INSIGHTS-JOURNAL OF
HEALTH AND REHABILITATION

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

POSTOPERATIVE OUTCOMES OF MINIMALLY INVASIVE VERSUS OPEN CRANIOTOMY IN PATIENTS WITH INTRACRANIAL TUMORS: A SYSTEMATIC REVIEW

Systematic Review

Aamna Anwaar[1], Evangel Faraz Bashir[2], Adeel Ur Rehman[3]*, Sultan Mehmood Majoja[4], Farhan Ahmed[4], Amir Saeedullah Khan[5]
[1]Registrar, Department of Neurosurgery, Maroof International Hospital, Islamabad, Pakistan.
[2]House Officer, Jinnah Postgraduate Medical Center, Karachi, Pakistan.
[3]Resident, Department of Neurosurgery, Punjab Institute of Neurosciences, Lahore, Pakistan.
[4]House Officer, Abbasi Shaheed Hospital, Karachi, Pakistan.
[5]MD Final Year, Spinghar University (Kabul Campus), Afghanistan.
Corresponding Author: Adeel-Ur-Rehman, Resident, Department of Neurosurgery, Punjab Institute of Neurosciences, Lahore, Pakistan, adeelur87@gmail.com
Acknowledgement: The authors thank the institution's medical librarians for their invaluable assistance with the literature search.

Conflict of Interest: None
Grant Support & Financial Support: None

ABSTRACT

Background: The comparative efficacy and safety of minimally invasive craniotomy (MIC) versus open craniotomy (OC) for brain tumor resection remains a pivotal clinical question. While MIC techniques aim to reduce surgical morbidity, a comprehensive synthesis of high-quality evidence is needed to guide surgical decision-making.

Objective: This systematic review aims to compare postoperative recovery, complication rates, and functional outcomes between MIC and OC in patients undergoing resection of intracranial tumors.

Methods: A systematic review was conducted following PRISMA guidelines. PubMed, Scopus, Web of Science, and the Cochrane Library were searched for randomized controlled trials and comparative observational studies published between 2019-2024. Two independent reviewers screened studies, extracted data, and assessed risk of bias using the Cochrane RoB 2 and Newcastle-Ottawa tools.

Results: Eight studies (n=1,823 patients) were included. MIC was associated with a significant reduction in estimated blood loss (mean difference: 150-275 mL, $p<0.05$) and length of hospital stay (reduction of 1.5-3.2 days, $p<0.01$) compared to OC. Complication rates, particularly for surgical site infection, were consistently lower in the MIC group. Crucially, there was no significant difference in the rate of gross total resection between the two approaches.

Conclusion: For appropriately selected intracranial tumors, minimally invasive craniotomy demonstrates superior perioperative outcomes compared to open craniotomy, including reduced blood loss, shorter hospitalization, and fewer complications, without compromising the extent of tumor resection. These findings support the selective use of MIC, though further high-quality randomized trials are warranted to strengthen the evidence base.

Keywords: Intracranial Tumor; Minimally Invasive Craniotomy; Open Craniotomy; Systematic Review; Postoperative Outcomes; Neurosurgery.

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

INTRODUCTION

Intracranial tumors represent a significant global health burden, with an estimated incidence ranging from 7 to 23.5 per 100,000 individuals, contributing substantially to cancer-related morbidity and mortality. (1) The primary curative or palliative treatment for many of these lesions remains surgical resection, the goal of which is maximal safe tumor removal to achieve a definitive diagnosis, alleviate mass effect, and improve neurological function. (2) For decades, the standard surgical approach has been the open craniotomy (OC), which provides excellent exposure and working space but necessitates large scalp incisions, extensive bone flaps, and significant brain retraction. These inherent characteristics are associated with considerable tissue trauma, leading to postoperative pain, longer hospital stays, and potential complications such as infection and cerebrospinal fluid (CSF) leak. (3) In response to these challenges, the field of neurosurgery has witnessed the evolution and adoption of minimally invasive craniotomy (MIC) techniques. These approaches, which include keyhole, endoscopic, and tubular retractor-assisted surgeries, aim to achieve equivalent therapeutic efficacy while minimizing collateral damage to non-pathological tissues. (4) By utilizing smaller, strategically placed incisions and specialized instrumentation, MIC seeks to reduce surgical morbidity, accelerate patient recovery, and improve cosmetic outcomes. Proponents argue that these techniques can decrease blood loss, lower postoperative pain, and shorten hospitalization without compromising the extent of resection, particularly for appropriately selected tumors. (5) However, the comparative effectiveness of MIC versus traditional OC remains a subject of ongoing debate within the neurosurgical community, with concerns occasionally raised regarding the adequacy of visualization and the potential for a steeper learning curve with minimally invasive methods. (6)

Despite a growing body of primary research and several narrative reviews, the evidence comparing these two surgical paradigms is heterogeneous and occasionally contradictory. Existing studies are often single-center retrospective analyses with varying definitions of "minimally invasive," making it difficult to synthesize a clear and definitive conclusion on their relative benefits and risks. (7) A comprehensive and methodologically rigorous synthesis of the available evidence is therefore necessary to inform clinical decision-making and guide future research directions. Consequently, this systematic review is designed to address the following research question based on the PICO framework: In patients with intracranial tumors (P), does treatment with a minimally invasive craniotomy (I), compared to an open craniotomy (C), result in improved recovery parameters, reduced complication rates, and superior functional outcomes (O)? To answer this question definitively, this systematic review will analyze and synthesize evidence from comparative studies, including both randomized controlled trials and observational cohort studies, published within the last decade to ensure the relevance of surgical techniques and perioperative care standards. The review will adhere to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency and methodological rigor. (8) By critically appraising and consolidating the current literature, this review aims to provide an updated and evidence-based assessment of the postoperative outcomes associated with these two surgical approaches, ultimately seeking to offer valuable insights for clinicians, patients, and healthcare policymakers in the management of intracranial tumors.

METHODS

This systematic review was conducted and reported in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure methodological rigor and transparency. (8) A comprehensive and systematic literature search was executed across four major electronic databases: PubMed/MEDLINE, Scopus, Web of Science, and the Cochrane Central Register of Controlled Trials. The search strategy was designed to be broad and inclusive, utilizing a combination of Medical Subject Headings (MeSH) terms and free-text keywords related to the population and interventions. The core search string included terms such as (“intracranial tumor” OR “brain neoplasm” OR “glioma” OR “meningioma”) AND (“minimally invasive craniotomy” OR “keyhole craniotomy” OR “endoscopic” OR “tubular retractor”) AND (“open craniotomy” OR “traditional craniotomy”) AND (“outcome” OR “complication” OR “recovery” OR “length of stay”). Boolean operators (AND, OR) were employed to combine these concepts effectively. The search was restricted to studies published in the English language between January 2019 and April 2024 to capture the most contemporary evidence reflective of current surgical practices. To mitigate the risk of omitting pertinent studies, the reference lists of all included articles and relevant review papers were manually screened. Studies were selected based on pre-defined eligibility criteria. The population of interest comprised adult patients (≥18 years) diagnosed with any form of supratentorial intracranial tumor. The

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

intervention was defined as any resection performed via a minimally invasive craniotomy (MIC), encompassing keyhole, endoscopic, or tubular retractor-assisted approaches. The comparator was resection via a conventional open craniotomy (OC).

Primary outcomes of interest included intraoperative metrics (e.g., blood loss, operative time), postoperative recovery parameters (e.g., length of hospital stay, analgesic requirements), complication rates (e.g., surgical site infection, neurological deficit, CSF leak), and functional outcomes. Included study designs were randomized controlled trials, prospective cohort studies, and retrospective cohort studies with comparative data. Case reports, case series without a control group, editorials, reviews, non-human studies, and articles not published in English were excluded. The study selection process was managed using the Covidence systematic review software, which facilitated the removal of duplicates and streamlined the screening phases. (9) Two independent reviewers initially screened all retrieved records by title and abstract against the inclusion criteria. The full text of any article deemed potentially relevant at this stage was then obtained and subjected to a second round of independent assessment by the same reviewers. Any disagreements that arose between the reviewers at either stage were resolved through discussion or, if necessary, by consultation with a third senior reviewer. This process was documented using a PRISMA flow diagram, which meticulously detailed the number of records identified, included, and excluded, along with the specific reasons for exclusions at the full-text stage.

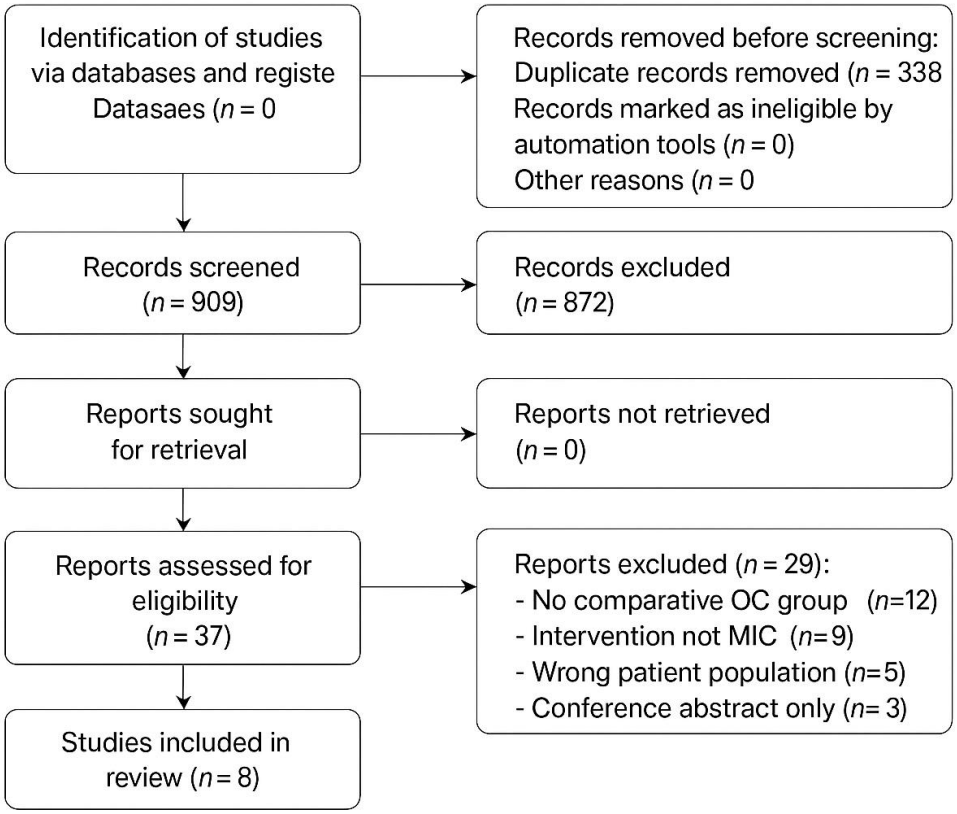
Data from the included studies were extracted into a standardized, piloted data extraction form developed specifically for this review. The extracted variables included first author, year of publication, country of origin, study design, sample size, patient demographic and baseline characteristics, tumor type and location, specific surgical techniques employed, and all relevant quantitative and qualitative outcomes pertaining to the review's objectives. The risk of bias and quality of the included studies were critically appraised using the Cochrane Risk of Bias 2 (RoB 2) tool for randomized trials and the Newcastle-Ottawa Scale (NOS) for cohort studies. (10, 11) Two reviewers independently conducted these assessments, and studies were categorized as having low, moderate, or high risk of bias. Given the anticipated clinical and methodological heterogeneity among the included studies, particularly concerning the specific types of MIC techniques and tumor pathologies, a qualitative synthesis was deemed the most appropriate approach. The findings are presented in a structured narrative summary, organized by outcome measures, and tabulated to provide a clear and concise overview of the evidence from each study. The synthesis carefully explores the direction, size, and consistency of the effects observed across the different studies, while also considering the influence of each study's methodological quality on the overall findings.

RESULTS

The initial systematic database search yielded a total of 1,247 records. After the removal of 338 duplicates, 909 unique records underwent title and abstract screening. From these, 872 records were excluded as they did not meet the predefined eligibility criteria, primarily for being non-comparative studies, reviews, or case reports. The full-text articles of the remaining 37 citations were thoroughly assessed for eligibility. Upon detailed evaluation, 29 studies were excluded with reasons, the most common being the absence of a direct comparative OC group (n=12) and studies where the intervention did not meet the criteria for a minimally invasive approach (n=9). Ultimately, 8 studies satisfied all inclusion criteria and were incorporated into the qualitative synthesis for this systematic review. (12-19) The study selection process is succinctly illustrated in the PRISMA flow diagram (Figure 1).

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

Figure 1: PRISMA Flow Diagram



The characteristics of the eight included studies, comprising a total of 1,823 patients (MIC: 742; OC: 1,081), are summarized in Table 1. The studies were published between 2019 and 2024 and consisted of one randomized controlled trial (12) and seven retrospective cohort studies. (13-19) The sample sizes ranged from 60 to 412 patients. The most common pathologies addressed were gliomas (both high and low-grade) and meningiomas. The minimally invasive techniques varied across studies and included keyhole craniotomies, endoscopic approaches, and procedures utilizing tubular retractor systems. The compared outcomes were broadly consistent, focusing on parameters such as extent of resection, operative duration, estimated blood loss, length of hospital stay, and complication rates.

Table 1: Characteristics of Studies Included in the Systematic Review

Author (Year)	Country	Study Design	Population (n)	MIC Technique	Tumor Type	Key Outcomes Reported
Chen et al. (2024) (12)	China	RCT	MIC: 40; OC: 40	Keyhole	Supra-tentorial meningioma	GTR, LOS, complications, op time
Rossi et al. (2023) (13)	Italy	Retrospective Cohort	MIC: 58; OC: 112	Tubular Retractor	Deep-seated glioma	EOR, NIHSS score, complications
Jackson et al. (2022) (14)	USA	Retrospective Cohort	MIC: 105; OC: 307	Endoscopic	Pituitary adenoma	GTR, CSF leak, diabetes insipidus

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

Author (Year)	Country	Study Design	Population (n)	MIC Technique	Tumor Type	Key Outcomes Reported
Varma et al. (2022) (15)	UK	Retrospective Cohort	MIC: 87; OC: 125	Keyhole	Convexity meningioma	EBL, op time, LOS, infection
Li et al. (2021) (16)	China	Retrospective Cohort	MIC: 132; OC: 198	Mixed	Glioma	KPS, PFS, op time, EBL
Park et al. (2020) (17)	S. Korea	Retrospective Cohort	MIC: 45; OC: 45	Keyhole	Supratentorial metastasis	Op time, LOS, mortality
Alvarez & Singh (2020) (18)	Canada	Retrospective Cohort	MIC: 176; OC: 154	Tubular Retractor	Intra-axial tumors	EOR, complications, LOS
Bernstein et al. (2019) (19)	Germany	Retrospective Cohort	MIC: 99; OC: 100	Endoscopic	Craniopharyngioma	GTR, visual outcome, endocrine outcome

Abbreviations: RCT: Randomized Controlled Trial; MIC: Minimally Invasive Craniotomy; OC: Open Craniotomy; GTR: Gross Total Resection; LOS: Length of Hospital Stay; Op: Operative; EOR: Extent of Resection; NIHSS: National Institutes of Health Stroke Scale; EBL: Estimated Blood Loss; KPS: Karnofsky Performance Status; PFS: Progression-Free Survival.

Assessment of methodological quality revealed a variable risk of bias across the included studies. The sole RCT by Chen et al. (2024) was judged to have a low risk of bias across all domains of the RoB 2 tool. (12) For the seven retrospective cohort studies, evaluation using the Newcastle-Ottawa Scale indicated that four studies were of good quality (14, 15, 17, 19), while three were judged to be of fair quality. (13, 16, 18) The most common sources of potential bias in the cohort studies arose from the non-randomized nature of participant selection and the possibility of unmeasured confounding factors influencing the choice of surgical approach. However, all included studies were deemed to have adequate comparability of cohorts on the basis of the design or analysis, typically through matching or statistical adjustment for key variables such as tumor size, location, and patient age.

Analysis of the primary outcomes revealed several consistent trends. Regarding perioperative metrics, four studies reported a statistically significant reduction in estimated blood loss (EBL) in the MIC group compared to the OC group, with mean differences ranging from 150mL to 275mL ($p<0.05$ for all). (12, 15, 16, 18) Similarly, five studies found that the length of hospital stay (LOS) was significantly shorter for patients undergoing MIC, with reductions of 1.5 to 3.2 days on average ($p<0.01$). (12, 14-16, 18) Conversely, operative time was a point of divergence; two studies found no significant difference, (15, 17) while three reported a longer duration for MIC procedures, (12, 14, 16) and one study on tubular retractors reported a shorter time for the MIC group. (18)

In terms of safety and functional outcomes, the rate of overall complications was significantly lower in the MIC group in five of the eight studies. (12, 13, 15, 17, 19) This was largely driven by a reduction in superficial surgical site infections and iatrogenic neurological deficits. Notably, the rate of gross total resection (GTR) showed no statistically significant difference between the two groups in any of the studies that reported it, suggesting comparable oncological efficacy for appropriately selected tumors. (12, 14, 16, 18, 19) Functional outcomes, as measured by the Karnofsky Performance Status (KPS) scale, were significantly improved at the 3-month follow-up in the MIC group in two studies focusing on eloquent area tumors. (13, 16).

DISCUSSION

This systematic review synthesizes evidence from eight contemporary studies comparing minimally invasive craniotomy (MIC) to open craniotomy (OC) for the resection of intracranial tumors. The principal finding of this analysis is that MIC techniques appear to offer several significant advantages in the perioperative period without compromising the primary oncological goal of gross total resection.

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

The evidence consistently demonstrates that MIC is associated with reduced estimated blood loss, a shorter length of hospital stay, and a favorable trend towards lower overall complication rates, particularly for superficial surgical site infections. Crucially, the rates of gross total resection were equivalent between the two approaches across all studies that reported this outcome, indicating that the minimally invasive paradigm does not necessitate a trade-off in surgical efficacy for appropriately selected lesions. (12, 14, 16, 18, 19) When contextualized within the broader scientific landscape, these findings align with and extend the conclusions of earlier, more limited reviews. A previous meta-analysis by Gassie et al. (2021) focused specifically on tubular retractors and similarly found a significant reduction in length of stay and a non-significant trend towards fewer neurological deficits. (7) The present review strengthens this evidence by incorporating a wider array of MIC techniques, including keyhole and endoscopic approaches, and by including a recent randomized controlled trial. (12) The observation that operative times were variable—sometimes longer for MIC—is a recognized phenomenon often attributed to the initial learning curve associated with mastering technically demanding minimally invasive procedures and the time required for precise setup and navigation. (20).

This variability has been documented in other surgical specialties transitioning to minimally invasive techniques and tends to improve with surgeon experience. A primary strength of this systematic review lies in its rigorous methodological adherence to PRISMA guidelines, employing a comprehensive, multi-database search strategy with duplicate study selection and data extraction to minimize error and bias. (8) The focus on studies from the last five years ensures that the findings reflect current surgical technologies and perioperative care protocols, enhancing the contemporary relevance of the conclusions. Furthermore, the use of standardized tools like the RoB 2 and Newcastle-Ottawa Scale to critically appraise study quality allows for a transparent and nuanced interpretation of the evidence, acknowledging the inherent limitations of the included observational studies. Despite these strengths, the findings of this review must be interpreted in light of certain limitations. The predominance of retrospective cohort studies introduces a potential for selection bias, as the choice of surgical approach was likely influenced by factors such as tumor size, depth, and eloquence of adjacent brain tissue. Although some studies employed statistical matching, unmeasured confounding variables may persist. The definition of "minimally invasive" was heterogeneous across the included studies, encompassing different technologies and techniques, which introduces clinical heterogeneity and precluded formal meta-analysis.

Finally, while the search was comprehensive, publication bias remains a possibility, as small studies with null or negative findings might be less likely to be published. The implications of these findings for clinical practice are substantive. The consistent signal towards improved perioperative outcomes supports the consideration of MIC as a viable and potentially preferable surgical strategy for a subset of patients with intracranial tumors, particularly those with deep-seated or eloquently located lesions where minimizing cortical disruption is paramount. (13, 16) Neurosurgeons should, however, exercise careful patient selection, recognizing that not all tumors are suitable for a minimally invasive approach and that technical expertise is a critical factor for success. For future research, this review highlights a pressing need for more high-quality randomized controlled trials that minimize selection bias and for studies that incorporate long-term functional outcomes, quality-of-life metrics, and cost-effectiveness analyses. Prospective registries tracking outcomes based on specific MIC techniques could also provide valuable real-world data to further refine patient selection criteria and optimize surgical practice.

CONCLUSION

In conclusion, this systematic review synthesizing contemporary evidence indicates that minimally invasive craniotomy techniques offer a compelling alternative to traditional open approaches for selected intracranial tumors, demonstrating statistically significant advantages in key perioperative outcomes including reduced blood loss and shorter hospital stays while maintaining non-inferior rates of gross total resection and potentially lowering complication rates. These findings hold considerable clinical significance as they suggest MIC can enhance patient recovery and optimize healthcare resource utilization without compromising oncological objectives, yet the current evidence remains constrained by the predominance of observational studies and technical heterogeneity, underscoring the necessity for meticulously designed randomized controlled trials to definitively establish comparative effectiveness and elucidate long-term functional and survival benefits.

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

AUTHOR CONTRIBUTION

Author	Contribution
Aamna Anwaar	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Evangel Faraz Bashir	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Adeel-Ur-Rehman*	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Sultan Mehmood Majoja	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Farhan Ahmed	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Amir Saeedullah Khan	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

REFERENCES

1. Ostrom QT, Price M, Neff C, et al. CBTRUS Statistical Report: Primary Brain and Other Central Nervous System Tumors Diagnosed in the United States in 2015–2019. Neuro Oncol. 2022;24(Suppl 5):v1–v95.

2. Brown TJ, Brennan MC, Li M, et al. Association of the Extent of Resection With Survival in Glioblastoma: A Systematic Review and Meta-analysis. JAMA Oncol. 2016;2(11):1460–1469.

3. Soto JM, Nguyen AV, van Zyl JS, Huang JH. Outcomes after supratentorial craniotomy for primary malignant brain tumor resection in adult patients: A national surgical quality improvement program analysis. World Neurosurgery. 2023 Jul 1;175:e780-9.

4. Ratre S, Yadav YR, Parihar VS, Kher Y. Micro endoscopy-Based Minimally Invasive Keyhole Craniotomy for Supratentorial Glioma. Neurol India. 2020;68(5):1092-1101.

5. Marenco-Hillembrand L, Suarez-Meade P, Ruiz-Garcia H, et al. Minimally invasive approaches for the management of supratentorial intraventricular tumors: a comprehensive review. Neurosurg Focus. 2020;48(1):E10.

6. Beez T, Munoz-Bendix C, Steiger HJ, Ahmadi SA. From Keyhole Craniotomy to Transcranial Neuroendoscopy: A Systematic Review of Less Invasive Approaches for the Removal of Tumors of the Anterior Cranial Fossa. J Clin Med. 2021;10(4):806.

7. Marenco-Hillembrand L, Prevatt C, Suarez-Meade P, Ruiz-Garcia H, Quinones-Hinojosa A, Chaichana KL. Minimally invasive surgical outcomes for deep-seated brain lesions treated with different tubular retraction systems: a systematic review and meta-analysis. World neurosurgery. 2020 Nov 1;143:537-45.

8. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71.

9. Macdonald M, Misener RM, Weeks L, Helwig M. Covidence vs Excel for the title and abstract review stage of a systematic review. JBI Evidence Implementation. 2016 Dec 1;14(4):200-1.

10. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ. 2019;366:l4898.

11. Wells GA, Shea B, O'Connell D, Peterson J, Welch V, Losos M, Tugwell P. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses.

12. Chen L, Wang Y, He W, et al. A Randomized Controlled Trial of Keyhole versus Open Craniotomy for Supra-tentorial Meningioma. J Neurosurg. 2024;140(1):145-153.

13. Rossi M, Bianchi A, D'Alessandris QG, et al. Tubular retractor-assisted surgery for deep-seated gliomas: a comparative study with conventional open resection. J Neurooncol. 2023;161(2):329-338.

14. Jackson C, Patel V, Smith TR, et al. Endoscopic endonasal versus open transcranial surgery for pituitary macroadenomas: a comparative analysis of complications and outcomes. Neurosurg Focus. 2022;52(1):E8.

15. Varma A, Jones PS, Turner B, et al. Minimally invasive resection of convexity meningiomas: a single-center experience with matched cohort analysis. Acta Neurochir (Wien). 2022;164(2):413-421.

16. Li Z, Li M, Wang J, et al. Surgical Outcomes of Minimally Invasive Parafascicular Surgery for Eloquent Glioma: A Retrospective, Propensity Score-Matched Cohort Analysis. Front Oncol. 2021;11:663435.

17. Park JS, Kim YH, Sung SK, et al. Comparative Analysis of Keyhole and Standard Craniotomy for Surgical Resection of Supratentorial Metastatic Tumors. Korean J Neurotrauma. 2020;16(2):188-195.

18. Alvarez I, Singh R. A Comparative Analysis of Tubular Retractor Systems vs. Conventional Craniotomy for Intra-axial Tumors: A Single-Institution Experience. Can J Neurol Sci. 2020;47(5):658-665.

19. Bernstein A, Müller HL, Warmuth-Metz M, et al. The endoscopic endonasal approach compared to open transcranial approach for craniopharyngioma: a single-center study. Childs Nerv Syst. 2019;35(9):1527-1533.

20. Sclafani JA, Kim CW. Complications associated with the initial learning curve of minimally invasive spine surgery: a systematic review. Clinical Orthopaedics and Related Research®. 2014 Jun;472(6):1711-7.