Endonasal endoscopic transsphenoidal excision of tuberculum sellae meningiomas: a systematic review

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ABSTRACT

INTRODUCTION: The endonasal endoscopic approach (EEA) for the resection of tuberculum sellae meningiomas (TSMs) has, more recently, been advocated as an alternative approach to deal with this challenging tumor. The aim of this study was to conduct a systematic review of publications of TSMs excised through the transsphenoidal route in the past 10 years and review data on the extent of excision, visual outcomes and complication rates.

EVIDENCE ACQUISITION: We performed a thorough systematic review of the medical literature following the PRISMA guidelines. A medical librarian retrieved a list of 3443 articles published from 2006-2015 from the MEDLINE, EMBASE and Cochrane Central databases. Two of the authors independently screened for titles and abstracts and excluded 3340 of them. We reviewed the full text of the remaining 103 articles and included in our analysis 12 that met the following inclusion criteria: 1) 5 or more cases reported; 2) the extent of resection, visual outcomes and complication rates that were specifically documented for TSMs excised through the transsphenoidal route.

EVIDENCE SYNTHESIS: Twelve studies that included 150 patients were analyzed. The mean age was 55 years. The mean tumor volume, reported in 2 studies, was 6.6 cc and mean maximum diameter, reported in 11 studies, was 25 mm. The gross total resection rate was 77.2%. Vision improved in 79.5% of cases and deteriorated in 7.3%. CSF leak postoperatively occurred in 15.3% of patients. In the 11 studies that reported hormonal outcomes, there was a 9.4% transient hyponatremia or diabetes insipidus and 2.2% of patients developed a new permanent endocrine dysfunction. A symptomatic vascular injury was reported in 2.6% of patients. There was one mortality (0.6%).

CONCLUSIONS: The endonasal endoscopic transsphenoidal excision of TSMs is a feasible, safe and effective surgical option with a low morbidity and mortality. The use of this approach has evolved in the last 10 years and in some centers has replaced the transcranial route for selected cases. Given the limited availability and heterogeneity of comparative observational studies, a direct comparison with transcranial approaches was not performed for the purpose of this review analysis. Likewise, from an epidemiological and statistical perspective a meta-analysis was deemed inappropriate.


Key words: Olfactory tubercle - Meningioma - Natural orifice endoscopic surgery - Skull base.

Introduction

Tuberculum sellae meningiomas (TSMs) are a distinct sub-group of meningiomas located in the suprasellar space, with dural attachment to the tuberculum sellae, chiasmatic sulcus and limbus sphenoidale. Distinct anatomical patterns differentiate this tumor from planum sphenoidale and diaphragma sella meningiomas. They are uncommon, encompassing roughly only 5-10% of all intracranial meningiomas. Patients usually present with gradual visual deterioration secondary to compression of the optic apparatus. They can be surgically challenging because of their close proximity to critical neurovascular/endocrine structures and their extension into the optic canal thus making a safe gross total resection (GTR) difficult.
Traditionally these tumors have been excised through a variety of transcranial approaches including the pterional, subfrontal or interhemispheric technique. More recently, less invasive transcranial approaches have been used including the mini-eyebrow craniotomy and the lateral supraorbital approach. Likewise endoscopic-assisted transcranial excision of these tumors have also been performed. Innovations in minimally invasive surgery have been further advanced by the introduction of the pure endoscopic endonasal techniques for the removal of these tumors. Following the successful application of endonasal endoscopic transsphenoidal approaches for pituitary adenomas, the technique has evolved and, with appropriate training and experience, the expanded variants have made resection of a number of intradural pathologies including TSMs feasible and safe. While there have been increasing reports in the literature on the excision of TSM by the Endoscopic endonasal approach (EEA), the indications and effectiveness of this approach remains uncertain and controversial.

The aim of this rigorous systematic review was to evaluate the results of TSMs excised via the endoscopic or endoscope-assisted transsphenoidal route and provide an updated analysis of outcomes and complications. This study has included all manuscripts published in the last decade that include detailed documentation of resections rates, visual outcomes and complications specifically related to the removal of this distinct tumor by the endoscopic transsphenoidal route.

Evidence acquisition

A research protocol was developed in advance and detailed all aspects of the conduct of this systematic review. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) were used for protocol development and manuscript preparation. Only English studies were included. The search of the literature was conducted by a medical librarian (MA) using 3 databases: OVID MEDLINE (1946 to February, week 1, 2016), OVID EMBASE (1974 to 2016 February 10) and OVID EBM Reviews – Cochrane Central Register of Controlled Trials (January 2016). For MEDLINE, we used the MeSH terms “neurosurgical procedures”, “microsurgery”, “endoscopy”, “neuro-endoscopy”, and MeSH addressing the anatomical locations of the comparative procedures as well as relevant keywords and subheadings. For EMBASE, we used the Emtree terms neurosurgery, endoscopic surgery, and Emtree terms for anatomical locations of the comparative surgeries as well as relevant keywords and subheadings. The search in Cochrane Central combined elements of the MEDLINE and EMBASE strategies. Our complete search strategies are available on request. Once the search results had been exported to EndNote, citations from 2005 and earlier were deleted.

Rationale of section criteria

We set out to obtain a pragmatic understanding of outcomes specifically related to TSMs, hence applied strict inclusion and exclusion criteria for the selection of papers to review. Combining several studies from various institutions can present variability in technique and operative experience and hence case reports and series describing less than 5 patients were excluded from this review. We only included studies with adequate numbers of patients (5 or more), because case reports or small series have low statistical power and are not generally suitable for systematic reviews. To avoid duplication of patients, we excluded manuscripts that reported the same patients with TSM in subsequent manuscripts from the same institution and the most updated paper with the larger number was included. Since some authors used both the microscope and the endoscope at varying stages of the operation, we included pure endoscopic as well as endoscopy-assisted transsphenoidal excision of TSMs.

We restricted our analysis to TSMs, since other anterior skull base and parasellar tumors operated though the transsphenoidal route have different presentations and their outcomes and complications are not directly comparable. This resulted in the exclusion of a large study of 75 patients that described combined outcomes of TSM and planum sphenoidale meningiomas. While clinically these two entities could be grouped together as suprasellar meningiomas, we chose to focus on TSMs. Likewise, studies that mentioned olfactory groove, and pure diaphragm sella meningiomas were also excluded. Only studies that reported outcomes including extent of resection, visual outcomes and postoperative complications were included. Gross total resection (GTR) was defined as no visible tumor remnant at surgery and on postoperative MRI and included Simpson grade 1 and 2 excision. Near-total resection (NTR) was defined as...
tumor removal >90% on a postoperative MRI and sub-total resection (STR) was defined as a <90% excision on postoperative MRI. Visual outcomes were reported as improved, unchanged or worsened.

A risk of bias analysis was not done, as it was unfeasible given the included studies largely comprised case series.

Evaluation of records

A total of 3443 titles and abstracts were screened and 3340 records were excluded, independently by two authors (MT and GT). After consensus by both authors, 103 full texts were assessed for eligibility and 91 were excluded for reasons based on the pre-specified criteria. Kappa statistics were done to evaluate reviewer agreement. Conflict in study selection was resolved by discussion and consensus. A total of 12 studies were finally included in the qualitative synthesis (Figure 1).

Evidence synthesis

On the basis of this systematic review we identified a total of 12 papers (2006-2015) with 5 or more cas-
es, involving a total of 150 patients that documented the extent of resection, complications and visual outcomes specifically for the transsphenoidal excision of TSMs.16-27 The kappa statistic for reviewer agreement for title and abstract review was 0.9 (95% CI: 0.879 to 0.955) and full text review was 0.8 (95% CI: 0.650 to 0.970). The strength of the agreement was very good.

The current systematic review also includes 17 patients in the senior author’s own institution. The average number of cases per series was 12.5, and 8 of the 12 series had more than 10 cases. While most authors used purely endoscopic technique, 3 papers described their experience using both the microscope and endoscope at different stages of tumor excision through the transsphenoidal route.

Table I summarizes the patient demographics including tumor volume/size, extent of resection, visual outcomes and complications such as CSF leak, endocrine dysfunction and vascular injury. Nine studies mentioned mean follow up and the average was 16.2±11.3 months. Three studies mentioned only a follow-up range without a mean/median (12-24, 1-51 and 2-70 months). There was one death. This patient had a postoperative CSF leak that required three operations for cranial base defect repair. This patient showed rapid and unexpected worsening with respect to level of consciousness and anisocoria. He had an intraventricular hemorrhage 3 weeks postoperatively, and died 6 days later.

### Patient demographics

Of the 150 patients identified for review, 115 (76.7%) were female and 35 (23.3%) were male. The mean age in the published series was 54.9±4.7 years. Two papers reported tumor volume (mean, 6.6 cc), while the remaining 11 publications reported the maximum diameter (mean 24.9±4.7 mm).

### Resection rates and visual outcomes

The GTR rates ranged from 50-98.5% with a mean of 77.2% while the NTR/STR rate was 21.4%. Improvement in vision was documented in 79.5±13.4% of patients and ranged from 54.5-100%. The vision deteriorated in 7.3% (range 0-38%) and it remained unchanged in 17.4% (0-45%).

### Complications

The average CSF leak rate was 15.3% (0-62%). In the first 4 published studies of this review the CSF leak rate was 32% (16/50) and in the last 8 papers reviewed was 7% (7/100). No patient developed meningitis as a result of a CSF leak. Eleven studies reported endocrine outcomes. The most common hormonal disturbance was a transient endocrinopathy (9.4%), most often either hyponatremia or diabetes insipidus (DI). Permanent hormonal dysfunction was documented in 2.2%. Two patients developed permanent DI and 1 panhypopituitarism.

The incidence of vascular injury was 2.6%. One patient had an anterior cerebral artery (ACA) stroke. Two patients developed a perforator vessel infarct. One patient suffered an intraventricular hemorrhage 3 weeks after surgery and died. There were no reported injuries to the internal carotid artery. The only other complication, reported in two patients, was anosmia. Table II summa-

### Table I—Summary of studies on demographics and characteristics of 150 patients with tuberculum sellae meningiomas.

<table>
<thead>
<tr>
<th>Total papers</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure endoscopic</td>
<td>9</td>
</tr>
<tr>
<td>Endoscopic and microscopic</td>
<td>3</td>
</tr>
<tr>
<td>Total patients</td>
<td>150</td>
</tr>
<tr>
<td>Mean age</td>
<td>54.9±4.7 years</td>
</tr>
<tr>
<td>Males</td>
<td>35 (23.3%)</td>
</tr>
<tr>
<td>Females</td>
<td>115 (76.7%)</td>
</tr>
<tr>
<td>M:F ratio</td>
<td>3.3:1</td>
</tr>
<tr>
<td>Follow-up</td>
<td></td>
</tr>
<tr>
<td>3 studies describing range alone</td>
<td>1-70 months</td>
</tr>
<tr>
<td>9 studies describing mean follow-up</td>
<td>16.2±11.3 months</td>
</tr>
<tr>
<td>Tumor size</td>
<td></td>
</tr>
<tr>
<td>Mean volume (2 studies)</td>
<td>6.6±1.2 cc</td>
</tr>
<tr>
<td>Mean diameter (11 studies)</td>
<td>24.9±4.7 mm</td>
</tr>
<tr>
<td>Extent of resection</td>
<td></td>
</tr>
<tr>
<td>Gross total resection</td>
<td>77.2% (range 50-98.5%)</td>
</tr>
<tr>
<td>Near-/sub-total resection</td>
<td>21.4% (range 1.5-50%)</td>
</tr>
<tr>
<td>Visual outcomes</td>
<td></td>
</tr>
<tr>
<td>Improved</td>
<td>79.5±13.4% (range 54.5-100%)</td>
</tr>
<tr>
<td>Worsened</td>
<td>7.3±13.6% (range 0-38%)</td>
</tr>
<tr>
<td>Unchanged</td>
<td>17.4±14.3% (range 0-45.5%)</td>
</tr>
<tr>
<td>Complications</td>
<td></td>
</tr>
<tr>
<td>Pituitary dysfunction</td>
<td>11 studies, 137 patients</td>
</tr>
<tr>
<td>Transient pituitary dysfunction</td>
<td>13/137 (9.4%)</td>
</tr>
<tr>
<td>Permanent pituitary dysfunction</td>
<td>3/137 (2.2%)</td>
</tr>
<tr>
<td>Vascular injury</td>
<td>4 (2.6%)</td>
</tr>
<tr>
<td>Anosmia</td>
<td>2 (1.3%)</td>
</tr>
<tr>
<td>Mortality</td>
<td>1 (0.6%)</td>
</tr>
</tbody>
</table>

CSF: cerebrospinal fluid; DI: diabetes insipidus; SIADH: syndrome of inappropriate antidiuretic hormone secretion.
### Table II.—Studies on transsphenoidal excision of tuberculum sellae meningiomas from 2006 to 2015.

<table>
<thead>
<tr>
<th>Author</th>
<th>N. cases (study period)</th>
<th>Mean age</th>
<th>Mean diameter/volume</th>
<th>Extent of resection</th>
<th>Visual outcome</th>
<th>Complications</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitano (2007)</td>
<td>16 (1994-2006)</td>
<td>53.8</td>
<td>7.5 cc</td>
<td>Percentage of tumor removed: 98.5% One patient had had transcranial surgery 2 years later due to recurrence</td>
<td>Improved (in at least one eye) 81% Worsened (in at least one eye) 38%</td>
<td>CSF leak: 2 (12.5%) Anosmia: 2 (12.5%) Perforator infarction: 2 (12.5%) Pituitary dysfunction: 0</td>
<td>All patients had a follow up at 3 months, long-term follow-up not reported</td>
</tr>
<tr>
<td>Gardner (2008)</td>
<td>13 (2002-2005)</td>
<td>52</td>
<td>7.5 cc</td>
<td>GTR 13 (85%) NTR 1 (7.7%) STR 1 (7.7%)</td>
<td>Improved 100% Worsened 0%</td>
<td>CSF leak: 8 (62%) Permanent DI: 1 (7.6%)</td>
<td>12-48 months</td>
</tr>
<tr>
<td>de Divitiis (2008)</td>
<td>7 (2004-2007)</td>
<td>59</td>
<td>25.1 mm</td>
<td>GTR 6 (85.7%) NTR 1 (14.2%)</td>
<td>Improved (71%) (includes one patient that had improvement in one eye and worsening vision in the other) Unchanged (29%)</td>
<td>CSF leak: 2 (29%) Transient DI: 1 (14.2) One death from intraventricular hemorrhage 3 weeks later</td>
<td>3 weeks to 51 months</td>
</tr>
<tr>
<td>Fatemi (2009)</td>
<td>14 (2000-2008)</td>
<td>51</td>
<td>25 mm</td>
<td>GTR 7 (50%) NTR 3 (21%) STR 4 (29%)</td>
<td>Improved 82% Unchanged 9% Worsened 7%</td>
<td>CSF leak: 4 (29%) New postop hypopituitarism: 1/14 (7%)</td>
<td>27 (6-65 months)</td>
</tr>
<tr>
<td>Wang (2010)</td>
<td>12 (2003-2008)</td>
<td>56.7</td>
<td>30.2 mm</td>
<td>GTR 11 (91.6%) NTR 1 (8.4%)</td>
<td>Improved 92% Unchanged 8%</td>
<td>CSF leak: 1 (8.4%) Transient DI: 1 (8.4%)</td>
<td>28 (6-60 months)</td>
</tr>
<tr>
<td>Van Gompel (2011)</td>
<td>13 (2003-2010)</td>
<td>62</td>
<td>24.3 mm</td>
<td>GTR 54% STR 46%</td>
<td>Improved 67% Worsened 33%</td>
<td>CSF leak: 0 ACA stroke: 1 (8%) Pituitary dysfunction not reported</td>
<td>13 months</td>
</tr>
<tr>
<td>Ogawa (2012)</td>
<td>19 (2006-2011)</td>
<td>58.9</td>
<td>21.6 mm</td>
<td>Simpson Grade 1: Simpson Grade 2: Simpson Grade 3: 15 GTR 15 (78.9%) STR 4 (13.8%)</td>
<td>Improved 73.6% Unchanged 15.7% Worsened 10.5%</td>
<td>CSF leak: 1 (5.2%) Pituitary dysfunction: 0</td>
<td>35.8 (6-59 months) One recurrence at 59 months treated with gamma knife</td>
</tr>
<tr>
<td>Bohman (2012)</td>
<td>5 (time period not reported)</td>
<td>53.2</td>
<td>20.4 mm</td>
<td>GTR 4 (80%) STR 1 (20%)</td>
<td>Improved 80% Unchanged 20%</td>
<td>CSF leak: 1 (20%) Transient hyponatremia: 2 (40%)</td>
<td>7.8 (2.2-17 months)</td>
</tr>
<tr>
<td>Chowdhury (2012)</td>
<td>6 (2009-2010)</td>
<td>47.4</td>
<td>35 mm</td>
<td>GTR 5 (83.3%) STR 1 (16.7%)</td>
<td>Improved 83.3% Unchanged 16.7% One patient had transient visual deterioration that improved</td>
<td>CSF leak: 1 (16.7%) Transient hyponatremia: 2 (33.3%)</td>
<td>7 (2-12 months)</td>
</tr>
<tr>
<td>Gadgil (2013)</td>
<td>5 (2009-2011)</td>
<td>51</td>
<td>19 mm/6.3 cc</td>
<td>GTR 4 (80%) STR 1 (20%)</td>
<td>Improved 100% Worsened 0%</td>
<td>CSF leak: 1 (20%) Transient DI: 3 (60%)</td>
<td>15 (3-27 months)</td>
</tr>
<tr>
<td>Khan (2014)</td>
<td>17 (2006-2013)</td>
<td>62</td>
<td>23.2 mm</td>
<td>GTR 11 (64.7%) STR 6 (35.3%)</td>
<td>Improved 54.5% Unchanged 45.5%</td>
<td>CSF leak: 2 (11.8%) Transient SIADH: 2/13 (15%) Transient DI: 1/13 (7.7%)</td>
<td>10 (3-26 months)</td>
</tr>
<tr>
<td>Ceylan (2015)</td>
<td>23 (2007-2013)</td>
<td>52</td>
<td>25.5 mm</td>
<td>GTR 17 (74%)</td>
<td>Improved 70% Unchanged 30%</td>
<td>CSF leak: 2 (8.6%) Transient DI: 1 (4.3%) Permanent DI: 1 (4.3%)</td>
<td>2-70 months One patient had TC approach subsequently</td>
</tr>
</tbody>
</table>

*Study mentioning outcomes of transcranial and endoscopic outcomes separately; †study mentioning microscope and endoscope use during transsphenoidal excision. ACA: anterior cerebral artery; MCA: middle cerebral artery; EEA: expanded endoscopic approach; TC: transcranial surgery; GTR: gross total resection; NTR: near-total resection (>95% resection); STR: subtotal resection (<95% resection); DI: diabetes insipidus; SIADH: syndrome of inappropriate secretion of antidiuretic hormone.*
Over the last decade, endoscopic approaches have been increasingly utilized successfully for the removal of a variety of extra-dural lesions of the skull base. With increasing experience these techniques have been applied to the removal of intradural pathology. Because of the midline location of TSMs, the EEA, being primarily a midline approach, has been advocated for resection of TSMs. The advantages cited for this approach include the avoidance of complications associated with open surgery that may be related to brain manipulation or retraction. The endoscope also allows for a very wide panoramic view of the relevant anatomy avoiding any

Discussion

The primary objective in meningioma surgery is maximal safe resection, because the volume of residual tumor correlates to the recurrence rate. Other prognostic factors for outcome include location, size, age of the patient and pathological grade. Also important is minimizing any brain retraction, decompressing and preserving all neurovascular and endocrine structures. There are a number of well-established open transcranial approaches that have been utilized for TSM with favorable outcomes. These include both bilateral (subfrontal and transbasal interhemispheric) and multiple unilateral (subfrontal, pterional, supra-orbital) approaches. 5-8, 10, 14, 28-34

![Figure 2](image-url)

Figure 2.—A, B) Gadolinium-enhanced sagittal and coronal MRI of a patient with a 2-cm tuberculosis sella meningioma (TSM) that is in the midline and medial to the optic nerve and carotid artery with limited dural attachment making it an ideal case for the endonasal endoscopic approach (EEA). C, D) Five-year follow-up MRI after EEA for excision of the TSM showing no residual tumor.
Eligibility for the transsphenoidal route in TSMs

Based on our own experience, we have developed certain selection criteria that we deem favorable for the endoscopic approach to TSMs.26 These include primarily small or medium size lesions (<2.5 cm), in the midline with dural attachment medial to the supraclinoid internal carotid artery and minimal lateral extension (Figures 2, 3). We also include lesions with sellar, retrochiasmal and interpeduncular extensions medial or inferior to the optic nerves. While a few reports do mention removal of tumors with vascular encasement,36 it is our view that any vascular encasement (internal carotid, anterior communicating or A1-A2 segments of the ACA) is a relative contraindication for the safe total removal of the tumor off critical neurovascular structures with improved results.13, 35

While the technique has gained popularity with increasing reports in the literature, the indications for and effectiveness of this approach remains uncertain and controversial. As for any new innovation/surgical technique it is important not only to document that it is feasible, safe, with acceptable complications but most importantly, based on peer-reviewed published reports, that it is at least equal to or more effective than traditional approaches. As a randomized study of open versus the endoscopic removal of TSMs, for a variety of reasons, will likely never be feasible to carry out, it is important that other assessment tools, including systemic reviews, be used to carefully scrutinize the results in the literature.

Figure 3.—A, B) Gadolinium-enhanced sagittal and coronal MRI of a patient with a 2.2-cm tuberculum sellae meningioma (TSM) that is in the midline with sellar extension. Despite its lobulated nature, it remains medial to the optic nerve and carotid artery with no optic canal extension making it amenable for the endonasal endoscopic approach (EEA). C, D) Six-year follow-up MRI after EEA for excision of the TSM showing no residual tumor.
Widespread dural attachment along the anterior cranial fossa floor, extensive hyperostosis and the degree of perilesional brain edema are also considered in our view relative contraindications to this approach and the decision to use this approach must be dealt with using an individualized surgical decision-making paradigm. The EEA may be an alternative approach for elderly or other patients who may have tumors with these unfavorable features but who may not be able to tolerate transcranial surgery or where the goal of surgery is not total removal but optic nerve decompression alone.

A major point of contention regarding the endoscopic approach for TSM is the presence of optic canal extension. While there are reports of endoscopic removal of tumors involving the optic canal, we believe that, with the exception of a limited medial canal extension of the tumor, any significant optic canal extension is a contra-indication for this approach. Specifically if there is any extension beyond the medial arc of the optic canal with circumferential optic canal involvement, the tumor is better addressed from the transcranial route. Widespread dural attachment along the anterior cranial fossa floor, extensive hyperostosis and the degree of perilesional brain edema are also considered in our view relative contraindications to this approach and the decision to use this approach must be dealt with using an individualized surgical decision-making paradigm. The EEA may be an alternative approach for elderly or other patients who may have tumors with these unfavorable features but who may not be able to tolerate transcranial surgery or where the goal of surgery is not total removal but optic nerve decompression alone.
Other authors have also used basal skull anatomy in their selection criteria and Guthikonda et al.\textsuperscript{39} suggested that a wide chiasmatic sulcus would present a favorable corridor for the endonasal approach, while a transcranial approach might be more appropriate when the sulcus is narrow. Likewise, a steep tuberculum sellae and involvement of the intrasellar space have also been cited as good indications for the EEA.\textsuperscript{40}

Advantages and disadvantages of the EEA for removal of TSMs

Advantages

As noted above, the major advantage of this approach is that it is the most direct midline approach to such a centrally-placed tumor, as it provides a wide better-illuminated view of relevant anatomy when compared with the tunnel view optics of the microscopic approaches. It is less invasive with minimal or no brain retraction, in contrast to the transcranial route where brain retraction to some degree is almost always required. As these tumors usually elevate the optic nerve or chiasm, the EEA minimizes any “blind” dissection eliminating any manipulation of the optic nerve/chiasm that can occur via the transcranial route especially when removing tumor inferior to the optic apparatus. It also allows earlier bilateral medial optic nerve decompression at the level of the optic canal. Since these tumors arise from the basal dura or more precisely the tuberculum arachnoid the approach may provide for early devascularization of the tumor by dealing with the blood supply during the extradural approach. The intervening arachnoid plane also protects the vascular supply of the optic apparatus allowing for clear visualization of the superior hypophyseal and ACAs, which can be dissected off the capsule once the tumor is debulked. The approach also allows for easier exposure, visualization and removal of intra/retrosellar/interpeduncular extensions that can occur with this tumor. Some proponents would cite that it also provides for a better cosmetic result.\textsuperscript{20}

The evolution of endoscopic surgery has driven the development or adaptation of surgical instruments that are ergonomic, offer good maneuverability through the transphenoidal route and allow safe tissue handling and tumor resection. While instrumentation may still not be optimal, examples of such technologies including high-speed drills and micro-ultrasonic aspirator, the intra-operative Doppler and the surgical micro-debrider all help in safe tumor removal.

Disadvantages

The EEA has a number of disadvantages that have to be considered. The technique is technically challenging with a steep learning curve. While technology continues to improve, there is still to some extent restricted maneuverability and workspace making instrument manipulation more difficult. Indeed, current instrumentation for intra-dural endoscopic skull base surgery is still not entirely adequate. With current technology there is a lack of binocular vision, which may be a factor when dealing with very fine intradural structures. While there are a number of 3D systems being developed, to date, none can duplicate the 3D visualization provided by the operating microscope. It is also more difficult with the EEA to achieve a total removal of larger tumors with extensions lateral to the optic nerve and carotid artery including any microscopic lateral dural attachment, which may not be visible from below. While some authors report more limited visibility of the posterior part of the tumor in this approach, this has not been our experience.\textsuperscript{27} Likewise despite the introduction of the nasoseptal flap, which has significantly reduced the incidence of CSF leak, this complication and the complex reconstruction required in this approach remain a significant challenge.

Resection rates of TSM

Safe GTR with preservation of all neurovascular structures and reversal of visual and endocrinological dysfunction should be the objectives of surgery for TSMs regardless of the approach. However, these objectives are not always attainable and the goals of surgery may need to be individualized for each patient depending on a number of both patient and tumor factors. These include the age of the patient, nature and chronicity of presenting symptoms, the size and radiological features of the tumor including its extensions, vessel encasement, intraoperative findings, and the availability of adjuvant treatments.

In our analysis, GTR rates ranged from 50-98.5% with a mean of 77.2% and NTR/STR rate of 21.4%. As mentioned, in some patients, due to a number of fac-
tors, GTR may not have been the goal of surgery resulting in a lower than expected GTR and a wider range among varying studies. In a previous systematic review on TSMs, GTR rates in the EEA group ranged from 60-92%. They compared these outcomes to contemporary studies of transcranial surgery where GTR rates of 74-92% were reported. There was no difference in tumor size between EEA and transcranial patients. In another review analysis, evaluating outcomes of 4 specific skull base tumors — olfactory groove meningioma, cranio-pharyngioma, chordomas and TSM’s, the GTR rates specifically for TSMs in the open surgical approach versus the EEA were comparable (85.3% vs 79.9%). However, one should be cautious of interpreting the results comparing the two approaches due to the retrospective nature of the studies and the selection bias. In centers that offer both approaches, the transcranial approach is usually reserved for larger tumors or for those not suitable for the endoscopic route. The experience and comfort level of the individual surgeon also affects surgical decision-making.

Visual outcomes

Preservation of visual function and minimization of trauma to the optic apparatus are of critical importance in surgery of TSMs. Visual deterioration may occur from both direct injury to the optic nerve/chiasm as well from disruption of its vascular supply. Overall, visual improvement was seen in 79.5% of patients and ranged from 54.5-100%. The extent of optic canal invasion was not routinely reported in the papers reviewed and we cannot correlate the visual outcomes to the extent of involvement or decompression of the optic canal. Optic canal invasion by TSMs has been reported to occur in up to 67% of transcranial cases and this feature has been cited as a major drawback for the use of the endoscopic approach to TSMs. Vision deteriorated in 7.3% of patients with a range of 0-38% and remained unchanged in 17.4% (0-45%). Clark et al. reported that the endoscopic cohort had higher rates of visual improvement 50-100% vs. 25-78% in the transcranial group. Likewise, Graffeo et al. reported visual decline in 11.4% and 2.1% of patients respectively in the open and endoscopic cohorts. However, a direct comparison of visual outcomes in the two groups should be made with caution due to difference in patient age, tumor size, tumor extensions and the varying goals of surgery.

Another important aspect to consider is that the visual outcomes may be related to other factors other than the adequacy of optic nerve decompression including the chronicity of the symptoms and compression. Zervadis et al. showed that visual prognosis was favorably affected by age under 54 years, duration of symptoms of less than seven months, and the presence of an intact arachnoid membrane around the lesion. Severe preoperative loss of visual acuity appeared to be an unfavorable prognostic factor.

Complications

CSF leak

CSF leak remains the most worrisome complication following transsphenoidal surgery for TSMs. In a review of TSMs that included patients with planum sphenoidale meningiomas by Ditzel Filho et al., the CSF leak rate was 19%. In our analysis, this figure was 15.3%. However when we compared the earlier series in the literature with those published from 2010 onwards, there was a dramatic decline in the CSF leak rates from 32% to 7%, a five-fold reduction. This is attributed to the evolution of improved reconstruction techniques and the use of the vascularized nasoseptal flap. Interestingly, no patient developed meningitis as a result of a CSF leak in the reported series.

In two systematic reviews that compared endoscopic versus open excision of TSMs, the CSF leak rates were 21% vs. 5% and 21.5 vs. 4.4%, respectively. Other techniques such as gasket seal and direct suturing of graft material have been reported and may be useful for recurrent cases or when one technique fails.

Endocrine dysfunction

While the pituitary stalk may be significantly displaced by TSMs, surrounding arachnoid sleeve is protective and provides a plane of cleavage for tumor dissection. This may partially explain the lower incidence of postoperative hormonal dysfunction in patients with suprasellar meningiomas when compared with other extra-axial suprasellar tumors. While 9.4% had transient pituitary dysfunction, only 2.2% required long-term hormonal replacement. Other studies have
also confirmed the very low rates of permanent endocrine dysfunction following transsphenoidal surgery of TSM.\textsuperscript{42, 46}

**Vascular injury**

A significant concern expressed with the transsphenoidal approach is the risk of injury to the internal carotid artery.\textsuperscript{47} While the overall incidence of vascular injury was 2.6\% no injuries to the internal carotid artery were reported in this review. The proximity of the ACA and its perforators to the tumor requires careful microdissection techniques. In larger tumors where the arachnoid plane may not be intact or there is encasement of vessels the risk of vascular injury is increased. Multilobar tumor configuration, lack of an arachnoid plane with invasion of pia may also contribute to incomplete removal and sub-optimal outcomes.\textsuperscript{12} While there are reports of TSMs with vascular encasement being removed via the EEA,\textsuperscript{36} we still endorse the view that vessel encasement remains a barrier to total removal of these tumors and increases the risk of vascular injury features that may favor a transcervical approach.

**Endonasal versus open transcranial approach**

Assuming that a center has the expertise and can offer both an open and endoscopic approach for removal of a TSM, the main question is which approach is better for the individual patient. For some lesions the decision is more straightforward and include tumors of a small size, with limited lateral extension and no vascular encasement at one end of the spectrum that favors an endoscopic route, while large tumors at the other end are best managed with a craniotomy approach. The clinical equipoise usually arises for a number of those tumors that lie in between and the lack of hard data in the literature often makes the surgical choice difficult. Ideally, a randomized study proposed by some might provide an answer. However, for a variety of reasons it is unlikely this will ever be feasible.

A prospective cohort study may be a more realistic option to provide us with reliable quality data on the best management of these tumors. Systematic reviews are the most reliable tool we currently have to evaluate the effectiveness of the surgical resection and our study may provide useful data that can inform patient selection and counseling. Further development of endoscopic technology may also improve the safety profile and expand the application of endoscopic resection of TSM to more challenging tumors.

**Conclusions**

The EEA to the skull base is an established less invasive alternative to open transcranial procedures. In experienced hands and with careful patient selection the technique is both feasible and safe. However, appropriate training and team approach are important prerequisites for success in these techniques. The choice of approach for anterior skull base meningiomas in general and TSM in particular remains controversial and a clear understanding of the limitations of the endoscopic approach is very important and helps guide patient selection for the use of this technique. For TSMs, based on observational data, this approach has proven to be effective with good resection rates equal to and visual outcomes equal or better than open approaches with low morbidity and mortality.

There is currently limited published data in the literature with relatively few patient numbers from single institutions with short follow-up periods, which preclude any accurate comparison to other open surgical approaches. In our hands with careful patient selection the EEA can result in equivalent GTR rates as open approaches with less postoperative brain changes on MRI and higher rates of visual improvement.\textsuperscript{48} While CSF leak rates are higher, on-going improvements in reconstruction techniques have continued to decrease this complication to acceptable levels. Analysis of larger series of patients with longer follow-up will be required to fully validate the efficacy of the approach especially in terms of rates of GTR, complication rates, incidence of recurrence and quality of life issues. While the EEA should technically have lower recurrence rates, this cannot be adequately assessed without longer follow-up.

Until larger studies are reported, these results can serve as a guideline to counsel patient of realistic outcomes. It is likely that for the majority of neurosurgeons traditional open surgical techniques will remain the approaches of choice for of TSMs. The EEA in those selective cases amenable to the technique will likely or should be limited to those specialized centers that have adequate experience with and can offer both open and endoscopic approaches to the patient.
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