

Olfactory groove meningiomas: supraorbital keyhole versus orbitofrontal, frontotemporal, or bifrontal approaches

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OBJECTIVE Olfactory groove meningiomas (OGMs) often require surgical removal. The introduction of recent keyhole approaches raises the question of whether these tumors may be better treated through a smaller cranial opening. One such approach, the supraorbital keyhole craniotomy, has never been compared with more traditional open transcranial approaches with regard to outcome. In this study, the authors compared clinical, radiographic, and functional quality of life (QOL) outcomes between the keyhole supraorbital approach (SOA) and traditional transcranial approach (TTA) for OGMs. They sought to examine the potential advantages and disadvantages of open/TTA versus keyhole SOA for the resection of OGMs in a relatively case-matched series of patients.

METHODS A retrospective, single-institution review of 57 patients undergoing a keyhole SOA or larger traditional transcranial (frontotemporal, pterional, or bifrontal) craniotomy for newly diagnosed OGMs between 2005 and 2023 was performed. Extent of resection, olfaction, length of stay (LOS), radiographic volumetric assessment of postoperative vasogenic and cytotoxic edema, and QOL (using the Anterior Skull Base Questionnaire) were assessed.

RESULTS Thirty-two SOA and 25 TTA patients were included. The mean EOR was not significantly different by approach (TTA: 99.1% vs SOA: 98.4%, $p = 0.91$). Olfaction was preserved or improved at similar rates (TTA: 47% vs SOA: 43%, $p = 0.99$). The mean LOS was significantly shorter for SOA patients (4.1 ± 2.8 days) than for TTA patients (9.4 ± 11.2 days) ($p = 0.002$). The authors found an association between an increase in postoperative FLAIR cerebral edema and TTA ($p = 0.031$). QOL as assessed by the ASBQ at last follow-up did not differ significantly between groups ($p = 0.74$).

CONCLUSIONS The keyhole SOA was associated with a statistically significant decrease in LOS and less postoperative edema relative to traditional open approaches.

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KEYWORDS meningioma; skull base; olfactory groove; supraorbital; eyebrow; transcranial; pterional; bifrontal; oncology

OLFACtory groove meningiomas (OGMs) arising from the skull base and cribriform plate can often present with subtle symptoms, such as diminished sense of smell or headaches, and can often go undetected until they have grown to a large size.¹ Resection is often indicated for OGMS causing symptoms, brain edema, or demonstrating growth. Multiple surgical approaches can be used for resection of OGMS including traditional transcranial approaches (TTAs) (unilateral frontotemporal/pterional, orbitozygomatic, or bifrontal craniotomies)^{2–7}

as well as minimally invasive alternatives such as the endoscopic endonasal approach (EEA)^{8,9} or keyhole, endoscope-assisted craniotomies such as the eyebrow/supraorbital approach (SOA).^{10–14}

Each approach has advantages and disadvantages. The bifrontal craniotomy, with or without a supraorbital osteotomy, allows the harvesting of a large pericranial flap so that if the cribriform plate is removed, a suitable reconstruction can be easily performed. However, sacrifice of the superior sagittal sinus and brain retraction can cause

ABBREVIATIONS ASBQ = Anterior Skull Base Questionnaire; DWI = diffusion-weighted imaging; EEA = endoscopic endonasal approach; EOR = extent of resection; LOS = length of stay; OGM = olfactory groove meningioma; QOL = quality of life; SOA = supraorbital approach; TTA = traditional transcranial approach.

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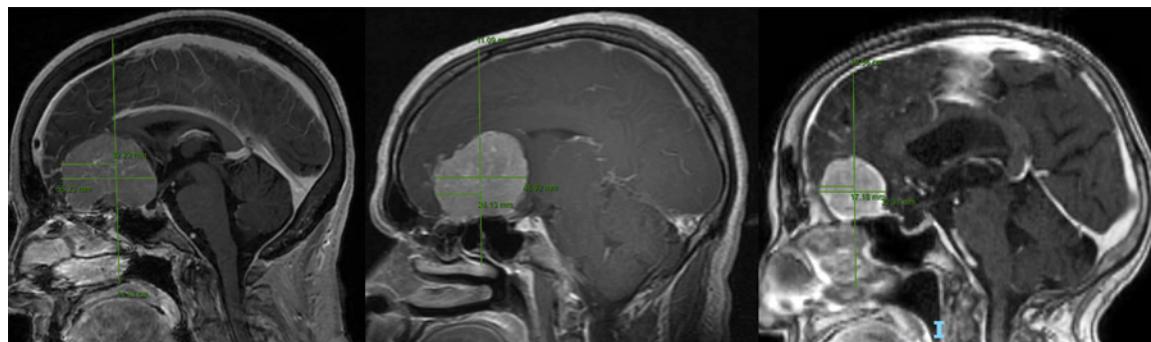


FIG. 1. Representative sagittal contrast-enhanced T1-weighted MR images obtained in 3 patients with OGMs included in this study based on > 25% of the anteroposterior tumor diameter overlying the cribriform plate and anterior to the insertion of the sphenoid sinus. Figure is available in color online only.

cerebral contusion or venous infarcts, and postoperative anosmia is common. With the advent of stereotactic radiosurgery, the need for complete cribriform plate removal is questionable for durable tumor control.¹⁵ The orbitofrontal and pterional approaches allow preservation of at least one of the olfactory nerves but still require some degree of brain retraction and often do not include removal of the cribriform plate.^{5,10,11} The EEA minimizes brain retraction and permits removal of the cribriform plate, which might decrease rates of recurrence, but anosmia is almost universal, and the narrow corridor may not provide appropriate exposure of the lateral extent of the tumor. Moreover, skull base reconstruction can be challenging, leading to higher rates of postoperative CSF leakage.^{9,16} The keyhole SOA, though an eyebrow incision, offers another minimal access option, with similar advantages and disadvantages as the orbitofrontal or pterional approaches but with a small skin incision and bone opening.¹¹ In theory, this smaller approach may be better tolerated by patients, leading to a shorter length of stay (LOS) in the hospital, possibly less brain retraction and injury, and improved quality of life (QOL). On the other hand, a small opening makes surgical exposure challenging, requiring endoscope assistance and leading to the possibility of a less extensive resection.

Head-to-head comparisons between different approaches are very difficult to perform since tumors can vary greatly in their size and morphology, so matching cases is challenging. Different surgeons tend to prefer certain approaches, so it is rare to accumulate enough cases at one center for such a comparison. Few data exist comparing open and keyhole craniotomies for OGMs with regard to clinical, radiographic, and QOL outcomes. In this retrospective, single-institution analysis, we aimed to examine the potential advantages and disadvantages of open/TTA versus keyhole SOA for the resection of OGMs in a relatively case-matched series of patients.

Methods

This study was approved by the institutional review board at Weill Cornell Medical College. Pathology records from 2000 to 2023 at NewYork-Presbyterian/Weill Cornell Medical College were queried to identify all pa-

tients who underwent surgery for a meningioma during this study period. From the 1947 patients identified with meningiomas, 74 OGMs were identified based on chart and radiology report and imaging review. OGMs were defined by greater than 25% of the tumor overlying the cribriform plate and anterior to the insertion of the front wall of the sphenoid sinus into the back of the cribriform plate (Fig. 1).

All reoperations and EEA cases were first excluded. To find a comparable group of tumors, we only aimed to include tumors that might be amenable to an SOA for inclusion in the study. To accomplish this, a de-identified series of preoperative images for the remaining patients with contrast-enhanced coronal, sagittal, and axial T1-weighted MR images through the maximal diameter of the tumor were evaluated by the senior author (T.H.S.) to identify lesions that would be amenable to SOA. The selection criteria used by the senior author for OGMs has been previously described.^{11,16} Patients were excluded ($n = 11$) for contraindications to SOA including a large frontal sinus, tumor extension into the middle fossa, anterior extent of tumor abutting the frontal bone, and convex/scaphoid shape of the sphenoid sinus that would prevent reaching the inferior extent of the tumor (Fig. 2). Tumor size is not specifically used as an exclusion criterion; however, larger OGMs may be excluded because of the other exclusion criteria listed. Tumors that are situated ventrally, against the back wall of the frontal sinus, have significant optic canal invasion or extension into the ethmoid sinuses, are less suitable for an SOA. Tumor extension laterally is not considered a limitation for the SOA, as the entire width of the anterior fossa can be reached with this approach. Case selection is vital to successful implementation of keyhole approaches.

At this point, there were 32 OGMs in the SOA group and 29 in the larger open craniotomy group. However, the average volume of the tumors in the open cranial group was $48.4 \pm 32 \text{ cm}^3$ and average volume in the keyhole SOA group was $25.6 \pm 20 \text{ cm}^3$. To better match the two groups, we excluded all cases removed by a TTA if the volume of the tumor was greater than the largest OGM resected by keyhole SOA ($> 75 \text{ cm}^3$, $n = 4$). The remaining patients underwent retrospective chart review including demographics, surgical approach, extent of resection, postop-



FIG. 2. Representative sagittal contrast-enhanced T1-weighted MR images obtained in patients who were excluded because of a large frontal sinus (**A**), tumor abutting frontal bone (**B**), and scaphoid shape of the sphenoid sinus (**C**). Figure is available in color online only.

erative complications, postoperative sense of smell, and postoperative LOS. Fifty-seven patients met these criteria and were included for complete analysis. All surgeries were completed by surgeons specializing in brain tumor surgery with experience in skull base meningiomas. The Anterior Skull Base Questionnaire (ASBQ), a 35-question quantitative QOL tool previously described by Gil et al.,¹⁷ was administered by telephone or email at the time of last follow-up.

Volumetric Analysis

Immediate pre- and postoperative MR images for each patient were imported into the AW Server 3.2 Volume Viewer Reformat software (GE Healthcare) for 3D volumetric analysis. Pre- and postoperative sequences included T1-weighted, T1-weighted postgadolinium contrast, T2-weighted FLAIR, diffusion-weighted imaging (DWI) and apparent diffusion coefficient sequences. When MR images were not available, CT scans were used instead. Images were interpreted and reviewed by trained board-certified or board-eligible radiologists.

The auto-select segmentation tool was used to draw borders around the object of interest, and the volume calculator was then used to report volume measurements (in cm³). Tumor volume was defined as T1-weighted postgadolinium enhancement on pre- and postoperative images. Intrinsically high T1 signal on postoperative precontrast imaging was assumed to be postsurgical blood products and was not recorded as residual tumor. Brain edema was defined as high signal on FLAIR sequences, and diffusion restriction was determined to be high signal on DWI sequences with a corresponding dark signal on apparent diffusion coefficient sequences. No patients had diffusion restriction in the brain parenchyma outside of the tumor area preoperatively. Postoperative DWI findings were recorded as high signal in the brain parenchyma surrounding the resected tumor and did not include the residual tumor volume itself, if applicable. The anteroposterior dimension of the tumor in the sagittal plane was measured on the T1-weighted postcontrast sequence in addition to the anteroposterior dimension of the tumor extending anterior to the sphenoid sinus. A percentage of the tumor

anterior to the sphenoid sinus was then calculated. Indeterminate cases were reviewed with a senior radiologist for verification. Patients with incomplete imaging were excluded from volumetric analysis.

Statistical Analysis

Descriptive statistics such as proportions, means, and standard deviations were used to characterize the cohort. Statistical significance was assessed using the Mann-Whitney U-test or chi-square test for continuous and categorical variables, respectively, with $\alpha < 0.05$ indicating significance. Fisher's exact test was used for categorical variables where the sample included fewer than 5 patients. Associations between approach and change in FLAIR volume were tested using multivariable linear regression with change in FLAIR volumes as the dependent variable and approach as the independent variable, including age, sex, and preoperative FLAIR volume as independent controls. All tests were performed using R (The R Foundation for Statistical Computing).

Results

Patient Demographics

Fifty-seven patients with OGMs were included in this study; 32 (56%) patients underwent a keyhole SOA for resection and 25 (44%) had a larger open/TTA (Table 1). Approaches used in the TTA group were unilateral frontotemporal or orbitozygomatic craniotomies in 56% ($n = 14$) and bifrontal craniotomies in 44% ($n = 11$). Overall, 70% of patients were female, with 76% in the TTA group and 66% in the SOA group. The mean age at the time of surgery was 58.16 years for the TTA cohort and 57.95 years for SOA patients. The median dates of service for SOA and TTA were July 8, 2016, and May 6, 2015, respectively. The most common presentation was as an incidental finding (26%) or with headache/dizziness (26%). Altered mental status was also seen in 25% of patients but was more common in the TTA group (36%) than the SOA group (16%); however, this did not reach significance ($p = 0.08$). Presence or absence of olfaction was recorded preoperatively in 50 patients. Overall, 62% of patients had intact

TABLE 1. Patient demographics

	SOA (n = 32)	TTA (n = 25)	p Value
Clinical description			
Age in yrs, mean \pm SD	57.95 \pm 14.02	58.16 \pm 16.16	0.87
Female, n (%)	21 (66)	19 (76)	0.40
Presenting symptom, n (%)			
Incidental finding	9 (28)	6 (24)	0.73
Headache/dizziness	11 (34)	4 (16)	0.14
Altered mental status	5 (16)	9 (36)	0.08
Seizure	2 (6)	3 (12)	0.65
Loss of smell	2 (6)	1 (4)	0.99
Loss of vision	3 (9)	2 (8)	0.99
Preop olfaction, n (%)			
Intact	21/30 (70)	10/20 (50)	
Diminished	1/30 (3)	7/20 (35)	
Anosmic	8/30 (27)	3/20 (15)	
Median follow-up, mos (range)	32 (0.36–180)	47 (0.91–215)	0.66

olfaction preoperatively (70% of the SOA group and 50% of the TTA group), while the remainder had diminished olfaction or were anosmic preoperatively. The median follow-up for the entire cohort was 39 months.

The mean \pm SD preoperative tumor volume was significantly larger in the TTA group ($38.3 \pm 20.3 \text{ cm}^3$) than in the SOA group ($25.6 \pm 20.0 \text{ cm}^3$; $p = 0.02$). Preoperative FLAIR volume was highly variable, but on average larger in the TTA group (44.5 ± 45.1 vs $27.1 \pm 45.65 \text{ cm}^3$, $p = 0.12$). The mean percentage of tumor anterior to the sphenoid was approximately 48% in the TTA group and 56% in the SOA group ($p = 0.19$).

Radiographic Outcome Measures

The mean extent of resection (EOR) did not differ significantly between the TTA and SOA cohorts (99.1% vs 98.4%, $p = 0.91$) (Table 2). The postoperative mean change in FLAIR volume was not significantly different by approach (TTA: $7.1 \pm 24.4 \text{ cm}^3$ vs SOA: $6.0 \pm 12.5 \text{ cm}^3$, $p = 0.54$). Similarly, the change in diffusion restriction (DWI) was not significantly different for TTA and SOA patients ($14.9 \pm 13.7 \text{ cm}^3$ and $13.2 \pm 13.1 \text{ cm}^3$, respectively; $p = 0.57$). After stratifying patients by change in FLAIR $> 0 \text{ cm}^3$ (23 SOA patients and 13 TTA patients) and FLAIR $< 0 \text{ cm}^3$ (6 SOA patients and 8 TTA patients), we found that an increase in FLAIR postoperatively (i.e., change in FLAIR $\geq 0 \text{ cm}^3$) was associated with male sex ($p = 0.021$) and approach ($p = 0.031$) with increased risk in the TTA group.

Clinical and QOL Outcomes

The mean LOS after surgery was significantly shorter in the SOA group than in the TTA group (4.1 ± 2.8 days vs 9.4 ± 11.2 days, $p = 0.002$). To assess the potential impact of changing practice guidelines, we stratified LOS by earlier versus later cases (e.g., before and after January 1, 2016) and found that the median LOS remained

TABLE 2. Radiographic, clinical, and QOL outcomes

	SOA	TTA	p Value
Radiographic outcomes, mean \pm SD*			
Preop tumor vol, cm^3	25.6 \pm 20.0	38.3 \pm 20.3	0.02
Preop FLAIR vol, cm^3	27.1 \pm 45.7	44.5 \pm 45.1	0.12
% tumor anterior to sphenoid	56 \pm 20	48 \pm 18	0.19
EOR, %	98.4 \pm 5	99 \pm 2	0.91
Postop change in FLAIR, cm^3	6.0 \pm 12.5	7.09 \pm 24.4	0.54
Postop change in DWI, cm^3	13.2 \pm 13.1	15.0 \pm 13.7	0.57
Clinical outcomes			
LOS in days, mean \pm SD	4.1 \pm 2.8	9.4 \pm 11.2	0.002
Postop olfaction, n (%)			
Stable intact	11/30 (37)	8/19 (42)	
Stable anosmic	7/30 (23)	3/19 (16)	
Worsened	10/30 (33)	7/19 (37)	
Improved	2/30 (7)	1/19 (5)	0.99
Recurrence, n (%)	3 (9)	2 (8)	0.99
Complications, n (%)			
Any complication†	6 (19)	3 (12)	0.72
CSF leak/pseudomeningocele	3 (9)	0	
Infection	1 (3)	0	
Seizure	1 (3)	1 (4)	
SAH/SDH/EDH	1 (3)	2 (8)	
Pulmonary embolism	1 (3)	0	
Mortality	1 (3)	0	
Quality of life, mean \pm SD			
ASQB total score‡	131.7 \pm 22.3	128.3 \pm 26.2	0.74
Performance	22.3 \pm 5.7	21.4 \pm 5.2	0.67
Physical function	28.4 \pm 7.2	28.5 \pm 6.6	0.95
Vitality	26.0 \pm 5.3	25.3 \pm 7.4	0.97
Pain	13.1 \pm 2.5	13.3 \pm 2.4	0.97
Emotions	17.5 \pm 3.8	16.8 \pm 4.9	0.66
Specific symptoms	24.9 \pm 5.1	23.0 \pm 5.7	0.23

EDH = epidural hematoma; SAH = subarachnoid hemorrhage; SDH = subdural hematoma.

* Two patients in the TTA group did not have preoperative MRI available and were excluded from radiographic analysis.

† Any complication is based on the number of patients experiencing complications, not the total number of complications.

‡ Available in 24 patients in the SOA group and 17 patients in the TTA group.

shorter for SOA than for TTA patients (4 vs 9 days prior to 2016, $p = 0.018$ [Mann-Whitney U-test]; and 3 vs 4 days after 2016, $p = 0.012$ [Mann-Whitney U-test]). Controlling for preoperative tumor volume as a covariate and LOS as the dependent outcome, linear regression found that SOA remained associated with significant reductions in LOS. There were no significant differences in olfaction outcomes by approach ($p = 0.99$). Improvement in preoperative anosmia or diminished smell was rare (6% of all patients with recorded postoperative olfaction outcomes; 6.7% in the SOA group and 5.3% in the TTA group). Sta-

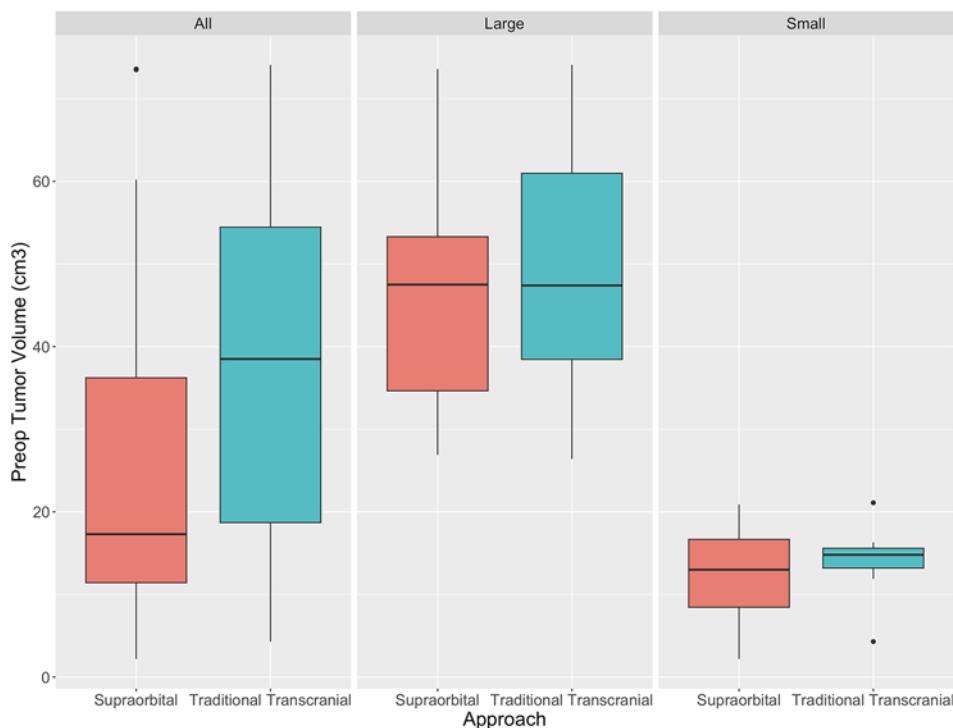


FIG. 3. Preoperative tumor volume distribution by SOA and TTA included in this study and stratified by large and small tumors. Dots indicate outliers. Figure is available in color online only.

ble olfaction was seen in 42% of TTA patients and 37% of SOA patients. A postoperative decrease in olfaction occurred in 36.8% and 33.3% of patients undergoing TTA and SOA, respectively.

QOL was assessed at the time of last follow-up and was compared between TTA and SOA patients, with responses from 72% ($n = 41$) of patients. ASBQ total scores were not significantly different for TTA or SOA patients (128.3 ± 26.2 vs 131.7 ± 22.3 , respectively; $p = 0.74$). ASBQ subscores including performance, physical function, vitality, pain, emotions, and specific symptoms were also assessed by approach, without statistically significant differences demonstrated within any category. Tumor recurrences occurred in 8% ($n = 2$) of TTA and 9.4% ($n = 3$) of SOA patients ($p = 0.99$). One patient underwent an endoscopic endonasal resection of a small residual with gross-total resection, 3 recurrences were referred for stereotactic radiosurgery, and the remaining patient was monitored with serial imaging.

Complications occurred in 6 (19%) SOA patients and 3 (12%) TTA patients ($p = 0.72$). One SOA patient required repeat surgery for postoperative infection. CSF leak/pseudomeningocele occurred in 3 (9.4%) SOA patients, but no TTA patients (0%). One patient was treated by lumbar drainage alone and another with lumbar drainage and dural repair. The remaining CSF leak was persistent and treated by ventriculoperitoneal shunt insertion, which was subsequently complicated by pulmonary embolism and death. Seizure occurred in 1 TTA and 1 SOA patient. Postoperative subdural hematoma occurred in 1 patient per group and required reoperation. One TTA patient ex-

perienced subarachnoid hemorrhage and new postoperative neurological deficits.

Outcomes of Small Versus Large Tumors

Despite efforts at matching tumors that could be accessed by either SOA or TTA, the median tumor sizes and distributions were different between the approaches (Fig. 3). As such, tumors were stratified into small or large according to the median tumor volume for the entire cohort (26.4 cm^3); 20 SOA patients and 8 TTA patients had small tumors ($< 26.4 \text{ cm}^3$), and 12 SOA patients and 15 TTA patients had large tumors ($> 26.4 \text{ cm}^3$).

For small tumors, no significant difference was noted between TTA or SOA outcomes in EOR (99.1% vs 98.5%, $p = 0.94$), change in FLAIR volume ($p = 0.98$), or change in DWI ($p = 0.77$). The LOS was shorter for SOA patients (3.6 ± 1.8 days) than for TTA patients (12.6 ± 18.5 days) but did not reach statistical significance ($p = 0.24$). Postoperative olfaction worsened in 35% of SOA and 28.6% of TTA patients with small tumors. ASBQ scores did not demonstrate a significant difference between approaches ($p = 0.85$).

For large tumors, SOA patients had shorter LOS at 5 ± 4.0 days versus 8.5 ± 5.8 days for TTA patients ($p = 0.02$). EOR ($p = 0.94$), change in FLAIR volume ($p = 0.53$), and change in DWI ($p = 0.46$) did not significantly differ between approaches. The increase in DWI, however, was significantly greater in large tumors than in small tumors for both approaches ($p < 0.001$). Postoperative olfaction worsened in 30% of SOA patients and 40% of TTA pa-

tients with large tumors. ASBQ scores did not significantly differ for large tumor outcomes ($p = 0.96$).

Discussion

The optimal method for the resection of OGMs is widely debated.^{8,16,18–22} This series is the largest known to date that directly compares a keyhole, endoscope-assisted eyebrow SOA with a traditional unilateral or bifrontal TTA to try and determine if the smaller opening provides any advantages with regard to a variety of different outcome metrics. First, we found that the keyhole approach does not lead to a lesser EOR compared with open craniotomy. In our experience, the liberal use of endoscope assistance and the use of angled instrumentation contributes greatly to the success of this surgery. Likewise, recurrence rates were similar, around 9% (albeit with limited follow-up), which was consistent with prior reports of 5%–17%.^{3,4,6,23} Postoperative anosmia rates are also comparable, with roughly half of patients who had preoperative smell losing it and the other half maintaining it, clearly showing superiority to the endonasal approach. The two areas where the SOA keyhole approach offered an advantage were in LOS, which was roughly half the LOS for the standard craniotomy, and in postoperative FLAIR signal in the brain, where the keyhole approach was a predictor of less risk of postoperative FLAIR volume increase. Long-term QOL was similar between the two approaches.

The most relevant finding of this study was that the SOA was statistically correlated with a shorter LOS compared with a larger traditional craniotomy. Shorter LOS translates not just to faster recovery but also more cost-effective care.²⁴ The average LOS in prior large open transcranial series ranged from 8 to 18 days, which is consistent with our TTA cohort.^{3,8,25,26} In prior EEA series, the average LOS ranged from 9.9 to 14 days.^{8,9,27} The SOA, on the other hand, has been previously reported to be associated with an LOS of approximately 2 days, and in this larger cohort an average of 4 days.^{11,28} The fast recovery in this SOA group supports a lower postoperative pain burden and earlier mobilization with the keyhole approach. Not only does the shorter LOS translate to reduced hospitalization costs and more cost-effectiveness, but it may also reduce morbidities related to long-term hospitalizations such as nosocomial infections or venous thrombosis.²⁶ Furthermore, as LOS has increasingly become used as a metric for quality-based healthcare, efforts to minimize LOS are vital for quality improvement efforts. With all else being equal, the decrease in patient and hospital burden cannot be overstated.

Comparisons have previously been made between different approaches for OGMs. Comparing unilateral or bifrontal TTAs, some studies have found less swelling, smaller parencephalic cavities, and fewer life-threatening complications with unilateral approaches.^{2,3} In this series, unilateral and bifrontal TTAs were not separated because, as a single-center study, our cases numbers were fairly limited to begin with, although more of the cases were unilateral rather than bifrontal approaches. We found that the SOA was indeed less likely to result in an increase in FLAIR volume in the brain, although on average, the

FLAIR changes were comparable between the two groups. However, a limitation to this study was that we were unable to perfectly match the sizes of the tumors in both groups, and so it remains possible that this result was skewed by the few larger tumors in the TTA group.

Several papers have tried to compare EEA with TTA for OGMs, and these have generally reported that TTA leads to a greater EOR, with less risk of CSF leak, shorter LOS, and less risk of anosmia.^{19,20,22,29–31} Although the EEA technique is improving,⁹ which may reduce postoperative brain injury⁸ and provides the opportunity for a Simpson grade I resection, it is debatable whether the Simpson scale is a desirable or useful metric in the modern age, where residual tumors are better appreciated by postoperative imaging and small residual tumor remnants can easily be treated with radiation therapy.^{11,15,30} One small study compared the SOA with EEA and found that the SOA provided a higher rate of gross-total resection with fewer complications.¹⁰

The ability to preserve olfaction is a primary advantage of the TTA and SOA over EEA for OGMs.^{10,11,16,19,20,29} Sense of smell has been reported to be preserved in 24%–55% of TTA cases.^{5,6,18,21,23} Prior reports have had inconsistent findings regarding a benefit of unilateral or bifrontal TTA olfactory outcomes. A systematic review by Bamimore et al. demonstrated no difference,²¹ while other case series suggested an advantage for a unilateral TTA.^{2,5} The findings in this series are consistent with prior reports, demonstrating that roughly half of patients with intact preoperative olfaction maintained some olfaction postoperatively regardless of whether SOA or lateral TTA were used.

QOL is another metric often used to compare outcomes from different surgical approaches. EEA and open techniques have been compared with respect to QOL, and most studies have found that after a brief decline in nasal QOL, the EEA tends to offer advantages given the lack of a skin incision or muscle and bone dismantlement.^{32,33} We compared long-term QOL and found no difference between the SOA and TTA. However, the majority of these questionnaires were administered more than 1 year after surgery. This was necessary given the retrospective nature of the study. However, given that OGMs are benign tumors with an overall excellent long-term outcome, it is perhaps not surprising that both approaches were comparable.

Limitations

As a retrospective comparison with limited sample sizes, patients could not be perfectly matched between the SOA and TTA groups. As such, there were differences in the distribution of tumor sizes between the cohorts. However, all cases were screened and considered amenable to either an open approach or SOA based on a variety of factors described above and also analyzed based on tumor size. The small sample sizes in this study also limited the power to determine statistical differences between the groups. Because of the limited follow-up in a benign, slow-growing tumor, no conclusions can be made regarding differences in overall recurrence rates between the groups. Moreover, although we found similar results across small and large tumors regarding LOS, it should be noted that SOA was more frequently used for smaller tumors and that

for the SOA, case selection is vital in its successful use and these findings do not apply to all OGMs. Radiological analysis was conducted by unbiased, trained radiologists who were technically blinded and not given information regarding the approaches used in the cases; however, this information could have been deduced from the imaging. The importance of radiographic FLAIR or DWI changes are unknown with regard to clinical correlation but are being used as a correlate for the amount of brain retraction and its effect on the brain.^{8,34} The administration of QOL measures at variable times from surgery was also limited by response biases and recall bias and did not control for other medical illnesses experienced between the time of surgery and the administration of the questionnaire.

Conclusions

The keyhole SOA, in select cases, offers comparable EOR and olfaction preservation to more traditional unilateral transcranial open approaches. However, the smaller opening may reduce the LOS and the incidence of increased FLAIR signal in the brain after surgery. More well-matched studies with larger numbers of patients will be required to definitively address these questions.

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Disclosures

Dr. Ramakrishna reported being the cofounder of Roon outside the submitted work. Dr. T. H. Schwartz reported being a consul-

tant for RPW Techonology, Integra, and Ellquence; and being an investor in Mivi Neuroscience, Serenity Medical, Endostream, and Neurotechonolgy LLC outside the submitted work.

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Conception and design: TH Schwartz, Bander, Stieg, Ramakrishna. Acquisition of data: Bander, Pandey, Yan, Giantini-Larsen, A Schwartz, Estin. Analysis and interpretation of data: Bander, Pandey, Yan, Giantini-Larsen, Estin, Ramakrishna, Tsouris. Drafting the article: Bander, Pandey, Yan, Giantini-Larsen. Critically revising the article: TH Schwartz, Bander, Pandey, Giantini-Larsen. Reviewed submitted version of manuscript: Bander, Pandey, Giantini-Larsen, Stieg, Tsouris. Approved the final version of the manuscript on behalf of all authors: TH Schwartz. Statistical analysis: TH Schwartz, Bander, Pandey, Yan. Administrative/technical/material support: TH Schwartz, Stieg, Ramakrishna. Study supervision: Tsouris.

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