Mortality and morbidity in surgically treated patients with petroclival meningiomas: a systematic review and meta-analysis of case series

Hrvoje Barić, Vladimir Trkulja, Vjerislav Peterković and Goran Mrak

Department of Neurosurgery, University Hospital Center Zagreb, Zagreb, Croatia; Department of Pharmacology, Zagreb University School of Medicine, Zagreb, Croatia

ABSTRACT
Background: Reports on petroclival meningioma (PCM) surgical mortality and morbidity often deviate from established standards; as such, a comprehensive summary is lacking.
Methods: Eligibility/sources. Peer-reviewed case series of at least 10 PCM patients identified from PubMed, Web of Science, Ovid, or Google Scholar. Outcomes. Primary: mortality, tumor recurrence, any cranial nerve deficit (CND); other: individual CNDs, other complications. Data synthesis. Random-effects meta-analysis/meta-regression [effects: surgical approach (supratentorial, S; infratentorial, I; combined, C), average age and follow-up, sample size, and percent of patients with gross-total resection (GTR)] of logit-transformed proportions.
Results: Data. 73 case-series/3553 patients. Mortality. Adjusted predicted mortalities of 2.4%, 2.5%, and 1.2% (50-month follow-up) for the S, I, and C approaches, respectively, with the upper limits of the 95% credibility intervals at 3.3%, 3.7%, and 3.6%, respectively. Recurrence. Adjusted predicted recurrences of 5.5%, 11.1%, and 12.0% (50-month follow-up and 57% GTR) for the S, I, and C approaches, respectively; recurrence was positively associated with follow-up period and negatively associated with having received GTR. At all covariates at median values but at GTR 90% predictions: 3.1% (95%CI 3.1–9.8), 6.3% (3.8–10.4), and 6.9% (3.4–13.2) with the S, I, and C; prediction credibility intervals 1–4% and 22.4%. Any CND. Adjusted predicted probabilities of 37.2%, 23.4%, and 29.5% (at median covariate values) for the S, I, and C approaches, respectively; prediction credibility intervals ranged from <1% to 78%. Other outcomes. The most common individual CNDs were nVII (14.4%), nV (11.5%), and nII (10.2%); other common complications included motor deficit (10.8%), infection (9.8%), and CSF leak (7.5%).
Conclusion: This is the first systematic review on PCM surgical mortality, recurrence, and morbidity. Outcomes differ between surgical approaches and reporting quality varies greatly.

Introduction
Petroclival meningiomas (PCMs) account for approximately 2% of intracranial meningiomas and for less than 0.15% of primary intracranial tumors.1,2 They present a neurosurgical challenge due to the deep anatomical location and proximity to vital neurovascular structures. This complexity is reflected in the abundance of viable surgical approaches and non-surgical treatment modalities for PCM, both of which are continuously evolving. Nevertheless, the mortalities and morbidities of these approaches are high.2 A recent systematic review addressed the problem of postoperative cranial nerve deficits (CNDs) in PCM surgery.3 However, a broader overview of the topic is missing and would be of value to guide the decision-making of both patients and neurosurgeons dealing with PCMs. Therefore, we conducted a comprehensive systematic review of surgery-related mortality, morbidity, and tumor recurrence in PCM patients.

Methods
We conducted a systematic review of a case-series of surgically treated PCM patients published until February 7, 2021, and performed a meta-analysis in an attempt to estimate the risk of post-surgical mortality, tumor recurrence, CNDs and other morbidity. We included a previously non-reported cohort of 11 PCM patients depicted as ‘Mrak 2021’ (all patients operated-on by one of the co-authors, GM).
disturbance, motor deficit, cerebrospinal fluid (CSF) leak, infection, hydrocephalus, seizures, stroke/intracranial hematoma, deep venous thrombosis and pulmonary embolism.

**Literature search and study selection process**

We searched PubMed Medline, Web of Science, Ovid (all resources), and Google Scholar using the search term ‘petroclival meningioma’ with no filters (the exception was Google Scholar, for which it was requested that the search term appeared in the title) to achieve a non-specific, yet highly sensitive search. We also manually searched the reference lists of published reviews for any relevant research that may not have been identified through our literature search. Following duplicate removal, the identified articles were independently screened (titles, abstracts) by four reviewers to exclude non-eligible studies; the final lists were compared and any disagreements were resolved. This process was repeated to complete the eligibility assessment of full-text reviews.

**Data extraction**

In the first step, four reviewers each extracted data from a subset of included studies. In the next step, each subset was assigned to a different reviewer for re-extraction; this was done to ensure the reliability of the process. Any disagreements were resolved by reaching a consensus. The following data were extracted: (a) number of patients (denominator); (b) number with outcomes throughout the observation period; (c) predominant surgical approach used in the cohort (supratentorial, infratentorial, combined supra-/infratentorial); (d) other potentially relevant covariates, i.e. (i) average patient age, (ii) proportion of women, (iii) tumor histology, (iv) average tumor volume (if not reported, tumor size data were used to calculate tumor volume, if three diameters were reported, an ellipsoid shape was assumed and the volume was calculated accordingly, if two diameters were reported, the third was assumed to be an average of the first two, if only one diameter was reported the tumor was assumed to be in the shape of a sphere, with volume calculated accordingly), and (v) proportion of patients for which gross total resection (GTR) was achieved. A few studies reported average extent of resection instead. The two values were considered interchangeable when proportion with GTR was addressed as a moderator.

In cases in which PCM patients were a subset of a larger cohort (other tumor locations were also reported) and covariate data were not specifically reported for the PCM patient subset, averages for the entire cohort were considered applicable. In the case that data concerning an individual CND were not explicitly stated, including a lack of an explicit statement of ‘no events’, it was considered that the study did not report these outcomes.

In the case that data concerning an individual CND were reported, but deficits of other cranial nerves were not mentioned (including a lack of an explicit statement of ‘no other cranial nerve deficits’), it was assumed that no deficit regarding the non-addressed cranial nerves had been observed. If CNDs were not mentioned at all, it was considered that the study did not report these outcomes.

Continuous variables reported as medians and ranges were converted into mean values, along with the corresponding standard deviations, to achieve uniform summaries across studies.

**Study quality**

We addressed several aspects suggested in a recently proposed tool for evaluating the quality of case-series/case reports. However, we later restricted the evaluation to the question of non-reporting and provided an overall comment about variability and inconsistency (across included studies) in the choice of outcomes and modes of their reporting (see Supplemental Methods for explanation).

**Data synthesis**

We considered mortality, tumor recurrence, and occurrence of any CND (number of patients with at least one CND) as outcomes of primary interest. The occurrence of individual CNDs and non-CND complications were considered secondary outcomes, in part due to the anticipated problems with (in)adequate reporting.

For primary outcomes, we first generated random-effects pooled estimates (with 95% prediction intervals) separately for each surgical approach/technique by fitting generalized linear mixed (GLMM) models with a random intercept to logit-transformed proportions (binomial-normal model) with ad hoc Hartung–Knapp variance correction. Individual study proportions are presented as Clopper-Pearson confidence intervals (a continuity correction in studies with no events only to generate single study estimates, but not implemented in data pooling). Funnel plots were generated, after which Peters' asymmetry test was implemented, as suggested for single proportions. Next, we implemented the Copas selection model analysis to generate publication bias-corrected estimates, after which we performed random (mixed)-effects meta-regression (GLMM, maximum likelihood for $\tau^2$, t-distribution) to obtain predicted probabilities (with 95% CI) and 95% credibility (prediction) intervals for each surgical approach adjusted for average patient age, cohort size, average length of follow-up (in months) and percent of patients with GTR. For exploratory purposes, the meta-regression estimates were used to evaluate differences between surgical approaches (as odds ratios). Regarding secondary outcomes, pooled and meta-regression estimates were generated. We used the R packages *meta*, *metasens* and *metafor* during the data synthesis.

**Results**

**Study selection and characteristics**

After duplicate removal and title/abstract screening, 121 out of the 1663 initially identified articles underwent full-text eligibility assessment (Figure 1), with 52 studies being excluded for various reasons (Figure 1, see Supplemental Results, Table S2 for details) and 69 publications (72 case-series) included in the review (Figure 1). Together with the current case-series, this amounted to 73 patient series (Figure 1): in 71 series patients had received open surgeries (20 supratentorial approach, 39 infratentorial approach, and 12 combined approach), while two series reported on endoscopically treated patients (Figure 1). The outcomes from the two endoscopic series (total $N=61$) were summarized, but the series did not involve enough data to be included in any other analysis.

Several study characteristics (e.g. tumor histology) were reported only sporadically, which prevented any systematic overview, while others were reported more regularly and are
summarized by approach: predominantly supratentorial (Table 1); infratentorial (Table 2); or combined supra-/infratentorial or endoscopic (Table 3). Data concerning patient age, length of follow-up or tumor size were occasionally missing and the reporting mode greatly varied and appeared uninformative at instances (Tables 1–3). The proportion of patients with GTR was missing from four studies (Tables 1 and 3), while two studies reported the mean extent of resection instead (Table 3).

Mortality

Mortality was reported in 19/20 of the supratentorial series (N = 873), 39/39 of the infratentorial series (N = 1984), and of the 11/12 series (N = 447) with a combined approach that included a low overall number of events and large proportions of studies with no events (Figure 2(A); see Supplemental Figure S1–S3 for forest and funnel plots). The pooled estimates were rather precise (tightly around 1.1–2.2%) (Figure 2(A)), but variance was large across the supratentorial series, resulting in a wide prediction interval (0.0–21.7%) (Figure 2(A)). A formal test indicated publication bias for each approach (Figure 2(A)); more specifically, bias-adjusted estimates indicated mortalities of around 4.7%, 3.3%, and 2.4% in the supratentorial, infratentorial, and combined series, respectively (Figure 2(B)). Meta-regression included 50 series (N = 3057, 64 events) (Figure 2(C)). There was no residual heterogeneity; hence, the CIs for adjusted predicted probabilities were identical to the credibility intervals which indicated mortalities of 2.4%, 2.5%, and 1.5% across the three subsets of case-series at median covariate values, respectively (Figure 2(C)). None of the covariates was associated with the outcome.

Tumor recurrence

Tumor recurrence was reported in 15/20 of the supratentorial series (N = 783), 34/39 of the infratentorial series (N = 1855), and 6/12 of the combined approach series (N = 325), with only sporadic series with no events (Figure 3(A), Supplemental Figures S4–S6 for forest and funnel plots). The pooled estimates indicated tumor recurrence rates of approximately 8%, 11%, and 13%, respectively (Figure 3(A)), but the prediction intervals were extremely wide (Figure 3(A)). In comparison, the bias-adjusted estimates indicated recurrence probabilities of around 18–21% (Figure 3(B)). The meta-regression included 49 series (N = 2800, 372 events) (Figure 3(C)). At median covariate values, the predicted probabilities of recurrence were 5.5% (95% CI 3.1–9.8%) for supratentorial series, 11.1% (8.2–14.9%) for infratentorial series,
### Table 1. Summary of case series in which the majority of patients were operated on using a supratentorial approach.

| Author         | Year | N   | Predominant approach (n/%)          | Age (x ± SD) | Women (%) | Follow-up (months) | Tumor size | With GTR (%) |
|----------------|------|-----|-------------------------------------|--------------|-----------|--------------------|------------|--------------|
| Al-Mefty       | 1988 | 13  | Transpetrosal (13/100)              | 45.3 ± 8.9   | 11 (84.6) | n/a                | n/a        | 11 (85)      |
| Kawase         | 1991 | 10  | Anterior transpetrosal (10/100)     | 53.5 ± 8.4   | 8 (80.0)  | 36.1 (6–76)        | 3.25 cm (1.5–6) | 7 (70)       |
| Thomas         | 1996 | 16  | Transtentorial/transpetrosal (11/68.6) | 53.5 ± 13.3 | 11 (68.8) | n/a                | n/a        | 7 (43.8)     |
| Goel           | 2000 | 24  | Extended lateral (24/100)          | 33.7 ± 15.5  | 15 (62.5) | 14.5 (3–40)        | 2.8–6 cm   | 16 (66.7)    |
| Jung           | 2000 | 38  | Transpetrosal (17/44.7)            | 47.5 ± 13.8  | 33 (86.8) | 47.5 (6–141)       | 36 cases > 3 cm | n/a          |
| Sato           | 2002 | 12  | Anterior petrosectomy (10/83.3)    | 57.4 ± 9.2   | 9 (75.0)  | 55                 | 25.3 cm (2.0–70) | 5 (41.6)     |
| Natarajan      | 2007 | 150 | Transpetrosal (119/80)             | 49.0 ± 16.7  | 121 (80.7) | 102 (15–180)        | 3.44 cm (0.8–8.4) | 48 (32)      |
| Ichimura       | 2008 | 91  | Anterior transpetrosal (91/100)    | 50.9 ± 12.7  | 70 (76.9) | n/a                | n/a        | n/a          |
| Nanda          | 2010 | 50  | Transpetrosal (16/32)              | 55.8 ± 19.3  | 36 (72.0) | 22.1 (6–156)       | n/a        | 14 (28)      |
| Yang           | 2011 | 25  | Subtemporal transpetrosal (25/100) | 52.4 ± 18.5  | 14 (56.0) | 3–69               | 16 cases > 4.5 cm | 17 (68)      |
| Yang           | 2011 | 41  | Subtemporal transpetrosal (17/41.5) | 46.8 ± 17.0  | 26 (63.4) | 35 (15–45)         | 4.4 cm; 46.5 cm | 25 (61)      |
| Shi            | 2011 | 14  | Transpetrosal (14/100)             | 56.3 ± 12.4  | 4 (28.6)  | 37                 | 38.9 cm (5.6–112.5) | 12 (68)      |
| Yamakami       | 2011 | 32  | Anterior petrosectomy (18/56.3)    | 57.0 ± 14.0  | 24 (75.0) | 66 ±4               | 20 cases > 3 cm | 19 (59)      |
| Yang           | 2012 | 16  | Subtemporal transpetrosal (16/100) | 56.9 ± 13.3  | 9 (56.3)  | 28.8 (4–69)        | 70.5 ± 5.5 cm2 | 14 (87.5)    |
| Xu             | 2016 | 20  | Transtentorial/transpetrosal (28/100) | 45.2 ± 12.2  | 11 (55.9) | 16.9 (6–24)         | 3.8 cm (2.5–5.6) | 17 (85)      |
| Gosal          | 2018 | 33  | Anterior transpetrosal-transventral (16/48.5) | n/a          | n/a       | 48                 | 4 cm (1.8–6.8) | 21 (75)      |
| Liao           | 2018 | 18  | Retromastoid suboccipital (18/100) | 53.3 ± 12.7  | 12 (66.7) | 18 (2–41)          | 38.4 cm     | 7 (38.9)     |
| Bernard        | 2019 | 154 | Anterior petrosectomy (65/42.2)    | 53.6 ± 19.0  | 121 (78.6) | 76.8 (6–380)       | All cases > 2.5 cm | 40 (26)      |
| Qiao           | 2019 | 176 | Subtemporal transpetrosal petrosal apex (65/36.9) | 48.8 ± 12.1  | 124 (70.5) | 135 (110–161)      | 112 cases 2.5–4.4 cm | 36 (20.5)    |
| Wang           | 2020 | 31  | Transpetrosal (24/77.4)            | 49.4 ± 11.9  | 27 (87.1) | 6                  | 59.7 ± 21.2 cm2 | 20 (64.5)    |

GTR: gross total resection; n/a: data not available.

*aNumbers are mean/or mean ± SD/or median (range)/or range/or mean (95% CI).

*bNumbers refer to diameters (in cm) or to tumor volume (in cm³) and are mean/or mean ± SD/or median (range).
and 12.0% (6.5–21.1) for combined approach series (Figure 3(C)), but were lower at 90% patients with GTR [3.1% (1.4–6.6), 6.3% (3.8–10.4), and 6.9% (3.4–13.2), respectively] (Figure 3(C)). Higher proportion of patients with GTR was associated with lower probability of recurrence, while the length of the follow-up was associated with a higher probability of recurrence (Supplemental Figure S7). Other covariates were not associated with the outcome. Odds of recurrence for the infratentorial and combined series were twice as high as what was calculated for the supratentorial series (Supplemental Figure S8). Other covariates were not associated with the outcome. Odds of recurrence for the infratentorial and combined series were twice as high as what was calculated for the supratentorial series (Supplemental Figure S8). Residual heterogeneity was high; hence, the credibility intervals were wide (Figure 3(C)).

**Any cranial nerve deficit**

Any CND was reported in 20/20 of the supratentorial series (N = 964), 37/39 of the infratentorial series (N = 1953), and 12/12 of the combined approach series (N = 544) (Figure 4(A), Supplemental Figures S9–S11 for forest and funnel plots). The point estimates indicated probabilities of 38%, 23%, and 31%, respectively, but included wide CIs and 95% prediction intervals that extended from <10% to 76% (Figure 4(A)). The bias-adjusted estimates were somewhat higher (31–38%) and equally as imprecise (Figure 4(B)). The meta-regression included 58 series (N = 3032, 881 events) (Figure 4(C)). At median values of covariates, the predicted point-estimates were 37% for supratentorial series, 23% for infratentorial series, and 30% for the combined approach series; however, the confidence intervals were wide and credibility intervals extended from <10% to 78% (Figure 4(C)). No covariate appeared to be associated with the outcome. The odds of any CND appeared lower in the infratentorial series than in the supratentorial series (Supplemental Figure S8).

**Individual cranial nerve deficits**

Meta-analyses of the proportions of patients with individual CNDs revealed considerable, and understandable, variability across individual nerve-by-surgical approach subsets in terms of observed proportions and proportion of cohorts with no events, and by considerable heterogeneity within each nerve-by approach subset (Supplemental Table S3). Moreover, each of the meta-regression models (one for each individual cranial nerve) demonstrated a high level of heterogeneity (Supplemental Table S4). The pattern of adjusted predicted probabilities of individual CNDs in the supratentorial series (nIII most commonly affected; declining probabilities with higher numbered nerves) (Figure 5) was almost a mirror image of the pattern observed for the infratentorial series (nVII most commonly affected; low probabilities of nIII-nVI deficits) (Figure 5), but most estimates were relatively imprecise (wide CIs) (Figure 5).

**Other morbidity**

The reporting of other morbidities included such a high degree of variability that no meaningful summaries could be drawn.
Nevertheless, three complications were commonly reported: CSF leak (44 series; 2452 cases; 190 events; 7.5%); motor deficit (hemiparesis/plegia) (35 series; 2334 cases; 253 events; 10.8%); and infection (29 series; 2040 cases; 199 events; 9.8%).

**Discussion**

To the best of our knowledge, only one previous systematic review has addressed PCM surgery-related outcomes; however, the review primarily focused on CNDs and included 12 studies with a total of 334 PCM patients. The present review embraced 73 case-series and a total of 3553 surgically treated PCM patients. Therefore, it could be justifiably viewed as the first comprehensive overview of surgery-related morbidity, mortality, and tumor recurrence in this patient population.

Until the microsurgical era pioneered by Yasargil, PCMs presented a formidable challenge due to their high surgical morbidity and mortality. The present review underscores the significant progress made in neurosurgical practice over the past four decades. A disease that was considered nearly inoperable and lethal only 40 years ago is today controllable in most patients.

The current pooled estimates of mortality ('simple' and meta-regression-based at the 50-month follow-up) (Figure 2) were rather precise, low (in the 1.1% to 2.5% range), comparable across different approaches (with only slight differences), and apparently not affected by study-level covariates. Incidence of tumor recurrence, on the other hand, increased as the follow-up period extended and was lower in patients who had received gross total resection (GTR) relative to other patients. This finding is in line with the established principles of meningioma treatment strategy – surgery is the gold standard of therapy (particularly considering the natural history of PCMs) and aimed at a high extent of tumor resection. The adjusted point-estimates (representing an average age of 50 years, case-series with 33 subjects, a 50-month follow-up, and [median] %GTR of 57%) of 5.5%, 11.1%, and 12.0% tumor recurrence for the supratentorial, infratentorial, and combined approach series, respectively, suggest that the latter two approaches demonstrate odds of tumor recurrence which are double than that associated with the supratentorial approach. This dynamic may be explained by tumor characteristics (better accessibility) that could not have been adequately adjusted for in the meta-regression analysis.

The supratentorial, infratentorial, and combined approaches demonstrated 37%, 23%, and 30% incidences, respectively, of any (novel) CNDs (both 'simple' and meta-regression-based). The incidence of novel CNDs was not found to be affected by any of the study-level covariates. A similar estimate (34% - a raw proportion, not a pooled estimate) was reported 10 years ago based on 19 case-series with a total of 1000 patients. The lower odds of CND incidence associated with the infratentorial approach in the present review may be explained by a similar dynamic as was noted for the lower recurrence rates among patients who had received GTR – a more aggressive resection might also result in higher morbidity. This notion was recently emphasized in a series of posterior fossa meningiomas, more specifically, a higher resection rate appeared to be associated with new-onset CNDs. Among individual cranial nerves (CN), CNVII was most
commonly affected in the infratentorial or combined approaches, and CNIII was most commonly affected in the supratentorial approach. This can be expected when considering the anatomical corridor and its neural content; for example, the descending ladder-like structure of CN morbidity in the supratentorial approach is roughly mirrored by the ascending structure of the remaining two approaches (Figure 5). Similar findings were reported in the only other published meta-analysis of PMC surgery-related CNDs; notably, CNVII deficits were the most common adverse effect, and the incidence (13.9%) was comparable with what was estimated for the combined approach (14.0%) in the current review, and higher than the present estimates for the supra- (5.3%) and infratentorial (7.7%) series.

Limitations

Al Mefty first introduced the definition of ‘true’ PCMs, which has been adopted throughout the literature. However, other authors have challenged the definition and many fail to adhere to the current standards. To overcome this issue, we included all PCM cohorts regardless of whether they adopted any diagnostic criteria. Study quality was not assessed due to reasons discussed in the methods section, but substantial heterogeneity and variability in the quantitative and qualitative reporting of results was obvious across the identified studies. This leads to the exclusion of some covariates (e.g. tumor volume) or outcomes (e.g. morbidities other than CNDs) from the quantitative synthesis. Also, missing or alternatively reported variables were handled based on assumptions (see methods), which might have introduced bias.

Radiosurgery as an adjunctive treatment was not considered in the analysis of recurrence, as the variable was reported sporadically across the identified studies. This important limitation has to be considered when interpreting the results.

The cohorts were grouped according to the prevalent approach (supra- or infratentorial, or combined) for pragmatic reasons, yet caution should be exercised when interpreting the analyses, especially the exploratory results that compare approaches. First, in individual studies the approach was conflated into a single (predominant) approach, even though the majority of studies reported diverse approaches.

Implications for practice and future research

This is the first comprehensive report on surgery-related mortality, morbidity, and tumor recurrence among PCM patients. The presented research is relevant because the results may inform patients about surgery-related risks and guide surgeons in tailoring their approach to the tumor characteristics. The presented...
Any cranial nerve deficit – data synthesis. (A) Summary of random-effects meta-analysis of proportions of patients who experienced a deficit of any of the cranial nerves by surgical approach (Supplemental Figures S8, S9 and S10 show forest plots and funnel plots by approach). Shown are random-effects estimates (95%CI) and 95% prediction intervals (PI), heterogeneity indicators (inconsistency index, I² and variance across case series, s²) and results of the Peters test of asymmetry of the funnel plots (publication bias). (B) Summary of the Copas selection model analysis by surgical approach. Shown are p-values (critical alpha = 0.1) from a test of the null-hypothesis that no selection remains unexplained, approximate number of unpublished studies suggested by the model and (bias)-adjusted estimates. (C) Summary of random-effects meta-regression analysis. Shown are adjusted predicted probabilities of events (95%CI) with 95% credibility intervals by surgical approach and residual heterogeneity indicators (I², s²). Adjustments are for average age and length of follow-up, series size and proportion of patients in whom gross total resection (GTR) was achieved. Estimates are given at median values of each covariate and also at median age, follow-up, sample size but at 90% GTR. k: number of included case series; N: total number of included patients; Events: number of subjects who died; No event k: series with no events.

Figure 5. Adjusted predicted probabilities (as percentages, 95%CI) of individual cranial nerve deficits (cumulative data for nIX-XII, i.e. lower cranial nerves) from meta-regression models (Supplemental Table S4) by predominant surgical approach. Point-estimates are depicted numerically.
findings also indicate that there is a strong need for establishing reporting standards for case-series of PCMs.

Acknowledgments

We would like to thank Zoya Jelkovecki Dokie, Marina Klijanc, and Guy Alush, medical students at the Zagreb University Medical School, for their assistance with data acquisition and management and Mikael Hietala, scientific editor, for language editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

1. Sassun T, Ruggeri A, Delfini R. True petroclival meningiomas: proposal of classification and role of the combined supra-infratentorial presigmoid retrosigmoidine approach. World Neurosurg 2016;96:111–23.
2. Al-Mefty O, DeMonte F, McDermott M, Al-Mefty’s Meningiomas. 2nd ed. New York: Thieme; 2011:270–282.
3. Di Carlo D, Capo G, Fava A, et al. Petroclival meningiomas: the risk of post-operative cranial nerve deficits among different surgical approaches—a systematic review and meta-analysis. Acta Neurochir 2020;162:2135–43.
4. Ichinose T, Goto T, Ishibashi K, Takami T, Ohata K. The role of radical microsurgical resection in multimodal treatment for skull base meningioma [published correction appears in J Neurosurg. 2010 Nov;113(5):1123]. JNS 2010;113:1072–8.
5. Javalkar V, Banerjee AD, Nanda A. Posterior cranial fossa meningiomas. J Neurol Surg B Skull Base 2012;73:1–10.
6. King WA, Black KL, Martin NA, Canalis RF, Becker DP. The petroclival approach with hearing preservation. J Neurosurg 1993;79:508–14.
7. Matsui T. Therapeutic strategy and long-term outcome of meningiomas located in the posterior cranial fossa. Neurol Med Chir (Tokyo) 2012;52:704–13.
8. Park HH, Kim WH, Jung HH, et al. Radiosurgery vs. microsurgery for newly diagnosed, small petroclival meningiomas with trigeminal neuralgia. Neurosurg Rev 2020;43:1631–40.
9. Pintea B, Kandenein JA, Lorenzen H, et al. Factors of influence upon the SF-36-based health related quality of life of patients following surgery for petroclival and lateral posterior surface of pyramid meningiomas. Clin Neurol Neurosurg 2018;166:36–43.
10. Seifert V, Raabe A, Zimmermann M. Conservative (labyrinth-preserving) transpetrosal approach to the clivus and petroclival region-indications, complications, results and lessons learned. Acta Neurochir 2003;145:631–42.
11. Pudar-Hozo S, Djulbegovic B, Hozo I. Estimating the mean and variance from the median, range and the size of a sample. BMC Med Res Methodol 2005;5:13.
12. Murad MH, Sultan S, Haffar S, Bazerbach F. Methodological quality and synthesis of case series and case reports. BMJ Evid Based Med 2018;23:60–3.
13. Page MJ, Higgins JPT, Sterne JAC, Chapter 13: assessing risk of bias due to missing results in a synthesis. In: Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA, editors. Cochrane Handbook for systematic reviews of interventions version 6.2 (updated February 2021). Cochrane; 2021. Available from www.training.cochrane.org/handbook.
14. Stijnen T, Hamza TH, Ozdemir P. Random effects meta-analysis of event outcome in the framework of the generalized linear mixed model with applications in sparse data. Stat Med 2010; 29:3046–67.
15. Schwarzer G, Chemaitelly H, Abu-Raddad LJ, Rücker G. Seriously misleading results using inverse of Freeman-Tukey double arcsine transformation in meta-analysis of single proportions. Res Synth Methods 2019;10:476–83.
16. Knapp G, Hartung J. Improved tests for a random effects meta-regression with a single covariate. Stat Med 2003; 22:2693–710.
17. Peters JL, Sutton AJ, Jones DR, Abrams KR, Rushton L. Comparison of two methods to detect publication bias in meta-analysis. JAMA 2006; 295:676–80.
18. Schwarzer G, Carpenter JR, Rucker G, Meta-analysis with R. Springer; 2015:121.
19. Copas JB, Shi QJ. A sensitivity analysis for publication bias in systematic reviews. Stat Methods Med Res 2001; 10:251–65.
20. Schwarzer G, Carpenter J, Rucker G. Empirical evaluation suggests Copas selection model preferable to trim-and-fill method for selection bias in meta-analysis. J Clin Epidemiol 2010; 63:282–8.
21. Balduzzi S, Rücker G, Schwarzer G. How to perform a meta-analysis with R: a practical tutorial. Evid Based Ment Health 2019; 22:153–60.
22. Schwarzer G, Carpenter JR, Rucker G. Meta-analyses: statistical methods for sensitivity analysis in meta-analysis. R package version 0.6–0.1. https://CRAN.R-project.org/package=metasens.
23. Viechtbauer W. Conducting meta-analysis in R with metafor package. J Stat Software 2010; 36:1–48.
24. Al-Mefty O, Fox JL, Smith RR. Petrosal approach for petroclival meningiomas. Neurosurgery 1988;22:510–7.
25. Al-Mefty R, Dunn IF, Pravdenkova S, Abolfotoh M, Al-Mefty O. True petroclival meningiomas: results of surgical management. J Neurosurg 2014;120:40–51.
26. Aziz K, Sanan A, van Loveren H, Tew J, Keller J, Pensak M. Petroclival meningiomas: predictive parameters for transpetrosal approaches. Neurosurgery 2000;47:139–52.
27. Bambakidis NC, Kakařa UK, Kim IJ, et al. Evolution of surgical approaches in the treatment of petroclival meningiomas: a retrospective review. Neurosurgery 2007;61:202–11.
28. Beniwal M, Bhat DI, Rao N, Bhagavatula ID, Somanna S. Surgical management of petroclival meningiomas: factors affecting early post-operative outcome. Br J Neurosurg 2015;29:559–64.
29. Bernard F, Troude L, Isnard S, et al. Long term surgical results of 154 petroclival meningiomas: a retrospective multicenter study. Neurochirurgie 2019;65:55–62.
30. Bricolo AP, Turazzi S, Talacchi A, Cristofori L. Microsurgical removal of petroclival meningiomas: a report of 33 patients. Neurosurgery 1992; 31:813–28.
31. Cantore G, Delfini R, Ciappetta P. Surgical treatment of petroclival meningiomas: experience with 16 cases. Surg Neurol 1994;42:105–11.
32. Chen LF, Yu XG, Bu B, Xu BN, Zhou DB. The retrosigmoid approach to petroclival meningioma surgery. J Clin Neurosci 2011;18:1656–61.
33. Couldwell WT, Fukushima T, Giannotta SL, Weiss MH. Petroclival meningiomas: surgical experience in 109 cases. J Neurosurg 1996;84:270–8.
34. Erkmen K, Pravdenkova S, Al-Mefty O. Surgical management of petroclival meningiomas: factors determining the choice of approach. Neurosurg Focus 2005;19:E7–Published 2005 Aug 15.
35. Goel A. Extended lateral subtemporal approach for petroclival meningiomas: report of experience with 24 cases. Br J Neurosurg 1999;13:270–5.
36. Goel A, Muzumdar D. Conventional posterior fossa approach for surgery on petroclival meningiomas: a report on an experience with 28 cases. Surg Neurol 2004;62:332–40.
37. Gosal JS, Behari S, Joseph J, et al. Surgical excision of large-to-giant petroclival meningiomas focusing on the middle fossa approaches: the lessons learnt. Neurol India 2018;66:1434–46.
38. Ichimura S, Kawase T, Onozuka S, Yoshida K, Ohira T. Four subtypes of petroclival meningiomas: differences in symptoms and operative findings using the anterior transpetrosal approach. Acta Neurochir 2008;150:637–45.
39. Isolan GR, Wayhs SY, Lepski GA, Dini LI, Lavinsky J. Petroclival meningiomas: factors determining the choice of approach. J Neurol Surg B 2018;79:367–78.
40. Jung HW, Yoo H, Paek SH, Choi KS. Long-term outcome and growth rate of subtotally resected petroclival meningiomas: experience with 38 cases. Neurosurgery 2006;59:627–35.
41. Kawase T, Shiobara R, Toya S. Anterior transpetrosal-transtentorial approach for sphenopetralvel meningiomas: surgical method and event results in 10 patients. Neurosurgery 1991;28:869–76.
42. Kim JW, Jung HW, Kim YH, et al. Petroclival meningiomas: long-term outcomes of multimodal treatments and management strategies based on 30 years of experience at a single institution. J Neurosurg 2019;121:1675–82. Published 2019 May 10.
43. Koutourousiou M, Fernandez-Miranda JC, Vaz-Guimarães Filho F, et al. Outcomes of endonasal and lateral approaches to petroclival meningiomas. World Neurosurg 2017;99:500–17.
44. Kusumi M, Fukushima T, Mehta AI, et al. Tentorial detachment technique in the combined petrosal approach for petroclival meningiomas. JNS 2012;116:566–73.
45. Lang DA, Neil-Dwyer G, Garfield J. Outcome after complex neurosurgery—the caregiver’s burden is forgotten. J Neurosurg 1999;91:359–63.
51. Panigrahi M, Vooturi S, Patibandla MR, Kulkarni D. Novel classification of tumor resectability and clinical outcome. J Neurosurg 2015;122:2365–73.
52. Morisako H, Goto T, Ohata K. Petroclival meningiomas resected via a combined transpetrosal approach: surgical outcomes in 60 cases and a new scoring system for clinical evaluation. J Neurosurg 2015;122:373–80.
53. Mathiesen T, Gerlich A, Kihlström L, Svensson M, Bagger-Sjöbäck D. Effects of using combined transpetrosal surgical approaches to treat petroclival meningiomas. Neurosurgery 2007;60:982–92.
54. Rong J, Wang Z, Liao CH, Wang JT, Lin CF, et al. Petroclival meningiomas: defining resection goals based on risk of neurological morbidity and tumor recurrence rates in 137 patients. Neurosurgery 2005;56:546–59.
55. Li D, Hao SY, Wang L, et al. Effects of using combined transpetrosal surgical approaches to treat petroclival meningiomas. Neurosurgery 2007;60:965–81.
56. Nanda A, Javalkar V, Banerjee AD. Petroclival meningiomas: study on outcomes, complications and recurrence rates. J Neurosurg 2011;114:1266–77.
57. Natarajan SK, Sekhar LN, Schossel D, Morita A. Petroclival meningiomas: multimodality treatment and outcomes at long-term follow-up. Neurosurgery 2007;60:965–81.
58. Panighi M, Vooturi S, Pattabandla MR, Kulkarni D. Novel classification for surgical approach of petroclival meningiomas: a single-surgeon experience. Neurol India 2015;63:718–22.
59. Park CK, Jung HW, Kim JE, Paek SH, Kim DG. The selection of the optimal therapeutic strategy for petroclival meningiomas. Surg Neurol 2006;66:160–6.
60. Pirayesh A, Petarakis I, Raab P, Polemikos M, Krauss JK, Nakamura M. Petroclival meningiomas: magnetic resonance imaging factors predict tumor resectability and clinical outcome. Clin Neurol Neurosurg 2016;147:90–7.
61. Qiao L, Yu C, Zhang H, et al. Clinical outcomes and survival analysis for petroclival meningioma patients receiving surgical resection: an analysis of 176 cases. CMAR 2019;11:5949–39.
62. Ramina R, Neto MC, Fernandes YB, Silva EB, Mattae TA, Aguiar PH. Surgical removal of small petroclival meningiomas. Acta Neurochir 2008;150:431–9.
63. Samii M, Ammirati M, Mehran A, Bini W, Sepehrnia A. Surgery of petroclival meningiomas: a single-center case series of 259 patients. Acta Neurochir 2013;155:1367–83.
64. Li D, Tang J, Ren C, Wu Z, Zhang LW, Zhang JT. Surgical management of medium and large petroclival meningiomas: a single institution’s experience of 199 cases with long-term follow-up. Acta Neurochir 2016;158:409–25.
65. Li D, Hao SY, Wang L, et al. Petroclival meningiomas: optimal therapeutic strategy for petroclival meningiomas. J Neurosurg 2019;120:1268–77.
66. Samii M, Tatagiba M, Carvalho GA. Retrosigmoid intradural supraclival meningiomas: analysis of recurrence and progression following surgical resection. J Neurosurg 2011;114:49–54.
67. Yamakami I, Higuchi Y, Horiguchi K, Saeki N. Treatment policy for petroclival meningioma based on tumor size: aiming radical removal in small tumors for obtaining cure without morbidity. Neurosurg Rev 2011;34:327–35.
68. Yang J, Ma SC, Fang T, Qi JF, Hu YS, Yu CJ. Subtemporal transpetrosal apical approach: study on its use in large and giant petroclival meningiomas. Chin Med J (Engl) 2011;124:49–55.
69. Yang J, Liu YH, Ma SC, et al. Subtemporal transtentorial petrosalapex approach for giant petroclival meningiomas: analysis and evaluation of the clinical application. J Neurosurg B Skull Base 2012;73:54–63.
70. Yang J, Fang T, Ma S, et al. Large and giant petroclival meningiomas: therapeutic strategy and the choice of microsurgical approaches - report of the experience with 41 cases. Br J Neurosurg 2011;25:78–85.
71. Zentner J, Meyer B, Vieweg U, Herberhold C, Schramm J. Petroclival meningiomas: is radical resection always the best option? J Neurosurg Psychiatry 1997;62:341–5.
72. Zhao Z, Yuan X, Yuan J, et al. Treatment strategy for petroclival meningiomas based on a proposed classification in a study of 168 cases. Sci Rep 2020;10:4655.
73. Zhou QJ, Liu B, Geng DJ, et al. Microsurgery with or without neuroendoscopy in petroclival meningiomas. Turk Neurosurg 2015;25:231–8.
74. Shi W, Mao Y, Zhou LF, Zhang R, Chen L. Keyhole approach surgery for petroclival meningioma. Chin Med J (Engl) 2006;119:1339–42.
75. Yasargil M, Mortara RW, Curcic M. Meningioma of basal posterior cranial fossa. In: Krayenbuhl H, editor. Advances and technical standards in neurosurgery. Vol. 7. Vienna: Springer-Verlag; 1980:1–115.
76. Apri C, Peyre M, Kalamarides M. Current treatment options for meningioma. Expert Rev Neurother 2018;18:241–9.
77. Mizimanoff RO, Dorsoret DE, Linggood RM, Ojemann RG, Martuza RL. Meningioma: analysis of recurrence and progression following neurosurgical resection. J Neurosurg 1985;62:18–24.
78. Díluna ML, Bulsara KR. Surgery for petroclival meningiomas: a comprehensive review of outcomes in the skull base surgery era. Skull Base 2010;20:337–42.
79. Schneider M, Schuss P, Güresir A, Borger V, Vatter H, Güresir E. Surgery for posterior fossa meningioma: elevated postoperative cranial nerve morbidity discards aggressive tumor resection policy. Neurosurg Rev 2021;44:953–9.