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Endoscopic endonasal versus transcranial approach to tuberculum sellae and planum sphenoidale meningiomas in a similar cohort of patients

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OBJECTIVE Planum sphenoidale (PS) and tuberculum sellae (TS) meningiomas cause visual symptoms due to compression of the optic chiasm. The treatment of choice is surgical removal with the goal of improving vision and achieving complete tumor removal. Two options exist to remove these tumors: the transcranial approach (TCA) and the endonasal endoscopic approach (EEA). Significant controversy exists regarding which approach provides the best results and whether there is a subset of patients for whom an EEA may be more suitable. Comparisons using a similar cohort of patients, namely, those suitable for gross-total resection with EEA, are lacking from the literature.

METHODS The authors reviewed all cases of PS and TS meningiomas that were surgically removed at Weill Cornell Medical College between 2000 and 2015 (TCA) and 2008 and 2015 (EEA). All cases were shown to a panel of 3 neurosurgeons to find only those tumors that could be removed equally well either through an EEA or TCA to standardize both groups. Volumetric measurements of preoperative and postoperative tumor size, FLAIR images, and apparent diffusion coefficient maps were assessed by 2 independent reviewers and compared to assess extent of resection and trauma to the surrounding brain. Visual outcome and complications were also compared.

RESULTS Thirty-two patients were identified who underwent either EEA (n = 17) or TCA (n = 15). The preoperative tumor size was comparable (mean 5.58 ± 3.42 vs 5.04 ± 3.38 cm^3 [± SD], p = 0.661). The average extent of resection achieved was not significantly different between the 2 groups (98.80% ± 3.32% vs 95.13% ± 11.69%, p = 0.206). Postoperatively, the TCA group demonstrated a significant increase in the FLAIR/edema signal compared with EEA patients (4.15 ± 7.10 vs –0.69 ± 2.73 cm^3, p = 0.014). In addition, the postoperative diffusion-weighted imaging signal of cytotoxic ischemic damage was significantly higher in the TCA group than in the EEA group (1.88 ± 1.96 vs 0.40 ± 0.55 cm^3, p = 0.008). Overall, significantly more EEA patients experienced improved or stable visual outcomes compared with TCA patients (93% vs 56%, p = 0.049). Visual deterioration was greater after TCA than EEA (44% vs 0%, p = 0.012). While more patients experienced postoperative seizures after TCA than after EEA (27% vs 0%, p = 0.038), there was a trend toward more CSF leakage and anosmia after EEA than after TCA (11.8% vs 0%, p = 0.486 and 11.8% vs 0%, p = 0.118, respectively).

CONCLUSIONS In this small single-institution study of similarly sized and located PS and TS meningiomas, EEA provided equivalent rates of resection with better visual results, less trauma to the brain, and fewer seizures. These preliminary results merit further investigation in a larger multiinstitutional study and may support EEA resection by experienced surgeons in a subset of carefully selected PS and TS meningiomas.

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KEY WORDS meningioma; skull base; tuberculum sellae; planum sphenoidale; endonasal; endoscopic; transsphenoidal; transcranial; volumetric; pituitary surgery

ABBREVIATIONS ADC = apparent diffusion coefficient; DWI = diffusion-weighted imaging; EBL = estimated blood loss; EEA = endonasal endoscopic approach; EOR = extent of resection; GTR = gross-total resection; NTR = near-total resection; PS = planum sphenoidale; STR = subtotal resection; TCA = transcranial approach; TS = tuberculum sellae.

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Anterior skull base meningiomas are benign, dural-based tumors that benefit from surgical removal. To minimize the risk of recurrence, the goals of surgery are complete removal of the tumor, dural tail, and invaded bone.[31] Subtotal resection (STR) followed by radiation therapy may also be reasonable depending on the age of the patient and the location of the tumor. Meningiomas originating from the tuberculum sellae (TS) and planum sphenoidale (PS) account for approximately 15% of WHO Grade I meningiomas and often present with visual disturbance due to compression of the optic nerves and chiasm.[14] Resection of these tumors can decompress the optic nerves and prevent further deterioration, or, in some cases, reverse damage to those nerves.[33]

The use of an endoscopic endonasal approach (EEA) for the resection of anterior skull base meningiomas has been developed as an alternative to the transcranial approach (TCA).[1,4–6,8,13,15–18,21,25,28,34] EEA arose as an extension of extended microscopic transsphenoidal surgery, which can also be used to remove meningiomas.[4] EEA offers several advantages over TCA, such as removal of all involved bone; less manipulation of the optic nerves, chiasm, and brain; and improved visualization of the medial optic canal. TCA, on the other hand, does not traverse an infected field and is more suitable for tumors that extend lateral to the carotid artery or optic nerve as well as those that may encase the vasculature, providing a wider view of the lateral extent of the tumor. TCA also avoids trauma to the nasal passages, which can cause nasal crusting and anosmia. While CSF leaks are less frequent following TCA, the rate of CSF leakage after EEA has been reduced dramatically.[9,11,18,22,26–30]

Few studies exist that directly compare EEA with TCA for resection of TS and PS meningiomas.[6,8,17] The difficulty with such studies is that the indications for each approach may differ, and it is impossible to compare 2 approaches for removal of the exact same tumor. To surmount this difficulty, we reviewed our institutional experience with EEA and TCA for TS and PS meningiomas and included only those tumors that were amenable to achieving a gross-total resection (GTR) using either approach, regardless of the approach chosen by the operating surgeon. The preoperative images were sent to a panel of 3 experts in both EEA and TCA surgery who determined which tumors could be removed equally well with either approach, and only those tumors were selected for inclusion in the study.

Methods

This study was approved by the institutional review board at Weill Cornell Medical College. Pathology records from 2000 to 2015 at NewYork-Presbyterian/Weill Cornell Medical College were queried to identify all patients who had undergone surgery for a meningioma. Of these 1188 patients, a retrospective chart review of radiology records was conducted to identify a subset with anterior skull base TS or PS meningiomas (n = 54). A deidentified series of images showing the coronal, sagittal, and axial T1-weighted images with contrast through the maximal diameter of each tumor in each plane was shown to 3 separate neurosurgeons specializing in both EEA and TCA surgery for meningiomas (Fig. 1). Patients were included in this study only if all 3 surgeons agreed that their tumors could be removed using either the EEA or TCA. These surgeons were blinded to the actual approach used to remove the tumor and blinded to the postoperative scans. Cases were not included if the tumor was an olfactory groove meningioma or if more than 50% of the tumor was above the cribriform plate in order to examine only PS or TS meningiomas. Tumors that were selected were between the carotid arteries without significant lateral extension into the middle fossa, beyond the clinoid processes, down the clivus, or beyond the lamina papyracea. A total of 37 patients were identified who met these criteria. TCA surgeries were performed by surgeons specializing in transcranial brain tumor surgery with experience removing skull base meningiomas as part of their practice. The EEA cases were completed by a surgeon specializing in endonasal surgery in addition to transcranial surgery. One case was eliminated; the surgeon had only performed this one EEA for meningioma and was felt not to be adequately experienced in the technique. Finally, since the EEA has evolved over time, particularly with respect to the development of novel closure techniques such as the gasket seal and vascularized nasoseptal flap,[9,12,22] cases treated prior to 2008 were eliminated (n = 5); these techniques had not yet been incorporated into our program. Since no significant changes in the TCA occurred during the study period, all patients who underwent a TCA were included in this study. Notably, the surgeons used the same navigation system, microscopes, and sets of instrumentation over the study period. A retrospective chart review of medical/surgical reports, pathology, and radiology records was conducted; variables included age, sex, date of surgery, surgeon of record, operative approach (TCA vs EEA), preoperative presenting symptoms, postoperative change in visual symptoms, and postoperative complications. Visual outcomes were based on visual acuity and/or visual field testing. Preoperative and postoperative formal neuroophthalmological visual field/acuity testing was compared in 70% (n = 16) of the patients with stated visual deficits (n = 23). For the remaining patients, subjective assessment of their symptoms as stable, worse, or improved was extracted from review of postoperative follow-up chart notes. Patients were excluded if they had undergone a previous EEA or TCA surgery so that no reoperations were included to avoid the influence of scarring on the surgical approach.

Volumetric Analysis

An individual (E.D.B.), who was not involved in the surgical or postoperative care of the patients in this study and was blinded to surgical approach, performed the volumetric analysis as previously described.[2] A second individual, a board-certified neuroradiologist (R.C.C.), also performed pre- and postoperative tumor volume analysis for interobserver reliability correlation. Briefly, MRI for each patient was imported into Brainlab software. Preoperative T1-weighted contrast-enhanced and T2-weighted FLAIR scans as well as postoperative T1-weighted, T1-weighted with contrast, T2-weighted FLAIR, and diffusion-weighted imaging (DWI) studies and apparent dif-

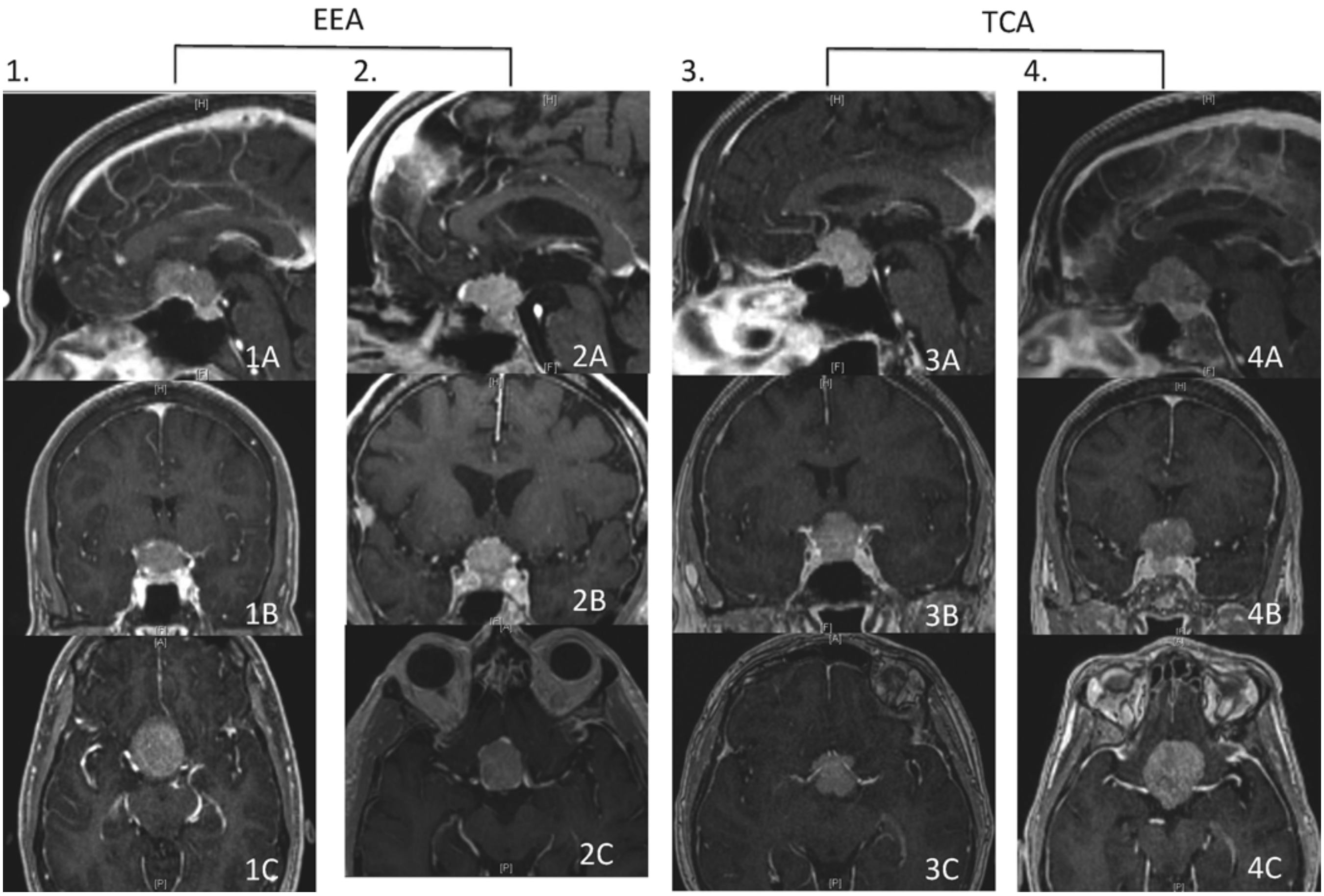

FIG. 1. Representative MR images of TS and PS meningiomas considered accessible by either a TCA or EEA. Sagittal (**A**), coronal (**B**), and axial (**C**) T1-weighted postcontrast MR images through TS and PS meningiomas of 4 representative patients. EEA was performed in Cases 1 and 2, and TCA was performed in Cases 3 and 4.

fusion coefficient (ADC) maps were coregistered to align the images. Using the Brainlab software SmartBrush tool, objects were drawn to measure 3D volumes (Fig. 2). Tumor burden was defined as enhancement on pre- and postoperative T1-weighted scans with contrast. GTR was defined as 100% tumor removal. Near-total resection (NTR) was defined as greater than 90% and subtotal resection (STR) as less than 90%. Brain edema and nonenhancing cellular infiltration around tumors was defined as hyperintensity on pre- and postoperative T2-weighted FLAIR images with the tumor burden subtracted out using the advanced manipulation tool. Change in volume of hyperintensity was determined arithmetically as postoperative edema – preoperative edema. DWI studies and ADC maps were used to determine areas with restricted diffusion (brain ischemia/damage) postoperatively.

Statistical Analysis

Two-sample t-tests were used to compare continuous variables between the EEA and TCA groups. Two-sample proportion Fisher's exact method was used to calculate p values for categorical variables including preoperative visual symptoms, postoperative visual symptom changes, and postoperative complications between the 2 groups. All statistical analysis was performed using Minitab Express and Microsoft Excel. A p value < 0.05 was considered statistically significant.

The Fisher's exact test and percentages for visual outcomes were calculated using a denominator of only patients with preoperative visual symptoms or a new postoperative visual symptom (EEA: n = 15 and TCA: n = 9). This was done to avoid skewing the results by the different number of patients in each group who had no visual symptoms. The percentage of postoperative complications was calculated out of total number of EEA (n = 17) or TCA (n = 15) patients.

Interobserver reliability for pre- and postoperative tumor volumes was calculated using a Pearson correlation coefficient.

Results

Demographics

Thirty-two patients (Table 1) were identified who fulfilled inclusion criteria for resection of a TS or PS meningioma and underwent either EEA (n = 17) between 2008 and 2015 or TCA (n = 15) between 2000 and 2015. The expert reviewers agreed on all cases except for one, which was eliminated. There were more females (n = 21) than males (n = 11), but they were split approximately evenly

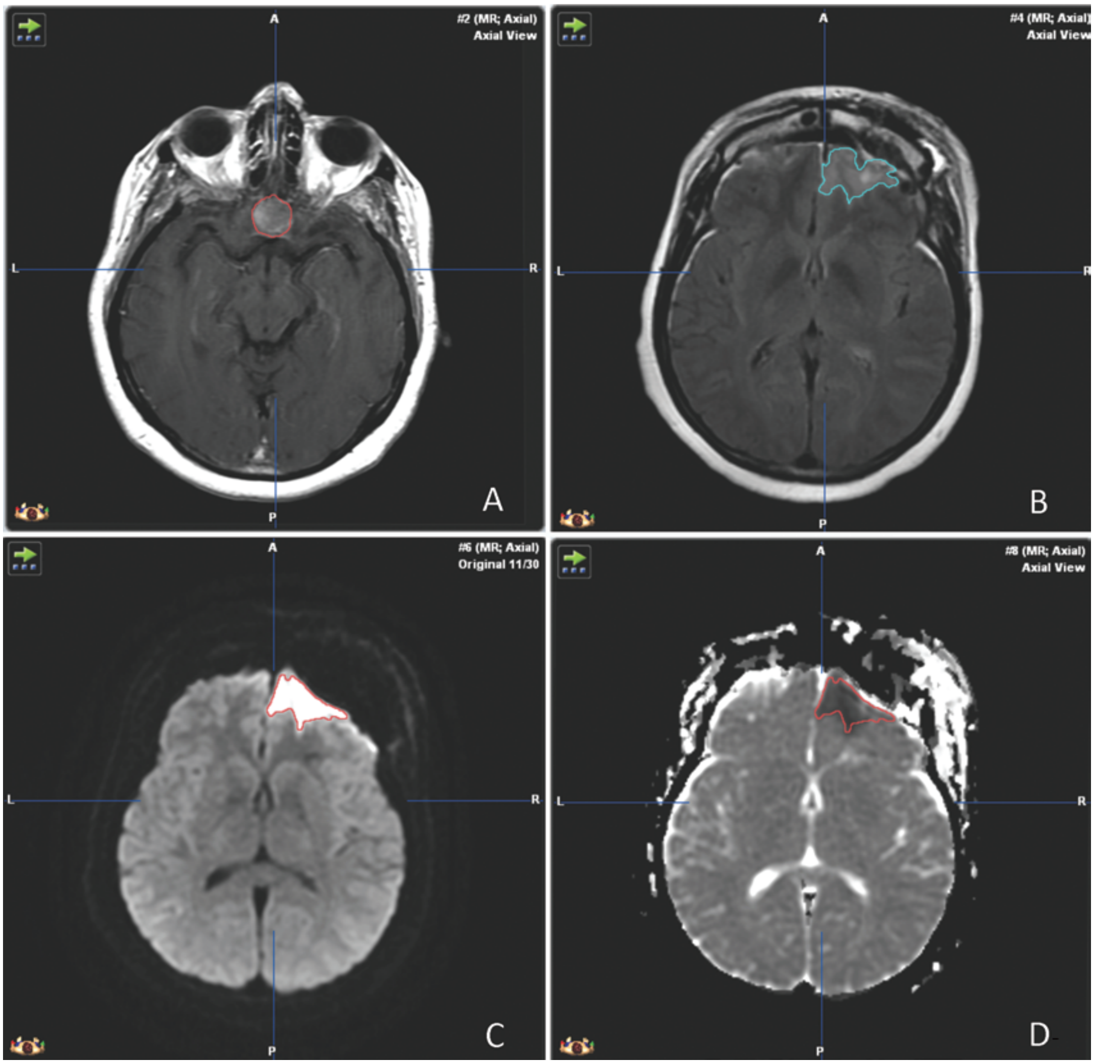

FIG. 2. Representative volumetric analysis of postoperative FLAIR and DWI after a TCA resection. **A:** Axial T1-weighted image with contrast demonstrating preoperative tumor (*red*). **B:** Postoperative FLAIR hyperintensity secondary to retraction injury (*blue*). This area of FLAIR hyperintensity was not present on preoperative imaging (not shown). **C and D:** DWI hyperintensity (*red*, C) that also shows diffusion restriction on the ADC map (D). Figure is available in color online only.

between the 2 groups. The mean age was 55 years for all patients. The follow-up period was approximately 2 years for the EEA group and 3 years for the TCA group ($p = 0.340$). The average length of surgery, measured from first entering into the operating room until being wheeled out of the operating room, was longer for EEA compared with TCA (7 hours and 46 minutes for EEA vs 6 hours and 22 minutes for TCA, $p = 0.056$). However, the length of surgery appears to trend down over time and with surgeon experience for the EEA group, with the first 9 cases (2008–2013) taking approximately 9 hours and 17 minutes and the last 8 cases (2014–2015) taking approximately 6 hours and 4 minutes, comparable to TCA. The average estimated blood loss (EBL) was not statistically different between the groups ($p = 0.70$), but was skewed by 1 outlier EEA case that, when excluded, results in significantly lower EBL in the EEA group (EEA: 75 ml vs TCA: 201.8 ml, $p = 0.002$). No significant difference in length of hospital stay ($p = 0.70$) was found between the groups.

Volumetric Analysis of Tumor Size, Extent of Resection, and Postoperative FLAIR/DWI Signal

Interobserver reliability was calculated for pre- and postoperative tumor volume to ensure that resection rates and extent of resection (EOR) were reproducible between 2 individuals conducting the volumetric analysis. Preoperative tumor volume measurements had a correlation value of $\rho = 0.99$, and postoperative values had a $\rho = 0.75$. The lower ρ value for postoperative correlation likely reflects the small range of postoperative volumes (range 0.0–0.67 cm^3), which causes small differences between observers to more strongly affect the correlation.

The average preoperative tumor volume for patients in the EEA group versus the TCA group was not significantly different (5.58 ± 3.42 vs 5.04 ± 3.38 cm^3 [± SD], $p = 0.661$) (Table 2). Preoperative FLAIR volume around the tumors was similarly low for both groups (EEA: 2.45 ± 3.92 vs TCA: 4.13 ± 7.97, $p = 0.447$). The average EOR achieved

TABLE 1. Demographic data in 32 patients undergoing EEA or TCA to treat PS or TS meningiomas

Variable	All	EEA	TCA	p Value*
No. of patients	32	17	15	
Sex				1.000
Female	21	11	9	
Male	12	6	6	
Age (yrs)				
Min	28	31	28	
Median	58	57.5	58	
Mean ± SD	54.97 ± 13.5	54.29 ± 14.3	55.73 ± 12.9	0.768
Max	80	80	73	
Mean length of op (hrs:mins)		7:46	6:22	0.056
Mean EBL (ml)		157.4	201.8	0.70
Mean length of stay (days)		4.6	4.3	0.70
Recurrence				1.000
Yes	4	2	2	
No	29	15	13	
Mean FU length (mos)	30.09	25.06	37.00	0.340

FU = follow-up.
* Two-tailed t-test.

TABLE 2. Volumetric comparison

Variable	EEA	TCA	p Value*
Preop tumor vol (cm^3)			
Min	0.58	0.95	
Median	5.35	5.62	
Mean ± SD	5.58 ± 3.42	5.04 ± 3.38	0.661
Max	11.16	13.64	
EOR (%)			
Min	87.11	57.99	
Median	100.00	100.00	
Mean ± SD	98.80 ± 3.32	95.13 ± 11.7	0.206
Max	100.00	100.00	
GTR vs NTR vs STR (%)			0.423
GTR	82	53	
NTR	12	33	
STR	6	13	
Preop FLAIR vol (cm^3)			
Min	0.00	0.00	
Median	1.51	0.58	
Mean ± SD	2.45 ± 3.92	4.13 ± 7.97	0.447
Max	17.27	23.65	
Postop FLAIR vol (cm^3)			
Min	0.00	0.00	
Median	0.00	5.34	
Mean ± SD	1.76 ± 3.34	8.28 ± 8.14	0.005
Max	11.20	28.83	
ΔFLAIR vol (cm^3)			
Min	−6.07	−10.02	
Median	−0.75	4.73	
Mean ± SD	−0.69 ± 2.73	4.15 ± 7.10	0.014
Max	8.18	20.85	
Postop DWI vol (cm^3)			
Min	0.00	0.00	
Median	0.04	1.35	
Mean ± SD	0.40 ± 0.55	1.88 ± 1.96	0.008
Max	1.63	5.90	

* Two-tailed t-test.

was not significantly different between the EEA and TCA groups (98.8% ± 3.32% EEA vs 95.13% ± 11.69% TCA, p = 0.206). Furthermore, no statistically significant difference in the proportion of patients achieving GTR was demonstrated between the EEA and TCA groups (82% vs 53%, p = 0.423), and there was no difference when considering GTR+NTR rates (94% vs 86%, p = 0.589).

Postoperatively, the TCA group demonstrated a significant increase in the FLAIR/edema signal compared with EEA patients (TCA: 4.15 ± 7.10 vs EEA: −0.69 ± 2.73 cm^3, p = 0.014). In addition, postoperative DWI signal of cytotoxic ischemic damage was significantly higher in the TCA group than in the EEA group (1.88 ± 1.96 vs 0.40 ± 0.55 cm^3, p = 0.008).

Visual Symptom Presentation and Outcome

The most common presenting symptom of patients in this study was visual disturbance, affecting 88% (n = 15) of patients in the EEA and 53% (n = 8) in the transcranial group (Table 3). Other presenting symptoms included incidental findings on imaging, headache, gait disturbance, and memory complaints. A greater proportion of patients with preoperative visual symptoms had improvement in those symptoms after EEA compared with TCA resection patients (67% vs 22%, p = 0.089); however, this failed to reach statistical significance (Fig. 3). Significantly fewer patients experienced worsening of visual symptoms after EEA compared with a TCA (0% vs 44%, p = 0.012). One patient in the TCA group had new postoperative visual symptoms that did not exist prior to surgery due to a postoperative subarachnoid hemorrhage. One patient in the EEA group was lost to follow-up. Overall, significantly more EEA patients experienced improved or stable visual outcomes than TCA patients (93% vs 56%, p = 0.049).

Postoperative Complications

Postoperative complications were classified as major (seizure, stroke, hemorrhage, hemiparesis, CSF leak, endocrine disorders, and DVT) to minor (headache and anosmia/ageusia) (Table 4). Significantly more patients experienced seizures after TCA than after EEA (27% vs 0%, p = 0.038). The most common complication in the EEA group was CSF leakage, occurring in 12% (n = 2) compared with 0% of TCA patients (p = 0.486). CSF leaks were treated with lumbar drainage and did not require re-

TABLE 3. Visual symptoms

	No. of Patients		
Visual Symptoms	EEA (n)	TCA (n)	p Value*
Preop			
Yes	15	8	0.049
No	2	7	
Postop			
Improved	10	2	0.089
Worsened	0	4†	0.012
Stable	4	3	1.000
Lost to FU	1	0	

* N-1 2-proportion test, p-value calculated using Fisher's exact method.
† One TCA patient had no preoperative visual symptoms but had a new/worsening postoperative visual outcome.

operation. Two patients who underwent TCA experienced a subarachnoid hemorrhage or stroke compared with none in the EEA group (13% vs 0%, p = 0.212). Minor complications in the TCA and EEA groups, respectively, included headaches (33% vs 47%, p = 0.491), anosmia/ageusia (0% vs 12%, p = 0.118), and frontalis nerve palsy (13% vs 0%, p = 0.212), which did not show statistically significant differences between the groups.

Recurrence or progression of disease occurred in 2 patients in each of the EEA and TCA groups (11.8% vs 15.4%, p = 1.0). Recurrence was treated by additional resection via craniotomy in 1 EEA patient and radiation therapy in 2 patients, and 1 patient underwent a wait-and-scan approach with serial imaging.

Discussion

This study provides compelling evidence that the endonasal endoscopic removal of PS and TS meningiomas may offer measurable benefits over transcranial surgery for tumors that are comparable, namely, good candidates for EEA. This group of patients is a subset of all patients with PS or TS meningiomas who are admittedly "cherry picked" for this approach. The results of this study are not intended to support EEA for all PS and TS meningiomas. These benefits do not necessarily include an increase in the EOS of the tumor but rather an overall decrease in complications and better visual outcomes. Although a trend toward higher rates of GTR in the EEA group was noted, this did not reach significance. A few important caveats should be mentioned. Given the limited follow-up for this series, we cannot make any assessments about recurrence rates following each approach. However, if rate of GTR and EOR predicts recurrences, then we expect the recurrence rates to be similar. Moreover, while the risks of several complications appear to be lower after the EEA, reflected in markedly reduced evidence of damage to the brain as seen on FLAIR and DWI, EEA still has a higher, albeit not statistically significant, rate of CSF leakage and anosmia compared with TCA, given the small size of this study. Hence, if EEA is offered to patients, these specific complications should be discussed.

Previous studies comparing TCA and EEA for TS and PS meningiomas have reported similar results, but our study differs in 2 specific and important ways that make it unique.[6,8,17] This is the first study to include only patients whose tumors were amenable to GTR using an EEA. Three surgeons blinded to the actual approach used re-

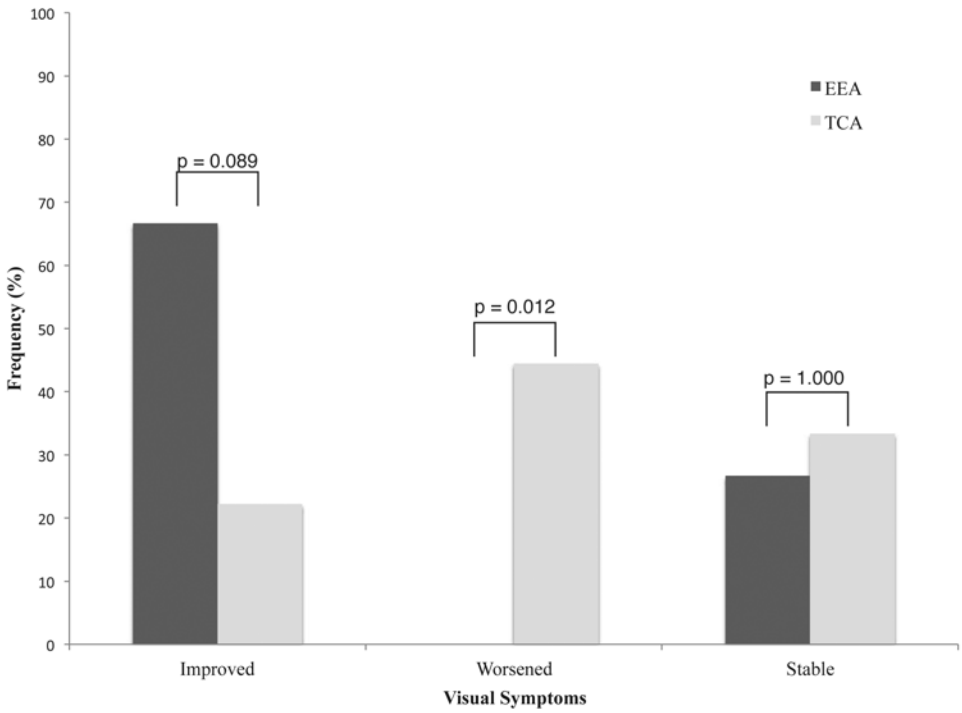

FIG. 3. Postoperative change in visual symptoms. Frequency of improvement, worsening, or stability of preoperative visual symptoms after an EEA or a TCA.

TABLE 4. Postoperative complications

Complication	EEA	TCA	p Value*
Major			
Seizure	0.0%	26.7%	0.038
CSF leakage	11.8%	0.0%	0.486
DI	0.0%	0.0%	1.000
Weakness	5.9%	6.7%	1.000
SAH/stroke	0.0%	13.3%	0.212
DVT	0.0%	6.7%	0.469
Total no. of events	3	8	0.062
Minor			
Headache	47.1%	33.3%	0.491
Anosmia/aguesia	11.8%	0.0%	0.118
Frontalis nerve palsy	0.0%	13.3%	0.212
Total no. of events	10	7	0.724

DI = diabetes insipidus; DVT = deep venous thrombosis; SAH = subarachnoid hemorrhage.
* N-1 2-proportion test, p-value calculated using Fisher's exact method.

viewed the preoperative images and only tumors amenable to GTR with either EEA or TCA were included. The importance of this inclusion criterion is that, in prior studies, the TCA group may have included larger tumors with a more lateral extent that might not have been candidates for EEA.[6,8,17] Such tumors may increase the potential complication rates of the TCA in these studies. Likewise, if such tumors were included in the EEA group, namely, tumors that experienced surgeons might feel were not good candidates for EEA, the results might be misleadingly inferior. The second unique aspect of this study was that volumetric measurements of pre- and postoperative tumor volume as well as FLAIR and DWI/ADC maps were assessed by an individual blinded to the actual approach that was used to remove the tumor. Once again, the attempt was to produce more objective measurements of outcome. However, it is impossible to truly blind the reviewer of the imaging to the approach since the route of entry is clearly apparent on the images.

Extent of Resection

The goal of attaining GTR with dural and bone resection in the treatment of meningiomas was established in 1957 by Simpson.[31] However, recent studies have suggested that with the development of improved intraoperative image guidance, microscopic visualization, and surgical instrumentation, as well as postoperative use of stereotactic radiosurgery, more aggressive resections of bone and dura may not be necessary to achieve similar recurrence rates as the original Simpson grades.[32] These studies suggested that residual tumor volume in the original Simpson study were likely much larger residuals than what we consider residual tumor on imaging today using volumetric measurements from high-resolution MRI scans. In our study, EEA resulted in a nonsignificantly higher EOR as well as GTR. Successful EEA removal of PS and TS meningiomas requires opening the medial optic canals in certain cases as well as careful case selection.[1,16] The rates of GTR in this paper were not as high as in prior reports for either EEA or TCA cases and may reflect the sensitivity of the high-resolution volumetric measurements used to assess GTR. Indeed, prior literature reviews have reported GTR rates of 84.1% (TCA) and 74.7% (EEA) for TS and PS meningiomas.[18] More recent EEA series have reported GTR rates as high as 91.7%.[28] Overall, given the fact that the Simpson grade may be overemphasized as a predictor of recurrence in the modern neurosurgical era, that radiation techniques are more precise and can be used to treat residual tumor and the noninferiority of most recent studies of the EEA compared with the TCA, it is likely that in experienced hands, both techniques are equally capable of achieving similar rates of radiographic tumor removal in well-selected cases. The key issues, then, become visual results and complications to differentiate these 2 approaches.

Visual Symptoms

Visual disturbance is the most common presenting symptom in TS and PS meningiomas. The findings in our study, of improved visual outcomes for patients undergoing EEA compared with TCA, support similar finding reported in other studies. In a review of the literature, Komotar et al. reported an insignificant trend toward better visual outcomes in EEA than in TCA surgery (69.1% vs 58.7%).[18] Kitano et al. compared quantitative visual outcomes after EEA and TCA for TS and PS meningiomas and found significantly higher rates of improvement in visual acuity for EEA than for TCA patients (59% vs 25%, $p = 0.01$).[17] Graffeo et al. also found higher visual improvement with EEA compared with TCA (87% vs 61%, $p < 0.001$) and fewer cases of deterioration in symptoms after EEA than after TCA (2.1% vs 11.4%, $p = 0.009$).[11] Some members of the neurosurgery community have suggested that visual outcome may be the most important end point given that it is the most prominent symptom caused by these tumors and small residual tumors can be controlled with stereotactic radiosurgery.[3,19,20] Based on our results and in corroboration of the growing literature, EEA may be the more appropriate approach to achieve the best visual outcomes in these tumors.

Complications

Although we did not assess all possible complications, the most frequently measured complications were included, and statistical significance was only found following TCA surgery. Moreover, there were significantly higher volumes of FLAIR signal and cytotoxic injury (DWI) in the brain after TCA than after EEA, undoubtedly from the brain retraction required for TCA. Consequently, seizures, stroke, and subarachnoid hemorrhage occurred in the TCA group and not the EEA group. Although EEA has its own unique complications, such as CSF leakage and anosmia, the former is becoming less of a problem over time and the latter is uncommon if the tumor does not extend over the cribriform plate. CSF leakage, which occurred in 12% of our patients, required only lumbar drainage to repair. These results are much better than those reported by other authors: 28% (de Divitiis et al.), 29% (Fatemi et al.), and 62% (Gardner et al.).[6,8,10] In other series the rates are as low as 0%.[28,29] The use of novel closure techniques, such as the gasket seal, the button, or the nasoseptal flap as well as the use of lumbar drainage, have contributed to these low numbers.[5,7,9,12,22–24]

Limitations

Given that our study is retrospective and not a randomized, controlled trial, there is inherent bias in the operative approach that was chosen for each tumor. We tried to limit this bias by having 3 attending neurosurgeons who were blinded to the surgical approach used examine anonymous coronal, axial, and sagittal preoperative images of the tumors to confirm that they could all be resected equally well via both EEA and TCA. Another criticism that could be raised about this study is that the cases selected were biased toward those that were easier to remove endonasally, or "chip shots." However, merely the existence of a case that could be considered a chip shot to remove endonasally implies the existence of a subset of tumors that are easier to remove endonasally. This criticism supports the main contention of this paper, which is that a subset of PS and TS meningiomas should be removed endonasally, if done in experienced hands, precisely because these tumors are easier to remove that way. It is important to understand that we are not stating that all TS and PS meningiomas should be removed endonasally, merely a specific subset. The range of possible tumors in this subset will vary based on the experience and comfort of the surgeon at TCA and EEA surgery. In this series, the tumors removed endonasally were actually slightly larger than those removed transcranially, so the groups were not biased with respect to volume.

The group sizes are comparable to previous studies of either transcranial or endonasal groups, but are relatively small, which can limit our power to demonstrate statistical differences between the 2 groups. Additionally, it is impossible to blind the reviewers of the imaging studies to the approach being used since the trauma of the approach is clearly visible. However, 2 separate reviewers were used to minimize such bias. The number of potential complications examined was not exhaustive and did not include nasal crusting but also did not include pain or numbness at the craniotomy site or temporal wasting. Also, the use of FLAIR/DWI signal change as a marker for brain trauma is potentially questionable since such damage may be clinically silent. However, asymptomatic encephalomalacia may be clinically apparent with detailed neuropsychological testing, which was not performed in this study. Nevertheless, it is generally agreed upon that damage to the brain should be minimized as a goal of neurosurgical interventions. The statistically significant increase in postoperative seizures in the TCA group supports relevance of these imaging markers as an indication of brain trauma. Our visual outcome analysis is limited by the fact that only 70% of the patients had formal pre- and postoperative visual field/acuity evaluation compared by a neuroophthalmologist. The remaining patients' subjective assessment of vision changes at postoperative follow-up appointments may not always be borne out in more formal assessments. However, patient satisfaction with surgical outcome is as much, if not more, related to their subjective assessment of symptoms than formal testing. So the remaining 30% of patients whom we included with subjective results remains clinically relevant.

Also, the time periods for the 2 groups were not identical. To increase the number of transcranial patients, we included patients who underwent surgery between 2000 and 2008. One could argue that improvements in transcranial surgery might have occurred over this time frame, which would bias toward worse results in patients who underwent surgery before 2008. However, the technique and equipment for transcranial surgery for meningiomas did not change at our institution during this time period, and we used essentially the same navigation system, microscope, and instrumentation. Any changes would have been subtle compared with radical changes in how we closed the skull base endonasally before and after 2008. Lastly, the limited follow-up time of approximately 2 years makes recurrence an impossible outcome measure given the slow growth rate of most WHO Grade I meningiomas.

Conclusions

We provide evidence demonstrating that in an appropriately selected population of TS and PS meningiomas, EEA can achieve resection rates equivalent to TCA with better visual outcomes and lower rates of brain trauma and seizures.

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Conception and design: Schwartz, Bander, Singh, Anand. Acquisition of data: Schwartz, Bander, Singh, Ogilvie, Cusic, Pisapia, Tsiouris. Analysis and interpretation of data: all authors. Drafting the article: Schwartz, Bander, Singh, Anand. Critically revising the article: Schwartz, Bander, Singh, Anand. Reviewed submitted version of manuscript: Schwartz, Bander, Singh, Ogilvie, Anand. Approved the final version of the manuscript on behalf of all authors: Schwartz. Statistical analysis: Schwartz, Singh. Administrative/technical/material support: Schwartz, Anand. Study supervision: Schwartz, Anand.

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