Pituitary (2017) 20:561–568
DOI 10.1007/s11102-017-0818-6

The extended, transnasal, transsphenoidal approach for anterior skull base meningioma: considerations in patient selection

Joseph P. Castlen[1] · David J. Cote[1] · Hasan A. Zaidi[1] · Edward R. Laws Jr.[1]

Published online: 8 July 2017

Abstract
Purpose In this study, we set out to define our institutional criteria for patient eligibility for transsphenoidal resection of parasellar meningiomas, and to report our experience with extended transnasal approaches for these lesions. We aimed to discuss the important considerations of patient selection and risk stratification to optimize outcomes for patients with these difficult lesions, and also include considerations that should be reviewed during surgical approach selection.
Methods Medical records from Brigham and Women's Hospital were retrospectively reviewed for all patients who underwent transsphenoidal surgery for pituitary disease with the senior author from April 2008 to March 2017 (938 procedures). Patients undergoing surgery for anterior skull base meningioma were identified and patient data were collected.
Results Seven patients (four women, three men) underwent transsphenoidal resection (five endoscopic, one microscopic, and one hybrid endoscopic/microscopic) of pathologically-confirmed anterior skull base meningiomas during the study period. Five patients presented with visual field deficits, three presented with headache, two presented with hypopituitarism, and one woman presented with infertility. The median maximum tumor diameter was 1.7 cm (range 1.4–4.2 cm). Six patients underwent subtotal resection, and one underwent gross total resection. The median MIB-1 index was 2.3 (range 1.0–7.6). Complications included two readmissions (one on POD11 for small bowel obstruction, one on POD48 for epistaxis), and the development of new onset thyroid deficiency and transient diabetes insipidus in one patient. Two patients had reoperations by craniotomy for tumor recurrence after 5 and 6 years, respectively.
Conclusions Although more commonly treated transcranially, anterior skull base meningiomas are sometimes amenable to resection transphenoidally. Patient selection is critical, and multiple factors, including tumor size, consistency, and location, patient and surgeon preference, and presenting symptoms each affect the optimum surgical approach. We have developed criteria for patient selection so that transsphenoidal surgery can be used to resect or debulk anterior skull base meningiomas safely and with favorable outcomes.

Keywords Endoscopic · Meningioma · Minimally invasive · Neurosurgery · Transsphenoidal

Introduction

Initially pioneered as a means of accessing the pituitary gland, the transsphenoidal approach is an increasingly popular method to treat a wide variety of anterior skull base lesions [1–4]. Since the 1960s, the evolving popularity of minimally invasive approaches and technological advances have allowed for the development of the extended, transnasal approaches to anterior skull base lesions [1, 5]. This technique, augmented by stereotactic intra-operative guidance, intra-operative MRI, and advances in endoscopic technology, has emerged as a relatively safe and effective approach for the resection or debulking of selected anterior skull base meningiomas (Table 1) [6–10].

✉ Edward R. Laws Jr.
elaws@bwh.harvard.edu

[1] Pituitary/Neuroendocrine Center, Department of Neurosurgery, Brigham and Women's Hospital, Harvard Medical School, 60 Fenwood Road, Boston, MA 02115, USA

Table 1 Types of meningiomas which may be operable via the extended, transsphenoidal approach

Tuberculum sellae meningioma
Planum sphenoidale meningioma
Diaphragmatic meningioma
Olfactory groove meningioma
Optic canal meningioma

Historically, the transcranial approach to the anterior skull base was thought to be beneficial for most lesions in this region, due to a wider operative exposure which improved visualization and surgical freedom of access [11, 12]. Although transcranial approaches are still the preferred approach for the majority of anterior skull base meningiomas, the transsphenoidal approach has recently emerged as a viable alternative, related in part to reduced approach-related morbidity. Some authors advocate that this approach can result in comparable surgical outcomes in carefully selected patients [13–15].

The criteria for selecting patients with anterior skull base meningiomas for whom extended transnasal surgery is a viable option are a hotly debated topic in the neurosurgical community. A multitude of factors are thought to play a role in patient selection, but vary depending on institutional and surgeon experience [16–21]. In this study, we set out to define our institutional recommendations for patient eligibility for transsphenoidal resection of parasellar meningiomas, and to report our experience with extended transnasal approaches for these lesions over the course of 8 years. In particular, we aimed to discuss the important considerations of patient selection and risk stratification in order to optimize outcomes for patients with these difficult lesions, and we also include a series of considerations that should be reviewed during approach selection.

Methods

Medical records from Brigham and Women's Hospital were retrospectively reviewed for all patients who underwent transsphenoidal surgery for pituitary disease with the senior author from April 2008 to March 2017 (938 procedures). Patient data, including demographics, pre- and post-operative symptoms, pathological analysis, and post-operative complications were collected. The extent of resection and tumor consistency were quantitatively determined based on the surgeon's operative report and post-operative radiographic imaging, and tumor size was determined on pre-operative radiographic imaging. The Institutional Review Board of Brigham and Women's Hospital approved this study.

Results

Seven patients (four women, three men) underwent transsphenoidal resection of anterior skull base meningiomas during the study period. The median length of follow-up was 19 months (mean 35.6, range 3–104). Five patients presented with visual field deficits, three presented with headache, two presented with hypopituitarism, and one woman presented with infertility. One patient was receiving steroid replacement preoperatively, and three were receiving thyroid replacement therapy. One patient had type-2 diabetes mellitus preoperatively, which was treated with oral medication.

The median maximum tumor diameter was 1.7 cm (mean 2.1 cm, range 1.4–4.2 cm). All seven tumors had suprasellar extension, four were primarily intrasellar, and five were parasellar (Fig. 1). No patient had lateral extension of the tumor beyond the anterior clinoid processes on coronal MRI. All patients underwent extended transnasal transsphenoidal resection (five endoscopic, one microscopic, and one hybrid endoscopic/microscopic). Six of seven patients received subtotal resection, four of whom had firm tumors intra-operatively and two of whom had loosely-organized tumors, while one patient received gross total resection (GTR) of a loosely-organized tumor (Fig. 2). On pathology all patients had meningioma, one of which was atypical and another of which was borderline, with a MIB-1 index of 4.5. The median MIB-1 index was 2.3 (mean 3.2, range 1–7.6). Six tumors were WHO grade I, and one was grade II (Table 2).

Prior interventions among these patients included craniotomy and Gamma Knife radiosurgery in one patient, and two prior craniotomies with linear accelerator radiation therapy in another. Complications included two readmissions (one on POD11 for small bowel obstruction, one on POD48 for epistaxis), and the development of new onset thyroid deficiency and transient diabetes insipidus in one patient.

Two patients had reoperations by craniotomy for recurrence after 5 and 6 years, respectively. Two years prior to the initial extended transsphenoidal operation with the senior author, the first patient presented with visual loss and hypopituitarism at an outside hospital, and underwent a craniotomy, which was complicated by the new onset of blindness in one eye. The subsequent transsphenoidal operation with the senior author resulted in a subtotal resection of the $3.2 \times 4.2 \times 2.5$ cm lesion due to the highly vascular nature of the tumor, and 5 years later the tumor recurred, requiring another craniotomy. The second patient presented with bilateral hemianopia and underwent transsphenoidal surgery with the senior author for a $1.7 \times 1.0 \times 1.7$ cm tumor. A subtotal resection was achieved, and a craniotomy was performed after

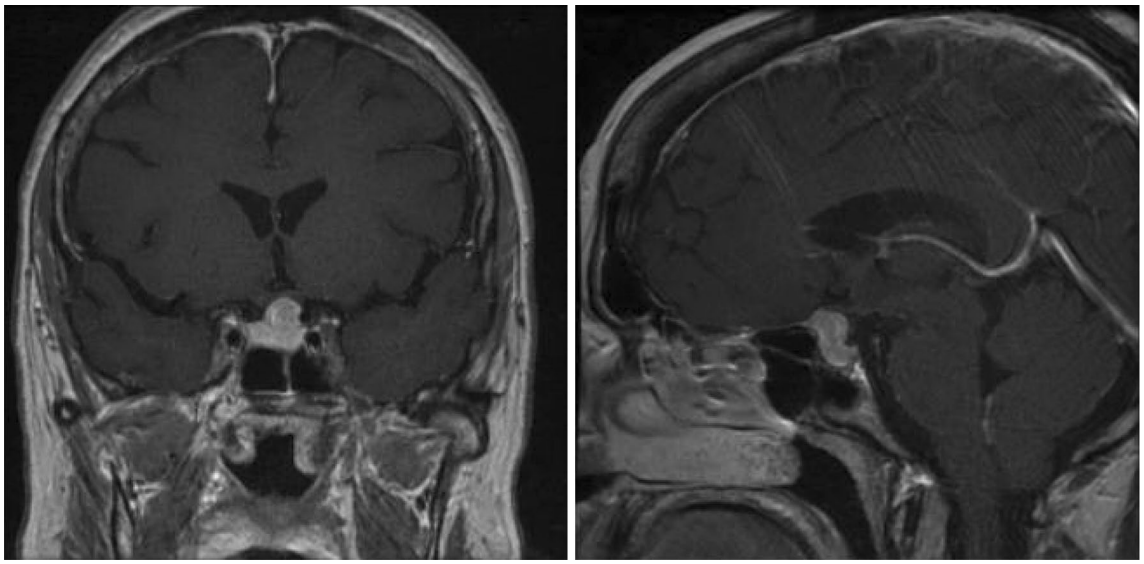

Fig. 1 Pre-operative coronal (*left*) and sagittal (*right*) post-gadolinium T1-weighted magnetic resonance imaging of anterior skull base meningioma

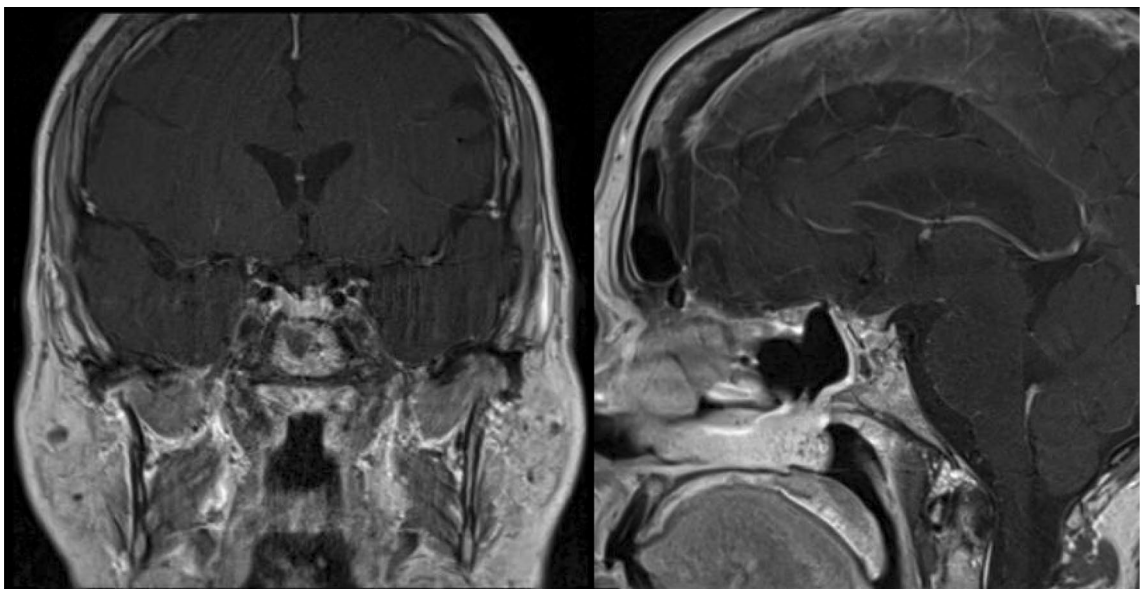

Fig. 2 Post-operative coronal (*left*) and sagittal (*right*) post-gadolinium T1-weighted magnetic resonance imaging of anterior skull base meningioma

6 years due to progressive vision loss caused by tumor recurrence.

Discussion

Gradual experience gained by skull base surgeons in the treatment of sellar lesions using endoscopic visualization in the last 2 decades have permitted the treatment of a variety of lesions previously considered inoperable via the transnasal corridor. Parasellar anterior skull base meningiomas represent one such challenging pathology. These lesions have a tendency to surround important neurovascular structures, invade adjacent skull base foramina, and often have unpredictable tumor consistency. Although standard transcranial approaches for these lesions are appropriate in the vast majority of cases, there are certain characteristics that make transsphenoidal surgery a viable or even preferred option for some lesions (Table 3). There remains much discussion in the literature on this issue, and

Table 2 Demographics and presenting symptoms of seven patients undergoing transsphenoidal surgery for anterior skull base meningiomas

Demographic characteristics	All patients
Male (no., %)	3 (43%)
Age, years (median, range)	68 (31–73)
Follow-up, months (median, range)	19 (3–104)
Presenting symptoms (no., %)	
Visual deficit	5 (71%)
Headache	3 (43%)
Hypothyroidism	2 (29%)
Hypocortisolism	1 (14%)
Infertility (% of female patients)	1 (25%)
Tumor characteristics (no., %)	
Intrasellar	4 (57%)
Suprasellar	7 (100%)
Parasellar	5 (71%)
Optic canal invasion on MRI	0
Maximum diameter (median, range)	1.7 (1.4–4.2)
MIB-1 index (median, range)	1.6 (1–7.6)
Hospital course (no., %)	
Endoscopic	5 (71%)
Microscopic	1 (14%)
Hybrid endoscopic/microscopic	1 (14%)
Abdominal fat graft	4 (57%)
Lumbar drain	1 (17%)
ICU stay	0
Length of stay, days (median, range)	4 (2–11)

reported rates of GTR and post-operative complications are heavily dependent on not only surgeon experience, but also patient selection [5, 19, 22].

Presenting symptoms and patient characteristics

Presenting symptoms of anterior skull base meningiomas can mimic other intrinsic pituitary tumors [5]. Mass effect on the pituitary gland by intrasellar lesions can result in hyposecretion and deficiency of pituitary hormones [23]. Patients for whom surgery is not expected to restore pituitary function may be more suited to a transsphenoidal approach given that the risk of iatrogenic damage to the pituitary gland is potentially greater due to the trans-sellar window. In addition to causing pituitary insufficiency, these lesions can result in mild hyperprolactinemia via the pituitary stalk effect, resulting in infertility, a presenting symptom in one patient in this series [24–26]. For this reason, female patients of child-bearing age may be better suited for transcranial approaches if it is expected that transsphenoidal surgery might result in permanent pituitary gonadotropin insufficiency.

Headaches are another common presenting symptom for patients with sellar lesions, as demonstrated in our series [27, 28]. The potential co-morbidities of each approach should be considered in patients who may be predisposed to headaches. For instance, patients who already have severe incapacitating headaches may be better suited for

Table 3 Considerations for surgical approach selection for patients with anterior skull base meningiomas

Consideration	Points of attention
Presenting symptoms	Patients with progressive visual loss may require a more urgent operation
	Risk of damage to the pituitary gland may be less of a concern in patients with pre-existing endocrine disease (e.g., Hashimoto's) or who have pituitary dysfunction
Tumor location	Tumors located above the optic nerves or that invade the optic canal may be more amenable to transcranial resection
	Tumors that displace neurovascular structures superiorly may be better suited to the transsphenoidal approach
	Lesions that involve the intracranial internal carotid artery or its branches may be better suited for transcranial approaches, given the surgeon's access to proximal vascular control
Tumor size	Larger tumors may be better suited to the wider operative field of the transcranial approach
	Small lesions may be adequately treated transsphenoidally
Tumor consistency	Patients with soft-suckable tumors may be more appropriate for transsphenoidal approach
	Fibrous tumors may require the improved access and visualization provided by the transcranial approach
Patient characteristics	Patients with aggressive lesions who have previously undergone craniotomy or transsphenoidal surgery may benefit from treatment by an alternative approach
	Many patients may favor the better cosmetic outcomes of the transsphenoidal approach, and avoidance of craniotomy
	Older patients or patients with more co-morbidities may benefit from the minimally invasive nature of transsphenoidal surgery
	Patients with significant co-morbid medical conditions may be more suitable for endonasal approaches, given reduced perioperative complication rates and faster postoperative recovery associated with endonasal approaches versus transcranial approaches
Surgeon experience	Surgeons will likely prefer the method with which they have more experience
	Emergent cases may limit surgeon or equipment availability and require a transcranial approach

transsphenoidal surgery given the reduced approach-related morbidity associated with this exposure.

There were two readmissions in this series: one for postoperative small bowel obstruction and one for epistaxis 6 weeks after surgery. One patient also developed new onset thyroid deficiency and transient diabetes insipidus. These recognized complications of transsphenoidal surgery should be considered in case selection and weighed against potential complications of transcranial surgery [29, 30]. Furthermore, transnasal approaches may be best suited for patients with extensive co-morbid medical conditions. Several studies indicate that transnasal approaches carry a lower risk for perioperative medical complications and shorter postoperative recovery versus traditional transcranial approaches [31, 32].

Tumor location and size

In this case series, patients with anterior skull base meningiomas most commonly presented with visual field deficits. This is an unsurprising finding given that these lesions usually originate in proximity to the optic chiasm [3]. A transnasal corridor can provide a more direct route to the lesion versus transcranial approaches, the latter of which necessitate dissection around the optic chiasm. In cases with significant suprasellar extension and optic nerve/chiasm deformation, the transcranial route can often place the optic nerve at significant risk given its splaying over the tumor. The goal of surgery in these cases may be debulking rather than gross total resection, which may make transnasal approaches the more favorable initial approach given the retrochiasmal view provided by this corridor. None of the patients in this series had tumor extension lateral to the anterior clinoid processes, which we believe will increase the potential for optic canal invasion. Since the optic canal in these patients can be decompressed via opening of the falciform ligament in the transcranial approach, but less effectively by the transnasal approach, these patients may be better suited for craniotomies [14, 33].

Tumor location plays a critical role in patient selection. Five patients in this series had lesions with parasellar extension. This poses the risk of carotid artery injury, which can be difficult to manage from a transnasal corridor. The degree of neurovascular encasement by the tumor can also influence whether the goal of surgery is gross total resection or debulking [14]. It is imperative that close analysis of radiographic imaging be performed before deciding on surgical approach, with particular emphasis on vascular studies. If neurovascular structures are displaced laterally, making a lesion more difficult to access transcranially, then the transsphenoidal approach may provide better access [14]. Likewise, when the meningioma inferiorly abuts the hypothalamus, the transsphenoidal approach may offer more direct access to the lesion [34].

Tumor characteristics

Tumor consistency also affects the degree to which tumor can be resected, and should be considered in patient selection, and anticipated outcomes [35]. All four patients with firm tumors in this series underwent subtotal resection, while the three patients with loosely-organized tumors underwent either subtotal (two patients) or gross total (one patient) resection depending on tumor involvement with neurovascular structures. Advances in MRI imaging, including the development of effective MR elastography, may soon provide the ability to detect differences in tumor consistency; however, at present the best practice is to rely on operative reports from past surgery (if any) to determine probable tumor type [36, 37]. Firm tumors pose a greater risk of adherence to the optic nerves or neurovascular structures during resection, and the wider operative field of the transcranial approach may help in the resection of these lesions [28].

Surgeon experience

Surgeon experience is an important factor in determining mode of visualization. Although most neurosurgeons are adept at standard transcranial approaches and often work independently, transnasal approaches on the other hand require subspecialty training and often a team-based approach. A well-coordinated team effort is necessary in order to successfully execute extended transnasal approaches, often with the assistance of ear, nose and throat (ENT) surgeons, and surgical technicians and assistants adept at maintaining, setting up, and holding endoscopes. Furthermore, extended transnasal approaches to the ventral skull base require that the primary surgeon has gained experience incrementally over time in both the intraoperative and postoperative management of these complex patients. Several studies indicate that surgeon experience plays a key role in the safety and efficacy of transnasal approaches to the skull base [22, 38].

The fact that two patients had a prior craniotomy followed by radiation therapy and two other patients underwent a craniotomy within 6 years subsequent to transsphenoidal surgery underscores how challenging these lesions can be. In some particularly difficult cases, transsphenoidal surgery for debulking of an anterior skull base meningioma can be seen as a salvage therapy for patients who have previously failed craniotomy or radiosurgery. These cases also highlight how critical case selection is, and how a variety of factors, including patient characteristics and prior treatment, as well as the exact size, positioning, and consistency

Table 4 Comparison of outcomes with other case series in the literature [14, 39–42]

	Present Series	Kassam et al. [40]	Koutourousiou et al. [14]	De Divitiis et al. [41]	Gardner et al. [39]	Van Gompel et al. [42]
Demographics (no., %)						
Patients undergoing TSS	938	800	–	51	–	–
Patients with meningioma	7 (0.7%)	94 (11.9%)	75	7 (13.7%)	35	13
Age, years (mean, range)	58 (31–73)	49 (3–96)[a]	57 (36–88)	–	55 (39–79)	62 (31–77)
Follow-up, months (median, range)	19 (3–104)	–	Mean: 29 (1–98)	(1–20)[c]	(12–48)	8 (0–65)
Complication (no., %)						
CSF leak	0	15.9%[a]	19 (25%)[b]	2 (29%)	14 (40%)	0
New neurological deficit	0	6 (0.6%)[a]	3 (4%)	0	1 (3%)	0
Death	0	7 (0.9%)[a]	0	1 (17%)	0	0
Transient DI	1 (14%)	–	–	–	1 (3%)	0
Permanent endocrine deficiency	1 (14%)	–	–	0	2 (6%)	0
Epistaxis	1 (14%)	–	–	0	1 (3%)	0
SBO	1 (14%)	–	–	0	–	0
Reoperation	2 (29%)	–	1 (1%)	0	0	0

–=Metric not reported

TSS transsphenoidal surgery, *DI* diabetes insipidus, *SBO* small bowel obstruction

[a]Complication rates reported for this series are for all patients undergoing endoscopic endonasal surgery, not just patients with meningiomas

[b]5 of these patients had post-operative meningitis; the rate of CSF leak in the most recent years of this study was 11.7%

[c]Median and mean not available, only range shown

of anterior skull base meningiomas, can affect the optimum surgical approach.

Institutional recommendations

It is clear that we have significant institutional bias in our patient selection. The fact that over 9 years only seven patients with meningiomas were taken to the operating room for transsphenoidal surgery speaks to the care put into selecting patients for whom a successful outcome is expected. Only certain tumor types, which we list in Table 1, may be safely resected transsphenoidally. The institutional availability of highly skilled open skull base surgeons also can assist in recommending the optimal approach in each case.

All of the previously discussed factors play a role in deciding if a patient is a surgical candidate, however, the size of the lesion is particularly important, as it can drive or exacerbate other factors, e.g., neurovascular involvement. The only lesion in this series with a maximum dimension greater than 3.0 cm was one of the two which required reoperation, and the average maximum tumor dimension in this series was relatively small at 1.7 cm. In a somewhat related vein, tumors closer to midline and with less lateral extension increase the appropriateness of being candidates for a transsphenoidal resection. If available, previous operative reports are used to exclude patients with very fibrous tumors from receiving transsphenoidal operations. Still, this is an imperfect criterion, as four of the patients in this series had firm tumors.

Other series report wide ranges of rates of CSF leak from 0 to 40%, a small incidence of neurological deficits, and even death as complications of the extended transsphenoidal approach (Table 4) [14, 39–42]. In this series, we did not experience any of these complications, perhaps due to the relatively small size of the lesions. Thus, although we did experience complications not included in other series, including reoperation, and despite the small size of this series, we believe that we have demonstrated that transsphenoidal resection of these lesions can be safely performed given proper surgeon experience and patient selection.

Conclusions

Although more commonly treated transcranially, meningiomas are sometimes amenable to resection transphenoidally. Patient selection is critical, and multiple factors, including tumor size, consistency, and location, patient and surgeon preference, and presenting symptoms each play a role in determining the optimum surgical approach. Transsphenoidal surgery for a select sub-group of patients can be used to resect or debulk tumor safely and to alleviate mass effect on parasellar structures, including neurovasculature and the optic chiasm.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

References

1. Soni RS, Patel SK, Husain Q, Dahodwala MQ, Eloy JA, Liu JK (2014) From above or below: the controversy and historical evolution of tuberculum sellae meningioma resection from open to endoscopic skull base approaches. J Clin Neurosc 21(4):559–568. doi:10.1016/j.jocn.2013.03.043
2. Wang AJ, Zaidi HA, Laws ER (2016) History of endonasal skull base surgery. J Neurosurg Sci 60(4):441–453
3. Jane JA, Thapar K, Kaptain GJ, Maartens N, Laws ER (2002) Pituitary surgery: transsphenoidal approach. Neurosurgery 51(2):435–442 (**discussion 442–434**)
4. Okonkwo DR, Laws ER (2008) Meningiomas: historial perspective. In: Lee JH (ed) Meningiomas: diagnosis, treatment, and outcome. Springer, Ohio, pp 3–10
5. Zada G, Du R, Laws ER (2011) Defining the "edge of the envelope": patient selection in treating complex sellar-based neoplasms via transsphenoidal versus open craniotomy. J Neurosurg 114(2):286–300. doi:10.3171/2010.8.JNS10520
6. Di Ieva A, Tam M, Tschabitscher M, Cusimano MD (2014) A journey into the technical evolution of neuroendoscopy. World Neurosurg 82(6):e777–e789. doi:10.1016/j.wneu.2014.09.005
7. Kacker A, Komisar A, Huo J, Mangiardi J (2001) Transsphenoidal surgery utilizing computer-assisted stereotactic guidance. Rhinology 39(4):207–210
8. de Lara D, Ditzel Filho LF, Prevedello DM, Otto BA, Carrau RL (2012) Application of image guidance in pituitary surgery. Surg Neurol Int 3(Suppl 2):S73–S78. doi:10.4103/2152-7806.95418
9. Zaidi HA, De Los Reyes K, Barkhoudarian G, Litvack ZN, Bi WL, Rincon-Torroella J, Mukundan S, Dunn IF, Laws ER (2016) The utility of high-resolution intraoperative MRI in endoscopic transsphenoidal surgery for pituitary macroadenomas: early experience in the advanced multimodality image guided operating suite. Neurosurg Focus 40(3):E18. doi:10.3171/2016.1.FOCUS15515
10. Patil CG, Laws ER, (2010) Intrasellar and diaphragma sellae meningiomas. In: Pamir MN, Black PM, Fahlbusch R (eds) Meningiomas: a comprehensive text. Elsevier Health Sciences, Amsterdam
11. Morales-Valero SF, Van Gompel JJ, Loumiotis I, Lanzino G (2014) Craniotomy for anterior cranial fossa meningiomas: historical overview. Neurosurg Focus 36(4):E14. doi:10.3171/2014.1.FOCUS13569
12. Komotar RJ, Starke RM, Raper DM, Anand VK, Schwartz TH (2012) Endoscopic endonasal versus open transcranial resection of anterior midline skull base meningiomas. World Neurosurg 77(5–6):713–724. doi:10.1016/j.wneu.2011.08.025
13. Jeswani S, Nuño M, Wu A, Bonert V, Carmichael JD, Black KL, Chu R, King W, Mamelak AN (2016) Comparative analysis of outcomes following craniotomy and expanded endoscopic endonasal transsphenoidal resection of craniopharyngioma and related tumors: a single-institution study. J Neurosurg 124(3):627–638. doi:10.3171/2015.3.JNS142254
14. Koutourousiou M, Fernandez-Miranda JC, Stefko ST, Wang EW, Snyderman CH, Gardner PA (2014) Endoscopic endonasal surgery for suprasellar meningiomas: experience with 75 patients. J Neurosurg 120(6):1326–1339. doi:10.3171/2014.2.JNS13767
15. Kim YH, Wang KC, Phi JH, Kim SK (2017) Endoscopic endonasal approach for suprasellar lesions in children: complications and prevention. J Korean Neurosurg Soc 60(3):315–321. doi:10.3340/jkns.2017.0101.012
16. Kulwin C, Schwartz TH, Cohen-Gadol AA (2013) Endoscopic extended transsphenoidal resection of tuberculum sellae meningiomas: nuances of neurosurgical technique. Neurosurg Focus 35(6):E6. doi:10.3171/2013.8.FOCUS13338
17. Liu JK, Christiano LD, Patel SK, Tubbs RS, Eloy JA (2011) Surgical nuances for removal of tuberculum sellae meningiomas with optic canal involvement using the endoscopic endonasal extended transsphenoidal transplanum transtuberculum approach. Neurosurg Focus 30(5):E2. doi:10.3171/2011.3.FOCUS115
18. Taha AN, Erkmen K, Dunn IF, Pravdenkova S, Al-Mefty O (2011) Meningiomas involving the optic canal: pattern of involvement and implications for surgical technique. Neurosurg Focus 30(5):E12. doi:10.3171/2011.2.FOCUS1118
19. Ottenhausen M, Banu MA, Placantonakis DG, Tsiouris AJ, Khan OH, Anand VK, Schwartz TH (2014) Endoscopic endonasal resection of suprasellar meningiomas: the importance of case selection and experience in determining extent of resection, visual improvement, and complications. World Neurosurg 82(3–4):442–449. doi:10.1016/j.wneu.2014.03.032
20. Abbassy M, Woodard TD, Sindwani R, Recinos PF (2016) An overview of anterior skull base meningiomas and the endoscopic endonasal approach. Otolaryngol Clin N Am 49(1):141–152. doi:10.1016/j.otc.2015.08.002
21. de Divitiis E, Laws ER Jr (2013) The transnasal versus transcranial approach to lesions of the anterior skull base. World Neurosurg 80(6):728–731. doi:10.1016/j.wneu.2013.01.027
22. Elhadi AM, Hardesty DA, Zaidi HA, Kalani MY, Nakaji P, White WL, Preul MC, Little AS (2015) Evaluation of surgical freedom for microscopic and endoscopic transsphenoidal approaches to the sella. Neurosurgery 11(Suppl 2):69–78. doi:10.1227/NEU.0000000000000601(**discussion 78–69**)
23. Jane JA, Laws ER (2001) The surgical management of pituitary adenomas in a series of 3,093 patients. J Am Coll Surg 193(6):651–659
24. Zaidi HA, Cote DJ, Castlen JP, Burke WT, Liu YH, Smith TR, Laws ER(2016) Time course of resolution of hyperprolactinemia after transsphenoidal surgery among patients presenting with pituitary stalk compression. World Neurosurg. doi:10.1016/j.wneu.2016.09.066
25. Kaiser UB (2012) Hyperprolactinemia and infertility: new insights. J Clin Invest 122(10):3467–3468
26. Shibli-Rahhal A, Schlechte J (2011) Hyperprolactinemia and infertility. Endocrinol Metab Clin North Am 40(4):837–846. doi:10.1016/j.ecl.2011.08.008

27. Rizzoli P, Iuliano S, Weizenbaum E, Laws E (2016) Headache in patients with pituitary lesions: a longitudinal cohort study. Neurosurgery 78(3):316–323. doi:10.1227/NEU.0000000000001067
28. Koutourousiou M, Fernandez-Miranda JC, Wang EW, Snyderman CH, Gardner PA (2014) Endoscopic endonasal surgery for olfactory groove meningiomas: outcomes and limitations in 50 patients. Neurosurg Focus 37(4):E8
29. Laws ER, Iuliano SL, Cote DJ, Woodmansee W, Hsu L, Cho CH (2016) A benchmark for preservation of normal pituitary function after endoscopic transsphenoidal surgery for pituitary macroadenomas. World Neurosurgery 91:371–375. doi:10.1016/j.wneu.2016.04.059
30. De Los Reyes KM, Gross BA, Frerichs KU, Dunn IF, Lin N, Rincon-Torroella J, Annino DJ, Laws ER (2015) Incidence, risk factors and management of severe post-transsphenoidal epistaxis. J Clin Neurosci 22(1):116–122. doi:10.1016/j.jocn.2014.07.004
31. Turel MK, Tsermoulas G, Reddy D, Andrade-Barazarte H, Zadeh G, Gentili F (2016) Endonasal endoscopic transsphenoidal excision of tuberculum sellae meningiomas: a systematic review. J Neurosurg Sci 60(4):463–475
32. Banu MA, Mehta A, Ottenhausen M, Fraser JF, Patel KS, Szentirmai O, Anand VK, Tsiouris AJ, Schwartz TH (2016) Endoscope-assisted endonasal versus supraorbital keyhole resection of olfactory groove meningiomas: comparison and combination of 2 minimally invasive approaches. J Neurosurg 124(3):605–620. doi:10.3171/2015.1.JNS141884
33. Gadgil N, Thomas JG, Takashima M, Yoshor D (2013) Endoscopic resection of tuberculum sellae meningiomas. J Neurol Surg B 74(4):201–210. doi:10.1055/s-0033-1342922
34. Puget S, Garnett M, Wray A, Grill J, Habrand JL, Bodaert N, Zerah M, Bezerra M, Renier D, Pierre-Kahn A, Sainte-Rose C (2007) Pediatric craniopharyngiomas: classification and treatment according to the degree of hypothalamic involvement. J Neurosurg 106(1 Suppl):3–12. doi:10.3171/ped.2007.106.1.3
35. Naganuma H, Satoh E, Nukui H (2002) Technical considerations of transsphenoidal removal of fibrous pituitary adenomas and evaluation of collagen content and subtype in the adenomas. Neurol Med Chir 42(5):202–212(**discussion 213**)
36. Smith KA, Leever JD, Chamoun RB (2015) Predicting consistency of meningioma by magnetic resonance imaging. J Neurol Surg B 76(3):225–229. doi:10.1055/s-0034-1543965
37. Smith KA, Leever JD, Hylton PD, Camarata PJ, Chamoun RB (2016) Meningioma consistency prediction utilizing tumor to cerebellar peduncle intensity on T2-weighted magnetic resonance imaging sequences: TCTI ratio. J Neurosurg. doi:10.3171/2016.1.JNS152329
38. Zaidi HA, Awad AW, Bohl MA, Chapple K, Knecht L, Jahnke H, White WL, Little AS (2016) Comparison of outcomes between a less experienced surgeon using a fully endoscopic technique and a very experienced surgeon using a microscopic transsphenoidal technique for pituitary adenoma. J Neurosurg 124(3):596–604. doi:10.3171/2015.4.JNS15102
39. Gardner PA, Kassam AB, Thomas A, Snyderman CH, Carrau RL, Mintz AH, Prevedello DM (2008) Endoscopic endonasal resection of anterior cranial base meningiomas. Neurosurgery 63(1):36–52. doi:10.1227/01.NEU.0000335069.30319.1E(**discussion 52–34**)
40. Kassam AB, Prevedello DM, Carrau RL, Snyderman CH, Thomas A, Gardner P, Zanation A, Duz B, Stefko ST, Byers K, Horowitz MB (2011) Endoscopic endonasal skull base surgery: analysis of complications in the authors' initial 800 patients. J Neurosurg 114(6):1544–1568. doi:10.3171/2010.10.JNS09406
41. de Divitiis E, Esposito F, Cappabianca P, Cavallo LM, de Divitiis O (2008) Tuberculum sellae meningiomas: high route or low route? A series of 51 consecutive cases. Neurosurgery 62(3):556–563. doi:10.1227/01.neu.0000317303.93460.24(**discussion 556–563**)
42. Van Gompel JJ, Frank G, Pasquini E, Zoli M, Hoover J, Lanzino G (2011) Expanded endonasal endoscopic resection of anterior fossa meningiomas: report of 13 cases and meta-analysis of the literature. Neurosurg Focus 30(5):E15. doi:10.3171/2011.1.FOCUS118