Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Surgical Corridor Selection in Deep-Seated Midline Meningiomas: A Propensity-Matched MRI Study of Cortical Injury

hasan ali aydın

drhasanaliaydin@gmail.com

Zonguldak Bülent Ecevit University

emrah keskin

Zonguldak Bülent Ecevit University

Murat Kalaycı

Zonguldak Bülent Ecevit University

Research Article

Keywords: Meningioma, Transcortical Approach, Interhemispheric Approach, Magnetic Resonance Imaging, Propensity Score

Posted Date: March 10th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8860293/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

Optimal surgical corridor selection for deep-seated midline meningiomas remains controversial, particularly regarding the balance between adequate exposure and preservation of surrounding cortex. Comparative data quantifying postoperative cortical injury between transcortical and interhemispheric approaches are limited.

Methods

We conducted a retrospective single-center study of patients with deep-seated midline meningiomas treated between 2002 and 2023. Cortical injury was quantified using early postoperative contrast-enhanced MRI and measured independently by two neuroradiologists. Propensity score matching (1:1, caliper = 0.2) was performed based on age, sex, and tumor location to compare transcortical and interhemispheric corridors. The primary endpoint was MRI-defined cortical injury burden (cm^2). Secondary outcomes included complications, reoperation, mortality, extent of resection, and recurrence-free survival.

Results

Among 38 patients with radiologically assessable cortical injury (13 transcortical, 25 interhemispheric), propensity score matching yielded 13 balanced pairs. Mean cortical injury was significantly lower with the transcortical approach both before matching (0.96 ± 0.42 cm^2 vs 1.96 ± 1.35 cm^2; $p < 0.001$) and after matching (0.96 ± 0.42 cm^2 vs 1.65 ± 1.10 cm^2; $p = 0.003$). Perioperative complication and reoperation rates were comparable between matched groups, whereas mortality occurred only in the interhemispheric cohort without reaching statistical significance. Recurrence was uncommon, with a 5-year recurrence-free survival rate of 98.2%.

Conclusions

In deep-seated midline meningiomas, surgical corridor selection is associated with measurable differences in cortical preservation. The transcortical approach demonstrated significantly lower MRI-defined cortical injury without compromising short-term clinical or oncological outcomes. These findings support selective use of transcortical access when anatomical conditions are favorable and highlight the importance of corridor-based decision-making in meningioma surgery.

Introduction

Meningiomas are among the most common primary tumors of the central nervous system and represent a biologically heterogeneous group of lesions with highly variable clinical behavior and surgical complexity (1–3). Although the majority are histologically benign, their anatomical location—particularly when situated along the midline or within deep-seated compartments—often determines operative risk, functional outcome, and long-term prognosis more than histological grade alone (4, 5). In such regions, the neurosurgeon is confronted not merely with tumor removal, but with the fundamental challenge of choosing the safest surgical corridor through vulnerable cortex and critical venous structures.

For deep-seated and midline meningiomas, the interhemispheric approach has traditionally been regarded as the standard operative route, providing direct access while avoiding transgression of eloquent cortical surfaces (6, 7). However, this corridor is not without consequence. Retraction-related cortical injury, venous compromise, and limited working angles may contribute to neurological morbidity despite technically successful tumor resection (8, 9). As microsurgical techniques and neuroimaging guidance have evolved, alternative strategies—most notably the transcortical approach through carefully selected non-eloquent cortex—have gained renewed attention as potentially less disruptive pathways to deep lesions (10–12).

The conceptual shift underlying transcortical access is subtle yet important. Rather than prioritizing anatomical tradition, modern corridor selection increasingly emphasizes quantifiable tissue preservation and minimization of collateral injury. Advances in postoperative magnetic resonance imaging (MRI) now allow objective measurement of cortical disruption, transforming what was once a qualitative surgical impression into a measurable biological outcome (13, 14). Despite this progress, comparative evidence directly evaluating cortical injury burden between transcortical and interhemispheric corridors in deep-seated meningiomas remains limited, and most available studies rely on heterogeneous tumor populations, small case series, or indirect functional endpoints (15–17).

Another persistent limitation in the literature is selection bias inherent to retrospective surgical decision-making. Surgeons intuitively choose corridors based on tumor geometry, venous anatomy, and perceived eloquence, making straightforward comparisons between approaches methodologically challenging. Propensity score matching (PSM) has emerged as a robust statistical strategy to mitigate such bias in observational neurosurgical research, enabling balanced comparison of treatment groups when randomized trials are impractical or ethically unfeasible (18, 19). However, the application of PSM specifically to corridor-based analysis in meningioma surgery has been scarce.

Beyond methodological considerations, an unresolved clinical question remains:

Does surgical corridor selection meaningfully influence measurable cortical preservation without compromising oncological adequacy or perioperative safety? Answering this question is not merely academic. Corridor-dependent tissue injury may underlie subtle neurological deficits, cognitive decline, or delayed functional recovery that are not fully captured by traditional outcome scales. Therefore, understanding the relationship between operative pathway and biological tissue impact is essential for refining contemporary meningioma surgery toward a more preservation-oriented paradigm.

In this context, the present study analyzes a consecutive single-center experience with deep-seated midline meningiomas, directly comparing transcortical and interhemispheric approaches using MRI-defined cortical injury burden as the primary outcome. By incorporating propensity score matching to balance baseline characteristics and by examining perioperative safety alongside recurrence outcomes, this work aims to provide a clinically meaningful assessment of corridor selection in modern meningioma surgery. We hypothesized that, in appropriately selected patients, the transcortical approach would be associated with reduced postoperative cortical injury while maintaining comparable short-term clinical and oncological results.

Through this focused evaluation of surgical corridors rather than tumor histology alone, the study seeks to contribute to an evolving neurosurgical principle:

that optimal tumor surgery is defined not only by the completeness of resection, but also by the degree of preserved brain integrity achieved along the path to removal.

Methods

Study Design and Ethical Approval

This retrospective single-center cohort study evaluated patients who underwent surgical treatment for deep-seated midline meningiomas between January 2002 and December 2023 at a tertiary neurosurgical referral center. The study protocol was approved by the institutional ethics committee (Protocol No. 2023/20), and the requirement for individual informed consent was waived because of the retrospective design and anonymized data analysis. All procedures were conducted in accordance with the Declaration of Helsinki and relevant institutional regulations.

Patient Selection and Cohort Definition

Patients were screened from a prospectively maintained surgical database including histopathologically confirmed intracranial meningiomas. For this corridor-focused analysis, only deep-seated midline tumors —specifically falcine, medial parasagittal, and intraventricular meningiomas—were included. Patients younger than 18 years, those with incomplete clinical or radiological records, and those lacking early postoperative magnetic resonance imaging (MRI) suitable for cortical injury assessment were excluded. Eligible patients were categorized according to the surgical corridor used for tumor access as either transcortical or interhemispheric.

Surgical Techniques

All operations were performed under operative microscopy using standard microsurgical techniques. In the transcortical approach, a tailored craniotomy was created to access the lesion through a limited corticotomy within non-eloquent cortex, guided by preoperative imaging and intraoperative anatomical

landmarks, followed by tumor debulking and capsule dissection with minimal fixed retraction to preserve surrounding parenchyma. In the interhemispheric approach, a midline craniotomy exposed the interhemispheric fissure, and microsurgical dissection proceeded along the falx and pericallosal cisterns with gentle medial retraction while preserving bridging veins and venous sinuses before standard internal decompression and circumferential tumor removal.

MRI Acquisition and Quantification of Cortical Injury

Early postoperative contrast-enhanced MRI obtained within three months after surgery was used to evaluate cortical injury. Imaging was performed on a 1.5-T system using standardized T1-weighted gadolinium-enhanced sequences. Cortical injury was primarily defined on contrast-enhanced T1-weighted imaging and corroborated by corresponding signal alteration on non-contrast T1 and T2/FLAIR sequences when available. Cortical injury was defined as a new postoperative hypointense or contrast-enhancing cortical signal alteration adjacent to the surgical corridor. Lesion surface area in square centimeters was independently measured by two blinded neuroradiologists, and interobserver agreement was assessed using Cohen's kappa statistics. The primary endpoint of the study was MRI-defined cortical injury burden.

Clinical and Surgical Variables

Collected clinical and surgical variables included age, sex, tumor location, World Health Organization grade, extent of resection according to the Simpson classification, perioperative complications, reoperation, postoperative mortality, and tumor recurrence with recurrence-free survival.

Propensity Score Matching

To reduce treatment-selection bias inherent to retrospective corridor choice, propensity score matching was performed using a logistic regression model incorporating age, sex, and tumor location to estimate the probability of receiving the transcortical approach. One-to-one nearest-neighbor matching without replacement was applied with a caliper width of 0.2, yielding balanced cohorts for comparative analysis.

Statistical Analysis

Continuous variables are presented as mean ± standard deviation and were compared using Student's *t* test after assessment of normality. Categorical variables were analyzed using the chi-square or Fisher's exact test as appropriate. Recurrence-free survival was estimated using the Kaplan–Meier method. All statistical tests were two-sided, and a p value < 0.05 was considered statistically significant. Statistical analyses were performed using SPSS version 25 and Stata version 17.

Results

Patient Cohort and Propensity-Matched Population

Among surgically treated patients with deep-seated midline meningiomas, 38 individuals had radiologically assessable postoperative cortical injury and were eligible for corridor-based comparison, including 13 treated via a transcortical approach and 25 via an interhemispheric approach. Propensity score matching generated 13 well-balanced pairs without significant differences in baseline demographic or tumor characteristics between groups (Table 1). The process of patient selection and propensity score matching is illustrated in Fig. 1.

Table 1
Baseline Characteristics Before and After Propensity Matching

Variable	Transcortical (n = 13)	Interhemispheric Unmatched (n = 25)	Interhemispheric Matched (n = 13)	p (matched)
Age, years (mean ± SD)	57.8 ± 15.7	61.2 ± 14.8	58.9 ± 14.2	> 0.05
Female sex, n (%)	9 (69.2)	17 (68.0)	9 (69.2)	> 0.05
Falx location, n (%)	7 (53.8)	17 (68.0)	8 (61.5)	> 0.05
Parasagittal medial, n (%)	3 (23.1)	6 (24.0)	3 (23.1)	> 0.05
Intraventricular, n (%)	3 (23.1)	2 (8.0)	2 (15.4)	> 0.05

MRI-Defined Cortical Injury

The primary endpoint—postoperative MRI-defined cortical injury burden—differed significantly between surgical corridors. Before matching, the transcortical approach demonstrated a markedly smaller mean cortical injury area compared with the interhemispheric approach (0.96 ± 0.42 cm² vs 1.96 ± 1.35 cm²; $p < 0.001$). This difference remained statistically significant after propensity matching, with cortical injury measuring 0.96 ± 0.42 cm² in the transcortical group versus 1.65 ± 1.10 cm² in the interhemispheric group ($p = 0.003$; Table 2).

Table 2
Surgical and Clinical Outcomes in the Propensity-Matched Cohort

Outcome	Transcortical (n = 13)	Interhemispheric (n = 13)	p value
Cortical injury, cm² (mean ± SD)	0.96 ± 0.42	1.65 ± 1.10	0.003
Any complication, n (%)	2 (15.4)	2 (15.4)	> 0.05
Reoperation, n (%)	1 (7.7)	1 (7.7)	> 0.05
Mortality, n (%)	0 (0)	1 (7.7)	> 0.05
Simpson grade I resection, n (%)	9 (69.2)	9 (69.2)	> 0.05
Tumor recurrence, n (%)	Rare	Rare	—

Functional Outcome (mRS Shift)

Functional outcomes differed by corridor. Postoperative mRS improvement was more frequent after the transcortical approach (76.9% vs 28.0%), while major adverse outcomes (death or mRS worsening) occurred only in the interhemispheric cohort (Table 3).

Table 3
Functional outcome (mRS shift) and major adverse events by surgical corridor (n = 38)

Outcome	Transcortical (n = 13)	Interhemispheric (n = 25)	p value*
Death (mRS 6)	0 (0.0%)	3 (12.0%)	0.538
mRS improved (any decrease)	10 (76.9%)	7 (28.0%)	0.006
mRS unchanged	2 (15.4%)	10 (40.0%)	—
mRS worsened (new deficit; any increase)	0 (0.0%)	5 (20.0%)	0.144
Major adverse outcome (death OR mRS worsening)	0 (0.0%)	8 (32.0%)	0.034

mRS indicates modified Rankin Scale. "Improved" was defined as any decrease in postoperative mRS compared with preoperative mRS; "worsened" as any increase; "unchanged" as no change. "Major adverse outcome" was defined as death (mRS 6) or mRS worsening. p values were calculated using two-sided Fisher's exact test for key binary comparisons

Perioperative Outcomes

Perioperative complication and reoperation rates were comparable between matched cohorts, while mortality occurred only in the interhemispheric group without reaching statistical significance (Table 2). Postoperative MRI-defined cortical injury remained significantly lower in the transcortical cohort after

propensity matching, as demonstrated by both quantitative distribution and representative imaging findings (Fig. 2).

Extent of Resection and Recurrence

Complete tumor removal according to the Simpson classification was achieved in the majority of cases across both groups. Tumor recurrence was uncommon, and Kaplan–Meier analysis demonstrated a 5-year recurrence-free survival rate of 98.2% for the overall cohort, without evidence of corridor-dependent oncological disadvantage.

Discussion

Deep-seated midline meningiomas force the surgeon into a familiar trade-off: obtain durable tumor control while minimizing collateral injury along the access corridor. Contemporary guidance emphasizes maximal safe resection and individualized risk–benefit decision-making in meningiomas, yet the concept of “surgical cost” is still often reduced to crude endpoints such as neurological deficit or reoperation (20). At the same time, the modern WHO framework and emerging molecular risk models increasingly refine the *oncologic* side of this equation, making it more important—not less—to quantify the *iatrogenic* side with comparable rigor (21,22).

In this propensity-matched comparison, we found that a transcortical corridor was associated with a substantially smaller burden of MRI-defined cortical injury than an interhemispheric corridor, while perioperative complication and reoperation rates remained comparable. This is clinically meaningful for two reasons. First, cortical injury adjacent to the surgical trajectory plausibly represents the “hidden half” of morbidity—structural change that may not translate into an immediate major deficit but could still contribute to seizures, subtle cognitive effects, or reduced neurological reserve. Second, this injury is, in principle, modifiable: corridor choice, retraction strategy, venous preservation, and the geometry of exposure are all surgeon-controlled variables.

Our findings align with a broader shift in meningioma surgery toward outcome measures that integrate imaging, technique, and biology. Classic extent-of-resection constructs such as Simpson grading remain relevant for describing operative intent and dural management, but multiple modern reviews have highlighted the limitations of Simpson grades as a proxy for durable control in the MRI era—particularly when tumor behavior is increasingly understood as a biologically stratified spectrum (23). In this context, demonstrating a low recurrence signal in both corridor groups supports the practical interpretation that reduced cortical injury does not necessarily require an oncologic compromise—at least within the follow-up horizon and surgical context of this series.

Why might the interhemispheric route show greater cortical injury burden despite its appeal as a “natural” midline corridor? The interhemispheric fissure is not a frictionless freeway; it is a crowded neurovascular ecosystem. Published interhemispheric series consistently emphasize that morbidity is often driven not by the tumor itself, but by venous anatomy, bridging veins, falcine attachments, and the

mechanical demands of sustained retraction (24). In contrast, the modern transcortical philosophy—especially for large falcine lesions—has been reframed as a deliberate widening of the operative corridor when interhemispheric constraints or venous risk dominate, with contemporary series supporting its feasibility and safety in selected cases (25). Endoscopic contralateral or transfalcine keyhole strategies further illustrate the same principle from another angle: the goal is not simply “smaller opening,” but a corridor that minimizes manipulative stress on eloquent structures while preserving venous outflow (26).

Our results also fit with the evolving science of brain retraction. Reviews of modern retractors emphasize that retraction injury is multifactorial—pressure, duration, edge effects, and tissue heterogeneity—rather than a binary event (27). Clinical series using tubular or parafascicular access technologies in deep lesions aim to distribute stress radially and reduce focal compression, reflecting a field-wide attempt to transform “corridor trauma” into a measurable, preventable variable (28). Importantly, large contemporary analyses of keyhole paradigms have begun to incorporate acute MRI signal changes (e.g. FLAIR/T2 alterations) as surrogate markers of brain manipulation and retraction injury, legitimizing postoperative imaging as a window into surgical invasiveness beyond traditional complication reporting (29). Mechanistic work using finite element modeling also supports the intuition that retraction geometry and device type influence predicted stress distributions—an engineering echo of what surgeons feel at the microscope (30).

Methodologically, the use of propensity score matching strengthens the corridor comparison by reducing confounding from baseline imbalances that often dominate retrospective surgical datasets. However, PSM is not a magic wand: it balances measured covariates, not unmeasured surgical nuances (31). We therefore treated PSM as a tool for pragmatic causal approximation, following contemporary recommendations for propensity-based analyses and transparent reporting (32). Even after matching, factors such as surgeon preference, microtechnical maneuvers, and fine-grained venous anatomy may still influence both corridor selection and cortical injury burden.

Several limitations deserve emphasis. This is a retrospective, single-center study with a modest matched sample size, and the cortical injury endpoint is imaging-defined rather than purely clinical. The measurement approach—surface area assessment adjacent to the corridor—captures an interpretable and reproducible signal but may underestimate three-dimensional injury extent or diffuse manipulation effects. Imaging timing within the early postoperative window may also introduce variability in enhancement patterns and evolving parenchymal changes. Finally, while our recurrence observations are reassuring, longer follow-up and molecular stratification would further clarify whether corridor-related differences in tissue injury interact with tumor biology or adjuvant strategy.

Despite these constraints, the central message is practical: when both corridors are technically feasible for deep-seated midline meningiomas, the transcortical route may reduce MRI-defined cortical injury burden without an obvious penalty in perioperative safety or early oncologic control. This supports a corridor-selection philosophy that explicitly treats “surgical corridor injury” as a quantifiable outcome—one that can be optimized alongside extent of resection, venous preservation, and functional protection.

Future multi-institutional datasets, volumetric injury quantification, and integration with cognitive/seizure outcomes may help translate this imaging endpoint into an actionable metric for surgical planning and quality improvement.

Conclusion

In this propensity-matched analysis of deep-seated midline meningiomas, the transcortical surgical corridor was associated with a significantly lower burden of postoperative MRI-defined cortical injury compared with the interhemispheric approach, without an apparent increase in perioperative complications or early oncological compromise. These findings suggest that corridor selection represents a modifiable determinant of structural brain preservation and should be considered alongside extent of resection, venous anatomy, and functional safety during operative planning.

Beyond traditional measures of surgical success, quantitative assessment of corridor-related tissue injury may provide a complementary framework for evaluating microsurgical quality and refining patient-specific decision-making in contemporary meningioma surgery. Prospective, multicenter studies integrating volumetric imaging metrics, neurocognitive outcomes, and molecular tumor stratification are warranted to validate cortical injury as a clinically actionable endpoint and to further define optimal corridor strategies.

Declarations

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

Ethics approval and consent to participate

This retrospective study was approved by the Institutional Ethics Committee of Zonguldak Bülent Ecevit University (Protocol No. 2023/20).

Use of Artificial Intelligence Tools

Artificial intelligence–assisted tools were used to support language refinement and editorial clarity during manuscript preparation. No artificial intelligence tools were used for data generation, data analysis, interpretation of results, or decision-making. All scientific content, interpretations, and conclusions are the sole responsibility of the authors.

Funding Statement

This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contribution

Author ContributionHAA conceived and designed the study, contributed to data acquisition, performed the data analysis, and drafted the manuscript.EK contributed to data collection, interpretation of the results, and critical revision of the manuscript for important intellectual content.MK contributed to study supervision, interpretation of data, and critical review of the manuscript.All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Acknowledgement

We thank the neuroradiology team and ethics committee for their contributions.

Data Availability

No new data were generated or analyzed in this study. Data sharing is not applicable.

References

1. Louis DN, Perry A, Wesseling P, Brat DJ, Cree IA, Figarella-Branger D, *et al.* The 2021 WHO Classification of Tumors of the Central Nervous System: a summary. *Neuro Oncol.* 2021;23(8):1231-1251. doi:10.1093/neuonc/noab106.
2. Ostrom QT, Cioffi G, Gittleman H, Patil N, Waite K, Kruchko C, *et al.* CBTRUS Statistical Report: Primary Brain and Other Central Nervous System Tumors Diagnosed in the United States in 2012–2016. *Neuro Oncol.* 2019;21(Suppl 5):v1–v100. doi:10.1093/neuonc/noz150.
3. Wiemels J, Wrensch M, Claus EB. Epidemiology and etiology of meningioma. *J Neurooncol.* 2010;99(3):307–314. doi:10.1007/s11060-010-0386-3.
4. Islim AI, Millward CP, Piper RJ, Fountain DM, Mehta S, Kolamunnage-Dona R, *et al.* External validation and recalibration of an incidental meningioma prognostic model—IMPACT: protocol for an international multicentre retrospective cohort study. *BMJ Open.* 2022;12(1):e052705. doi:10.1136/bmjopen-2021-052705.
5. Deng MY, Maas SLN, Anil G, Sievers P, Lischalk J, Zhao E, *et al.* Postoperative radiotherapy in subtotally resected recurrent WHO grade 1 meningiomas with intermediate-/high-risk molecular profiles. *Neuro Oncol.* 2025;27(9):2370-2381. doi:10.1093/neuonc/noaf125.
6. Casali C, Del Bene M, DiMeco F. Falcine meningiomas. *Handb Clin Neurol.* 2020;170:101-106. doi:10.1016/B978-0-12-822198-3.00032-X.

7. Qasem LE, Al-Hilou A, Oros J, Weber KJ, Keil F, Jussen D, *et al.* Single-stage versus two-stage resection for large anterior midline skull base meningiomas with bihemispheric peritumoral edema. *Sci Rep.* 2025;15(1):7926. doi:10.1038/s41598-025-92516-5.
8. Sughrue ME, Rutkowski MJ, Shangari G, Fang S, Parsa AT, Berger MS, *et al.* Incidence, risk factors, and outcome of venous infarction after meningioma surgery in 705 patients. *J Clin Neurosci.* 2011;18(5):628-632. doi:10.1016/j.jocn.2010.10.001.
9. Umbach G, Kanungo I, Quintana D, Choudhury A, Morshed R, Villanueva-Meyer J, *et al.* Calcified meningiomas demonstrate equivocal grade, proliferation, and immediate surgical outcomes. *World Neurosurg.* 2024;189:e591-e597. doi:10.1016/j.wneu.2024.06.120.
10. Luther E, Ramsay I, Berke C, Makhoul V, Lu V, Elarjani T, *et al.* Widening the operative corridor—evaluating the transcortical approach to giant falcine meningiomas. *World Neurosurg.* 2024;185:e442-e450. doi:10.1016/j.wneu.2024.02.046.
11. Elarjani T, Luther E, Morell AA, Eichberg DG, Shah AH, Lu VM, *et al.* Transcortical resection of a giant bilobed falcine meningioma. *Br J Neurosurg.* 2024;38(6):1422-1425. doi:10.1080/02688697.2022.2034744.
12. Yaşargil MG, von Ammon K, Cavazos E, Doczi T, Reeves JD, Roth P. Tumours of the limbic and paralimbic systems. *Acta Neurochir (Wien).* 1992;118(1-2):40-52. doi:10.1007/BF01400725.
13. Saloner D, Uzelac A, Hetts S, Martin A, Dillon W. Modern meningioma imaging techniques. *J Neurooncol.* 2010;99(3):333-340. doi:10.1007/s11060-010-0367-6.
14. Hwang WL, Marciscano AE, Niemierko A, Kim DW, Stemmer-Rachamimov AO, Curry WT, *et al.* Imaging and extent of surgical resection predict risk of meningioma recurrence better than WHO histopathological grade. *Neuro Oncol.* 2016;18(6):863-872. doi:10.1093/neuonc/nov285.
15. Couldwell WT, Nassiri F, Rawanduzy C, Cole K, Jha AK. Resectability of spheno-orbital meningiomas: surgical outcome in 93 cases and a proposed clinically relevant anatomical classification. *J Neurosurg.* 2025;144(2):336-345. doi:10.3171/2025.7.JNS242730.
16. Goldbrunner R, Stavrinou P, Jenkinson MD, Sahm F, Mawrin C, Weber DC, *et al.* EANO guideline on the diagnosis and management of meningiomas. *Neuro Oncol.* 2021;23(11):1821-1834. doi:10.1093/neuonc/noab150.
17. Rogers L, Barani I, Chamberlain M, Kaley TJ, McDermott M, Raizer J, *et al.* Meningiomas: knowledge base, treatment outcomes, and uncertainties. A RANO review. *J Neurosurg.* 2015;122(1):4-23. doi:10.3171/2014.7.JNS131644.
18. Austin PC. An introduction to propensity score methods for reducing the effects of confounding in observational studies. *Multivariate Behav Res.* 2011;46(3):399-424. doi:10.1080/00273171.2011.568786.
19. Benedetto U, Head SJ, Angelini GD, Blackstone EH. Statistical primer: propensity score matching and its alternatives. *Eur J Cardiothorac Surg.* 2018;53(6):1112-1117. doi:10.1093/ejcts/ezy167.

20. **De Andrade EJ, Kshettry VR.** Atrium meningioma: Transtubular posterior intraparietal sulcus approach. *Clin Neurol Neurosurg.* 2023;230:107756. doi:10.1016/j.clineuro.2023.107756.
21. **Feng QI, Zheng Y, Cheong TKF, Hwang PYK.** Revisiting traditional transcranial approaches for anterior skull base meningiomas: a systematic review and meta-analysis of transcranial approaches against minimally invasive surgical techniques. *Neurosurg Rev.* 2025;49(1):68. doi:10.1007/s10143-025-04001-2.
22. Maas SLN, Stichel D, Hielscher T, Sievers P, Berghoff AS, Schrimpf D, *et al.* Integrated molecular-morphologic meningioma classification: a multicenter retrospective analysis, retrospectively and prospectively validated. *J Clin Oncol.* 2021;39(34):3839-3852. doi:10.1200/JCO.21.00784.
23. **Chotai S, Schwartz TH.** The Simpson grading: is it still valid? *Cancers (Basel).* 2022;14(8):2007. doi:10.3390/cancers14082007.
24. Aftahy AK, Barz M, Wagner A, Liesche-Starnecker F, Negwer C, Meyer B, *et al.* The interhemispheric fissure—surgical outcome of interhemispheric approaches. *Neurosurg Rev.* 2021;44(4):2099-2110. doi:10.1007/s10143-020-01372-6.
25. Passeri T, Giammattei L, Abbritti R, di Russo P, Bernat AL, Penet N, *et al.* A new simple and free tubular device for microscopic transcortical approach to deep-seated lesions: technical note and case example. *Acta Neurochir (Wien).* 2022;164(8):2049-2055. doi:10.1007/s00701-021-04927-8.
26. Sakaeyama Y, Morisako H, Ohata H, Nakajo K, Valenzuela JC, Fernandez-Miranda JC, *et al.* Endoscopic contralateral interhemispheric transfalcine keyhole approach for large falcine meningiomas. *World Neurosurg.* 2022;166:e237-e244. doi:10.1016/j.wneu.2022.06.148.
27. **Zagzoog N, Reddy KK.** Modern brain retractors and surgical brain injury: a review. *World Neurosurg.* 2020;142:93-103. doi:10.1016/j.wneu.2020.06.153.
28. **Smith S, Mediratta S, Knight J, Patel B, Paraskevopoulos D.** An update on current devices for the port technique: a systematic review. *Neurosurg Rev.* 2025;48(1):391. doi:10.1007/s10143-025-03513-1.
29. Thakur JD, Mallari RJ, Corlin A, Yawitz S, Eisenberg A, Rhee J, *et al.* Critical appraisal of minimally invasive keyhole surgery for intracranial meningioma in a large case series. *PLoS One.* 2022;17(7):e0264053. doi:10.1371/journal.pone.0264053.
30. **Griffiths E, Jayamohan J, Budday S.** A comparison of brain retraction mechanisms using finite element analysis and the effects of regionally heterogeneous material properties.*Biomech Model Mechanobiol.* 2024;23(3):793-808. doi:10.1007/s10237-023-01806-2.
31. **Austin PC, Yu AYX, Vyas MV, Kapral MK.** Applying propensity score methods in clinical research in neurology.*Neurology.* 2021;97(18):856-863. doi:10.1212/WNL.0000000000012777.
32. **Zhao QY, Luo JC, Su Y, Zhang YJ, Tu GW, Luo Z.** Propensity score matching with R: conventional methods and new features. *Ann Transl Med.* 2021;9(9):812. doi:10.21037/atm-20-3998.

Figures

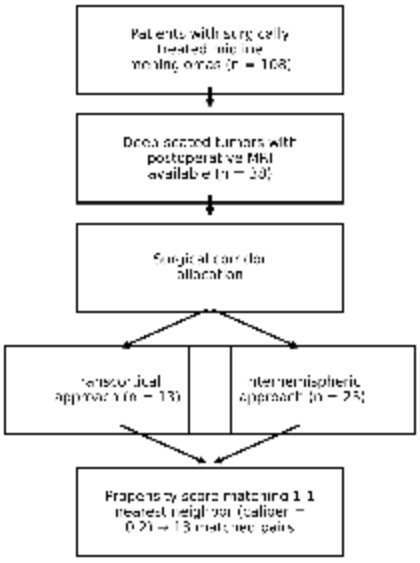


Figure 1

Flow diagram of patient selection and propensity score matching

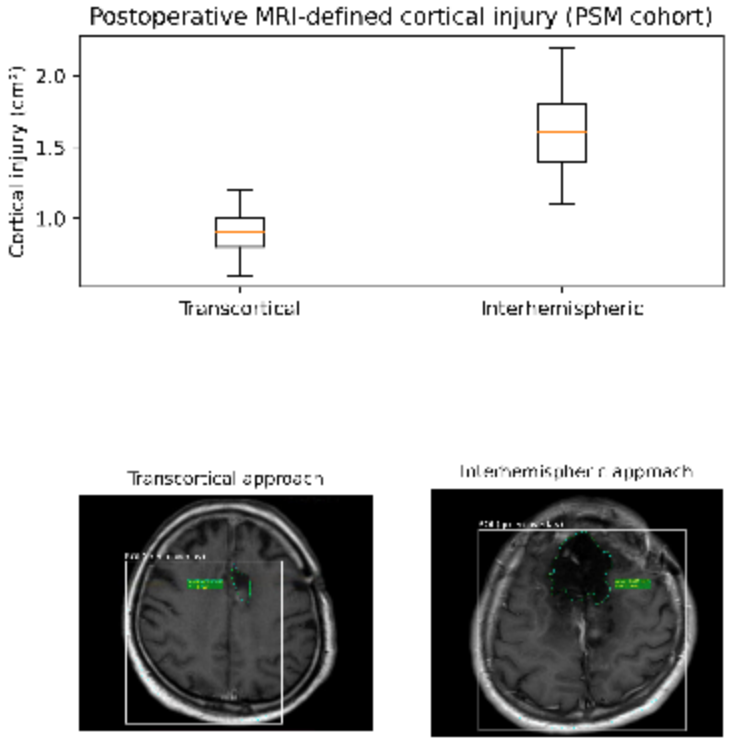


Figure 2

Postoperative MRI-defined cortical injury according to surgical corridor in the propensity-matched cohort