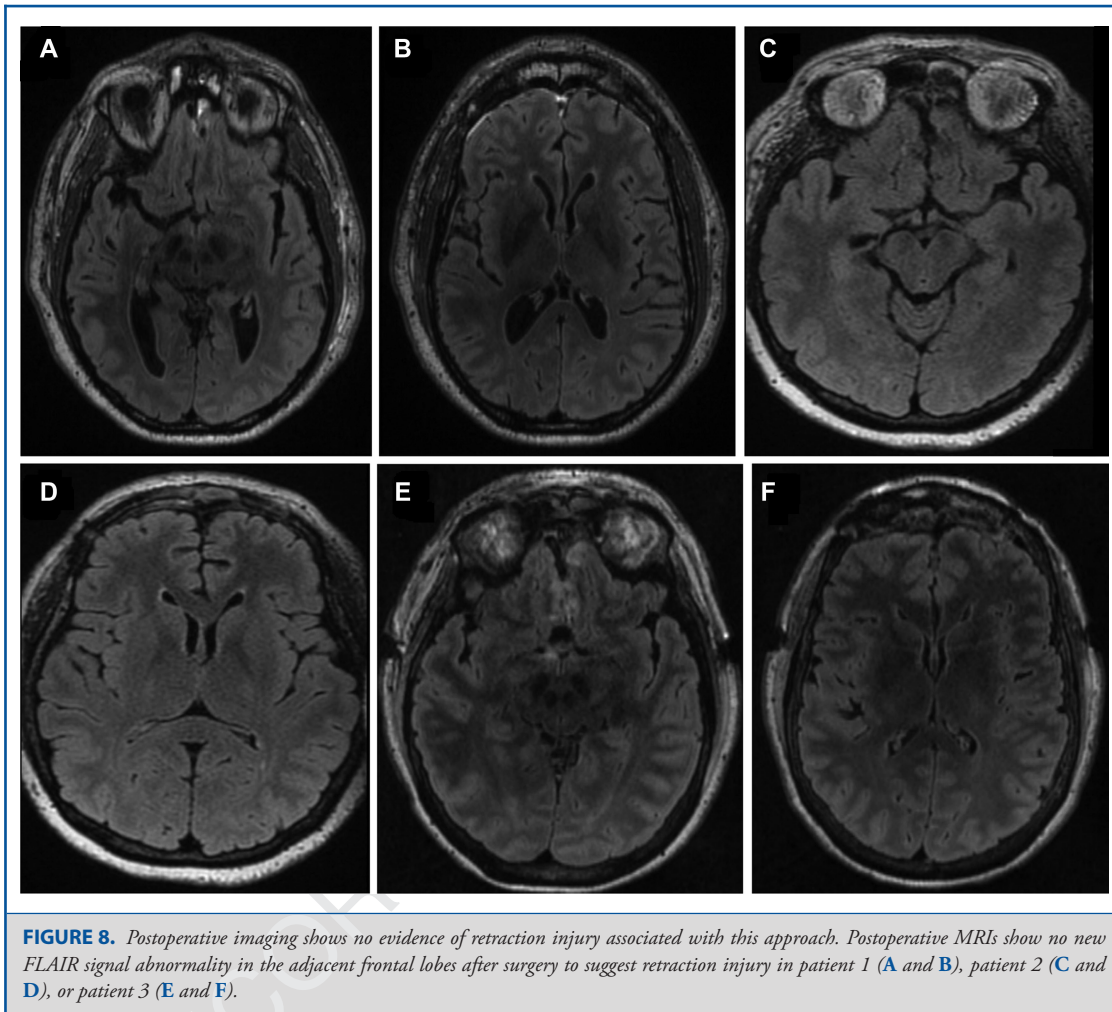


FIGURE 7. Patient 3 pre- and postoperative imaging. Preoperative MRI shows a $2.2 \times 1.9 \times 2.7$ cm tuberculoma meningeoma encasing bilateral internal carotid arteries in the sagittal **A**, coronal **B**, and axial **C**, and axial **C** planes. Postoperative MRI shows good resection with trace residual tumor left encasing perforators off the internal carotids in the sagittal **D**, coronal **E**, and axial **F**, and axial **F** planes.

was complete and dura closed, the pericranial flap was rotated down to cover the defect and the supraorbital bar reattached and secured with titanium plates and screws. Finally, with increasing focus on anatomic preservation of the both or at least 1 olfactory tract, contemporary series of bifrontal and craniofacial approaches have reported excellent preservation of olfaction.²¹⁻²³ In our series, 2 patients had preexisting olfactory deficits and 1 patient developed a new deficit postoperatively.

This modification of the extended bifrontal craniotomy represents a safe and effective approach for resection of anterior skull base lesions, but by no means represents the only viable option. Compared to lateral approaches like the pterional approach, midline approaches allow for early visualization of both optic nerves and tumor, which subsequently facilitates safe dissection of tumor away from the optic nerves bilaterally. Since these tumors are generally between the optic nerves, this approach allows for visualization of tumor without significant manipulation of the optic nerves. Unilateral approaches are “blind” to the contralateral

nerve and one has to work around the ipsilateral nerve, putting it at risk. The pterional approach provides access to the optic canal for removal of invading tumor, but both optic canals can be exposed and decompressed through a bifrontal approach as well. “Eyebrow” or “eyelid” approaches can also be used, but are hindered by the same limitations as unilateral approaches with less working room. With respect to removal of the orbital bar, this represents an important component of the operation since it limits the amount of retraction and potential for associated injury. For tubercular meningiomas, a standard bifrontal approach, even with splitting of the interhemispheric fissure, provides limited access to the base of the tumor and visualization of the optic nerves; this modification of the extended bifrontal provides a safe and effective means for exposure and resection of tumor. It is important to emphasize that there are a number of approaches that can be used for safe resection when utilized appropriately, but they must be tailored to the specific tumor and account for its relationship to adjacent vascular and neural structures.



CONCLUSION

We present a modification of the standard extended bifrontal approach to anterior skull base lesions. The tailored supra-orbital osteotomy avoids orbital dissection and minimizes ocular morbidity while at the same time providing adequate exposure for safe and effective tumor resection. Although several different approach corridors remain effective in managing anterior cranial fossa lesions, we believe that the technique therein allows for further refinement of bifrontal skull base approaches.

Disclosure

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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