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Petroclival meningiomas: Remaining controversies in light of minimally invasive approaches

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ABSTRACT

Surgical resection of petroclival meningiomas remains challenging due to their deep location and relationship to vital neurovascular structures. Although the natural history of these tumors involves a slow course, the incidence of cranial nerve deficits and the extent of tumor resection vary widely in the literature. Some reviews on this topic have been conducted, but data remain fragmentary and based on retrospective case series, which hinders attempts at meta-analysis. Within this context, research into the use of minimally invasive approaches, including in neuroendoscopy, continues to emerge. The objective of this narrative review is to analyze the available literature on the surgical treatment of petroclival meningiomas, with a focus on attempts at endoscopy-assisted resection.

Contents

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1. Introduction

Meningiomas are usually benign lesions that account for 20–25% of intracranial tumors, and 10% occur in the posterior fossa. Of these, 5–11% affect the petroclival region, accounting for 0.15% of intracranial masses overall [1,2]. Surgical resection of petroclival meningiomas remains challenging due to their depth and relationship to vital neurovascular structures.

In 1953, Castellano and Ruggiero classified posterior fossa meningiomas into five groups: cerebellar convexity, tentorial, posterior aspect of the petrous bone, clival, and foramen magnum [1]. Yasargil et al. revised this classification in 1980, suggesting that these tumors arose along the petroclival line and graded them into clival, petroclival, sphenopetroclival, foramen magnum, and cerebellopontine angle meningiomas [3]. In 1986, Mayberg and Symon published a series using the terminology "meningiomas of the clivus and apical petrous bone," popularizing the term "petroclival meningioma" [4].

Although the natural history of petroclival meningiomas involves a slow course, the incidence of cranial nerve deficits and the extent of tumor resection vary widely in the literature (Table 1).

This reflects different treatment philosophies, which often include planning for subtotal resection, especially since the advent of radiosurgery [36–39] and new radiotherapy techniques [40]. In general, these approaches are complex, time-consuming and require substantial expertise. Some reviews on this topic have been conducted [5,18,41], but data remain fragmentary and based on retrospective case series, which hinders attempts at meta-analysis. Within this context, research on the use of minimally invasive approaches is emerging, including in neuroendoscopy [42–48]. The objective of this narrative review is to analyze the available literature on the surgical treatment of petroclival meningiomas, with particular emphasis on endoscopy-assisted resections.

2. Definitions

The petroclival area corresponds to the body of the sphenoid and the anterior central portion of the occipital bones, and is bounded laterally by the petrous apex. Its important neurovascular structures, such as the basilar artery and its branches, are often surrounded or displaced by petroclival meningiomas. The petrous vein is usually displaced posteriorly; cranial nerves III and IV are displaced superiorly and cranial nerve VI is usually surrounded by tumor or displaced superiorly [18].

By definition, petroclival meningiomas originate medial to cranial nerves V, VII, VIII, IX, X, and XI and reach the tentorium. They often extend to the middle fossa, cavernous sinus, prepontine space and down to the foramen magnum; they may invade the pia mater and cause compression of the brainstem [18]. Lower clivus meningiomas (foramen magnum meningiomas) [19], cerebellopontine angle meningiomas (tentorial or petrous meningiomas) [49], and sphenoid wing meningiomas can reach these areas, but are not considered petroclival in origin [18]. Petroclival meningiomas that involve the cavernous sinus may be classified as sphenopetroclival [31].

Table 1
Major published surgical series of petroclival meningiomas.

Author, year	n	Gross total resection [a] (%)	Mortality (%)	Major morbidity (%)	New cranial nerve deficits (%)
Yasargil et al. [3]	20	35	10	26	50
Mayberg and Simon [4]	35	26	9	34	54
Nishimura et al. [2]	24	63	8	33	91
Tatagiba et al. [5]	54	70	2	24	37
Bricolo et al. [6]	33	79	9	39	76
Spetzler et al. [7]	18	78	0	11	39
Kawase et al. [8]	42	76	0	12	36
Coudwell et al. [9]	109	69	3.7	15	33
Zentner et al. [10]	19	68	5	11	34
Goel [11]	24	67	0	29	29
Abdel Aziz et al. [12]	35	37	0	9	31
Little et al. [13]	137	40	0.7	26	22
Park et al. [14]	49	20	2	28.6	28.6
Mathiesen et al. [15]	29	48	0	7	21
Natarajanet et al. [16]	150	32	0	22	20.3
Bambakidis et al. [17]	46	43	0	41	30
Ramina et al. [18]	67	55	3	12	33
Tahara et al. [19]	15	50	13	20	50
Seifert [20]	148	37	0	31	22
Li et al. [21]	57	58	2	42	67
Yang et al. [22]	41	61	0	66	8
Yamakami et al. [23]	32	59	6	28	22
Watanabe et al. [24]	26	42	0	15	15
Shi et al. [25]	14	86	0	43	43
Chen et al. [26]	82	56	5	44	39
Nanda et al. [27]	50	28	6	44	32
Kusumi et al. [28]	23	47	0	22	43
Matsui [29]	15	67	0	27	27
Li et al. [30]	259	52.5	1.2	54	28.2
Almefty et al. [31]	64	64	8	25	39
Morisako et al. [32]	$60_{(24/36)}$ [b]	EOR 96.1/92.7 [c]	1.7	25	46.7
Silva et al. [33]	8/16	87.5	0	37.5	37.5
[d] Tatagiba et al. [34]	29/87	66	0	24	34
[d]Zhou et al. [35]	24	33.3	0	20.8	37.5

[a] Simpson grades 1, 2, and 3.
[b] 24 cases in the early group (1990–1999) and 36 cases in the late group (2000–2009).
[c] Extent of resection (EOR) was calculated as follows: EOR(%) = (preoperative tumor volume – postoperative tumor volume)/preoperative tumor volume × 100.
[d] Employed endoscopic assistance.

3. Diagnosis

Headache, gait disturbances, hearing loss, and facial paresthesias are the main symptoms. Cranial nerve V is most often affected, followed by IX and X. Facial palsy occurs in 30% of patients [18]. Visual disturbances, cerebellar signs, and sensorimotor deficits usually occur late in the course of the disease. Hydrocephalus is rare due to slow tumor growth. Characteristically, patients with petroclival meningiomas may have good hearing, which stands in contrast to severe involvement of the trigeminal and lower cranial nerves [6,9–19,31,50,51].

Head CT may show bone erosion, hyperostosis, or both, as well as calcifications. The tumor usually appears slightly hyperdense to brain and demonstrates strong contrast enhancement. It generally infiltrates the dura, with a large attachment zone, and magnetic resonance imaging (MRI) shows strong, homogeneous gadolinium uptake. Petroclival meningiomas are usually T1-isointense, T2- and FLAIR-hyperintense. They usually indent the porus acusticus without widening it, or may penetrate the auditory meatus without invading the petrous portion of the temporal bone [18].

Vascularity can be demonstrated by magnetic resonance angiography, three-dimensional multislice CT angiography [52,53], or digital angiography [54–56]. This assessment plays an important role in evaluating displacement, stenosis, or occlusion of the basilar or internal carotid arteries and their branches. Branches of the external carotid arteries usually supply petroclival meningiomas and hypervascular tumors can be embolized in the early preoperative period [54–56]. Preoperative assessment for surgical planning enables preservation of the superior petrosal vein, and prevention of venous complications [52,57]. When using the subtemporal surgical corridor via the petrosal or fronto-orbito-zygomatic approaches, it is important to recognize and secure the vein of Labbé.

4. Treatment modalities and controversies

Van Havenberg et al. studied 21 patients with petroclival meningiomas treated conservatively, with a minimum follow-up of 4 years. They reported tumor growth in 76% of cases and clinical deterioration in 63% [58]. Jung et al. reported a series of 38 subtotal resection patients with linear growth of 0.37 cm/year and volume increasing by 4.94 cm^3/year, but up to 60% of patients showed no signs of disease progression [59]. Hence, watchful waiting may be a treatment option, especially in poor candidates for surgery, elderly patients, very small asymptomatic lesions, or when the patient is unwilling to undergo surgical treatment; in these cases, MRI may be repeated every 6 months or when new symptoms arise.

However, small tumors may carry the greatest potential for cure, possibly with the least morbidity [19,30,60]. The surgical removal of small, asymptomatic tumors has been controversial, because even small petroclival meningiomas require complex surgical procedures that can carry substantial morbidity. Reinert et al. reported 201 patients with small meningiomas treated by microsurgery, of which 33 were located in high-risk regions (group III – petroclival, cerebellopontine angle, foramen magnum). They found a 46.1% rate of permanent morbidity in group III lesions, with 78.8% of patients achieving complete resection [61]. On the other hand, in a series of 18 small petroclival meningiomas, Ramina et al. reported Simpson grade 1 or 2 resection in all patients, with no major morbidity or mortality, in a mean post-operative follow-up of 41.8 months [60].

Nicolato et al. reported, in a series of posterior fossa meningiomas, that the only factor to significantly influence the efficacy of gamma knife radiosurgery (GKS) was the biological nature of the meningioma (WHO grades II and III) [38]. In 1998, Subach et al. had reported 62 cases of petroclival meningioma, with cranial nerve deficits occurring in only 8% of patients [39]. Iwai et al. reported a seven-patient series of large petroclival and cavernous sinus meningiomas treated with gamma knife radiosurgery in a two-stage procedure [37]. Three of these patients had been surgically treated and four (57%) were only followed with MR imaging. The mean tumor volume was 53.5 cm^3, and the mean treatment volume was 18.6 cm^3. Six patients exhibited tumor growth control during a mean 39 months of follow-up, and three patients (43%) experienced tumor regression. Three patients (43%) had improved clinically by the time of follow-up examination, and no patient suffered from symptomatic radiation injury.

Three main surgical approaches can be used: fronto-orbital-zygomatic, petrosal, and retrosigmoid, which may be combined [18]. The retrosigmoid approach is simpler to perform than the petrosal approaches, and is indicated when the tumor is located mainly in the posterior fossa [18]. It allows tumor resection from the jugular foramen up to the posterior part of the cavernous sinus. Opening the tentorium and drilling out the suprameatal tubercle and petrous apex enables resection of tumor extensions into the middle fossa [62].

The fronto-orbito-zygomatic approach is used for petroclival tumors extending far into the middle fossa and the cavernous sinus. It allows proper control of the internal carotid artery, but does not provide good exposure below the internal auditory meatus, even with opening of the tentorium [31]. The pterional approach may be used in sphenopetroclival meningiomas for partial resection of the epidural component of the middle fossa, in a separate stage from the clival portion, which is generally performed via the suboccipital approach. This more conservative strategy may be an alternative to the petrosal approach, or to enable safer subsequent radiosurgery.

The petrosal approaches can be used when the lesion involves the middle and posterior fossa and clivus, especially giant tumors crossing the midline in the prepontine region. The presigmoid translabyrinthine approach includes removal of the labyrinth, but opening of the semicircular canals causes deafness. Petrosal approaches do not provide access to the inferior third of the clivus [18]. Ichimura et al. used the anterior transpetrosal approach in 91 patients with petroclival meningiomas, for lesions located predominantly in the middle fossa, as it provides access to Meckel's cave [50]. Da Silva et al. [33] used the posterior petrosal approach in 8 patients with petroclival meningiomas out of 49 patients with large and giant skull base meningiomas (3 cm or larger at presentation), and were able to preserve the labyrinthine structures.

5. The role of endoscopy

Although previous conventional cranial base approaches have the potential to reduce patient morbidity by removing bony structures to limit brain retraction, they still require some brain manipulation by virtue of their lateral-to-medial trajectory [43]. Conceptually, the extended transsphenoidal approach could provide direct access to the ventral cranial base via a midline trajectory. Gardner et al. [43] demonstrated the feasibility, safety, and early efficacy of anterior cranial base meningioma resection via a fully endoscopic transnasal route, the endoscopic expanded endonasal approach (EEA). Besides direct tumor access, potential advantages include shorter exposure times; early tumor devascularization; complete, bilateral optic canal decompression; and avoidance of brain retraction. They included five primary parasellar tumors with secondary petrous involvement and two primary petroclival tumors. In all five primary parasellar tumors, successful resection of the parasellar portion was achieved with relief of visual symptoms, and no patient underwent complete resection. Also, these tumors were associated with the lowest rate of cerebrospinal fluid (CSF) leak in the series (0 of 5), which may have reflected the

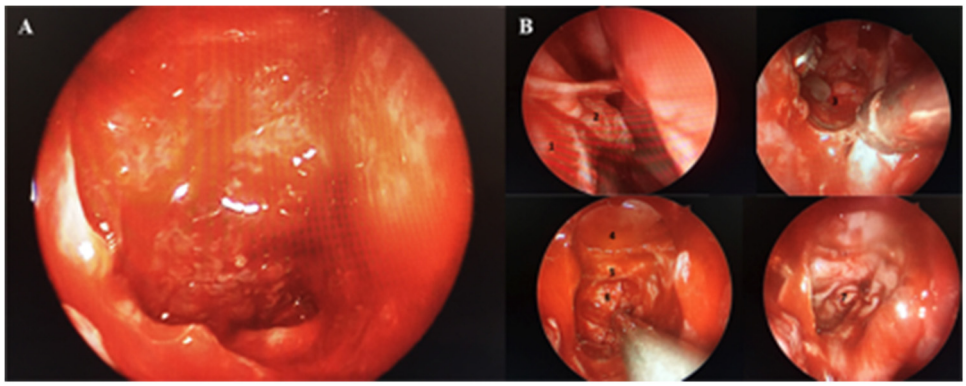

Fig. 1. Illustrative case: a 47-year-old female presenting with right facial hypoesthesia. MRI showed an extra-axial lesion in the cavernous sinus and upper clivus. Endoscopic transsphenoidal biopsy and partial resection were performed. Anatomopathological examination revealed a grade I meningioma. The patient reported improvement of facial hypoesthesia after fractionated stereotactic radiotherapy and remained asymptomatic at 29 months of follow-up. Control MRI showed a slight reduction in tumor size. (A) Endoscopic view of the tumor, eroding the sellar floor and upper clivus. (B) At the start of surgery, a nasoseptal flap is elevated (top left). After opening the anterior wall of the sphenoid sinus, the meningioma is seen invading the clivus and sellar region (top right). Biopsy and sphenoid component resection views (lower left). Nasal septum (1), nasoseptal pedicled flap (2), tumor (3), posterior ethmoidal cell (4), sellar floor (5), upper clivus (6), skull base reconstruction with nasoseptal pedicled flap (7).

fact that parasellar debulking was not thoroughly dissected from an arachnoid cistern. However, the overall postoperative CSF leak rate was 40% (14 of 35), even though all leaks were resolved without craniotomy. After adopting multilayer closure with a pedicled nasosseptal flap, their authors reduced the overall CSF leak rate after EEAs to 5.4% in the last year of their series. Residual tumor was either observed or treated with radiosurgery, but the lateral or tentorial portion could be controlled with transcranial approaches in younger patients.

New devices have been developed and have facilitated surgical techniques. Promising studies have shown that the three-dimensional (3D) endoscope is a safe and feasible tool for endoscopic skull base surgery. It has improved the precision of transnasal microneurosurgical dissection and may improve depth perception and performance for novices [47].

The introduction of endoscopic techniques and an endonasal approach to the skull base has created new challenges; one of the greatest is reconstruction of the dural defect and prevention of postoperative CSF leakage. Some articles have suggested alternatives for reconstruction following endoscopic endonasal skull base surgery with pedicled flaps [44,45]. Figs. 1 and 2 show an illustrative case treated with endoscopy.

Many recent studies of endoscopy and skull base surgery or petroclival meningioma are anatomic studies. De Notaris et al. [42] explored the clival/petroclival area, via both the endonasal transclival and retrosigmoid endoscopic routes, in 12 fresh cadaver heads positioned to simulate a semi-sitting position. The authors defined three subregions over the clival area (cranial, middle, and caudal levels). The most anterior (endonasal) and the most lateral (retrosigmoid) routes were at the extremes of the spectrum of approaches to the petroclival area. The authors identified critical structures that limit lateral extension of the bone opening via the endonasal route: the paraclival segment of the internal carotid artery, the dural porus of the sixth cranial nerve, and the hypoglossal canal. On the other hand, the endoscopic retrosigmoid approach provides a wide view over the lateral surface of the brainstem.

Van Gompel et al. [48] published a comparison of an open microscopic anterior petrosectomy (OAP) versus endoscopic endonasal anterior petrosectomy (EAP). Four cadaveric heads were used and the limits of bony resection were defined through pre-dissection and post-dissection thin-slice CT scans. OAP achieved nearly a 50% larger volumetric resection than EAP. While OAP appeared to completely address the superior portion of the petrous apex, EAP appeared to have a niche in approaches to lesions in the inferior petrous apex. The authors proposed that OAP should be redefined as the "superior anterior petrosectomy", while EAP could be referred to as the "inferior anterior petrosectomy".

Differently, Russo et al. [46] described the microsurgical anatomy of the high anterior cervical approach to the clivus and foramen magnum. Eight adult cadaveric specimens were prepared for minimal anterior clivectomy and its lateral skull base extensions, the extended anterior far-lateral clivectomy and the inferior petrosectomy, with complementary endoscopy. Minimal anterior clivectomy could expose the vertebrobasilar junction, proximal basilar artery, anteroinferior cerebellar arteries, and cranial nerve VI. The lateral skull base extensions provided access to the anterior foramen magnum, mid-lower clivus, and petroclival region, up to Meckel's cave, contralateral to the side of the surgical approach. The major anatomical advantages of such an approach lie in the anterior access to the neural axis and cranial nerves, avoiding retraction and potential damage of the brainstem, cranial nerves, and vascular structures. Also, it could be suitable for both microscopic and endoscopic microsurgical techniques. However, the anatomy of the upper cervical spine and posterior pharynx is unfamiliar to most neurosurgeons, and collaboration with ear, nose, and throat or head and neck surgeons should be considered. Potential approach-related morbidity includes injury to the superior and inferior laryngeal nerve, hypoglossal nerve, perforation of the posterior pharynx, postoperative dysphagia, injury of the carotid artery entering the skull base, and profuse venous bleeding associated with the venous plexus around the foramen magnum and hypoglossal canal. Other important considerations include cervical mobility, body habitus, and absence of cervical stenosis.

Recently, Tatagiba et al. [34] reported a clinical series of 29 patients with petroclival meningioma extending into the supratentorial space operated by the endoscopic-assisted posterior intradural petrous apicectomy approach (PIPA). Through a retrosigmoid approach, the authors performed intradural anterior resection of the petrous apex and microsurgical removal of the tumor, followed by endoscopic-assisted visualization and removal of tumor parts in the middle fossa or anterior to the brainstem. Total resection was achieved in 19 patients (66%), a Karnofsky score >60% was recorded in 27 patients (93%), and the surgical complications included CSF leak in 3 patients, bleeding in the surgical cavity in 2 patients, and pneumocephalus in one patient. The most frequent postoperative neurological deficit was facial palsy (34%).

Zhou et al. [35] conducted a retrospective analysis comparing 12 patients with petroclival meningioma who had undergone neuroendoscope-assisted microscopic resection versus 12 patients who had undergone microscopic surgery. Total and subtotal

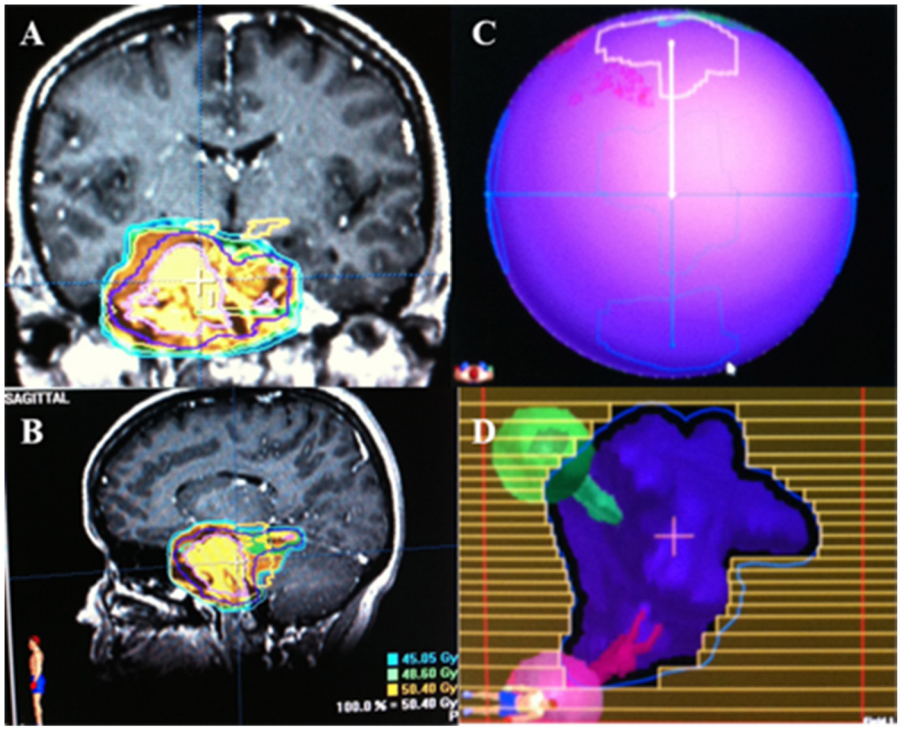

Fig. 2. Fractionated stereotactic radiotherapy plan for the patient described in Fig. 1. A total dose of 50.4 Gy was delivered in 28 fractions, prescribed to the 90% isodose line (corresponding to the yellow area) (A, B). Treatment was performed using static shaped beams (C) and a micro-multileaf collimator (D). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

resection rates of petroclival meningioma in the neuroendoscope-assisted group were significantly higher than in the microscopic surgery group. The intraoperative neuroendoscopy utilization rate was 75% (n = 9). No difference in short-term and long-term complications was observed between the two groups.

6. Discussion

Most petroclival meningiomas are benign lesions. The treatment of choice is radical resection, and the best results are usually achieved with small tumors [17,19,30,60]. These patients are also the best candidates for radiosurgery [18,36]. The real challenge in the field is the treatment of large lesions. In those, total resection is often not possible due to involvement of critical neighboring structures like the cavernous sinus, cranial nerves, or large vessels.

Subtotal resection with or without adjuvant therapy is usually performed when there is invasion of the cavernous sinus. Little et al. performed subtotal resection in patients with adherent or fibrous tumors, and found that it significantly reduced the rate of postoperative neurological deficits without a significant increase in the rate of tumor recurrence [13]. Nanda et al. achieved total resection in 28% of 50 cases, with good functional outcomes in 92% of patients, highlighting the main goal of achieving maximal tumor resection while maintaining or improving functional outcomes. Residual or recurrent tumors could be treated by stereotactic radiosurgery [27].

Radiosurgery [36–39] and fractionated stereotactic radiotherapy may be indicated as first-line or adjuvant treatment for skull base meningiomas [40]. Feng Xu et al. recommended radiosurgery for petroclival meningiomas taking account patient age, size, location of residual tumor, and pathologic features [63]. Flannery et al. avoided initial or additional resection in 98% of patients in their 21-year experience with gamma-knife treatment of petroclival meningiomas, with a median follow-up of 72 months. They believe that radiosurgery should be considered a first-line option in patients with small, symptomatic petroclival meningiomas [36]. Starke et al., in their retrospective review of 255 patients with skull base meningiomas, considered larger tumor volume (>10 cm^3), inadequate conformity index, and treatment for recurrent tumor as factors associated with worse long-term local control [64]. Moreover, Combs et al. [65] reported 260 patients randomly assigned to a prospective clinical trial of proton and carbon ion radiotherapy for primary brain tumors and tumors of the skull base. They showed 107 skull base meningiomas, of which 71 (all low-grade) were treated with a median dose of 57.6 Gy E; local control over a median follow-up of 12 months was 100% [65].

In addition, long-term follow-up surgical series with adjuvant radiosurgery or radiotherapy have been reported [16,32]: Natarajan et al. had a mean follow-up period of 102 months, and Morisako et al., a mean follow-up of 149.3 months, but the latter performed SRS only in cases of recurrent tumor or regrowth of residual tumor detected on MRI (17 patients). Kondziolka et al. reported 22 petrous apex meningiomas among 99 meningiomas treated with stereotactic gamma knife radiosurgery [66]. The median tumor volume was 4.7 mL; 57% had undergone prior resection, and 93% had clinical tumor control 10 years after radiosurgery. Kreil et al. [67] reported the outcomes of 200 patients with benign skull base meningiomas in 5–12 years of follow-up: 99 patients received gamma knife radiosurgery after microsurgical resection and 101 patients underwent upfront SRS. The median tumor volume was 6.5 cm^3, and there were 44 petroclival meningiomas in the series. Five patients needed repeated microsurgical resection following SRS (2.5%) [67].

In the other hand, Almefty et al. [31] reported a series of 64 patients treated between 1988 and 2012 and stressed that total resection (grade I or II) of petroclival meningiomas was possible in 76.4% of cases. The authors suggested that, when circumstances prevent total resection, residual tumors could be managed by watchful waiting until progression, at which time a new intervention could be planned. Furthermore, Morisako et al. [32] reported, in a retrospective series of 60 patients, that patients with an extent of resection (EOR) < 85% had significantly shorter

recurrence-free survival than those in whom radical tumor excision (EOR ≥ 85%) was achieved. The authors believe that maximal resection via a combined transpetrosal approach is the best treatment for medium-sized or large petroclival meningiomas; SRS can be considered after resection for recurrent or residual tumor, and may be the preferred primary treatment for asymptomatic patients with small tumors, but more aggressive treatment is recommended for young patients or those with short symptom duration [32].

Retrospective and historical comparisons between microsurgical resection and radiosurgery or radiotherapy have been sought. The critical limitations of these comparisons notwithstanding, Reinert et al. reasoned that SRS could provide better results than microsurgery for skull base meningiomas, especially those with a petroclival, cerebellopontine angle, or foramen magnum location. For these lesions, the morbidity of surgery can be excessively high (46% in their series), and resection is often incomplete (approximately 80% of the series) [61]. Vera et al. [68] cited two retrospective series that had compared SRS as primary treatment with surgical resection in their review of SRS for skull base meningiomas: Pollock et al. [69] and Linskey et al. [70]. Pollock et al. reported 27 petroclival meningiomas treated with microsurgery and 20 with SRS, from a series of 188 small benign meningiomas treated with resection (126) or SRS alone (62). The 7-year progression free survival for radiosurgery and Simpson grade I resection were equivalent, but recurrence was more common in the surgical group (12% versus 2%). Linskey et al. reported only three petroclival meningiomas from their 74 cranial meningiomas, but concluded that radiosurgery might stabilize rather than improve preoperative symptoms, whereas surgery may be more likely to improve symptoms because of faster relief of mass effect [70].

More recently, endoscopy has gained importance in skull base neurosurgery because of its less invasive nature, the possibility of visualization around bone corners, and better viewing angle at depth. Tatagiba et al. [34] noted that, with the advent of endoscopic-assisted surgery, previously inaccessible corners in the middle fossa, cranial nerves III and VI, and basilar trunk or anterior brainstem could be better visualized, enabling safe petroclival tumor removal. EEA could provide early removal of involved bone and dura, which may lead to a greater number of Simpson grade I resections, thereby potentially resulting in lower recurrence rates. Other advantages include potential avoidance of brain retraction, direct tumor access, and complete, bilateral optic canal decompression, avoiding manipulation of the often ischemic and compressed optic apparatus [43]. Its major drawback, two-dimensional visualization, is being overcome by the recent development of 3D endoscopes [47]. Other limitations include the learning curve associated with endoscopic endonasal work; the narrow working canal; the higher risk of vascular injury and the difficulty of managing bleeding; accessibility of optic canal extension; lesion size; tumor consistency; and CSF leak [43].

Endoscopic neurosurgery must follow the basic principles of microsurgery for tumor removal. If the tumor cannot be visualized completely while maintaining microsurgical principles, endoscopic removal should be contraindicated. Some considerations are specifically important in expanded endoscopic approaches for petroclival extension, such as adequate bone removal and precise dura opening, generally not beyond the tumor margins, to prevent herniation of normal brain through the defect, which could obscure visualization. Furthermore, appropriate instruments are essential: an adequate suction tip (6F or 8F); an EEA ultrasonic aspirator for firmer tumors; small, square Teflon pledgets or cottonoid micropatties for manipulation of critical neurovascular structures; and an appropriately shaped and angled endonasal bipolar. Care must be taken to avoid thermal injury to important neurovascular structures from heat dispersion. All in all, Gardner et al. [43] suggested that surgeons treating skull base disease should be equally facile with both open and endonasal approaches, to offer the patient a truly unbiased opinion as to the best approach for each particular tumor.

7. Conclusion

A single retrosigmoid route can neatly handle purely petroclival meningiomas. This has the advantage of less invasiveness and a shorter operative time. Petrosal approaches could be reserved for larger tumors with a supratentorial, but extracavernous, component. Tumors invading the cavernous sinus could be addressed by resection of the clival component. In patients with small sphenopetroclival tumors, radiosurgery should be considered. Endoscopic assistance, regardless of the chosen approach, is a promising additional option for skull base tumors. Petroclival meningiomas are best managed with combined approaches: medial (EEA), transclival approaches; and open posterior, lateral, retrosigmoid corridors, preferably with endoscopic assistance.

Conflict of interest

None.

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Authors' contributions

Conception and design: all authors. Acquisition of data: Isolan, Frighetto. Analysis and interpretation of data: all authors. Manuscript writing: Wayhs, Lepski. Critical revision of the manuscript: all authors. Review of submitted version of manuscript: all authors. Administrative/technical/material support: Isolan. Study supervision: Isolan.

Ethical standards

This manuscript is part of a postgraduate research project, which was approved by the local research ethics committee.

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