# Endonasal versus Supraorbital Keyhole Removal of Craniopharyngiomas and Tuberculum Sellae Meningiomas

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**OBJECTIVE:** Endonasal and supraorbital "eyebrow" craniotomies are increasingly being used to remove craniopharyngiomas and tuberculum sellae meningiomas. Herein, we assess the relative advantages, disadvantages, and selection criteria of these 2 keyhole approaches.

**METHODS:** All consecutive patients who had endonasal or supraorbital removal of a craniopharyngioma or tuberculum sellae meningioma were analyzed.

**RESULTS:** Of 43 patients, 22 had a craniopharyngioma (18 endonasal, 4 supraorbital), and 21 had a meningioma (12 endonasal, 7 supraorbital, 2 both routes); 33% had prior surgery. Craniopharyngiomas were primarily retrochiasmal in location in 78% of endonasal cases versus 25% of supraorbital cases ($P = 0.08$). Meningiomas were larger when approached by the supraorbital route versus the endonasal route (33 ± 10 versus 25 ± 8 mm, respectively; $P = 0.008$). Endoscopy was used in 84% of endonasal approaches and in 31% of supraorbital approaches ($P = 0.001$). Of patients having first-time surgery for a craniopharyngioma (n = 14) or meningioma (n = 15), total/near total removal was achieved in 83% and 80% of patients by the endonasal route and in 50% and 80% of patients by the supraorbital route, respectively. Vision improved in 87% and 70% of patients who had surgery by an endonasal versus supraorbital route, respectively ($P = 0.3$). Visual deterioration occurred in 2 patients with meningiomas, 1 by endonasal (7%), and 1 by supraorbital (11%) removal. The endonasal approach was associated with a higher rate of postoperative cerebrospinal fluid leaks (16 versus 0%; $P = 0.3$), 4 of 5 of which occurred in patients with meningioma.

**CONCLUSION:** The endonasal route is preferred for removal of most retrochiasmal craniopharyngiomas, whereas the supraorbital route is recommended for meningiomas larger than 30 to 35 mm or with growth beyond the supraclinoid carotid arteries. For smaller midline tumors, either approach can be used, depending on surgeon experience and tumor anatomy. Compared with traditional craniotomies, the major limitation of both approaches is a narrow surgical corridor. The endonasal approach has the added challenges of restricted lateral suprasellar access, a greater need for endoscopy, and a more demanding cranial base repair.

**KEY WORDS:** Cerebrospinal fluid leak, Craniopharyngioma, Endoscopy, Extended transsphenoidal, Meningioma, Supraorbital craniotomy

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Over the past 2 decades, keyhole surgical approaches have been increasingly used to access parasellar tumors. The 2 most common approaches are the extended transsphenoidal route and the supraorbital "eyebrow" craniotomy (6, 18, 32, 36, 38, 41, 47, 51, 63, 67, 78, 80). The transsphenoidal approach has been shown to be effective and safe for suprasellar tumors that are predominantly located in the midline (6, 10, 18, 32, 33, 41–45, 47, 51, 53, 56, 64). This approach obvi-

**ABBREVIATIONS: CSF**, cerebrospinal fluid; **MRI**, magnetic resonance imaging; **SRS**, stereotactic radiosurgery; **SRT**, stereotactic radiotherapy; **UCLA**, University of California, Los Angeles ates brain retraction, minimizes optic apparatus manipulation, and allows early identification of the pituitary gland and infundibulum. It is being increasingly performed using an endonasal approach with a microscope and endoscopic assistance or by a solely endoscopic approach (6, 18, 20, 42–44, 53). The 2 major drawbacks of the endonasal approach are: 1) limited access to lesions lateral to the supraclinoid carotid arteries and optic nerves, and 2) achieving an effective cranial base closure. The supraorbital "eyebrow" craniotomy is also performed with minimal or no brain retraction and allows excellent access to the frontal fossa and parasellar area (35, 63, 68, 78). The minimal scalp and muscle dissection promote a rapid, less painful recovery compared with standard craniotomies (36, 52, 62, 63, 67, 78). The major drawback of this approach is the potential for limited maneuverability because of the small bony opening, which typically measures 15 to 20 mm by 25 to 30 mm.

Our use of the extended endonasal approach for parasellar tumors began 8 years ago followed by use of the supraorbital craniotomy 3 years ago. We adopted the supraorbital approach for parasellar tumors because others had reported good success with its use (67, 78, 80) and because of the acknowledged limitations of the endonasal approach. Herein, we describe our experience with these approaches for the 2 most common parasellar brain tumors, craniopharyngiomas and tuberculum sellae meningiomas. To our knowledge, a comparison of these keyhole approaches has not been previously reported. However, Kitano et al. (48) and de Divitiis et al. (16) recently presented comparative analyses of tuberculum sellae meningioma removal by a traditional transcranial approach (pterional or frontal craniotomy) versus a sublabial transsphenoidal approach or an endonasal endoscopic approach. In both reports, the authors described their earlier experience with the transcranial route followed by their more recent experience with the transsphenoidal route. In contrast, in the present series, although we began using the endonasal approach before the supraorbital approach, in the latter half of the series, we used both approaches selectively based on the specifics of each patient and the tumor anatomy.

Because of the increasing use of these minimally invasive approaches that traverse radically different terrain to reach the same anatomic region, an assessment of their relative benefits and potential pitfalls in removing these 2 common parasellar tumors is warranted. Based on our relatively small experience and the increasing collective experience worldwide, we also provide recommendations on the optimal approach for a particular tumor in a given patient.

## PATIENTS AND METHODS

### Patient Population and Data Collection

Between September 2000 and January 2008, all patients with a craniopharyngioma or tuberculum sellae meningioma who underwent an extended endonasal removal or supraorbital transcranial removal were identified. We began using the extended endonasal approach in 2000 and the supraorbital craniotomy approach in 2005. All procedures were performed by the senior author (DFK) at the University of California, Los Angeles (UCLA) Medical Center, Harbor-UCLA Medical Center, or Saint John's Health Center. Patients' medical records, clinical visits, and imaging studies were reviewed; and data on tumor characteristics, intraoperative and postoperative complications, and surgical outcomes of patients were collected. All patients had at least a 3-month follow-up clinic visit and a magnetic resonance imaging (MRI) scan. Patients with tumors approached by a conventional frontotemporal route were not included in this analysis. Similarly, other frontal fossa tumors such as olfactory groove meningiomas approached by the supraorbital route were not included because these are not tumors we have approached by the endonasal route. This retrospective study was approved by the Institutional Board of UCLA Medical Center, Harbor-UCLA Medical Center, and Saint John's Health Center.

### Extended Endonasal Transsphenoidal Approach

As previously described (18), the direct endonasal approach is performed with an operating microscope and in most cases with endoscopic assistance. A relaxing alar incision is not used. For tumors projecting more to 1 side, the contralateral nostril is chosen to provide better tumor access. After the initial approach with a handheld speculum, a short (60-mm) endonasal trapezoidal-shaped speculum (Mizuho America, Inc., Beverly, MA) is placed to maximize instrument maneuverability and to facilitate endoscopy (26). Surgical navigation (VectorVision cranial software; BrainLAB, Westchester, IL), although initially used in only selected cases, is now used for all cases. After a wide sphenoidotomy is performed, the sellar face is removed, followed by removal of the tuberculum sellae and proximal planum sphenoidale (60). This bony removal is performed with Kerrison rongeurs and a high-speed diamond-bit drill (Anspach Co., Palm Beach Gardens, FL) and is tailored to the patient's specific tumor anatomy. The width-limiting structures at the level of the tuberculum sellae are the optic canals, and care must be taken in the bony removal in this region. Additionally, the micro-Doppler probe is used for cavernous carotid localization before dural opening (19).

A Y-shaped dural opening is performed that extends both above and below the level of the diaphragma sellae. Venous bleeding from the superior circular sinus is controlled with Surgifoam (Ethicon, Inc., Johnson & Johnson Co., Piscataway, NJ), Gelfoam (Pfizer Inc., New York, NY) and bipolar cautery as needed. The dura is further opened inferiorly as needed to better visualize the inferolateral recesses of the suprasellar space and the superior surface of the pituitary gland and infundibular insertion. In patients with craniopharyngiomas that extend into the retrochiasmal space, the optic chiasm is typically prefixed and in many cases directly against the planum dura. This situation necessitates a central debulking of the tumor below, behind, and then cephalad to the chiasm in a piecemeal manner and by drainage of accessible tumor cysts. In patients with tuberculum sellae meningiomas, after the initial midline suprasellar dural opening has been extended laterally, additional dural cauterization is typically needed to reduce tumor blood supply. These typically fibrous and rubbery tumors are then debulked internally with microscissors and cauterization. After the tumor volume has been reduced in cases of craniopharyngioma or meningioma, the tumor capsule is gently dissected away from arachnoid attachments using sharp dissection and gentle traction. Preservation of the infundibulum in craniopharyngiomas can be difficult, particularly if the tumor has engulfed it. In contrast, in tuberculum sellae meningiomas, the infundibulum is displaced posteriorly and can typically be preserved. Intermittent endoscopic visualization with the 0-, 30- and 45-degree angled lenses is used in a

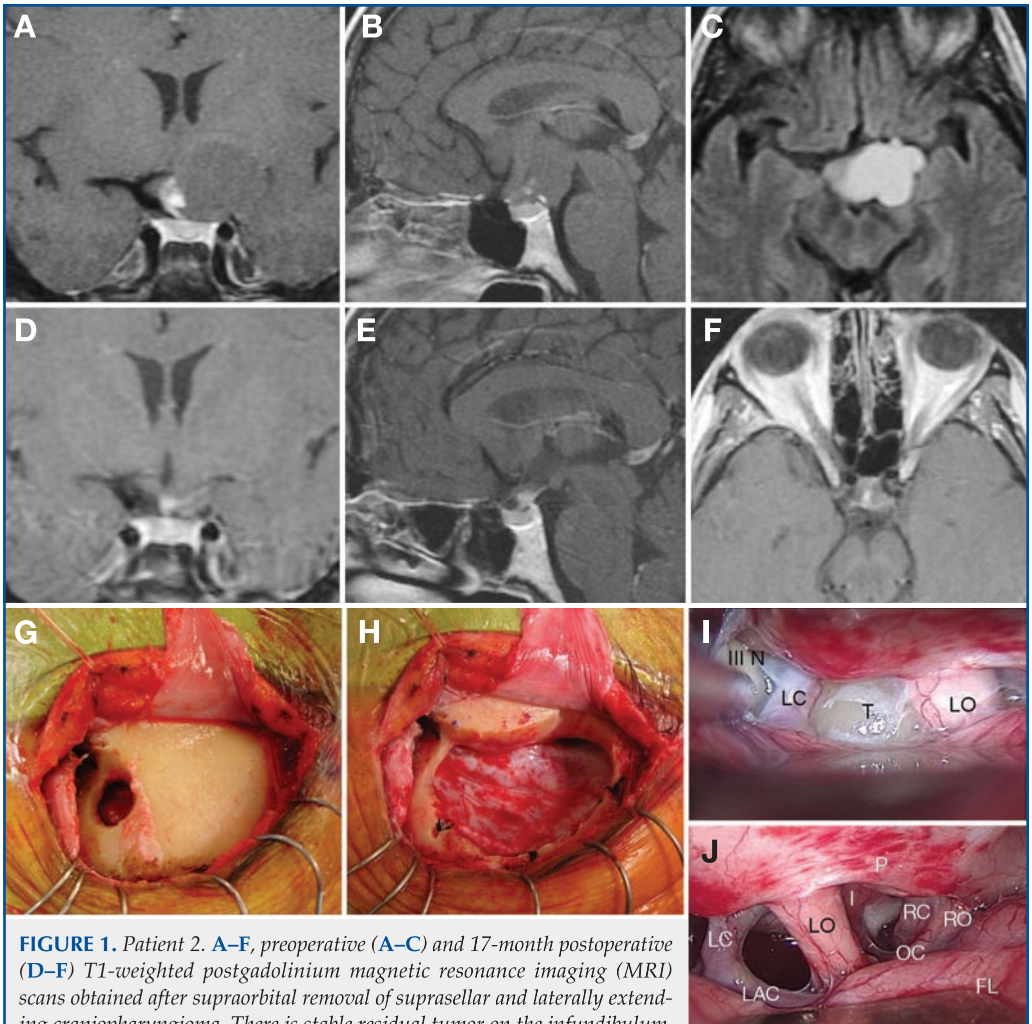


**FIGURE 1.** *Patient 2.* **A–F**, *preoperative (***A–C***) and 17-month postoperative (***D–F***) T1-weighted postgadolinium magnetic resonance imaging (MRI) scans obtained after supraorbital removal of suprasellar and laterally extending craniopharyngioma. There is stable residual tumor on the infundibulum.* **G** *and* **H**, *intraoperative photographs showing a left supraorbital "eyebrow" craniotomy to remove a cystic craniopharyngioma with left suprasellar extension. The pericranial cuff is reflected over the brow, and multiple fishhooks are placed superiorly and laterally to gain exposure to the supraorbital region. One burr hole is placed below the superior temporal line and behind the frontozygomatic process. The craniotomy encompasses the entire bony exposure, and the inferoanterior bony shelf is drilled away to be flush with the floor of the frontal fossa.* **I**, *microscopic photograph showing the parasellar area before tumor removal with tumor cyst elevating and distorting the left optic nerve and carotid artery.* **J**, *a 0-degree endoscopic image showing the suprasellar region after tumor removal. The supraclinoid carotid arteries, optic nerves, optic chiasm, and infundibulum are all visible. III N, third cranial nerve; FL, frontal lobe; LC, left carotid; RC, right carotid; LAC, left anterior cerebral artery; LO, left optic nerve; RO, right optic nerve; OC, optic chiasm; I, infundibulum; P, planum; T, tumor.*

3-hand technique to help remove residual tumor and identify neurovascular structures beyond the microscopic view. Endoscopy is particularly essential for maximal but safe tumor removal in the retrochiasmal space and for a tumor that extends into the suprasellar space anterior to the chiasm.

The repair of dural defects is based on the grade of the cerebrospinal fluid (CSF) leak and the size of the defect, as previously described (23). In most instances of craniopharyngiomas and tuberculum sellae meningiomas, a large (grade 3) CSF leak results, which is closed in a multilayered manner with abdominal fat, collagen sponge, titanium mesh or synthetic plate buttress, BioGlue sealant (CryoLife, Kennesaw, GA), and 48 hours of lumbar drain CSF diversion. No nasal packing is placed.

## Supraorbital "Eyebrow" Craniotomy

As previously described by others (63, 77), patients are placed supine in the 3-point headholder and angled 20 to 30 degrees to the contralateral side based on the location and projection of tumor to the right or left. The patient's head is slightly extended with the malar eminence most superior. The skin incision is placed within the eyebrow; it extends just medial to the supraorbital notch and courses laterally and inferiorly to the termination of the eyebrow. It can be extended up to 1 cm beyond the eyebrow in a skinfold along the frontozygomatic process. Medially, the skin incision remains superficial to avoid injury to the supraorbital nerve. The skin flap is retracted superiorly with fishhooks to gain supraorbital exposure (Fig. 1, G and H). A pericranial flap is then created and incised in a half-moon–shaped manner, then retracted inferiorly along the supraorbital rim area. In preparation for the burr hole, a short anterior segment of temporalis fascia and muscle are released at the superior temporal line. The muscle and fascia are retracted inferiorly and laterally with fishhooks to expose the keyhole below and posterior to the frontozygomatic process. A single burr hole is placed below the superior temporal line and posterior to the keyhole. A free supraorbital half-moon–shaped bone flap is made, which does not include the orbital rim, as others have previously described (37, 40), and measures approximately 15 to 20 mm by 20 to 25 mm. The inferior aspect of the frontal bone at the orbital rim is drilled down to provide better exposure to the floor of the anterior fossa. Additionally, if there are bony protuberances along the floor of the frontal fossa in the trajectory to the parasellar area, these should be drilled as well. If the frontal sinus has been entered (which rarely occurs), it can be repaired with abdominal fat and the pericranial flap.

The dura is opened in a C-shape manner with its base toward the orbital rim. Under microscopic visualization, the olfactory tract is identified and followed back to the ipsilateral optic nerve and carotid cistern. The arachnoid here is opened sharply with egress of CSF and

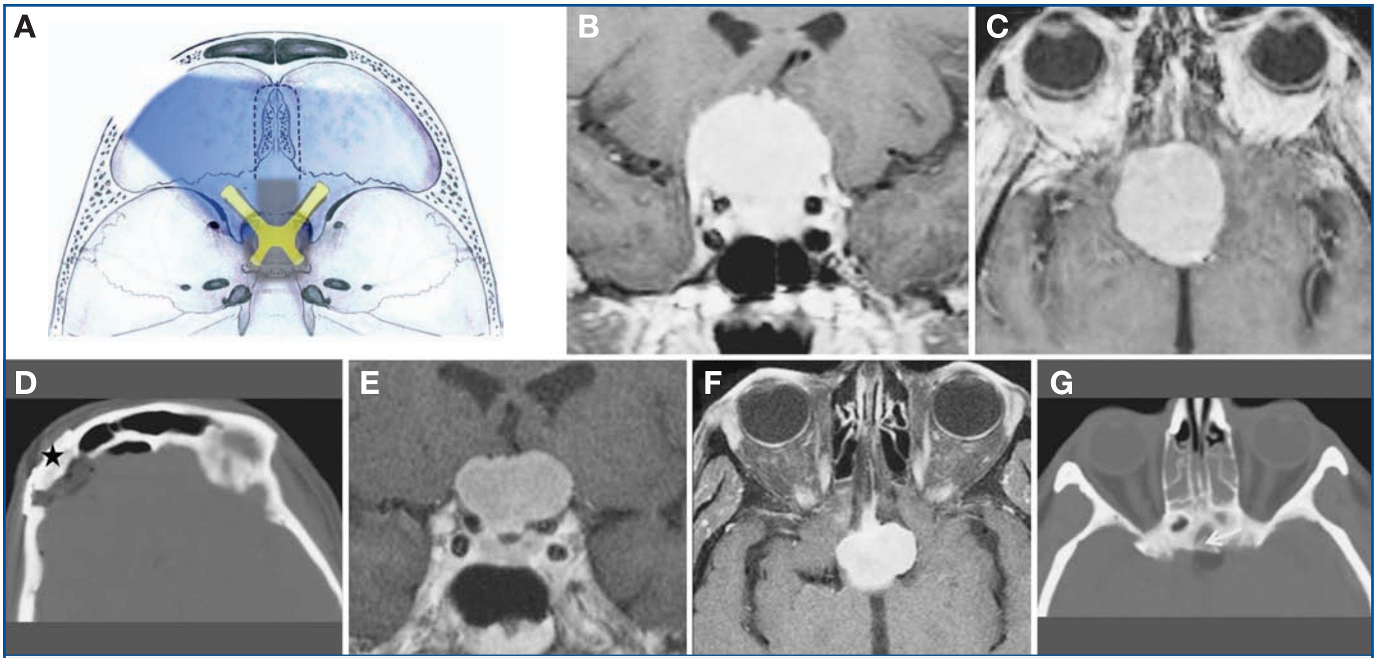


**FIGURE 2.** **A**, *drawing showing the relative intracranial exposures of the supraorbital (blue shading) and endonasal (gray shading) approaches. Note that the width-limiting structures for the endonasal approach to the parasellar area are the optic nerves. The dotted line extending anteriorly to the cribriform plate area shows the additional exposure possible with the endonasal endoscopic approach, as described by Kassam et al. (43).* **B–G**, *preoperative MRI scans (***B***,* **C***,* **E***, and* **F***) and early postoperative axial computed tomographic (CT) scans (***D** *and* **G***) of 2 illustrative patients with tuberculum sellae meningiomas.* **B–D**, *a 57-year-old woman with a 35-mm meningioma and right supraclinoid carotid encasement (***B** *and* **C***) was treated via a right supraorbital craniotomy (star) (***D***). She had near complete removal, with tumor remnants densely adherent to the right supraclinoid carotid artery and within the optic canals. She was treated with stereotactic radiosurgery and was doing well 23 months after surgery with no tumor progression.* **E–G**, *a 73-year-old woman with a 26-mm noninvasive meningioma (***E** *and* **F***) underwent total tumor removal by an endonasal approach.* **G**, *postoperative CT scan showing the surgical defect in the tuberculum sellae and planum; the triangular hyperdensity (arrow) within the bony defect is the titanium mesh buttress. Her MRI scan 39 months after surgery showed no recurrent tumor.*

further brain relaxation. A self-retaining brain retractor can be placed over the frontal lobe, although in most cases retraction is only needed at the beginning of the procedure, before tumor removal. Standard microsurgical dissection and tumor removal then proceeds with care to preserve arachnoid membranes. After tumor removal, the dura is closed in a watertight manner. A collagen sponge (Helistat; Integra LifeSciences Corp., Plainsboro, NJ) is placed over the dura and the calvarium bone edge. The bone flap is reapproximated with a single burr hole cover that is then covered with temporalis muscle, fascia, and a single straight plate spanning the medial edge of the craniotomy. To minimize visible scalp depressions in the supraorbital area, the gaps between the bone flap and calvarium can be filled with collagen sponge. The pericranial flap, if not needed for a frontal sinus defect, is re-placed over the bone flap in anatomic position. The scalp incision is closed with galeal and subcutaneous stitches followed by topical skin adhesive (Dermabond; Ethicon, Inc.).

## Approach Selection and Surgical Goals

From 2000 to 2005, we used the endonasal but not the supraorbital approach; traditional frontotemporal craniotomies were used to approach parasellar lesions deemed unresectable by the endonasal route. Since 2005, the endonasal or supraorbital route was chosen on the basis of the preference of the senior author (DFK), reflecting issues of tumor size, location, invasiveness, and prior treatments (Fig. 2).

Although the surgical goal in most patients was total tumor removal, when dense tumor adhesions to the optic apparatus, pituitary stalk, or circle of Willis vessels were encountered, tumor remnants were left behind, particularly in patients with prior surgery and radiotherapy. Similarly, with cavernous sinus invasion or extensive tumor growth into the optic canals, attempts to remove such tumor were limited to minimize the risk of neurological deficits.

## Outcome Analysis

Tumor characteristics were recorded, including maximal diameter, location, presence of cavernous sinus and optic canal invasion, as well as partial or complete vascular encasement of the supraclinoid carotid arteries or anterior cerebral complex. Clinical notes were reviewed for patient demographics, prior tumor removal surgery, preoperative and postoperative visual status (with results of both visual acuity and visual field tests), and new hormonal replacement. To evaluate for hypopituitarism, all patients' anterior and posterior pituitary function was assessed by measurement of preoperative and postoperative levels (at least 3 months after surgery) of morning cortisol, adrenocorticotropic hormone, thyroid-stimulating hormone, free thyroxin, growth hormone, insulin growth factor-1, luteinizing hormone, follicle-stimulating hormone, free and/or bioavailable testosterone, and urine specific gravity (18). Intraoperative and postoperative complication rates were recorded. As previously described,

**TABLE 1. Craniopharyngioma patient cohort**

| Craniopharyngiomas (n = 22) | Treatment approach | |
|---|---|---|
| | Endonasal (n = 18) | Supraorbital (n = 4) |
| Mean age, y | 40 ± 22 | 60 ± 12 |
| Median follow-up, mo (range) | 20 (3–60) | 14 (11–18) |
| Mean maximum tumor diameter, mm | 31 ± 15 | 32 ± 14 |
| Anatomic location | | |
| *Retrochiasmal*[a] | 14 (78%) | 1 (25%) |
| *Sellar and suprasellar* | 18 (100%) | 4 (100%) |
| *Cavernous sinus invasion* | 1 (6%) | 0 |
| *Far lateral extension*[b] | 3 (18%) | 2 (50%) |
| Preoperative visual loss | 12 (67%) | 2 (50%) |
| Preoperative hypopituitarism | 15 (83%) | 3 (75%) |
| Prior surgery | 6 (33%) | 2 (50%) |
| Prior radiation therapy | 3 (18%) | 0 |
| Median length of hospital stay, d (range) | 4 (2–31) | 3.5 (2–6) |

[a] $P = 0.08$.
[b] $P = 0.2$.

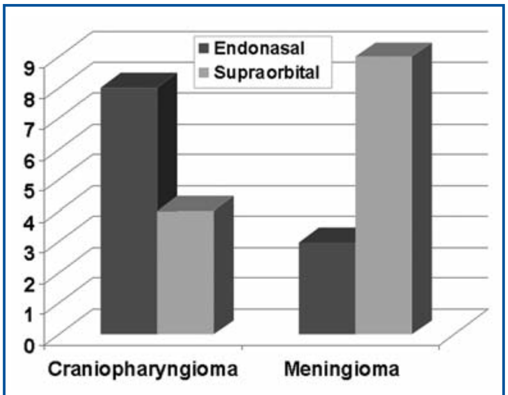


**FIGURE 3.** *Graph showing the use of the endonasal versus supraorbital approach in the last 24 treated patients. For 12 patients with a craniopharyngioma, 8 (67%) were treated by the endonasal route; 6 (75%) of the 8 patients had tumors that were primarily retrochiasmal in location, and 2 patients (25%) had prior craniotomies with sellar and suprasellar recurrences. For 12 patients with a meningioma, 9 (75%) were treated by the supraorbital route; all 9 had tumor extending lateral to at least 1 supraclinoid carotid artery, 5 (56%) had a maximal tumor diameter of more than 30 mm, 5 (56%) had cavernous sinus invasion, and 4 (44%) had prior surgery.*

tumor removal rates were defined as the following: gross total removal if no residual tumor was seen on the immediate and 3-month postoperative MRI scans, near total removal if more than 90% of the tumor was removed, or subtotal removal if less than 90% of the tumor was removed. The Simpson grading scale was not used because, in the endonasal approach, it is not possible to clearly visualize all of the intradural parasellar surfaces in most cases, and previous researchers have not used it (15, 16, 33, 48, 73). Follow-up data included tumor recurrence, functional outcome, and subsequent need for repeat surgery, stereotactic radiotherapy (SRT), or stereotactic radiosurgery (SRS).

### Statistical Analysis

The statistical comparisons of data in each group were analyzed using the Wilcoxon rank-sum test for 2 independent samples and Fisher's exact test for dichotomous variables. All statistical analyses were performed using SPSS software (Version 15.0; SPSS, Inc., Chicago, IL). Values are presented as means ± standard deviation. Probability values of <0.05 are considered statistically significant.

## RESULTS

### Overall

Among 43 patients (22 with craniopharyngiomas and 21 with tuberculum sellae meningiomas), 38 extended transsphenoidal procedures and 13 supraorbital craniotomies were performed. In 2 patients with meningiomas, both approaches were used. Fourteen patients (33%) had prior transcranial or transsphenoidal surgery, and 5 patients (12%) had prior radiotherapy (Tables 1–4).

### Approach Selection over Time and Endoscopic Assistance

Of a total of 51 procedures performed for removal of a craniopharyngioma or tuberculum sellae meningioma from September 2000 to January 2008, 24 (47%) were performed beginning in 2005, when use of the supraorbital approach was adopted for these tumors. As shown in Figure 3, these 24 procedures included 11 extended endonasal procedures (8 for craniopharyngioma and 3 for meningioma) (46%) and 13 supraorbital procedures (4 for craniopharyngioma and 9 for meningioma) (54%).

Overall, endoscopy was used in 84% of endonasal and in 31% of supraorbital approaches ($P = 0.001$). For patients with a craniopharyngioma, endoscopy was used in 15 (83%) of 18 patients treated by the endonasal route and in 1 patient (25%) treated by the supraorbital route ($P = 0.05$). For patients with a meningioma, endoscopy was used in 12 patients treated by the endonasal route (86%) versus 3 by the supraorbital route (33%) ($P = 0.02$). Surgical navigation was used in 6 craniopharyngioma patients treated by the endonasal approach (33%) and in no supraorbital cases, and was used in 9 meningioma patients treated by the endonasal route (64%) versus 5 by the supraorbital route (56%) ($P = 1$).

### Craniopharyngioma

#### *Tumor Characteristics*

As shown in Tables 1 and 2, 18 patients underwent 24 endonasal procedures, and 4 patients underwent a supraor-

**TABLE 2. Craniopharyngioma patients in detail[a]**

| | Age (y)/ sex | Maximum tumor diameter (mm) | Tumor location | Prior surgery | Prior radiation | Cavernous sinus invasion/ vascular encasement | Extent of resection | Visual changes[b] | Additional therapy | Follow-up (mo) |
|---|---|---|---|---|---|---|---|---|---|---|
| Endonasal | | | | | | | | | | |
| *1* | 50/M | 40 | RC, SS, S | 0 | 0 | 0 | Subtotal | ↑ | N/A | 3 |
| *2* | 45/M | 25 | RC, SS, S | Yes | 0 | 0 | Near total | ↔ | SRT | 29 |
| *3* | 46/M | 25 | RC, SS, S | 0 | 0 | 0 | Near total | ↑ | SRT | 14 |
| *4* | 8/F | 60 | RC, Ext | 0 | 0 | Yes | Subtotal | ↑ | SRT | 60 |
| *5* | 13/F | 13 | SS, S | Yes | 0 | 0 | Total | ↔ | 0 | 33 |
| *6* | 13/F | 50 | Pre-C, SS | Yes | Yes | Yes | Subtotal | → | SRT | 20 |
| *7* | 78/M | 40 | RC, SS, S | 0 | 0 | Yes | Subtotal | ↑ | SRT | 3 |
| *8* | 41/F | 21 | RC, SS, S | 0 | 0 | 0 | Near total | ↑ | SRT | 36 |
| *9* | 79/M | 60 | RC, SS, Ext | 0 | 0 | Yes | Near total | ↑ | SRT | 22 |
| *10* | 34/F | 20 | RC, SS, S | 0 | 0 | 0 | Total | ↔ | 0 | 21 |
| *11* | 59/F | 18 | RC, SS, S | 0 | 0 | 0 | Near total | ↑ | SRT | 34 |
| *12* | 43/M | 23 | RC, SS, S | 0 | 0 | Yes | Near total | ↑ | N/A | 3 |
| *13* | 48/M | 20 | RC, SS, S | 0 | 0 | 0 | Near total | ↑ | SRT | 30 |
| *14* | 21/M | 40 | RC, SS, S | 0 | 0 | Yes | Near total | ↑ | SRT | 9 |
| *15* | 10/F | 14 | SS, S | Yes | Yes | 0 | Near total | ↔ | 0 | 22 |
| *16* | 25/F | 20 | SS, S | Yes | Yes | 0 | Cyst drainage | ↑ | 0 | 3 |
| *17* | 61/M | 41 | RC, SS, S | 0 | 0 | 0 | Total | ↔ | 0 | 12 |
| *18* | 45/M | 25 | RC, SS, S | Yes | 0 | 0 | Subtotal | ↔ | SRT | 6 |
| Supraorbital | | | | | | | | | | |
| *1* | 71/M | 13 | SS | 0 | 0 | 0 | Subtotal | ↔ | SRS | 18 |
| *2* | 70/F | 30 | SS | Yes | 0 | 0 | Near total | ↑ | 0 | 12 |
| *3* | 55/F | 40 | RC, SS | 0 | 0 | 0 | Near total | ↑ | SRT | 17 |
| *4* | 46/M | 45 | SS | Yes | 0 | 0 | Subtotal | ↔ | SRT | 11 |

[a] RC, retrochiasmal; SS, suprasellar; S, sellar; SRT, stereotactic radiotherapy; Ext, extensive; Pre-C, prechiasmal; SRS, stereotactic radiosurgery; N/A, not available.
[b] ↑, improved postoperative vision; ↓, worsened postoperative vision; →, preoperative visual impairment not improved; ↔, no visual impairment pre- or postoperatively.

bital craniotomy. Maximal tumor size was similar between the 2 approach groups. Of 18 patients undergoing endonasal removal, 14 (78%) had a major tumor component within the retrochiasmal space, whereas only 1 (25%) of 4 patients undergoing supraorbital removal had retrochiasmal tumor extension ($P = 0.08$). Of the remaining 3 patients undergoing supraorbital removal, 1 had a suprasellar and suprachiasmal location, 1 a prechiasmal location, and 1 a sellar, suprasellar, and far lateral extension (see patients 1 and 2 under Illustrative Cases [Figs. 1 and 4]).

### *Tumor Removal Rates and Visual Outcome*

Of 18 patients who had endonasal surgery, 1 had planned cyst drainage only for progressive visual loss 12 months after prior craniotomy and radiation therapy, performed elsewhere. Of the remaining 17 patients who had endonasal tumor removal, gross total, near total, and subtotal resection were achieved in 3 patients (18%), 9 patients (53%), and 5 patients (29%), respectively. Of 4 patients who underwent supraorbital removal, near total and subtotal removal were performed in 2 patients (50%) and 2 patients (50%), respectively. Of patients undergoing first-time endonasal surgery versus supraorbital craniotomy, total or near total removal (>90%) was achieved in 10 (83%) of 12 patients versus 1 (50%) of 2 patients, respectively (Table 5). Subtotal or near total craniopharyngioma removal was associated with prior surgery, prior radiation treatment, cavernous sinus invasion, other vascular encasement, or planned cyst drainage in 12 (63%) of 19 patients. Of the remaining 7 cases, 6 patients had near total removal with small adherent remnants left behind on key neurovascular structures, and 1 patient (a 71-year-old man) had subtotal removal of a calcified tumor that was densely adherent to the optic chiasm. Preoperative visual loss resolved in 11 patients (92%) and was unchanged in 1 patient (8%) after endonasal

**TABLE 3. Meningioma patient cohort[a]**

| Meningiomas (n = 21) | Treatment approach | |
|---|---|---|
| | Endonasal (n = 14) | Supraorbital (n = 9) |
| Mean age, y | 51 ± 15 | 49 ± 7 |
| Median follow-up, mo (range) | 27 (6–65) | 14 (3–28) |
| Mean maximum tumor diameter, mm[b] | 25 ± 8 | 33 ± 10 |
| Anatomic location | | |
| *Tumor lateral to supraclinoid ICA*[c] | 9 (64%) | 9 (100%) |
| *Vascular encasement* | 10 (71%) | 8 (89%) |
| *Cavernous sinus invasion*[d] | 7 (50%) | 5 (56%) |
| Preoperative visual loss[d] | 11 (79%) | 8 (89%) |
| Preoperative hypopituitarism[d] | 7 (50%) | 3 (33%) |
| Prior surgery[d] | 4 (28%) | 4 (44%) |
| Prior radiation therapy[e] | 1 (7%) | 2 (22%) |
| Median length of hospital stay, d (range) | 4 (1–13) | 4 (3–14) |

[a] ICA, internal carotid artery.
[b] $P = 0.008$.
[c] $P = 0.1$.
[d] Includes 2 patients who had tumor removal via both routes.
[e] Includes 1 patient who had tumor removal via both routes.

surgery; vision loss resolved completely in 2 of 2 patients after supraorbital removal (Table 6).

### *Follow-up and Recurrence Rate*

Of 18 patients undergoing endonasal removal (median follow-up, 20 months; range, 3–60 months), 2 with residual tumor, who were expected to receive SRT, were lost to follow-up 3 months after surgery. Of the remaining 16 patients, 3 who had total removal have had no recurrence (although 1 patient had prior craniotomy and SRT before endonasal tumor removal). Of 13 patients with near total or subtotal removal, 11 received SRT, including 3 who had an additional endonasal cyst drainage or tumor removal. No tumor regrowth occurred in these 13 patients in a median follow-up of 22 months (range, 3–60 months).

Of 4 patients undergoing supraorbital removal, 3 patients (2 with subtotal resection and 1 with near total resection) received postoperative SRT and remained stable at last follow-up, ranging from 11 to 18 months (median, 14 months). The fourth patient, who had a prior craniotomy and underwent SRT after supraorbital craniotomy, developed a cyst reaccumulation in the temporal lobe and had successful cyst drainage through a temporal craniotomy.

### *Complications*

As shown in Table 7, among 18 patients who had endonasal surgery, there was 1 patient (6%) with a postoperative CSF leak treated with reoperation, and 1 patient with chemical meningitis. Of 13 patients without preoperative panhypopituitarism, new permanent diabetes insipidus and/or anterior hormonal loss occurred in 6 patients (46%), although all 6 had some degree of preexisting anterior hypopituitarism. Complications after supraorbital tumor removal included 1 subdural hygroma requiring burr hole drainage 2 months after surgery and 2 instances of mild frontalis muscle paresis, from which both patients recovered. No new pituitary dysfunction developed in these 4 patients after surgery, although 3 of them had preoperative hypopituitarism. All 22 patients at last follow-up were fully functional, although several had preexisting visual deficits and most were receiving hormone replacement therapy.

## Tuberculum Sellae Meningioma

### *Tumor Characteristics*

As shown in Tables 3 and 4, of 21 patients, 14 underwent endonasal removal, and 9 had supraorbital removal, including 2 patients who underwent both approaches (Tables 3 and 4). Meningiomas approached by the supraorbital versus the endonasal route were larger in maximum diameter (33 ± 10 versus 25 ± 8 mm, respectively; $P = 0.008$), had higher rates of tumor extension beyond the supraclinoid carotid arteries (100% versus 64%, respectively; $P = 0.1$), and had higher rates of partial or complete encasement of the supraclinoid carotid arteries or anterior cerebral complex (89% versus 71%, respectively) (see patients 3 and 4 under Illustrative Cases [Figs. 5 and 6]). The 2 patients who had both an endonasal and supraorbital approach are described below.

### *Tumor Removal Rates and Visual Outcome*

Total, near total, and subtotal tumor removal by the endonasal route was accomplished in 7 patients (50%), 3 patients (21%), and 4 patients (29%), respectively, and by the supraorbital route in 2 patients (22%), 2 patients (22%), and 5 patients (56%), respectively. Of patients undergoing first-time endonasal surgery versus supraorbital meningioma removal, total/near total removal (>90%) was achieved in 8 (80%) of 10 patients versus 4 (80%) of 5 patients, respectively (Table 5). Overall, incomplete tumor removal by either approach occurred in 12 (57%) of 21 patients and was associated with at least 1 or more of the following factors in all 12 patients: prior surgery, prior radiotherapy, cavernous sinus invasion, or other vascular encasement.

Of patients treated by endonasal removal, preoperative visual loss resolved in 9 (82%) of 11 patients, was unchanged in 1 patient (9%), and mildly worsened in 1 (7%) of 14 patients; 5 (63%) of 8 patients treated by supraorbital removal had visual improvement, and 3 had no change (all with severe preoperative loss and optic atrophy); 1 (11%) of 9 patients had delayed monocular loss of an inferior field (Table 6).

### *Follow-up and Recurrence Rate*

Of 14 patients who had endonasal meningioma removal, 7 had total removal of noninvasive tumors (tumor diameter ranging from 15 to 26 mm), and none had tumor recurrence at a median follow-up of 24 months (range, 15–64 months). Of

**TABLE 4. Meningioma patients in detail[a]**

| | Age (y)/ sex | Maximum tumor diameter (mm) | Prior surgery | Prior radiation | Cavernous sinus invasion/ vascular encasement | Extent of resection | Visual changes[b] | Additional therapy | Follow-up (mo) |
|---|---|---|---|---|---|---|---|---|---|
| Endonasal | | | | | | | | | |
| *1* | 33/F | 21 | 0 | 0 | Yes | Total | ↑ | 0 | 64 |
| *2* | 54/F | 20 | 0 | 0 | 0 | Total | ↑ | 0 | 15 |
| *3* | 32/F | 30 | Yes | 0 | Yes | Near total | ↑ | SRS | 65 |
| *4* | 52/F | 15 | 0 | 0 | 0 | Total | ↑ | 0 | 58 |
| *5* | 46/M | 20 | Yes | 0 | 0 | Total | ↔ | 0 | 24 |
| *6* | 59/M | 26 | 0 | 0 | Yes | Near total | ↑ | SRS | 6 |
| *7*[c] | 54/M | 23 | Yes | 0 | Yes | Subtotal | ↔ | SRT | 43 |
| *8* | 72/F | 25 | 0 | 0 | Yes | Near total | ↑ | SRT | 33 |
| *9* | 73/F | 26 | 0 | 0 | 0 | Total | ↑↓[d] | 0 | 39 |
| *10* | 77/F | 25 | 0 | 0 | Yes | Total | ↔ | 0 | 24 |
| *11* | 50/F | 24 | 0 | 0 | Yes | Subtotal | ↑ | 0 | 31 |
| *12* | 31/F | 25 | 0 | 0 | Yes | Total | ↑ | 0 | 19 |
| *13*[e] | 43/M | 55 | Yes | Yes | Yes | Subtotal | → | Chemo | 13 |
| *14* | 45/F | 25 | 0 | 0 | Yes | Subtotal | ↑ | SRT | 17 |
| Supraorbital | | | | | | | | | |
| *1* | 57/F | 35 | 0 | 0 | Yes | Near total | ↑ | SRT | 23 |
| *2*[c] | 56/M | 27 | Yes | 0 | Yes | Subtotal | ↑ | SRT | 17 |
| *3* | 37/F | 37 | 0 | 0 | Yes | Total | → | 0 | 28[f] |
| *4* | 43/F | 31 | 0 | 0 | 0 | Total | ↑ | 0 | 22 |
| *5*[e] | 43/M | 55 | Yes | Yes | Yes | Subtotal | → | Chemo | 14 |
| *6* | 57/F | 38 | Yes | 0 | Yes | Subtotal | → | 0 | 3 |
| *7* | 47/F | 22 | 0 | 0 | Yes | Near total | ↑ | 0 | 12 |
| *8* | 50/F | 26 | 0 | 0 | Yes | Subtotal | ↓ | SRT | 7 |
| *9* | 53/M | 27 | Yes | Yes | Yes | Subtotal | ↑ | 0 | 5 |

[a] SRS, stereotactic radiosurgery; SRT, stereotactic radiotherapy; Chemo, chemotherapy.
[b] ↑, improved postoperative vision; ↓, worsened postoperative vision; →, preoperative visual impairment not improved; ↔, no visual impairment pre- or postoperatively.
[c] This patient with a typical meningioma was treated by prior craniotomy in 1991, underwent endonasal tumor debulking in 2003, and underwent a supraorbital craniotomy 26 months later.
[d] This patient had resolution of a bitemporal hemianopsia but developed a new partial nasal hemianopsia.
[e] This patient with a large recurrent atypical meningioma underwent staged debulking 3 weeks apart through a supraorbital approach and then an endonasal approach.
[f] This patient had a new 6-mm tumor recurrence 28 months after surgery.

7 patients with cavernous sinus invasion, 2 received SRS and 2 received SRT without evidence of tumor progression 6 to 65 months (median, 25 months) after radiotherapy, and 1 is being followed without tumor progression 31 months after surgery. The 2 patients who had subsequent supraorbital craniotomies are described below.

Of the 9 patients who had a supraorbital craniotomy, 2 had total tumor removal, and of these, 1 (patient 4 [Fig. 6, A–I]) had a 6-mm tumor recurrence 28 months after surgery, and 1 had no recurrence 22 months after surgery. Of the remaining 7 patients who had incomplete removal of invasive tumors, 2 had postoperative SRT (with 1 and 17 months of follow-up), 2 had SRS or SRT before surgery, and 1 had a stable small residual 12 months after surgery. The 2 patients who underwent both approaches had prior conventional craniotomies. The first patient, a 54-year-old man, had a frontotemporal craniotomy in 1991 elsewhere for a typical meningioma. In 2003, because of progressive suprasellar tumor growth, he underwent endonasal tumor debulking of a 23-mm recurrent meningioma (Table 4, endonasal patient 7). However, 26 months after his endonasal surgery, he had further tumor growth and new visual loss; he underwent a supraorbital craniotomy with subsequent visual improvement (Table 4, supraorbital patient 2). He later underwent SRT for residual tumor and was doing

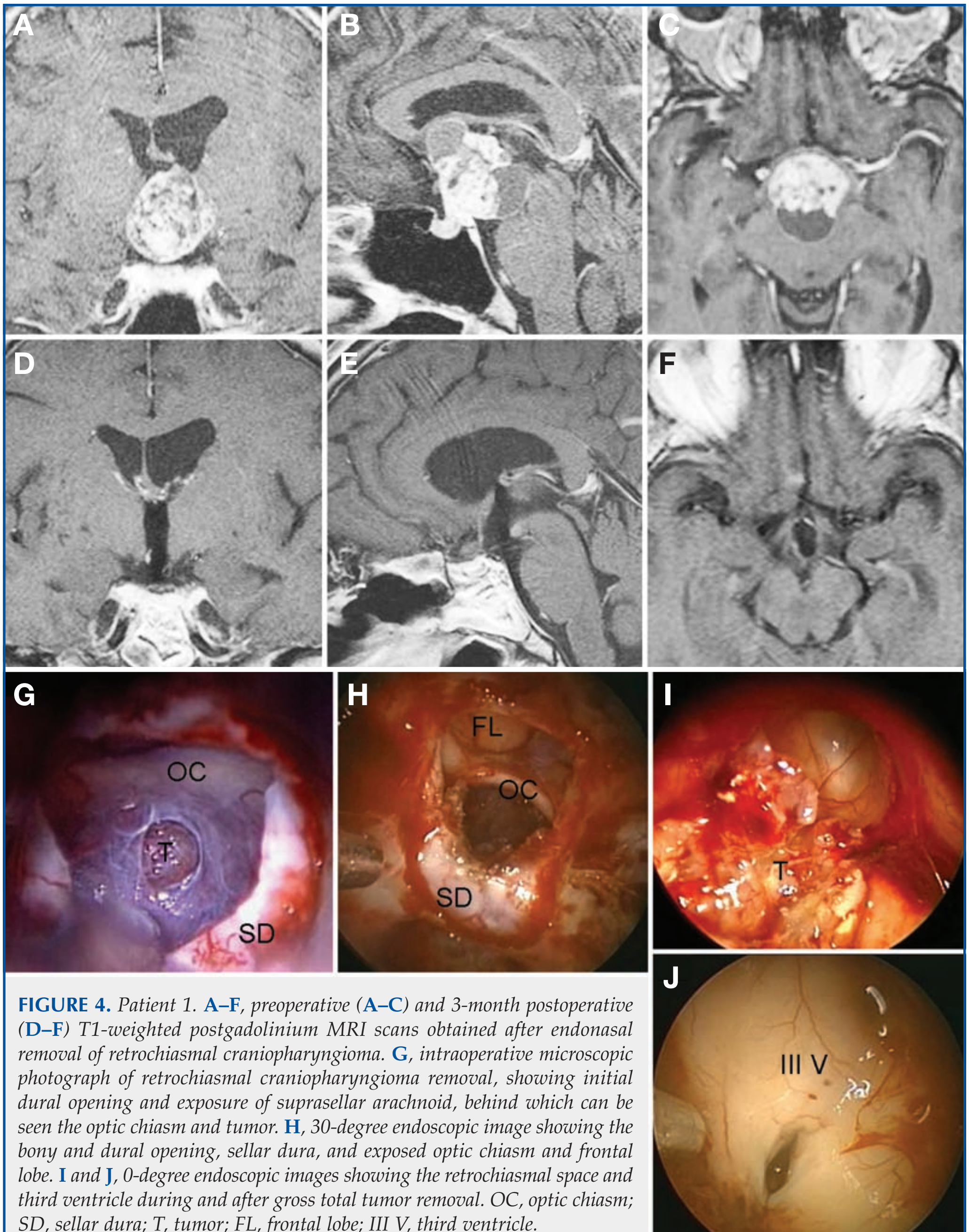


**FIGURE 4.** *Patient 1.* **A–F**, *preoperative (***A–C***) and 3-month postoperative (***D–F***) T1-weighted postgadolinium MRI scans obtained after endonasal removal of retrochiasmal craniopharyngioma.* **G**, *intraoperative microscopic photograph of retrochiasmal craniopharyngioma removal, showing initial dural opening and exposure of suprasellar arachnoid, behind which can be seen the optic chiasm and tumor.* **H**, *30-degree endoscopic image showing the bony and dural opening, sellar dura, and exposed optic chiasm and frontal lobe.* **I** *and* **J**, *0-degree endoscopic images showing the retrochiasmal space and third ventricle during and after gross total tumor removal. OC, optic chiasm; SD, sellar dura; T, tumor; FL, frontal lobe; III V, third ventricle.*

well 17 months after his supraorbital craniotomy without tumor progression.

The second patient, a 43-year-old man diagnosed with type II neurofibromatosis in 1995, had SRS of an acoustic schwannoma and a suprasellar meningioma elsewhere. Progressive suprasellar tumor growth in 2002 prompted bifrontal and frontotemporal craniotomies elsewhere. Additional SRT was given thereafter, but the patient had progressive tumor growth with severe visual loss in 2006. Because of the tumor size (55-mm diameter), his multiple prior craniotomies, and radiotherapy, the patient underwent staged supraorbital then endonasal debulkings separated by 3 weeks with the goal of optic apparatus decompression (Table 4, supraorbital patient 5, endonasal patient 13). These operations occurred without complication, but the patient's vision did not improve. Pathology confirmed an atypical meningioma. The patient became progressively moribund from tumor growth despite chemotherapy and died 13 months after his last surgery.

### *Complications*

As shown in Table 7, of 14 patients who underwent endonasal meningioma removal, 4 (29%) experienced a postoperative CSF leak (3 in the first half of the series); 2 patients were treated by reoperation and 2 patients were treated by transient lumbar CSF diversion. Two patients early in the series required revision of excessively large fat grafts, which led to 1 of the 4 CSF leaks. Two patients required internal maxillary artery embolization for delayed epistaxis. One patient with prior surgery and hypopituitarism developed new hypoadrenalism, 2 had delayed hyponatremia, and 2 had transient diabetes insipidus.

Of 9 patients undergoing supraorbital meningioma removal, there was 1 probable cavernous carotid artery puncture in a patient who had prior craniotomy and endonasal debulking (Table 4, supraorbital patient 2). The injury occurred despite the use of the micro-Doppler probe in an area of dense scar tissue immediately medial to the right optic nerve at the most proximal aspect of the optic canal. The Doppler revealed no vascular sound immediately before removing tumor in this area with microscissors; the Doppler was thought to be malfunctioning based on the use of another Doppler after the presumed injury. Arterial bleeding was controlled, and the bleeding site was repaired with muslin gauze. An immediate postoperative cere-

**TABLE 5. Tumor removal rate after first-time operation**

| Pathology/procedure | Gross total | Near total (≥90%) | Subtotal (<90%) |
|---|---|---|---|
| Craniopharyngiomas | | | |
| *Endonasal (n = 12)* | 2 (17%) | 8 (67%) | 2 (17%) |
| *Supraorbital (n = 2)* | 0 | 1 (50%) | 1 (50%) |
| Meningiomas | | | |
| *Endonasal (n = 10)* | 6 (60%) | 2 (20%) | 2 (20%) |
| *Supraorbital (n = 5)* | 2 (40%) | 2 (40%) | 1 (20%) |

bral angiogram and subsequent computed tomographic angiogram 2 days later were both normal, and the patient had no new neurological deficits.

Overall, 20 of 21 patients with a meningioma were fully functional at last follow-up, although 2 had slightly worsened vision and several had preexisting visual deficits that did not improve after surgery. One patient, described above, died from tumor progression.

## ILLUSTRATIVE CASES

Four patient examples are shown below to illustrate selection criteria used in the approach of a particular tumor. The first case (patient 1) illustrates the advantage of the endonasal approach for accessing retrochiasmal craniopharyngiomas. The second case (patient 2) demonstrates the benefit of the supraorbital approach for accessing a craniopharyngioma with both retrochiasmal and far lateral extension. The third case (patient 3) shows a tuberculum sellae meningioma that is ideal for endonasal removal because of its relatively small size and lack of lateral extension beyond the supraclinoid carotid arteries and

**TABLE 6. Visual recovery**

| Pathology/procedure | Preoperative vision impaired | Postoperative vision | | |
|---|---|---|---|---|
| | | Improved | Unchanged | Worsened |
| Craniopharyngioma | | | | |
| *Endonasal* | 12 | 11 (92%) | 1 (8%) | 0 |
| *Supraorbital* | 2 | 2 (100%) | 0 | 0 |
| Meningioma | | | | |
| *Endonasal* | 11 | 9 (82%) | 1 (9%) | 1/14 (7%) |
| *Supraorbital* | 8 | 5 (63%) | 3 (37%) | 1/9 (11%)[a] |

[a] This patient with normal vision preoperatively had delayed monocular inferior hemianopsia.

**TABLE 7. Complications[a]**

| Complications | Endonasal | | Supraorbital | |
|---|---|---|---|---|
| | Cranio (n = 18) | Meningioma (n = 14) | Cranio (n = 4) | Meningioma (n = 9) |
| Death | 0 | 0 | 0 | 0 |
| Carotid or other vascular injury | 0 | 0 | 0 | 1 (11%) |
| Postoperative worsening vision | 0 | 1 (7%) | 0 | 1 (11%) |
| New ocular palsies | 0 | 0 | 0 | 0 |
| New postoperative hypopituitarism[b] | 6/13 (48%) | 1 (7%) | 0 | 0 |
| Postoperative CSF leaks | 1 (6%) | 4 (29%)[c] | 0 | 0 |
| Bacterial meningitis | 0 | 0 | 0 | 0 |
| Endonasal-specific complications (n = 32) | | | | |
| *Reoperation for overly large fat graft* | | 2 (6%) | | |
| *Delayed epistaxis needing embolization of IMA* | | 2 (6%) | | |
| Supraorbital-specific complications (n = 13) | | | | |
| *Subdural hygroma* | | 1 (8%) | | |
| *Transient frontalis paresis* | | 2 (15%) | | |

[a] Cranio, craniopharyngioma; CSF, cerebrospinal fluid; IMA, internal maxillary artery.
[b] Of 18 patients with craniopharyngioma undergoing the endonasal approach, 15 had preoperative hypopituitarism, including 5 who had preoperative panhypopituitarism.
[c] Of 4 patients with CSF leaks, 2 underwent reoperation, and 2 were treated with lumbar drain CSF diversion only; 3 of 4 repair failures occurred in the first half of the series.

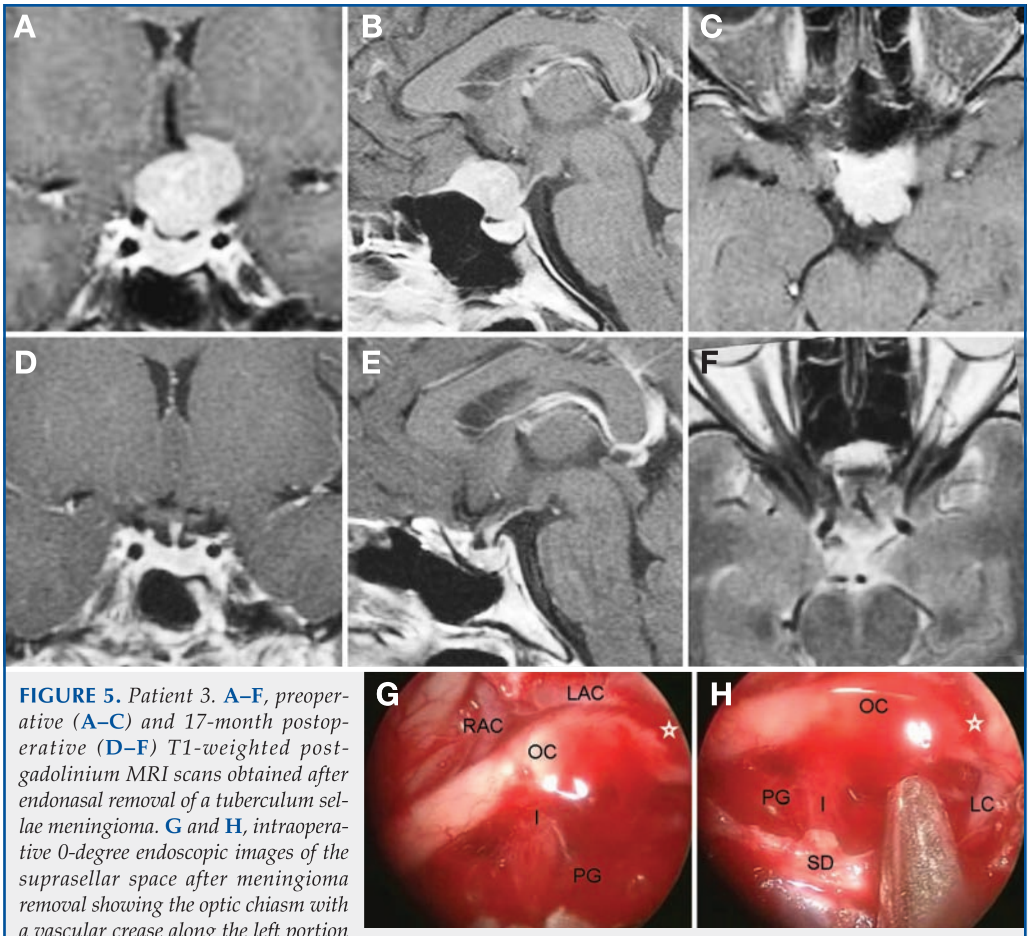


**FIGURE 5.** *Patient 3.* **A–F**, *preoperative (***A–C***) and 17-month postoperative (***D–F***) T1-weighted postgadolinium MRI scans obtained after endonasal removal of a tuberculum sellae meningioma.* **G** *and* **H**, *intraoperative 0-degree endoscopic images of the suprasellar space after meningioma removal showing the optic chiasm with a vascular crease along the left portion of the chiasm (star), the anterior cerebral artery complex above, and the infundibulum coursing to the pituitary gland below. RAC, right anterior cerebral artery; LAC, left anterior cerebral artery; LC, left supraclinoid carotid artery; OC, optic chiasm; I, infundibulum; PG, pituitary gland; SD, sellar dura.*

optic canals. The fourth case (patient 4) illustrates a typical meningioma that warrants a transcranial approach because of its far lateral extension and vascular encasement.

### Patient 1: Endonasal Removal of Craniopharyngioma

A 65-year-old man with a 6-month history of forgetfulness and polyuria was diagnosed with a 41- × 38-mm cystic and solid sellar, suprasellar, and retrochiasmal craniopharyngioma with early hydrocephalus. He underwent right endonasal tumor removal with endoscopic assistance and surgical navigation. His 3-month postoperative MRI scan showed a gross total tumor removal, his cognitive status normalized, his vision remained normal, and he was receiving full hormone replacement therapy (Fig. 4).

### Patient 2: Supraorbital Removal of Craniopharyngioma

A 55-year-old woman had 2 months of progressive visual loss, a right homonymous hemianopsia, and headaches. An MRI scan showed a 30- × 40-mm, mostly cystic suprasellar and retrochiasmal mass with extension to the left suprasellar space. She had a left supraorbital craniotomy with endoscopic assistance and near total tumor removal with a small tumor nubbin left densely adherent to the infundibulum. Her vision normalized after surgery. Her pituitary hormonal function remained normal. She received SRT, and her MRI scan 17 months after surgery showed no tumor progression (Fig. 1).

### Patient 3: Endonasal Removal of Meningioma

A 31-year-old woman had progressive visual loss to light perception only in the left eye with left optic atrophy. Her MRI scan showed a 25- × 21-mm tuberculum sellae meningioma causing severe chiasmal compression with tumor extending along the left optic canal. She underwent endonasal tumor removal using endoscopic assistance and surgical navigation, with a gross total tumor removal including tumor along the medial left optic canal. At 19 months after surgery, her vision had improved modestly, she had normal pituitary function, and her MRI scan showed no residual or recurrent tumor (Fig. 5).

### Patient 4: Supraorbital Removal of Meningioma

A 37-year-old woman had progressive right-sided visual loss that worsened to light perception only and right optic atrophy. The MRI scan showed a 37- × 33- × 32-mm tuberculum sellae meningioma, and the patient had loss of adrenal and thyroid axes. She had a right supraorbital craniotomy and gross total tumor removal. Six months after surgery, her vision and endocrinopathy remained stable, and her MRI scan showed no residual tumor. As shown in Figure 6, G–I, at 28 months after surgery, her MRI scan showed a new 6-mm recurrence along the right tuberculum sellae. The patient will likely be treated with SRT.

## DISCUSSION

### Summary of Results

In this series of 43 patients, the overall safety and efficacy of the endonasal and supraorbital eyebrow approaches for removal of craniopharyngiomas and tuberculum sellae meningiomas are demonstrated. The 2 approaches yielded similar rates of total/near total tumor removal after first-time surgery and similar rates of visual recovery and visual worsening, although the number of patients with craniopharyngiomas who underwent surgery by the supraorbital route was small. The most notable differences between the 2

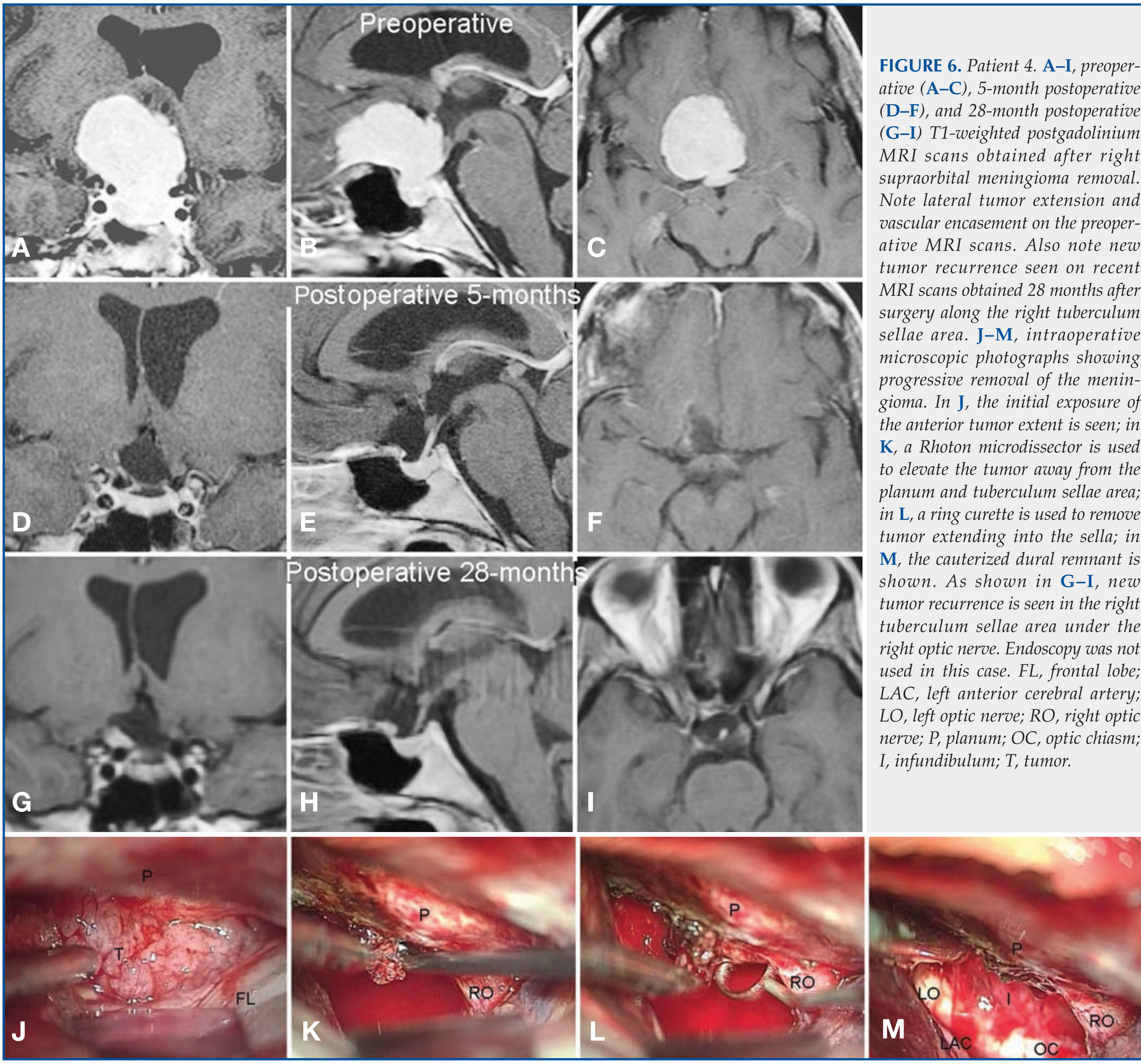


**FIGURE 6.** *Patient 4.* **A–I**, *preoperative* (**A–C**), *5-month postoperative* (**D–F**), *and 28-month postoperative* (**G–I**) *T1-weighted postgadolinium MRI scans obtained after right supraorbital meningioma removal. Note lateral tumor extension and vascular encasement on the preoperative MRI scans. Also note new tumor recurrence seen on recent MRI scans obtained 28 months after surgery along the right tuberculum sellae area.* **J–M**, *intraoperative microscopic photographs showing progressive removal of the meningioma. In* **J**, *the initial exposure of the anterior tumor extent is seen; in* **K**, *a Rhoton microdissector is used to elevate the tumor away from the planum and tuberculum sellae area; in* **L**, *a ring curette is used to remove tumor extending into the sella; in* **M**, *the cauterized dural remnant is shown. As shown in* **G–I**, *new tumor recurrence is seen in the right tuberculum sellae area under the right optic nerve. Endoscopy was not used in this case. FL, frontal lobe; LAC, left anterior cerebral artery; LO, left optic nerve; RO, right optic nerve; P, planum; OC, optic chiasm; I, infundibulum; T, tumor.*

approach groups were that meningiomas removed by the supraorbital route were larger and had a greater degree of lateral extension and vascular encasement, whereas craniopharyngiomas removed by the endonasal route were predominantly retrochiasmal in location. Additionally, postoperative CSF leaks occurred in 16% of patients treated by an endonasal approach and in no patients treated by a supraorbital approach. In the latter half of the series, when both approaches were used, the majority of craniopharyngiomas (67%) were approached by the endonasal route, whereas the majority of meningiomas (75%) were approached by the supraorbital route. Below, we discuss the evolution of keyhole surgery and the relative advantages and limitations of these 2 specific techniques, and we suggest selection criteria for using 1 approach over another.

## The Keyhole Concept Applied to Parasellar Tumors

As stated by Wilson (79) more than 35 years ago, "The ideal exposure is one which is large enough to do the job well, while preserving the integrity of as much normal tissue as possible." This "keyhole" concept has been increasingly used for removing a wide spectrum of intracranial lesions. Perneczky et al. (63)

and others (67, 68, 77) have shown the utility of the supraorbital craniotomy for parasellar lesions. Similarly, multiple groups (6, 11, 18, 27, 53, 54, 64) have used the transsphenoidal keyhole approach for parasellar tumors with the microscope and endoscope. The increasing use and success of keyhole surgery have been further accelerated by the development of frameless surgical navigation, refinements in low-profile instrumentation, and endoscopy (4, 5, 7, 18, 21). Considering the potential advantages of these more direct and simplified approaches, including less scalp, muscle, and bone dissection, minimal or no brain retraction, and a less painful recovery, there has been a shift away from traditional larger anterior and anterolateral cranial base approaches such as the pterional, bifrontal, and orbitozygomatic craniotomies and the midface degloving transsphenoidal approach (11, 14, 18, 28, 35, 63, 67, 68). Likewise, there is waning enthusiasm for the transpetrosal approach for petroclival tumors and a resurgence of the retrosigmoid craniotomy and endonasal transclival approach to reach such tumors (22, 29, 57, 69, 70).

## Approach Selection Criteria

The decision to approach a craniopharyngioma or suprasellar meningioma by the endonasal, supraorbital, or traditional craniotomy should be based on several factors including tumor pathology, size and growth pattern, cranial base repair requirements, available instrumentation, and surgeon experience. If the surgeon has limited transsphenoidal experience or rarely uses endoscopy, then endonasal removal of these tumors is not recommended, and a transcranial approach should be used.

## Instrumentation

Because of the narrow working corridor of these keyhole approaches, low-profile microinstruments, surgical navigation, the micro-Doppler probe, and endoscopy are all highly recommended if not essential for such cases. Surgical navigation allows precise cranial base landmark identification. The micro-Doppler probe allows carotid localization in the endonasal approach and localization of the anterior circle of Willis vessels in both approaches. Doppler localization is particularly helpful when the vessels are draped over or running in a thin rind of tumor late in the procedure, when surgical navigation is no longer accurate (19). Endoscopy is clearly essential for the endonasal approach. Although a 3- or 4-hand endoscopic technique can be effectively applied with a short endonasal speculum, we increasingly use the endoscope with the speculum removed during the latter part of the procedure, facilitating greater instrument maneuverability. Endoscopy is also now used for all supraorbital cases because it often reveals residual tumor not seen with the microscope. An area where the endoscope is particularly helpful in the supraorbital approach is the region directly under the ipsilateral optic nerve and carotid artery. The tumor recurrence in patient 4 (Fig. 6, G–I) 28 months after gross total tumor removal might have been avoided if endoscopy had been used to better visualize this area to identify accessible tumor remnants.

## Sellar Anatomy

Both craniopharyngiomas and meningiomas can be associated with a deepened or normal-sized sella. Whereas a normal-sized sella is no longer a contraindication for the transsphenoidal approach, a tumor with a deep (inferior) sellar extension might be a relative contraindication for the supraorbital approach. However, as shown in Figure 6, significant sellar tumor extensions can still be reached by the supraorbital route.

## Cranial Base Closure

A supraorbital craniotomy is relatively simple to close even if the frontal air sinus is transgressed, which occurs in fewer than 10% of cases. In contrast, endonasal removal of a craniopharyngioma or tuberculum sellae meningioma will invariably result in an extensive cranial base defect and a large grade 3 CSF leak (23). In our experience, the closure is somewhat easier after craniopharyngioma removal because there is typically less dural opening and dural cauterization than with a meningioma. Others (8), however, have found that endonasal closure is more challenging after craniopharyngioma removal because the third ventricle has been entered. Although our postoperative CSF leak rate for grade 3 leaks has decreased to less than 10% with increasing experience, and repair methods have improved for the purely endoscopic endonasal approach, cranial base repair remains a major consideration before embarking on endonasal brain tumor removal (8, 16, 23, 53, 75).

## Craniopharyngiomas

Although total resection of craniopharyngiomas has been advocated by some, it is associated with a higher morbidity and mortality (81, 82). Consequently, many now opt for subtotal removal if dense adhesions to neurovascular structures are present (3, 65, 76). In recent reports, total removal rates have ranged from 7% to 89% in transsphenoidal series with the microscope and/or endoscope (9, 11, 13, 27, 41, 50, 54, 56), 40% to 74% in supraorbital series (12, 36, 67), and 6% to 100% by the subfrontal or pterional routes (3, 25, 65, 72, 76). Notably, in our series, 78% of tumors approached transsphenoidally had a major component in the retrochiasmal space, whereas only 1 tumor approached by the supraorbital route had retrochiasmal extension. This common growth pattern of craniopharyngiomas into the retrochiasmal space displaces the chiasm into a prefixed or superior location and, in our opinion, facilitates endonasal removal by allowing one to pass under the chiasm and directly into the retrochiasmal space (42). As shown in Figure 4, even large retrochiasmal craniopharyngiomas can be removed with progressive internal debulking and endoscopic visualization. The endonasal approach also obviates the need to transgress the lamina terminalis, a requirement for transcranial removal of most retrochiasmal tumors (2, 17, 72, 76). Although the translamina terminalis approach for craniopharyngiomas is an effective route in experienced hands, it can pose greater risk to the optic apparatus than the endonasal approach (2, 17, 72, 76). In contrast, craniopharyngiomas within the prechiasmatic space can be removed via a supraorbital or endonasal route, whereas tumors with lateral extensions or suprachiasmatic extensions can be most effectively removed by a supraorbital or traditional transcranial approach, as shown in Figure 1.

### Tuberculum Sellae Meningiomas

With progressive growth, tuberculum sellae meningiomas develop lateral and superior extensions, resulting in vascular encasement and optic canal invasion. In the microsurgical era, total or near total tumor removal has ranged from 85% to 100% for cranial base approaches (15, 48, 58, 59), from 66% to 100% by the pterional or subfrontal routes with tumor sizes ranging from 8 to 60 mm (1, 24, 30, 31, 34, 46, 66), and from 70% to 100% by the supraorbital route with tumor sizes up to 85 mm (although not all tumors were located in the tuberculum sellae) (12, 67, 71, 78). The transsphenoidal approach for suprasellar meningiomas has yielded total or near total removal rates of 57% to 85% with tumor sizes ranging from 12 to 37 mm (10, 11, 14, 15, 33, 39, 41, 45, 47). Although the overall rate of total removal was only 47% in this series of meningiomas, all 12 patients who underwent incomplete removal had prior surgery, prior radiotherapy, cavernous sinus invasion, or other vascular encasement—factors previously shown to be associated with incomplete tumor removal (30, 55, 58, 59, 74). Considering that typical meningiomas are highly responsive to SRS and SRT with a low complication rate, attempts at radical resection in patients previously treated or with invasive tumors seem unwarranted and ill-advised (49, 61). The fact that all patients in this series are alive and functional, except 1 who died with an atypical meningioma, suggests that this approach is reasonable.

Prior reports including those of Kitano et al. (48) and de Divitiis et al. (16), along with our results, suggest that transcranial approaches, including the supraorbital route, tend to have higher total or near total tumor removal rates and are better suited for larger tumors. As reflected by our selection of cases, we recommend use of the supraorbital route for meningiomas larger than 30 to 35 mm, those extending well lateral to the supraclinoid carotid arteries, or those with major vascular encasement (Fig. 2). Smaller, less-invasive midline meningiomas can be approached by either route (15, 48, 53). Both approaches allow effective decompression of the optic apparatus with a high rate of visual recovery (16, 48, 53, 67, 78). However, the endonasal approach precludes safe access to the tumor lateral to the optic nerves and along much of the optic canal except medially. In contrast, the supraorbital approach generally allows bilateral access to these areas. Regarding pituitary function, because the infundibulum is pushed posteriorly by these tumors, both approaches yield a low rate of new endocrinopathy (18).

### Study Limitations

In this retrospective technique assessment, we compared 2 keyhole craniotomy approaches for parasellar tumors. Use of the 2 approaches was begun several years apart, follow-up was relatively short, and the study size was small, particularly for patients undergoing supraorbital craniopharyngioma removal. Additionally, no direct comparison was made to patients treated by a traditional craniotomy. These results also reflect an unavoidable personal preference regarding the choice of approach; this selection bias evolved over time based on both personal and collective experience using these approaches. Although our conclusions are logical and anatomically based, longer follow-up and confirmation by others are needed.

## CONCLUSION

The endonasal and supraorbital keyhole approaches provide minimally invasive access for the majority of craniopharyngiomas and tuberculum sellae meningiomas. The optimal approach for a particular patient should be based on tumor anatomy and surgeon experience. Although in many cases either approach can be used, our experience, as well as that of others, suggests that the endonasal route is more appropriate for craniopharyngiomas situated predominantly in the retrochiasmal space. In contrast, the supraorbital route is recommended for tuberculum sellae meningiomas larger than 30 to 35 mm in diameter, those with far lateral extension beyond the supraclinoid carotid arteries, or those with vascular or lateral optic canal encasement. An additional consideration that favors the supraorbital approach over the endonasal route is the simplified cranial base closure and lower risk of a postoperative CSF leak. Finally, although these approaches typically yield an excellent cosmetic result and rapid patient recovery relative to traditional larger craniotomies, they are technically demanding, requiring low-profile instrumentation, endoscopy in most cases, and an ability to maneuver through a narrow operative corridor.

### Disclosure

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## COMMENTS

The study presented by Fatemi et al. deals with a current and controversial topic: the indications for extended transsphenoidal and transcranial approaches used to remove suprasellar tumors. The authors assess the relative advantages, restrictions, and selection criteria of 2 keyhole techniques: endonasal and "eyebrow" craniotomies, which were used in a series of 43 consecutive patients with 22 craniopharyngiomas and 21 tuberculum sellae meningiomas. The majority of the surgical procedures were performed as endoscope-assisted microsurgery. The endoscope was used, in addition to the microscope, in the majority of endonasal procedures (84%) and in only 31% of the procedures using the supraorbital approach, thus confirming the great utility of this tool as a visualizing device during the transnasal approach.

The decision to approach these tumors by endonasal, supraorbital, or other wider craniotomies should be based on tumor features, extension, growth pattern, size, and, last but not least, the extent of the surgeon's experience with both transcranial and transnasal cranial base surgery. The authors clearly outline some of the restrictive situations in which the endonasal approach would be difficult, such as a conchal sella, "kissing" internal carotid arteries, too-lateral extension, main vessel encasement, large size, or asymmetric shape. To overcome these problems the endoscope and neuronavigation are crucial to these procedures, since the fusion of the live endoscopic images with virtual computer-generated images creates additional spatial orientation for the surgeon.

Concerning craniopharyngiomas I completely agree with the authors when they state that the growth pattern of these tumors into the retrochiasmatic space is the major indication for the transnasal approach. In these cases, the displacement of the chiasm into a prefixed or superior location facilitates the endonasal removal; the surgeon passes underneath the chiasm and removes the tumor, working alternatingly on both sides of the stalk, with a wide view of the third ventricle, thus avoiding the transgression of the lamina terminalis.

The authors clearly demonstrate and discuss the benefits and pitfalls of the 2 techniques from a very practical point of view. Their results are reported in a rigorous manner, without trying to influence the reader to prefer one approach over the other, and that makes their conclusions much more reliable. The authors provide a good review of their surgical and clinical experience on minimal access to the midline cranial base. We look forward to more vigorous assessment of long-term results; random allocation of a large number of patients into each group (transnasal versus transcranial) would have allowed for a better comparison of the 2 techniques.

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This is an outstanding article written by very accomplished minimally invasive surgeons. The article describes 2 routes to the perichiasmatic space, both of which are minimally invasive. The authors have had extensive experience with both of these routes as pioneers in the supraorbital keyhole approach as well as the endonasal approach. This uniquely positions them to give insight into the advantages of each. Their results are outstanding and honestly reported. Their technique is nicely described, and the article is written in a thoughtful, articulate manner that is geared toward helping the reader develop understanding and experience.

As champions of the supraorbital approach, they have addressed all of the key nuances of this approach and beautifully describe it. With regard to the endonasal approach, there are some slight variations in the authors' technique, of which the reader should be aware. Endonasal approaches can vary significantly between institutions according to surgeon experience, personal preference, background, and training, and this is reflected in all of the literature that we read. The technique that is described in this report is one that has been a mainstay in endonasal surgery using a combination of microscopy and endoscopy. This technique is also speculum based, although, as the authors point out, they have now moved more and more toward a speculum tailored for expanded approaches as well as the endoscope. This has been a beautiful addition to the instrumentation. In addition, toward the end of the procedure, the speculum is removed altogether. These minor variations in technique may affect the selection of tumor types that are reported herein.

At our institution, we have generally relied more on a completely endoscopic approach, with binarial access using microsurgical principles and purely endoscopic visualization. Using this technique, what we have found is that rather than lesion size being a limitation, lateral extent and position relative to the orbit are the limiting factors. Specifically, although we have removed tumors that are over 3 cm, in general we have restricted this technique to tumors that are between the midlines of the orbits. Lesions that extend beyond this are best approached from a lateral, supraorbital approach. With regard to craniopharyngiomas, rather than location relative to the chiasm, it has really been location relative to the infundibulum that has been the determining factor in the specific endonasal approach that has been used (1). When deciding to use a transcranial route for craniopharyngiomas, if the lesion spills lateral to the plane of a cranial nerve, we have opted not to cross the plane of that nerve endonasally but have instead used transcranial or combined approaches.

Despite these minor variations, we are glad to see that the authors have detailed an approach to managing these lesions that is both efficacious and safe, based on their results. The authors' contribution to the field is demonstrated in this excellent article.

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1. Kassam AB, Gardner PA, Snyderman CH, Carrau RL, Mintz AH, Prevedello DM: Expanded endonasal approach, a fully endoscopic transnasal approach for the resection of midline suprasellar craniopharyngiomas: A new classification based upon the infundibulum. **J Neurosurg** 108:715–728, 2008.

When a successful novel technique or concept in surgery is introduced, the evolution is fairly predictable. The originators have difficulty in restraining their enthusiasm, push the edge of the envelope of indications, and attempt to convince others that the innovation is a bona fide advance. This infectious enthusiasm is often met with resistance, if not scorn, from the "old-timers," experienced surgeons who have a fine record of excellent outcomes using standard, time-tested methods.

The minimally invasive craniotomy and transnasal endoscopic anterior cranial base approaches discussed in this article are cases in point. This article comes along well after the techniques described have been accepted and validated by many (1, 2, 4, 5). It provides, however, a unique and balanced critical assessment of the advantages and disadvantages, described by a thoughtful and mature devotee, who himself has added important concepts to the basic ideas discussed.

A number of provocative questions are implicit in this article. Is it always necessary to use a pure endoscopic approach (3)? How does one best combine basic principles of cranial base surgery and microneurosurgery in the quest for better outcomes regarding tumor removal, reversal of visual loss, and preservation of pituitary endocrine function? What new complications and pitfalls accompany these novel procedures? As with many new techniques, more time must pass before one can evaluate the impact they may have on long-term results.

The numbers of patients reported in this article are relatively small, particularly for comparing one technique against the other. There is an acknowledged selection bias, but this is helpful in considering patient selection for one or the other approach.

For these reviewers, the article provides important insights into the relative merits and concerns of the supraorbital keyhole and endonasal extended transsphenoidal routes of exposure. It also makes important distinctions related to the surgical implications of both craniopharyngiomas and tuberculum sellae meningiomas.

For craniopharyngiomas that enlarge the sella and extend into the suprasellar space, the transsphenoidal approach is eminently suitable (6, 7). One should keep in mind the finding of Jules Hardy, noted many years ago, that an intrasellar origin usually means that the diaphragm is a barrier between the dorsal aspect of the tumor and the optic chiasm and hypothalamus. For craniopharyngiomas that arise anterior or superior to the optic chiasm, the supraorbital approach is excellent, providing a fine scope of exposure for most centrally placed lesions. For the suprasellar retrochiasmatic craniopharyngioma, this article provides further evidence of the suitability of the extended transsphenoidal approach, which has been highly effective in tumor removal and in preservation and restoration of vision (1, 5). Difficulties with cranial base closure remain, but they are not insurmountable.

For relatively small, centrally oriented tuberculum sellae meningiomas, traditional craniotomy approaches, the supraorbital keyhole approach, or the extended transsphenoidal approach may all provide excellent results with regard to improvement of visual loss (2). These approaches may differ significantly, however, with regard to completeness and safety of tumor removal, particularly if there is lateral spread of the meningioma origin toward the optic canals or the supraclinoid carotid arteries. The careful surgeon cannot accept constraints to lateral exposure in such tumors, and comprehensive imaging analysis and neuro-ophthalmological studies can often lead to an optimal choice of exposure. With these tumors, when it is appropriate, the extended transsphenoidal approach has several advantages. These include lack of brain exposure and retraction and the ability to devascularize the tumor by cauterization of its dural origin along the planum and tuberculum. Once again, cranial base closure can be a difficult aspect of the procedure.

This excellent and reflective article reinforces the potential virtues of 2 relatively new minimally invasive approaches. In doing so, it adds to our versatility as surgeons in dealing with difficult centrally located lesions. It reminds us that the welfare of the patient is the dominant goal of our efforts, and the matching of the procedure to the lesion and to the patient is our ultimate challenge.

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1. Dumont AS, Kanter AS, Jane JA Jr, Laws ER Jr: Extended transsphenoidal approach, in Sheehan JP, Laws ER (eds): *Frontiers of Hormone Research: Pituitary Surgery—A Modern Approach.* Springer, New York, 2006, vol 34, pp 29–45.
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The present study reported by Fatemi et al. regards a series of patients operated on by the same surgeon, who is an expert in both endonasal transsphenoidal surgery and supraorbital "eyebrow" craniotomy. The article retrospectively analyzes craniopharyngiomas and tuberculum sellae meningiomas operated on using both of these minimally invasive techniques. The title may be misleading because it seems to compare these 2 minimally invasive approaches. In fact, the selection criteria adopted for choosing the approach preclude comparison of the 2 groups of patients. Nevertheless, the article is original and interesting because it describes a rationale and the indications and contraindications for using the supraorbital versus the endonasal approach for these 2 tumor types. The authors' opinion is that the endonasal route should be preferred for most retrochiasmal craniopharyngiomas, whereas the supraorbital route is recommended for meningiomas that are more than 30 mm in diameter or that have grown beyond the supraclinoid carotid arteries. For smaller midline tumors, both approaches are effective, and the choice depends on the anatomy of the tumor and the surgeon's experience. The value of such selection criteria is confirmed by the satisfactory results and the low complication rate obtained.

The merit of the study consists in its innovative characteristics and suggestions; however, since the technique is new and in the process of being developed, the series is small and has only a short follow-up. The latter is the main limitation of the study, which renders it only an "author's opinion" or technical assessment. In the near future, a cooperative study is needed with a larger series of patients and a longer follow-up to change opinion into scientific evidence.

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The authors have retrospectively reviewed a series of 43 patients with 2 different pathologies: meningioma and craniopharyngioma. The title of the article is "Endonasal versus supraorbital keyhole removal of craniopharygiomas and tuberculum sellae meningiomas" because these two approaches were used. However, even though the title suggests a comparitive approach, the authors have, wisely, avoided an actual comparison. Indeed, it would have been futile to compare the 2 different pathologies treated, depending of the surgeons choice, by 1 of 2 (of many possible) different approaches, none of which can be designated a "gold standard." Such an analysis would be similar to comparing apples and oranges or the different cooking techniques of oven baking and juicing. One technique is superior for apple pie, whereas another results in orange juice. The choice reflects what you already know and what you want to achieve.

Although this study reflects high quality surgical treatment, its actual aim remains unclear. The authors formulate a number of recommendations, but these do not follow from the data and should already be obvious to any surgeon endeavouring to perform minimally invasive surgery for difficult lesions in the vicinity of the optic chiasm. This study has many shortcomings as a scientific report. The narrow scope of treatment and the rationale of choosing between only 2 minimally invasive approaches are not explained. Follow up-data are nonsystematic and insufficient. The authors acknowledge these weaknesses and state that they will collect prospective data in the future. The extent of critical analysis is minimal, and the authors have justified, rather than revised, their text and analyses throughout the reviewing process. Subsequently, this article is of limited value for the neurosurgical community. It is a presentation of good technical surgery with minimally invasive approaches.

I must, however, question whether the choice of minimal approaches was adequate for complex lesions that were not radically treatable. Moreover, why did the authors not change to a more adequate approach that would have possibly allowed radical meningioma surgery? Many patients underwent minimally invasive, but subtotal, surgery, and are still exposed to all dangers of recurrence: a Simpson grade 4 removal carries a recurrence rate greater than 80%.

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*Johannes Scultetus, 1595–1645,* ***Armamentarium chirurgicum XLIII. tabvlis æri elegantissime incisis, nec ante hac visis, exornatum. New York: Editions Medicina Rara, 1972*** *(reproduced from the original 1655 Ulm edition by B. Kühnen). Courtesy, Rare Book Room, Norris Medical Library, University of Southern California, Los Angeles, California.*