Current Otorhinolaryngology Reports (2023) 11:437–451
https://doi.org/10.1007/s40136-023-00489-8

Approach Selection for Planum Sphenoidale and Tuberculum Sellae Meningiomas

Ali Tayebi Meybodi[1] · **Andrea L. Castillo**[1] · **James K. Liu**[1]

Accepted: 4 September 2023 / Published online: 7 October 2023

Abstract

Purpose of Review Tuberculum sellae (TS) and planum sphenoidale (PS) meningiomas are common lesions of anterior skull base posing a surgical challenge due to their proximity to the optic apparatus and vessels of the anterior circle of Willis.

Recent Findings Traditionally, these lesions were attacked surgically via large transcranial approaches. However, with the advent and evolution of expanded endoscopic endonasal approaches as well as development of the minimally invasive "eyebrow" approaches, different choices of approach became available for these lesions. Regardless, the wide, yet smooth spectrum of anatomical features of these tumors in relation to the adjacent neurovascular structures and osseous skull base anatomy may make one or more of these approaches superior to others with regard to ability to achieve gross total resection, clinical outcomes, and complication profile. Not surprisingly, there is considerable controversy in the literature regarding the choice of approach for these lesions.

Summary This paper summarizes the historical evolution, relative advantages and disadvantages, and clinical outcomes of these approaches when used to resect TS/PS meningiomas and provide a simple decision-making algorithm for selection of surgical approach based on the current literature.

Keywords Endoscopic endonasal approach · Optic canal · Planum sphenoidale · Supraorbital approach · Transbasal approach · Tuberculum sellae

Introduction

Tuberculum sellae (TS) and planum sphenoidale (PS) meningiomas comprise about 10% of skull base meningiomas and are more common in females [1, 2]. Common symptoms of presentation include headaches, visual complaints, and personality changes. With very large and giant lesions, loss of olfaction and/or hydrocephalus may arise. These lesions pose a surgical challenge because of their proximity to critical neurovascular structures and to the nasal cavity and paranasal sinuses. As potentially benign extra-axial intracranial mass lesions, safe gross total resection (GTR) is the primary goal of treatment when possible. However, this objective may not be always attainable because of special anatomic relationships between the tumor and the adjacent structures. Therefore, the surgeon sometimes may resort to a "less-than-GTR" goal to minimize complications. Regardless of this consideration, selection of the best surgical approach to achieve the therapeutic goal may not always be straightforward. Traditionally, these lesions were approached using a large transcranial approach (TCA) through the frontal (or frontotemporal) regions. Beginning in the 1980s, the pioneering works of Perneczky and others opened a new avenue of the less "generous" minimally invasive craniotomies with comparable surgical exposure and results for these lesions [3–9].

With the addition of endoscope to the transsphenoidal approach for resection of pituitary adenomas, the arena of skull base approaches expanded significantly and the endoscopic endonasal approach (EEA) to meningiomas of the anterior skull base began to gain progressive popularity because of its efficiency, cosmetic results, ability to resect the involved skull base dura (hence a Simpson I resection), and avoidance of neural tissue retraction during surgery to name a few. With all these options "on the table," a new question arose: "What is the approach of

✉ James K. Liu
james.liu.md@rutgers.edu

Ali Tayebi Meybodi
tayebi.a77@gmail.com

1 Department of Neurosurgery, Rutgers New Jersey Medical School, 90 Bergen Street, Suite 8100, Newark, NJ 07103, USA

choice for these challenging lesions?" To this date, there is no definitive answer because all of the series published on the topic report acceptable outcomes and mostly include expert opinions about approach selection strategy. Obviously, performing a randomized controlled trial to assess the true advantages and disadvantages of these approaches and establish clearcut indications is extremely difficult and may not be even ethical when sound clinical judgment clearly rules out an approach in some cases (e.g., a minimally invasive eyebrow approach for a giant planum sphenoidale meningioma). Therefore, the alternate means to selection of a safe and efficient surgical approach to these lesions is to review the experience with any specific approach in an attempt to identify *relatively* favorable and unfavorable candidates for each one. In this work, the authors aimed to provide a brief review of the advantages and limitations of each approach in comparison to others and the parameters that would significantly affect the decision-making process to select optimal surgical approach.

Human and Animal Rights

This article does not contain any studies with human or animal subjects performed by any of the authors.

TS Versus PS Meningiomas

Cushing categorized the anterior fossa meningiomas near the optic apparatus as parasellar meningiomas and provided a staging system for their growth [10]. Al-Mefty distinguished between clinoidal, suprasellar, TS, and PS meningiomas [11]. Although one could associate the PS and TS meningiomas with their anatomic origin, these tumors show different growth patterns helping with their nosological categorization. TS meningiomas tend to grow laterally, posteriorly, and superiorly and compress and deform the optic apparatus, hence visual symptoms. The distinction between TS and PS meningiomas is arbitrary and it seems that a working definition of PS meningiomas is still lacking/controversial [2, 12, 13]. While Hullay stated that PS meningiomas are associated with remodeling and hyperostosis of PS [12], others have shown that the thickness of underlying skull is not different between TS and PS meningiomas [14]. Henderson et al. reviewed a large series of TS/PS meningiomas ($n = 47$) over an 18-year period and showed that TS/PS meningiomas exist as a smooth continuum. In their series, optic canal invasion was more frequent in PS meningiomas [14].

Evolution of Surgical Approaches to TS/PS Meningiomas

Unilateral Frontal, Bilateral Frontal, Pterional, and Orbitozygomatic Approaches

Surgery of anterior skull base did not begin with removal of the TS and PS meningiomas. In 1879, the Scottish surgeon, Sir William MacEwen, reported successful removal of an anterior cranial fossa lesion causing periorbital edema, miosis, and seizures in a 14-year-old girl [15]. A few years later in 1884, Francesco Durante reported an anterior cranial fossa tumor (not proven to be meningioma) resected via "frontal craniectomy" [16]. The first TS meningioma was reported as an autopsy finding in 1899 by Stewart [17]. The most salient early experience with PS and TS meningiomas was published in detail by Cushing and Eisenhardt in 1929 where they categorized these lesions as "parasellar" meningiomas [10]. Cushing reported the first removal of a TS meningioma in 1916 [18]. His preferred approach to anterior skull base meningiomas was unilateral frontal craniotomy [18]. Dandy's work evolved this approach to bifrontal and transbasal approaches while he described them as requiring resection of the frontal lobe to gain access to the skull base [19]. Tönnis described a bifrontal approach to anterior communicating artery aneurysms without the need for resecting the frontal lobes [20]. Orbital osteotomies were later added to bifrontal approach by Chi et al. [21].

Use of lateral approaches to anterior skull base meningiomas was started after Yaşargil's description of the frontotemporal (pterional approach) based on the pioneering works of Heuer and Dandy [22, 23]. Hassler and Zentner reported the first resection of anterior skull base meningiomas via a pterional approach [24]. Later, addition of orbital rim and zygoma resection to the pterional craniotomy was used to improve the unilateral exposure of anterior skull base meningiomas (and other lesions). Works of many pioneer surgeons during the twentieth century contributed to this evolution. McArthur and Frazier added the removal of the supraorbital ridge to frontal craniotomy in 1912 and 1913, respectively, for resection of pituitary tumors [25, 26]. Jane et al. revived this approach by integrating the orbital rim resection into the frontotemporal bone flap as a single piece [27]. During the 1980s, Perellin [28] and Hakuba [29] described the full fronto-orbito-zygomatic-malar approach after which multiple modifications were described for [30–35].

Minimally Invasive Supraorbital Approaches

In 1908, Fedor Krause reported the first supraorbital, subfrontal approach for resection of a skull base meningioma

[36]. In 1971, Wilson published a paper on the efficiency of surgical approaches to deep cerebral lesions with smaller craniotomies or as he called it "Limited Exposure" [37]. The idea of being able to see (and possibly access) the entire "room" through a "keyhole" was adopted by Emery et al. ("*Cone d'Approach*") [38] and Honeybul et al. (window of access) [39]. Brock and Dietz introduced a "small frontolateral" approach to minimize the dissection of temporalis muscle while providing ample access to the anterior circulation aneurysms [40]. During the 1990s, Axel Perneczky and his co-workers were working on efficient usage of a supraorbital keyhole craniotomy for various intracranial lesions including but not limited to anterior skull base meningiomas in Germany [8, 9]. This approach has been subsequently used by many other authors as a robust and efficient method for successful resection of TS/PM meningiomas among other lesions.

Endoscopic Endonasal Approach

The EEA for transsphenoidal resection of pituitary tumors has a rich history thanks to the works of giants such as Herman Schloffer [41], Theodor Kocher [42], Oskar Hirsch [43], Albert Halstead [44], Harvey Cushing [45], Norman Dott [46], Gerard Guiot [47], and Jules Hardy [48]. However, the extension of the usage of EEA to the skull base lesions involving parasellar and suprasellar areas was probably pioneered by Martin Weiss who described the "extended" transsphenoidal approach via a sublabial incision [49]. Weiss described the essential technique of removing the parasellar bony regions (such as TS and PS) to provide access to tumors extending to the parasellar, suprasellar, and cribriform plate extension. Combination of endoscopy, stereotactic neuronavigation, and extended transsphenoidal approach led to the birth of expanded EEA during the early 2000s [50–52].

Use of Transcranial and Endonasal Approaches for TS/PS Meningiomas

While the details of the technical steps of these approaches are beyond the scope of this piece, relative advantages and limitations with regard to resection of TS/PS meningiomas will be highlighted.

Subfrontal Approach

The unilateral subfrontal approach (SFA) was probably the first approach used to resect anterior skull base meningiomas [10]. Many authors reported their results with unilateral subfrontal approach [53–58]. One of the earlier notable reports of the use of this approach for suprasellar meningiomas is by Symon and Rosenstein in 1984 [58]. They reported 101 suprasellar meningiomas undergoing resection using unilateral subfrontal approach in 92 patients (91%). They used operating microscope in less than a third of the patients and reported a total resection rate of (78%). The unilateral SFA provides several advantages such as a short surgical corridor and the ability to manage the hyperostotic skull base and to unroof the optic canal. It could be designed to avoid opening the frontal sinuses and ligation of the superior sagittal sinus. This approach is, however, associated with the retraction of the ipsilateral frontal lobe and may not provide optimal exposure of the contralateral optic nerve or vascular structures. Removal of the orbital bar might improve exposure and minimize brain retraction [59].

On the other hand, bifrontal approach (first described by Tönnis [20]) provides a wide bilateral view of the anterior cranial base, bilateral optic nerves, and the anterior circle of Willis. It provides equal opportunity to unroof and decompress both optic canals and is advantageous in enabling the surgeon to visualize both optic nerves from either side and to remove the tumor from the undersurface of the medial aspect of the optic nerve in the first 6–8 mm of optic canal [60]. This approach could be extended to a transbasal/subcranial approach [61–63], or to include the orbital resection bar uni- or bilaterally [64, 65]. Disadvantages of this approach include the necessity to open the frontal sinuses, possible need for superior sagittal sinus ligation, and retraction of bilateral frontal lobes. The bilateral SFA has been and continues to be one of the workhorse approaches for tackling TS/PS meningiomas [1, 56, 66, 67].

Frontotemporal (Pterional) Approach

Many pioneer and recent surgeons reported their experience with pterional approach for TS/PS meningiomas [1, 55, 68–77]. The pterional approach and its orbitozygomatic extension provide an anterolateral angle of attack as opposed to SFA which offers a direct anterior view of the tumor. It allows early recognition and control of the ipsilateral internal carotid artery (ICA) as well as the intradural optic nerve and proximal optic canal and may prove especially useful in cases of more laterally located tumors. Sometimes, an orbital rim osteotomy is added turning it into an orbitopterional approach [77]. Sylvian fissure dissection reduces the depth of the surgical bed and improves illumination and visualization. The frontal sinus could be avoided during craniotomy. On the other hand, there is still need for some degree of frontal lobe retraction, and although the superolateral aspect of the ipsilateral optic nerve/canal is easily exposed, the inferomedial aspect of the optic nerve, pituitary stalk, and undersurface of the optic chiasm are poorly visualized and even their suboptimal exposure requires some degree of optic apparatus manipulation which may contribute to relatively poor visual outcomes (10–20% of visual deterioration) associated with this approach [68, 71, 78–80]. Unfortunately, such worsening does not tend to improve [71]. Needless to say, the contralateral optic-carotid complex is exposed after the majority of tumor is removed which could be a disadvantage especially for larger TS/PS meningiomas.

Supraorbital Approaches

The supraorbital approaches (SOA) use an exposure avenue to tackle TS/PS meningiomas similar to the unilateral subfrontal corridor. As stated before, the idea of minimally invasive approaches to these meningiomas through an SOA is to minimize brain exposure while keeping a robust deep exposure of the tumor; i.e., the keyhole concept. Anatomical evaluation of this approach in comparison to the classic pterional approach has shown its non-inferiority [81]. Various modifications of this approach have been described [3, 40, 82–84], and many authors have reported favorable outcomes using this approach for resection of TS/PS meningiomas [85–91, 92•, 93–96]. Additionally, SOA has the advantages of being cosmetically more favorable, with shorter hospital stays while providing outcomes comparable to traditional TCAs [85, 93, 97–99]. While the addition of orbital osteotomy to SOA has been advocated by some authors [100], it is not necessarily advantageous for exposure according to some others [81, 101].

Endoscopic Endonasal Approach

Specifically for TS/PS meningiomas, EEA offers several advantages: there is no brain retraction and potentially the entire dural base of the tumor and hyperostotic bone are exposed and could be resected. Additionally, EEA provides optimal panoramic view of the skull base, bilateral optic nerves, and the carotid arteries. The exposure of the inferomedial aspect of the optic canals allows early optic nerve decompression and removal of the intracanalicular tumor without the need to manipulate the optic apparatus. Also, a perfect view of the inferior aspect of the optic chiasm and pituitary stalk is provided. Additionally, the EEA allows good visualization and protection of infrachiasmatic perforators while debulking and dissecting the tumor from inferiorly [102]. The major downside of the EEA is the relatively high rate of CSF leakage which has dramatically decreased after the introduction of advanced skull base reconstruction techniques, most notably the nasoseptal flap [103–105]. Risk of olfaction loss is particularly high with EEA when the tumor involves the cribriform plates and/or extends anterior to the level of posterior ethmoidal arteries [102, 106]. Another potential disadvantage posed by some authors is that the exposure of the entire area of dural tail is difficult with EEA if the tumor is large [107]. Additionally, dissection of tumor off the vessels of the anterior circle of Willis (i.e., ICA, anterior cerebral and anterior communicating arteries (ACoA)) in the "narrow corridor" of EEA exposure could be challenging and potentially dangerous [107]. Another concern with EEA is that when the tumor extends anterior to crista galli/fovea ethmoidalis and makes contact with the posterior wall of the frontal sinus, the angle of attack becomes too steep and both resection and reconstruction become extremely difficult [107, 108].

Parameters Affecting Approach Selection

While most of the series of TS/PS meningiomas report favorable outcomes with all approaches, some authors compared their results with regard to rates of GTR, complications, and visual outcomes and correlated those outcome measures with certain patient/tumor characteristics. These studies help us determine which approach might be a better fit for a certain tumor.

Tumor Characteristics

1. Size

   Tumor size is usually a major determinant factor for approach selection regardless of location and pathology. Typically, for superficial meningiomas, the craniotomy size positively correlates with the size of the tumor; i.e., the larger the tumor, the larger the craniotomy needs to be. This is especially important because if a Simpson I resection grade is planned; i.e., the craniotomy should encompass the dural tail region as well. However, for skull base meningiomas, a Simpson I resection is not always attainable nor is it always the goal of surgery (especially considering the availability of radiosurgery). Also, from a surgical maneuverability perspective, the size of the craniotomy does not necessarily need to correlate with the size of the tumor—as suggested by the idea of "keyhole surgery." Regardless, it has been suggested that a larger size of a TS/PS meningioma makes the surgery more difficult irrespective of the approach [57, 58, 60, 79, 109], making GTR more difficult [110–112], though this idea has been questioned by some [14, 106, 113]. A TCA (typically bilateral SFA) with a large bone flap may be a good choice for a large PS/TS meningioma, especially with lateral extension over the optic canals and/or orbital roof (i.e., > 1 cm lateral to lamina papyracea) or lateral to the cavernous carotid artery [74, 90, 114–116]. Mallari et al. suggest that tumors larger than 21.5 mm in diameter favor the SOA versus EEA [92•]. It has been suggested that tumors larger than 3 cm may not have an intact arachnoid plane which might increase the risk of intra-operative vascular injury and post-operative visual impairment [58, 68].

On the other hand, with smaller tumors being amenable to both supraorbital and transnasal approaches, the size becomes a critical factor. With larger tumors, EEA becomes more problematic as the transnasal exposure of a large area of the anterior cranial base and its reconstruction after tumor resection would be challenging [110–112]. In a report on 21 TS meningiomas, Fatemi et al. recommended TCA over EEA for tumors larger than 30–35 mm [88]. Others recommend a TCA for tumors > 3 cm in diameter as it significantly affects the ability to obtain GTR via EEA [92•, 117].

2. Tumor height

   Craniocaudal extension of the tumor relative to the axial plane of the TS was not a significant factor affecting extent of resection (EOR) in one study [1]. However, others have posited that if a tumor has deep intrasellar extension, SOA would be suboptimal and EEA would be more favorable [14, 88].

3. Lateral extension

   Lateral extension of the tumor should always be studied as it could make one approach more favorable than others. EEA provides suboptimal exposure for tumors extending > 5 mm lateral to lamina papyracea (or middle orbital line) [14, 93, 113, 115, 118]. Anterior clinoid process is a likely location for residual tumor [119], and if the tumor extends over the clinoid process, a TCA is preferred [93]. Youngerman et al. found that complete extension of the tumor (i.e., 100%) over either optic nerve is a major restrictive parameter in achieving GTR via EEA [121•].

4. Tumor calcification and skull base hyperostosis

   Heavy tumor calcification can make resection invariably difficult, but a tumor with this feature may be more manageable via a TCA [120, 121•], although this has been questioned by others [14, 106]. Presence of hyperostotic PS may make EEA more favorable as it may facilitate drilling the hyperostotic bone [92•].

5. Optic canal involvement

   Involvement of the optic canal in the case of TS meningiomas is extremely common (66–100%) with inferomedial involvement of the proximal optic canal being the most common pattern [14, 60, 96, 108, 122]. Extension of the tumor into the optic canal may be underestimated by pre-operative MRI [123]. Such invasion makes GTR a challenge [60]. It is important to note that many TS meningiomas present early in their course with visual presentation because of early involvement of the optic canal. Safe and efficient decompression of the optic canal and removal of the intracanalicular portion of the tumor are important in achieving a favorable visual outcome and minimizing the risk of recurrence [14]. Koutourousiou et al. reported 25% involvement of the medial aspect of the optic canal in a series of 75 TS/PS meningiomas [117]. Many authors have reported favorable visual outcomes with EEA and more recent series show better visual outcomes with EEA, especially in patients with optic canal involvement [14, 74, 124]. EEA enables 270° decompression of the optic canal and safe opening of the inferomedial aspect of the optic nerve dura to resect the intracanalicular tumor [115]. Of note, some authors advocate a TCA for TS/PS meningiomas because it enables decompression of the optic canal early during the operation [76, 77]. On the other hand, a TCA necessitates some degree of optic nerve manipulation to access the inferomedially located tumor in the optic canal which might contribute to its inferior visual outcomes compared to EEA [117, 124]. However, when the tumor extends laterally and involves the superolateral optic canal, EEA may be less than ideal, and a TCA may provide better exposure and control over the optic canal and its contents [14, 107, 108]. A prefixed optic chiasm could make a TCA extremely difficult [106].

6. Vascular encasement

   Encasement of surrounding vessels poses a technical challenge for resection of meningiomas leading to failure to achieve a GTR or complicating the procedure [1, 60, 90, 106, 108, 110–112, 117, 121•]. According to Koutourousiou et al., the prevalence of vascular encasement was 25% in a series of 75 TS/PS meningiomas [117]. Typically, to avoid vascular injury, the surgeon needs to continue dissection in the plane between the arachnoid membrane and tumor capsule. However, undertaking this strategy is sometimes difficult and requires ample surgical freedom and maneuverability which might be compromised when a "minimally invasive" approach or EEA is selected. In the case of TS/PS meningiomas, the vulnerable surrounding vessels include the cavernous and intradural ICA, and the ACoA complex. When the tumor invades the cavernous sinus and abuts or encases the ICA, EEA may not be the ideal to achieve a GTR [14, 108, 121•]. In fact, some authors recommend a TCA for tumors with extension lateral to the ICA or ACoA complex, or any cavernous sinus invasion [14, 93, 113, 115, 118]. It should however be noted that even if a tumor is significantly extending laterally, the EEA may not be totally contraindicated as a GTR may not be attainable via a TCA either. Therefore, the goal of surgery may not be GTR in such cases and a subtotal resection and favorable decompression of the optic nerve through EEA may be perfectly achievable [114].

7. Cortical cuff and cerebral edema

   When using EEA, some authors state that to safely dissect the vessels off the tumor, a "cortical cuff" should be present between the tumor and the vessels [108, 125, 126]. Also, the presence of edema in the adjacent brain may indicate pial invasion requiring complex vessel dissection and hemostasis techniques that may not be easily performed during EEA [108, 113, 116, 125]. However, several studies showed that "cortical cuff" and brain edema are not significant factors affecting GTR rate in modern series [113, 121•]. In our opinion, the issue of cortical cuff does not really apply to TS meningiomas since these tumors will invariably make contact with the optic chiasm and ACoA complex without intervening brain as they get larger due to the regional anatomy. Cortical cuff may be a more applicable entity (if at all) for olfactory groove and PS meningiomas.

Anatomical Relationships

1. Sellar anatomy

   The suprasellar notch angle (SNA) represents the relative depth of the recess formed between superior aspect of the sella and the declining part of the planum sphenoidale. It is measured between 2 lines: (1) a line perpendicular to the cribriform plate passing through the center of TS and (2) a line connecting limbus sphenoidale to TS [127]. De Notaris et al. proposed a wider SNA (> 138°) to be more favorable for EEA [127]. Henderson et al. did not find a relationship between the SNA and GTR of TS/PS meningiomas via EEA although based on personal experience believed that an acute SNA (< 118°) would make EEA more challenging [14]. On the contrary, Mallari et al. proposed that an acute tubercular angle (< 135°) and presence of hyperostosis make EEA more favorable [92•]. Also, when a tumor has deep sellar extension or extends significantly above the level of the PS, EEA may be a better choice [92•], a point that is not agreed upon by Henderson et al. [14], who posit that the lateral extension of the tumor is more important in predicting outcome.
2. Anatomy of the sphenoid sinus

   During EEA, ample pneumatization of the sphenoid sinus is paramount to a seamless exposure of the tumor along and across the floor of the anterior cranial fossa. In a pre-sellar or conchal-type sinus [128], recognition of landmarks is very difficult if not impossible, hence a contraindication to EEA. Additionally, with a very small sella, the coronal distance between the optic nerves and between the carotid arteries (kissing carotids) may be too small and make the EEA risky [106, 118]. A *pneumosinus dilatans* may theoretically require more brain retraction during a TCA but Kong et al. did not find this parameter to be impacting GTR via TCA versus EEA [1].

Clinical Outcomes

1. Visual outcome

   Visual symptoms (and the classic chiasmal syndrome [129]) are very common (up to 85%) in TS/PS meningiomas [14, 122, 130], and early post-operative visual improvement seems to be an important factor in long-term visual outcomes [72]. Resection of TS meningiomas has been associated with an 8–42% risk of post-operative visual impairment which is attributed to manipulation of the optic apparatus or its vascular supply [68, 72, 78, 80, 96, 115, 122, 131]. Although some authors have reported tumor size to significantly affect the visual outcome, it seems that the pattern of optic nerve compression is more important. Koutourousiou et al. did not find the size of the tumor (< 2.5 cm vs > 2.5 cm) to be statistically significant in predicting the visual outcome [117]. Others have found pre-operative duration and extent of visual impairment, age, and tumor invasion of the optic canal and its effective decompression to be more determining of the visual outcome after tumor resection [122]. Although some series show excellent visual outcomes using TCA [77], multiple studies have shown the superiority of EEA over TCA for achieving better visual outcomes, especially when optic canal is involved with tumor and decompressed early [1, 76, 96, 102, 115, 122–124, 132]. More recent meta-analyses showed EEA superiority over TCA regarding visual outcomes [133, 134]. Such superiority was not shown in a previous meta-analysis [135].
2. Endocrine outcome

   Pre-operative endocrine dysfunctions are less common and usually subtle in TS/PS meningiomas (e.g., decrease libido, amenorrhea, and hypothyroidism) [102]. Post-operative endocrine dysfunction is reported at a rate of 0–33% after EEA surgery for TS/PS meningiomas [102, 107, 136, 137]. With TCA, the post-operative pituitary dysfunction is reported at 0–13% [68, 138].
3. Tumor recurrence

   According to Fahlbusch and Schott, 4 main factors impact the risk of tumor recurrence: (1) EOR, (2) histological grading of the tumor, (3) length of the post-operative follow-up period, and (4) mode and quality of the assessment of tumor recurrence [68]. Therefore, achieving a GTR has a significant role in reduction of tumor recurrence rate. Two meta-analyses have compared this outcome between TCA and EEA. In 2012, Komotar et al. meta-analyzed 60 eligible studies and found that the rate of GTR with TCA is significantly higher [135]. Later in 2018, Muskens et al. meta-analyzed 64 studies and concluded that neither approach is superior regarding the rate of GTR [133].

Approach Selection Strategy

Relative Benefits and Limitations

Authors generally report favorable results with every and each surgical approach but these results are obviously biased because of arbitrary patient selection criteria. A few systematic reviews and meta-analyses have reported the trends with approach selection and compared reported outcomes [133–135]. It seems that with smaller tumors that tend to have inferomedial optic canal invasion, a EEA may be preferred. The meta-analysis by Komotar et al. concluded that EEA is associated with higher risk of CSF leak but TCA has probably a higher rate of GTR. However, the visual outcomes were not different between the 2 approaches [135]. On the other hand, 2 more recent meta-analyses showed that EEA provides superior visual outcomes and that GTR rates were not significantly different between approaches [133, 139•].

Proposed Classification Scales for TS/PS Meningiomas

Cushing and Eisenhardt were the first to propose a simple staging framework for TS meningiomas primarily based on the following post-mortem parameters: tumor size, chiasmal deformity, and clinical presentation: I, initial stage; II, probably presymptomatic; III, early stage of syndrome, still surgically favorable (10–18 g); and IV, surgically unfavorable (> 20 g) [10]. This staging system nicely represents the growth stages of TS meningiomas but fails to include other important parameters such as vascular encasement and optic canal invasion and was not used in clinical series afterwards. Yaşargil focused on tumor size for these tumors (< 2 cm, 2–4 cm, and > 4 cm) and believed that tumors > 4 cm pose a greater surgical challenge [140].

Mortazavi et al. proposed a classification system to predict resectability and surgical complexity and also to assist with approach selection based on 6 parameters: (1) prior surgery, (2) prior radiation, (3) brain invasion (i.e., FLAIR signal in MRI), (4) vascular encasement, (5) optic canal invasion, and (6) tumor size. They categorize TS/PS meningiomas into 3 classes and suggest that the operative complexity increases progressively with class. Their system is not able to predict EOR but they propose EEA for class I and TCA for class III tumors; class II tumors are amenable to both EEA and TCA (Table 1) [77]. Of note, patients in their series were mostly operated on using TCA.

Youngerman et al. attempted to revise Magill et al.'s scoring system tailored for EEA approach for resection TS/PS meningiomas [121•]. They further elaborated on the pattern of vascular encasement by suprasellar meningiomas and added a new score for "optic nerve laterality score" (Table 1), based on the maximal lateral extension of the tumor relative to the optic nerve as well as the maximal anterior extension of the tumor beyond the limbus sphenoidale. Their multivariate analysis showed that prior surgery, complete ICA encasement, and extension > 100% lateral to the optic nerve significantly affected resectability [121•]. Surprisingly, and possibly because of excellent surgical technique and careful approach selection, no independent risk factor was found for lack of visual improvement. On the other hand, absolute size of the tumor, medial optic canal involvement, anterior cerebral artery or partial ICA encasement, and brain edema did not impact resectability via EEA [121•]. GTR rates in this study approached those obtained with TCA [133, 139•]. EEA was advantageous over TCA regarding visual outcomes in keeping with previous studies.

Ottenhausen et al. proposed their decision-making strategy for anterior skull base meningiomas (including olfactory groove, TS, and PS meningiomas) in 2019 [93]. Their strategy is based on several parameters including (1) anterior sagittal extension of tumor, lateral extension of tumor, (3) invasion of cribriform plate, and (4) status of olfaction. Using these parameters, they stratify lesions into 7 groups and provide choice of approach recommendation for each group.

Our Strategy

Our strategy for TS/PS meningiomas is based on (1) tumor size (< 3 cm versus > 3 cm), (2) pattern of optic canal invasion/position of optic nerve displacement, (3) relationship of the anterior extent of the tumor with sphenoethmoidal suture, and (4) lateral extent of tumor relative to the optic nerve and lamina papyracea. Larger tumors that extend beyond the lamina papyracea and may be harder to resect via EEA. We reserve EEA for smaller midline tumors that may have inferomedial optic canal invasion and inferomedial position to the prechiasmatic optic nerves, but do not extend too anteriorly to the sphenoethmoidal suture. In these cases, EEA allows optimal view of the base of the tumor and favorable decompression of the optic nerve without manipulation of the optic apparatus and without compromising olfaction. Repair of the skull base defect after resection of these small tumors is relatively easy. When midline tumor extends laterally beyond the optic nerve and lamina papyracea, or is extended anteriorly beyond the sphenoethmoidal suture, a TCA (uni- or bilateral) provides ample exposure of the medial and lateral aspects of the optic canal. With large tumors, we usually use the orbitopterional or bilateral SFA (transbasal). If the tumor invades the cavernous sinus or encases the cavernous ICA, we usually do not chase the tumor in the cavernous sinus. However, if the tumor encases the intradural ICA and/or anterior cerebral artery, we select a TCA (usually orbitopterional or transbasal) since we believe in obtaining adequate

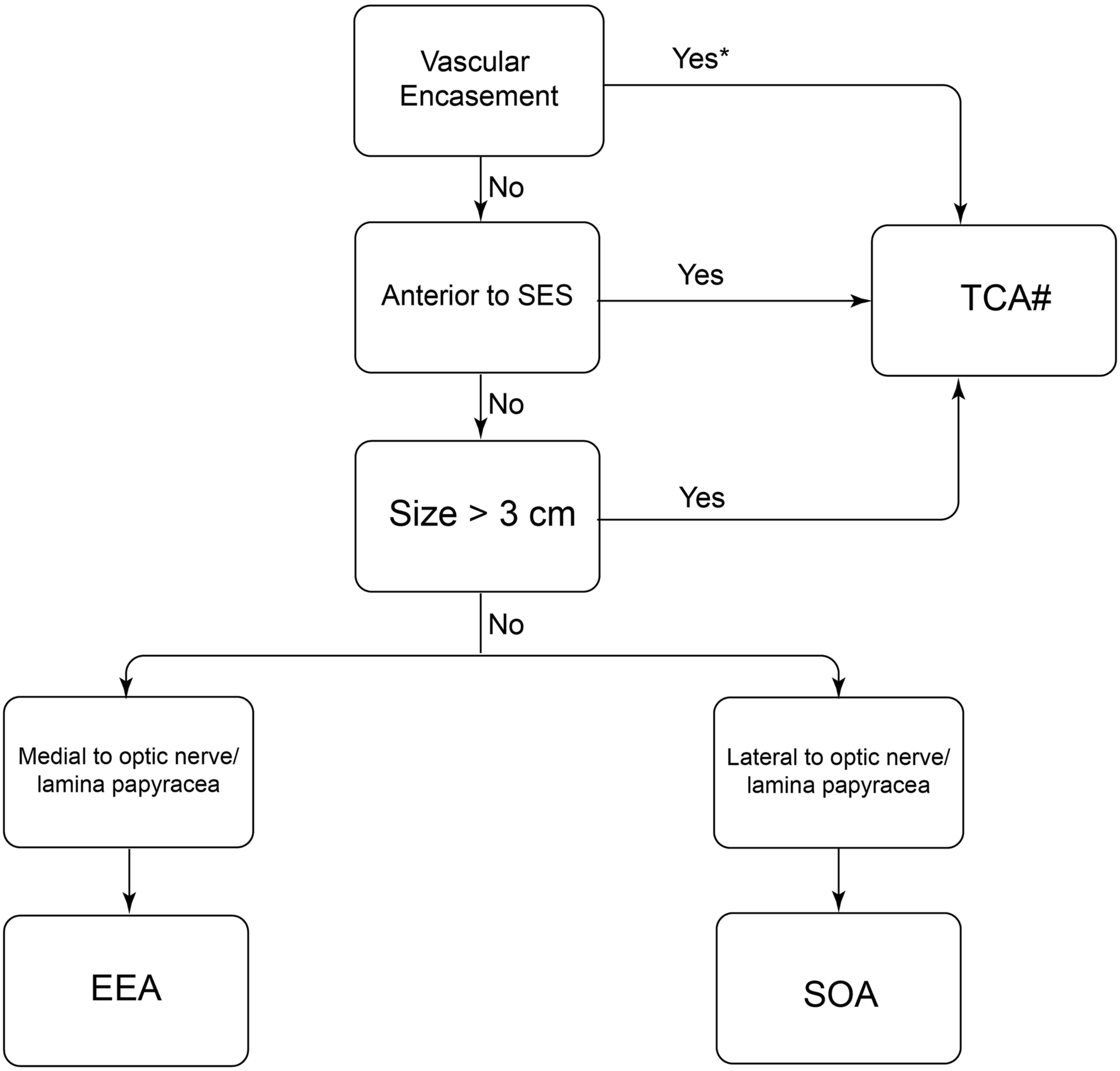

Fig. 1 Proposed algorithm for selection of surgical approach to TS/PS meningiomas. * may choose EEA if GTR is not the goal. # may be chosen from a variety of approaches mostly transbasal and orbitopterional. EEA, endoscopic endonasal approach; SES, sphenoethmoidal suture; SOA, supraorbital approach; TCA, transcranial approach

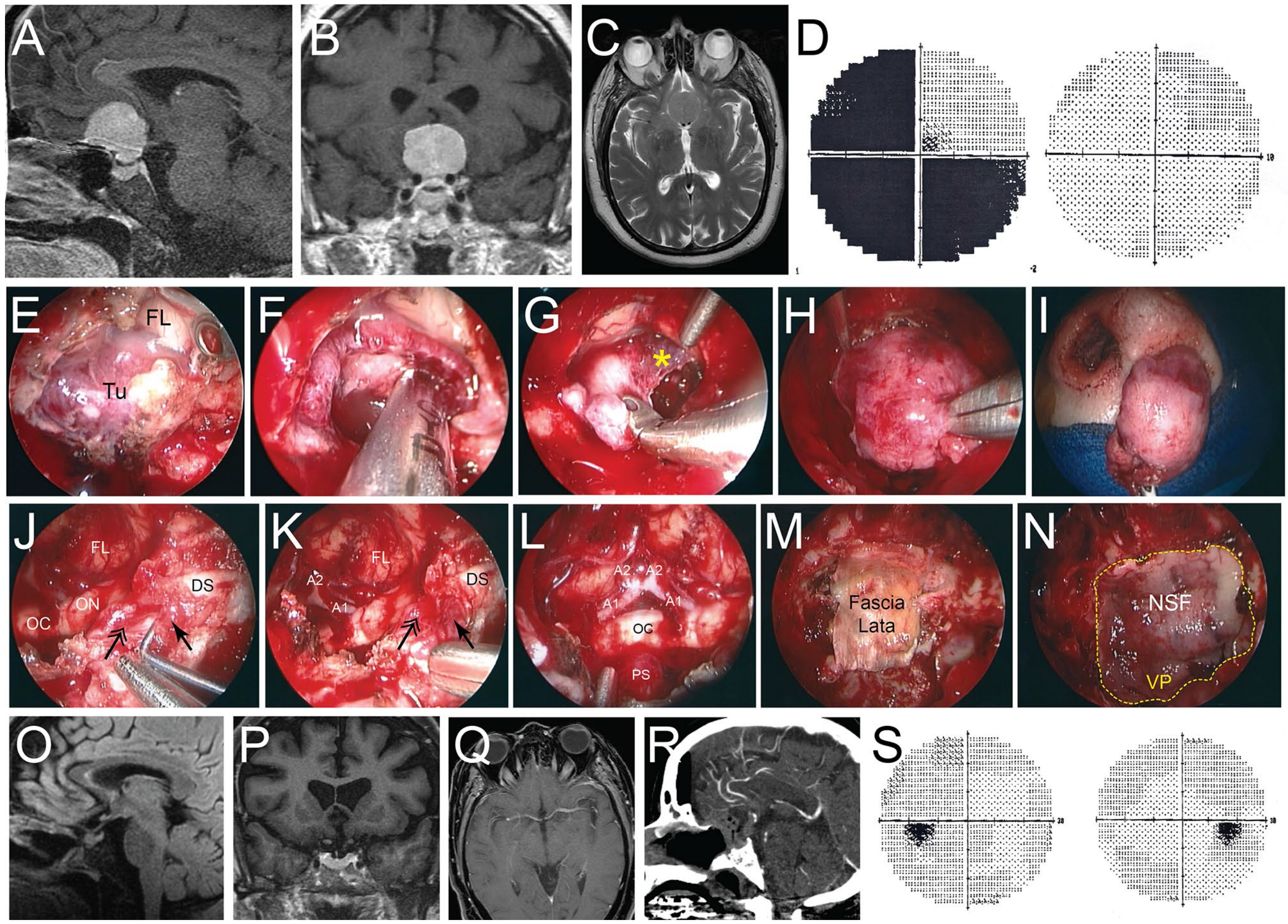

Fig. 2 Resection of a TS meningioma via EEA. Sagittal (**A**), coronal (**B**), and axial (**C**) magnetic resonance images of the tumor. **D** Visual field examination showing compromise of the left optic nerve. **E**–**N** Expanded transtuberculum transplanum EEA for tumor resection. **E** Tumor (Tu) exposure with abutment of the frontal lobe (FL), **F** internal debulking of tumor, **G** dissection between the tumor capsule and the arachnoid (*) of the chiasmatic cistern, **H**, **I** recession of the major bulk of the tumor, **J**, **K** opening the dural sheath (DS) of the left optic nerve to resect the intracanalicular portion of the tumor and inferomedial decompression of the optic nerve. Note the ophthalmic artery (double arrow) and the last part of the tumor in the optic canal (arrow) being removed. The A1 and A2 segments of the anterior cerebral artery, optic chiasm (OC) and optic nerve (ON) are shown. **L** Final view of the resection bed after total removal of the tumor. Pituitary stalk (PS) is visible. **M**, **N** Reconstruction with on-lay fascia lata over the resection cavity boosted by nasoseptal flap (NSF) marked with yellow dashed line. VP, vascularized pedicle. **O**–**R** Post-operative images showing GTR. **S** Visual field examination at 3-month follow-up

proximal and distal control of the points of encasement in the event a vascular injury occurs and direct vascular repair and potential microanastomosis are required. It is much more feasible to perform direct vascular repair when the cranium is opened than in a narrow EEA corridor. It should be noted that we may still opt for EEA in the case of vascular encasement or lateral optic canal involvement if GTR is not set as the goal of surgery. Figure 1 shows our proposed decision-making algorithm. With small lateral tumors that do not invade the medial aspect of the optic canal and do not have vessel encasement, a minimally invasive SOA may be advocated in the hands of the experienced surgeon. If the tumor is asymmetric displacing one optic nerve, a contralateral unilateral TCA can be considered since there is less optic nerve manipulation and risk of injury when coming from the contralateral side to the affected nerve. Case illustrations are provided in Figs. 2 and 3.

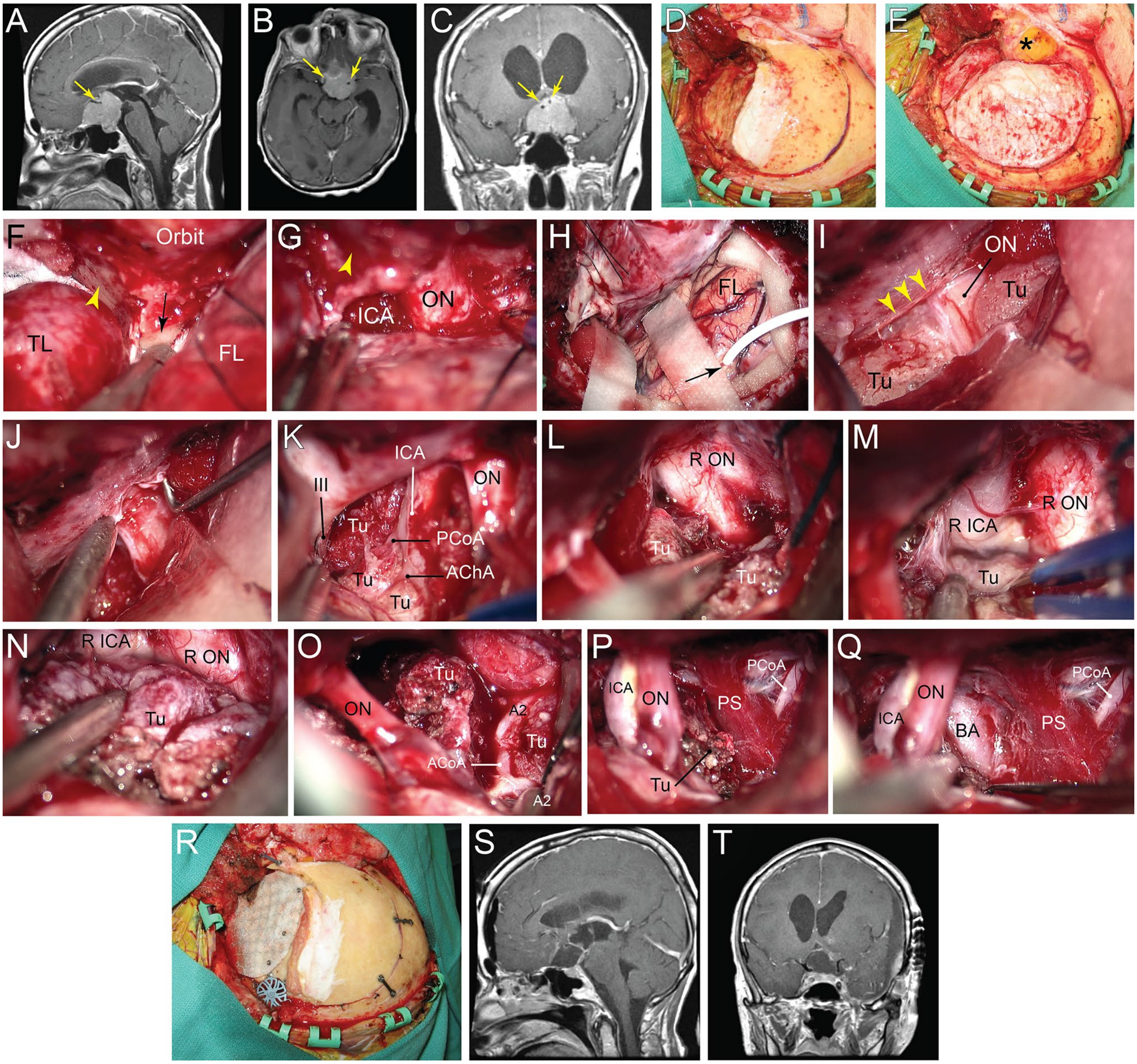

Fig. 3 Transcranial resection of a large TS meningioma with vascular encasement. Sagittal (**A**), axial (**B**), and coronal (**C**) magnetic resonance images of the tumor showing encasement of the branches of the anterior cerebral artery (yellow arrows) and extension towards the left cavernous sinus. **D**, **E** Left orbitopterional craniotomy (* = orbital contents). **F** Extradural anterior clinoidectomy is performed. Black arrow shows the last portion of the anterior clinoid process. Yellow arrowhead shows the greater sphenoid wing. FL, frontal lobe; TL, temporal lobe. **G** Dura is opened and optic nerve (ON) and left internal carotid artery (ICA) are visualized. Arrowhead points to the region of anterior clinoidectomy. **H** A ventriculostomy (black arrow) helps with brain relaxation. **I** Tumor (Tu) is seen engulfing the optic nerve (ON), arrowheads show the falciform ligament. **J** Falciform ligament is opened to decompress the optic canal. **K** Extension of the tumor (Tu) towards the left cavernous sinus is shown. Identification of the critical neurovascular structures is critical (III, oculomotor nerve; AChA, anterior choroidal artery; PCoA, posterior communicating artery; ON, optic nerve; ICA, internal carotid artery). **L**–**N** Continued resection of the tumor (Tu) towards the contralateral (right) optic nerve. Right ICA is also visualized. **O** Exposure of the tumor in the interoptic and perichiasmatic area shows encasement of the anterior cerebral artery complex (ACoA, anterior communicating artery). **P** After removal of the perichiasmatic portion of the tumor, the sellar portion and pituitary stalk (PS) are exposed. **Q** Final view after completion of resection with the basilar artery (BA) exposed. **R** Closure of craniotomy. **S**, **T** Post-op contrasted MRIs showing near total resection with minimal residue in the left cavernous sinus

Table 1 Summary of some of the major existing classification systems for TS/PS meningiomas

Magill et al. [60]		Youngerman et al. [121•]		Mortazavi et al. [77][a]	
		Prior Surgery		**Prior Surgery**	
			No prior surgery (0)		No prior surgery (0)
			Prior surgery (1)		Prior surgery (1)
Tumor size				**Tumor size**	
	< 17 mm (1)				< 20 mm (0)
	≥ 17 mm (2)				21-40 mm (1)
					>40 mm (2)
Optic canal invasion		**Optic nerve laterality**		**Optic canal invasion**	
	≤3 mm bilaterally (0)		Anything <100% extension (0)		<5 mm (0)
	>3 mm unilaterally (1)		extended laterally 100% over the nerve (1)		>5 mm (1)
	>3 mm bilaterally (2)				Complete (2)
Arterial encasement[b]		**ICA encasement**		**Arterial encasement (2 ICAs, 2 ACAs)**[c]	
	Abuts medial wall only (0)		<100% (360°) ICA encasement (1)		No encasement (0)
	Envelops < 180° around the artery (1)		100% (360°) ICA encasement (1)		encasement <180° (1)
	Encases ≥ 180° around the artery (2)				encasement 2180° (2)
				Brain Invasion	
					No or mild FLAIR signal (0)
					Significant FLAIR signal (1)
				Previous Radiation	
					No prior radiation (0)
					Prior radiation (0)

[a]Class I: 0-3 points, class II: 4-7 points, and class III: 8-11 points

[b]medial wall of the ICA or the anterior wall of the ACA

[c]maximum of 4 points for any combination of vascular encasement, even if the sum is > 4

Conclusions

TS/PS meningiomas are challenging lesions and proper approach selection significantly impacts the ability to achieve GTR and favorable outcomes. Major approaches include the classic TCA, minimally invasive SOA, and EEA. Goals of resection must be set based on patient and tumor characteristics. Sometimes, a specific approach might provide superior outcomes with regard to tumor control, visual outcomes, cosmetic results, and complication profile. Skull base surgeons must familiarize themselves with these various approaches and be able to use them efficiently in a tailored fashion to specific patient pathoanatomy.

Author Contribution A.T.M.: conception and design, literature review, drafting manuscript, final review on behalf of all authors; A.C.L.: drafting manuscript, critical review of the manuscript; J.K.L.: conception and design, drafting manuscript, critical review of the manuscript, study supervison.

Declarations

Conflict of Interest The authors declare no competing interests.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance

1. Kong DS, Hong CK, Hong SD, et al. Selection of endoscopic or transcranial surgery for tuberculum sellae meningiomas according to specific anatomical features: a retrospective multicenter analysis (KOSEN-002). J Neurosurg. 2018;130:838–47.
2. Chi JH, McDermott MW. Tuberculum sellae meningiomas. Neurosurg Focus. 2003;14:e6.

3. Delashaw JB, Jane JA, Kassell NF, Luce C. Supraorbital craniotomy by fracture of the anterior orbital roof. Technical note J Neurosurg. 1993;79:615–8.
4. Cohen AR, Perneczky A, Rodziewicz GS, Gingold SI. Endoscope-assisted craniotomy: approach to the rostral brain stem. Neurosurgery. 1995;36:1128–9; discussion 9–30.
5. Czirják S, Szeifert GT. Surgical experience with frontolateral keyhole craniotomy through a superciliary skin incision. Neurosurgery. 2001;48:145–9; discussion 9–50.
6. Fries G, Perneczky A. Endoscope-assisted keyhole surgery for aneurysms of the anterior circulation and the basilar apex. Oper Tech Neurosurg. 2000;3:216–30.
7. Menovsky T, Grotenhuis JA, de Vries J, Bartels RH. Endoscope-assisted supraorbital craniotomy for lesions of the interpeduncular fossa. Neurosurgery. 1999;44:106–10; discussion 10–2.
8. Perneczky A, Fries G. Endoscope-assisted brain surgery: part 1--evolution, basic concept, and current technique. Neurosurgery. 1998;42:219–24; discussion 24–5.
9. van Lindert E, Perneczky A, Fries G, Pierangeli E. The supraorbital keyhole approach to supratentorial aneurysms: concept and technique. Surg Neurol. 1998;49:481–9; discussion 9–90.
10. Cushing H, Eisenhardt L. Meningiomas arising from the tuberculum sellae: with the syndrome of primary optic atrophy and bitemporal field defects combined with a normal sella turcica in a middle-aged person. Arch Ophthalmol. 1929;1:168–206.
11. Al-Mefty O, Holoubi A, Rifai A, Fox JL. Microsurgical removal of suprasellar meningiomas. Neurosurgery. 1985;16:364–72.
12. Hullay J. Planum (Jugum) Sphenoidal Meningioma. Acta Neurochir (Wien). 1965;12:717–45.
13. Hullay J, Gombi R, Velok G, Rozsa L, Borus F. Planum sphenoidale meningioma. Attachment and blood supply Acta Neurochir (Wien). 1980;52:9–12.
14. Henderson F, Youngerman BE, Niogi SN, et al. Endonasal transsphenoidal surgery for planum sphenoidale versus tuberculum sellae meningiomas. J Neurosurg. 2023;138:1338–46.
15. Macewen W. Intra-cranial lesions: illustrating some points in connexion with the localisation of cerebral affections and the Advantages of Antiseptic Trephining. The Lancet. 1881;118:581–3.
16. Durante F. Contribution to endocranial surgery.1. The Lancet. 1887;130:654–5.
17. Stewart J. The symptomatology of tumors involving the hypophysis cerebri. Trans Assoc Am Physicians. 1899;14:282–9.
18. Cushing H, Eisenhardt L. Meningiomas: their classification, regional behaviour, life history, and surgical ends results. Springfield, IL: Charles C. Thomas. 1938.
19. Morales-Valero SF, Van Gompel JJ, Loumiotis I, Lanzino G. Craniotomy for anterior cranial fossa meningiomas: historical overview. Neurosurg Focus. 2014;36:E14.
20. Tonnis W. Erfolgreiche Behandlung eines Aneurysma der Art. commun. ant. cerebri. Zentralbl Neurochir. 1936;1:39–42.
21. Chi JH, Parsa AT, Berger MS, Kunwar S, McDermott MW. Extended bifrontal craniotomy for midline anterior fossa meningiomas: minimization of retraction-related edema and surgical outcomes. Neurosurgery. 2006;59:ONS426–33; discussion ONS33–4.
22. Heuer G. A new hypophysis operation. Bull Johns Hopkins Hosp. 1918;29:154.
23. Dandy WE. Intracranial Arterial Aneurysms: Comstock Publishing Company. Incorporated: Cornell University; 1944.
24. Hassler W, Zentner J. Pterional approach for surgical treatment of olfactory groove meningiomas. Neurosurgery. 1989;25:942–5; discussion 5–7.
25. McArthur LL. An aseptic surgical access to the pituitary body and its neighborhooD. J Am Med Assoc. 1912;LVIII:2009–11.
26. Frazier CHI. An approach to the hypophysis through the anterior cranial fossa. Ann Surg. 1913;57:145.
27. Jane JA, Park TS, Pobereskin LH, Winn HR, Butler AB. The supraorbital approach: technical note. Neurosurgery. 1982;11:537–42.
28. Pellerin P, Lesoin F, Dhellemmes P, Donazzan M, Jomin M. Usefulness of the orbitofrontomalar approach associated with bone reconstruction for frontotemporosphenoid meningiomas. Neurosurgery. 1984;15:715–8.
29. Hakuba A, Liu S, Nishimura S. The orbitozygomatic infratemporal approach: a new surgical technique. Surg Neurol. 1986;26:271–6.
30. McDermott MW, Durity FA, Rootman J, Woodhurst WB. Combined frontotemporal-orbitozygomatic approach for tumors of the sphenoid wing and orbit. Neurosurgery. 1990;26:107–16.
31. Kanaan IN. Trans-eyebrow mini-orbitozygomatic pterional approach for minimally invasive skull base surgery. Minim Invasive Neurosurg. 2005;48:34–8.
32. Zabramski JM, Kiriş T, Sankhla SK, Cabiol J, Spetzler RF. Orbitozygomatic craniotomy. Technical note. J Neurosurg. 1998;89:336–41.
33. Alaywan M, Sindou M. Fronto-temporal approach with orbito-zygomatic removal. Surgical anatomy Acta Neurochir (Wien). 1990;104:79–83.
34. Aziz KM, Froelich SC, Cohen PL, Sanan A, Keller JT, van Loveren HR. The one-piece orbitozygomatic approach: the MacCarty burr hole and the inferior orbital fissure as keys to technique and application. Acta Neurochir (Wien). 2002;144:15–24.
35. Lemole GM, Henn JS, Zabramski JM, Spetzler RF. Modifications to the orbitozygomatic approach. Technical note J Neurosurg. 2003;99:924–30.
36. Krause F. Chirurgie des gehirns und rückenmarks nach eigenen erfahrungen. 1.- bd. ... ed. Berlin etc.: Urban & Schwarzenberg. 1908.
37. Wilson DH. Limited exposure in cerebral surgery. Technical note J Neurosurg. 1971;34:102–6.
38. Emery E, Alaywan M. Sindou M [Respective indications of orbital and/or zygomatic arch removal combined with fronto-pteriono-temporal approaches. 58 cases]. Neurochirurgie. 1994;40:337–47.
39. Honeybul S, Neil-Dwyer G, Lees PD, Evans BT, Lang DA. The orbitozygomatic infratemporal fossa approach: a quantitative anatomical study. Acta Neurochir (Wien). 1996;138:255–64.
40. Brock M, Dietz H. The small frontolateral approach for the microsurgical treatment of intracranial aneurysms. Neurochirurgia (Stuttg). 1978;21:185–91.
41. Schloffer H. Erfolgreiche Operation eines Hypophysentumors auf nasalem Wege. Wien Klin Wochenschr. 1907;20:621–4.
42. Kocher T. Ein Fall von Hypophysis tumor mit operativer Heilung. Dtsch Z Chir. 1909;100:13–37.
43. Hirsch O. Endonasal method of removal of hypophyseal tumorswith report of two successful cases. J Am Med Assoc. 1910;55:772–4.
44. Halstead A. Remarks on the operative treatment of tumors of the hypophysis. With the report of two cases operated on by an oronasal method. Trans Am Surg Assoc. 1910;28:73–93.
45. Cushing H. The Weir Mitchell lecture: surgical experiences with pituitary disorders. J Am Med Assoc. 1914;LXIII:1515–25.
46. Dott NM, Bailey P, Cushing H. A consideration of the hypophysial adenomata. BJS (British Journal of Surgery). 1925;13:314–66.
47. Guiot G, Thibaut B. L'extirpation des adenomes hypophysaires par voie trans-sphenoidale. Neurochirurgia. 1959;1:133–50.
48. Hardy J. Excision of pituitary adenomas by trans-sphenoidal approach. Union Med Can. 1962;91:933–45.
49. Weiss MH. Transnasal transsphenoidal approac. In: Apuzzo MLJ, editor. Surgery of the third ventricle. Baltimore: Williams & Wilkins; 1987. p. 476–94.

50. de Divitiis E, Cappabianca P, Cavallo LM. Endoscopic transsphenoidal approach: adaptability of the procedure to different sellar lesions. Neurosurgery 2002;51:699–705; discussion -7.
51. Dehdashti AR, Ganna A, Witterick I, Gentili F. Expanded endoscopic endonasal approach for anterior cranial base and suprasellar lesions: indications and limitations. Neurosurgery. 2009;64:677–87; discussion 87–9.
52. Jho HD, Ha HG. Endoscopic endonasal skull base surgery: part 1–the midline anterior fossa skull base. Minim Invasive Neurosurg. 2004;47:1–8.
53. Brihaye J, Brihaye-van GM. Management and surgical outcome of suprasellar meningiomas. Acta Neurochir Suppl (Wien). 1988;42:124–9.
54. Ehlers N, Malmros R. The suprasellar meningioma. A review of the literature and presentation of a series of 31 cases. Acta Ophthalmol Suppl. 1973:1–74.
55. Gokalp HZ, Arasil E, Kanpolat Y, Balim T. Meningiomas of the tuberculum sella. Neurosurg Rev. 1993;16:111–4.
56. Gregorius FK, Hepler RS, Stern WE. Loss and recovery of vision with suprasellar meningiomas. J Neurosurg. 1975;42:69–75.
57. Solero CL, Giombini S, Morello G. Suprasellar and olfactory meningiomas. Report on a series of 153 personal cases. Acta Neurochir (Wien). 1983;67:181–94.
58. Symon L, Rosenstein J. Surgical management of suprasellar meningioma. Part 1: the influence of tumor size, duration of symptoms, and microsurgery on surgical outcome in 101 consecutive cases. J Neurosurg. 1984;61:633–41.
59. Downes AE, Freeman JL, Ormond DR, Lillehei KO, Youssef AS. Unilateral tailored fronto-orbital approach for giant olfactory groove meningiomas: technical nuances. World Neurosurg. 2015;84:1166–73.
60. Magill ST, Morshed RA, Lucas CG, et al. Tuberculum sellae meningiomas: grading scale to assess surgical outcomes using the transcranial versus transsphenoidal approach. Neurosurg Focus. 2018;44:E9.
61. Liu JK, Watanabe K. Modified one-piece extended transbasal approach for endoscopic-assisted microsurgical resection of tuberculum sellae meningioma: operative video and technical nuances. J Neurol Surg B Skull Base. 2018;79:S213–4.
62. Liu JK, Silva NA, Sevak IA, Eloy JA. Transbasal versus endoscopic endonasal versus combined approaches for olfactory groove meningiomas: importance of approach selection. Neurosurg Focus. 2018;44:E8.
63. Barzaghi LR, Spina A, Gagliardi F, Boari N, Mortini P. Transfrontal-sinus-subcranial approach to olfactory groove meningiomas: surgical results and clinical and functional outcome in a consecutive series of 21 patients. World Neurosurg. 2017;101:315–24.
64. Chokyu I, Goto T, Ishibashi K, Nagata T, Ohata K. Bilateral subfrontal approach for tuberculum sellae meningiomas in long-term postoperative visual outcome. J Neurosurg. 2011;115:802–10.
65. Li MS, Portman SM, Rahal A, Mohr G, Balasingam V. The lion's mane sign: surgical results using the bilateral fronto-orbito-nasal approach in large and giant anterior skull base meningiomas. J Neurosurg. 2014;120:315–20.
66. Finn JE, Mount LA. Meningiomas of the tuberculum sellae and planum sphenoidale. A review of 83 cases. Arch Ophthalmol. 1974;92:23–7.
67. Kunicki A, Uhl A. The clinical picture and results of surgical treatment of meningioma of the tuberculum sellae. Cesk Neurol. 1968;31:80–92.
68. Fahlbusch R, Schott W. Pterional surgery of meningiomas of the tuberculum sellae and planum sphenoidale: surgical results with special consideration of ophthalmological and endocrinological outcomes. J Neurosurg. 2002;96:235–43.
69. Conforti P, Moraci A, Albanese V, Rotondo M, Parlato C. Microsurgical management of suprasellar and intraventricular meningiomas. Neurochirurgia (Stuttg). 1991;34:85–9.
70. Ojemann RG. Meningiomas of the basal parapituitary region: technical considerations. Clin Neurosurg. 1980;27:233–62.
71. Park CK, Jung HW, Yang SY, Seol HJ, Paek SH, Kim DG. Surgically treated tuberculum sellae and diaphragm sellae meningiomas: the importance of short-term visual outcome. Neurosurgery. 2006;59:238–43; discussion –43.
72. Jallo GI, Benjamin V. Tuberculum sellae meningiomas: microsurgical anatomy and surgical technique. Neurosurgery. 2002;51:1432–39; discussion 9–40.
73. Benjamin V, Russell SM. The microsurgical nuances of resecting tuberculum sellae meningiomas. Neurosurgery. 2005;56:411–7; discussion –7.
74. de Divitiis E, Esposito F, Cappabianca P, Cavallo LM, de Divitiis O. Tuberculum sellae meningiomas: high route or low route? A series of 51 consecutive cases. Neurosurgery. 2008;62:556–63; discussion –63.
75. Nanda A, Ambekar S, Javalkar V, Sharma M. Technical nuances in the management of tuberculum sellae and diaphragma sellae meningiomas. Neurosurg Focus. 2013;35:E7.
76. Nozaki K, Kikuta K, Takagi Y, Mineharu Y, Takahashi JA, Hashimoto N. Effect of early optic canal unroofing on the outcome of visual functions in surgery for meningiomas of the tuberculum sellae and planum sphenoidale. Neurosurgery. 2008;62:839–44; discussion 44–6.
77. Mortazavi MM, Brito da Silva H, Ferreira M, Jr., Barber JK, Pridgeon JS, Sekhar LN. Planum sphenoidale and tuberculum sellae meningiomas: operative nuances of a modern surgical technique with outcome and proposal of a new classification system. World Neurosurg. 2016;86:270–86.
78. Chicani CF, Miller NR. Visual outcome in surgically treated suprasellar meningiomas. J Neuroophthalmol. 2003;23:3–10.
79. Goel A, Muzumdar D, Desai KI. Tuberculum sellae meningioma: a report on management on the basis of a surgical experience with 70 patients. Neurosurgery. 2002;51:1358–63; discussion 63–4.
80. Zevgaridis D, Medele RJ, Muller A, Hischa AC, Steiger HJ. Meningiomas of the sellar region presenting with visual impairment: impact of various prognostic factors on surgical outcome in 62 patients. Acta Neurochir (Wien). 2001;143:471–6.
81. Cheng CM, Noguchi A, Dogan A, et al. Quantitative verification of the keyhole concept: a comparison of area of exposure in the parasellar region via supraorbital keyhole, frontotemporal pterional, and supraorbital approaches. J Neurosurg. 2013;118:264–9.
82. Abdel Aziz KM, Bhatia S, Tantawy MH, et al. Minimally invasive transpalpebral "eyelid" approach to the anterior cranial base. Neurosurgery. 2011;69:ons195–206; discussion –7.
83. Arnaout MM, Luzzi S, Galzio R, Aziz K. Supraorbital keyhole approach: pure endoscopic and endoscope-assisted perspective. Clin Neurol Neurosurg. 2020;189:105623.
84. Berhouma M, Jacquesson T, Jouanneau E. The fully endoscopic supraorbital trans-eyebrow keyhole approach to the anterior and middle skull base. Acta Neurochir (Wien). 2011;153:1949–54.
85. Reisch R, Perneczky A. Ten-year experience with the supraorbital subfrontal approach through an eyebrow skin incision. Neurosurgery. 2005;57:242–55; discussion –55.
86. Borghei-Razavi H, Truong HQ, Fernandes-Cabral DT, et al. Minimally invasive approaches for anterior skull base meningiomas: supraorbital eyebrow, endoscopic endonasal, or a combination of both? Anatomic study, limitations, and surgical application. World Neurosurg. 2018;112:e666–74.
87. Eroglu U, Shah K, Bozkurt M, et al. Supraorbital keyhole approach: lessons learned from 106 operative cases. World Neurosurg. 2019;124:e667–74.

88. Fatemi N, Dusick JR, de Paiva Neto MA, Malkasian D, Kelly DF. Endonasal versus supraorbital keyhole removal of craniopharyngiomas and tuberculum sellae meningiomas. Neurosurgery. 2009;64:269–84; discussion 84–6.
89. Iacoangeli M, Nocchi N, Nasi D, et al. Minimally invasive supraorbital key-hole approach for the treatment of anterior cranial fossa meningiomas. Neurol Med Chir (Tokyo). 2016;56:180–5.
90. Linsler S, Fischer G, Skliarenko V, Stadie A, Oertel J. Endoscopic assisted supraorbital keyhole approach or endoscopic endonasal approach in cases of tuberculum sellae meningioma: which surgical route should be favored? World Neurosurg. 2017;104:601–11.
91. Gazzeri R, Nishiyama Y, Teo C. Endoscopic supraorbital eyebrow approach for the surgical treatment of extraaxialand intraaxial tumors. Neurosurg Focus. 2014;37:E20.
92.• Mallari RJ, Thakur JD, Rhee JH, et al. Endoscopic endonasal and supraorbital removal of tuberculum sellae meningiomas: anatomic guides and operative nuances for keyhole approach selection. Oper Neurosurg (Hagerstown). 2021;21:E71–E81. **Relatively large series of TS meningiomas operated on using minimally invasive approaches with detailed discussion on parameters affecting approach selection.**
93. Ottenhausen M, Rumalla K, Alalade AF, et al. Decision-making algorithm for minimally invasive approaches to anterior skull base meningiomas. Neurosurg Focus. 2018;44:E7.
94. Igressa A, Pechlivanis I, Weber F, et al. Endoscope-assisted keyhole surgery via an eyebrow incision for removal of large meningiomas of the anterior and middle cranial fossa. Clin Neurol Neurosurg. 2015;129:27–33.
95. Telera S, Carapella CM, Caroli F, et al. Supraorbital keyhole approach for removal of midline anterior cranial fossa meningiomas: a series of 20 consecutive cases. Neurosurg Rev. 2012;35:67–83; discussion.
96. Mahmoud M, Nader R, Al-Mefty O. Optic canal involvement in tuberculum sellae meningiomas: influence on approach, recurrence, and visual recovery. Neurosurgery. 2010;67:ons108–18; discussion ons18–9.
97. Reisch R, Perneczky A, Filippi R. Surgical technique of the supraorbital key-hole craniotomy. Surg Neurol. 2003;59:223–7.
98. Wiedemayer H, Sandalcioglu IE, Wiedemayer H, Stolke D. The supraorbital keyhole approach via an eyebrow incision for resection of tumors around the sella and the anterior skull base. Minim Invasive Neurosurg. 2004;47:221–5.
99. da Costa MDS, Hardesty DA, Priddy B, Noiphithak R, Revuelta Barbero JM, Prevedello DM. Extended supraorbital approach with modified eyebrow incision: technical note. World Neurosurg. 2019;128:354–9.
100. Dare AO, Landi MK, Lopes DK, Grand W. Eyebrow incision for combined orbital osteotomy and supraorbital minicraniotomy: application to aneurysms of the anterior circulation. Technical note J Neurosurg. 2001;95:714–8.
101. Figueiredo EG, Deshmukh V, Nakaji P, et al. An anatomical evaluation of the mini-supraorbital approach and comparison with standard craniotomies. Neurosurgery. 2006;59:ONS212–20; discussion ONS20.
102. Gardner PA, Kassam AB, Thomas A, et al. Endoscopic endonasal resection of anterior cranial base meningiomas. Neurosurgery. 2008;63:36–52; discussion –4.
103. Liu JK, Schmidt RF, Choudhry OJ, Shukla PA, Eloy JA. Surgical nuances for nasoseptal flap reconstruction of cranial base defects with high-flow cerebrospinal fluid leaks after endoscopic skull base surgery. Neurosurg Focus. 2012;32:E7.
104. Garcia-Navarro V, Anand VK, Schwartz TH. Gasket seal closure for extended endonasal endoscopic skull base surgery: efficacy in a large case series. World Neurosurg. 2013;80:563–8.
105. McCoul ED, Anand VK, Singh A, Nyquist GG, Schaberg MR, Schwartz TH. Long-term effectiveness of a reconstructive protocol using the nasoseptal flap after endoscopic skull base surgery. World Neurosurg. 2014;81:136–43.
106. Elshazly K, Kshettry VR, Farrell CJ, Nyquist G, Rosen M, Evans JJ. Clinical outcome after endoscopic endonasal resection of tuberculum sella meningiomas. Oper Neurosurg (Hagerstown). 2018;14:494–502.
107. Khan OH, Krischek B, Holliman D, et al. Pure endoscopic expanded endonasal approach for olfactory groove and tuberculum sellae meningiomas. J Clin Neurosci. 2014;21:927–33.
108. Ottenhausen M, Banu MA, Placantonakis DG, et al. Endoscopic endonasal resection of suprasellar meningiomas: the importance of case selection and experience in determining extent of resection, visual improvement, and complications. World Neurosurg. 2014;82:442–9.
109. Ciric I, Rosenblatt S. Suprasellar meningiomas. Neurosurgery. 2001;49:1372–7.
110. Frank G, Pasquini E. Tuberculum sellae meningioma: the extended transsphenoidal approach–for the virtuoso only? World Neurosurg. 2010;73:625–6.
111. Ogawa Y, Tominaga T. Extended transsphenoidal approach for tuberculum sellae meningioma–what are the optimum and critical indications? Acta Neurochir (Wien). 2012;154:621–6.
112. Bowers CA, Altay T, Couldwell WT. Surgical decision-making strategies in tuberculum sellae meningioma resection. Neurosurg Focus. 2011;30:E1.
113. Khan OH, Anand VK, Schwartz TH. Endoscopic endonasal resection of skull base meningiomas: the significance of a “cortical cuff” and brain edema compared with careful case selection and surgical experience in predicting morbidity and extent of resection. Neurosurg Focus. 2014;37:E7.
114. Liu JK, Christiano LD, Patel SK, Tubbs RS, Eloy JA. Surgical nuances for removal of tuberculum sellae meningiomas with optic canal involvement using the endoscopic endonasal extended transsphenoidal transplanum transtuberculum approach. Neurosurg Focus. 2011;30:E2.
115. Attia M, Kandasamy J, Jakimovski D, et al. The importance and timing of optic canal exploration and decompression during endoscopic endonasal resection of tuberculum sella and planum sphenoidale meningiomas. Neurosurgery. 2012;71:58–67.
116. Schroeder HW. Indications and limitations of the endoscopic endonasal approach for anterior cranial base meningiomas. World Neurosurg. 2014;82:S81–5.
117. Koutourousiou M, Fernandez-Miranda JC, Stefko ST, Wang EW, Snyderman CH, Gardner PA. Endoscopic endonasal surgery for suprasellar meningiomas: experience with 75 patients. J Neurosurg. 2014;120:1326–39.
118. de Divitiis E, Cavallo LM, Esposito F, Stella L, Messina A. Extended endoscopic transsphenoidal approach for tuberculum sellae meningiomas. Neurosurgery. 2007;61:229–37; discussion 37–8.
119. Bernat AL, Priola SM, Elsawy A. et al. Recurrence of anterior skull base meningiomas after endoscopic endonasal resection: 10 years’ experience in a series of 52 endoscopic and transcranial cases World Neurosurg. 2018;120:e107–e113.
120. Kshettry VR, Elshazly K, Evans JJ. Endoscopic transnasal surgery for planum and tuberculum sella meningiomas: decision-making, technique and outcomes. CNS Oncol. 2016;5: 211–22.
121.• Youngerman BE, Banu MA, Gerges MM, et al. Endoscopic endonasal approach for suprasellar meningiomas: introduction of a new scoring system to predict extent of resection and assist in case selection with long-term outcome data. J Neurosurg. 2020;135:113–25. **Practical modern scoring system for selection of surgical approach for suprasellar meningiomas**.

122. Sade B, Lee JH. High incidence of optic canal involvement in tuberculum sellae meningiomas: rationale for aggressive skull base approach. Surg Neurol. 2009;72:118–23; discussion 23.
123. Margalit NS, Lesser JB, Moche J, Sen C. Meningiomas involving the optic nerve: technical aspects and outcomes for a series of 50 patients. Neurosurgery. 2003;53:523–32; discussion 32–3.
124. Bander ED, Singh H, Ogilvie CB, et al. Endoscopic endonasal versus transcranial approach to tuberculum sellae and planum sphenoidale meningiomas in a similar cohort of patients. J Neurosurg. 2018;128:40–8.
125. Zada G, Du R, Laws ER Jr. Defining the "edge of the envelope": patient selection in treating complex sellar-based neoplasms via transsphenoidal versus open craniotomy. J Neurosurg. 2011;114:286–300.
126. Kassam AB, Prevedello DM, Carrau RL, et al. Endoscopic endonasal skull base surgery: analysis of complications in the authors' initial 800 patients. J Neurosurg. 2011;114:1544–68.
127. de Notaris M, Solari D, Cavallo LM, et al. The "suprasellar notch", or the tuberculum sellae as seen from below: definition, features, and clinical implications from an endoscopic endonasal perspective. J Neurosurg. 2012;116:622–9.
128. Rhoton AL Jr. The sellar region. Neurosurgery. 2002;51:S335–74.
129. Holmes G, Sargent P. Suprasellar endotheliomata. Brain. 1927;50:518–37.
130. Ganna A, Dehdashti AR, Karabatsou K, Gentili F. Fronto-basal interhemispheric approach for tuberculum sellae meningiomas; long-term visual outcome. Br J Neurosurg. 2009;23:422–30.
131. Pamir MN, Ozduman K, Belirgen M, Kilic T, Ozek MM. Outcome determinants of pterional surgery for tuberculum sellae meningiomas. Acta Neurochir (Wien). 2005;147:1121–30; discussion 30.
132. Mathiesen T, Kihlstrom L. Visual outcome of tuberculum sellae meningiomas after extradural optic nerve decompression. Neurosurgery. 2006;59:570–6; discussion -6.
133. Muskens IS, Briceno V, Ouwehand TL, et al. The endoscopic endonasal approach is not superior to the microscopic transcranial approach for anterior skull base meningiomas-a meta-analysis. Acta Neurochir (Wien). 2018;160:59–75.
134. Lu VM, Goyal A, Rovin RA. Olfactory groove and tuberculum sellae meningioma resection by endoscopic endonasal approach versus transcranial approach: a systematic review and meta-analysis of comparative studies. Clin Neurol Neurosurg. 2018;174:13–20.
135. Komotar RJ, Starke RM, Raper DM, Anand VK, Schwartz TH. Endoscopic endonasal versus open transcranial resection of anterior midline skull base meningiomas. World Neurosurg. 2012;77:713–24.
136. de Divitiis E, Esposito F, Cappabianca P, Cavallo LM, de Divitiis O, Esposito I. Endoscopic transnasal resection of anterior cranial fossa meningiomas. Neurosurg Focus. 2008;25:E8.
137. Padhye V, Naidoo Y, Alexander H, et al. Endoscopic endonasal resection of anterior skull base meningiomas. Otolaryngol Head Neck Surg. 2012;147:575–82.
138. Bassiouni H, Asgari S, Stolke D. Tuberculum sellae meningiomas: functional outcome in a consecutive series treated microsurgically. Surg Neurol. 2006;66:37–44; discussion –5.
139.• Khan DZ, Muskens IS, Mekary RA, et al. The endoscope-assisted supraorbital "keyhole" approach for anterior skull base meningiomas: an updated meta-analysis. Acta Neurochir (Wien). 2021;163:661–76. **Recent updated meta-analysis on the outcomes of different surgical approaches to anterior skull base meningiomas**.
140. Yasargil MG. Microneurosurgery, vol. 4B. Microneurosurgery of CNS tumors. Stuttgart: Georg Thieme Verlag. 1984.