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Minimally invasive surgery versus open surgery for intraspinal tumors: a meta-analysis based on 15 observational studies

Chuanhui Xun^{1†}, Haonan Li^{1†}, Yukun Hu¹, Shutao Gao¹, Jianlin Xu², Yanlong Wang¹, Ting Wang¹ and Weibin Sheng^{1*}

Abstract

Objectives This study compared the clinical outcomes of minimally invasive surgery (MIS) and open surgery (OS) for patients with intraspinal tumors.

Methods A systematic search of PubMed, Cochrane Library, EMBASE, Web of Science, China National Knowledge Infrastructure (CNKI), and Wanfang databases was conducted to identify relevant studies. Continuous variables, including estimated blood loss, surgery duration, time to mobilization, length of hospitalization, visual analog scale (VAS) score, and incision length, were reported as mean differences (MD) with 95% confidence intervals (95% CIs). Dichotomous variables, such as gross total resection, blood transfusion, cerebrospinal fluid (CSF) leakage, and overall complications, were presented as risk ratios (RR) with 95% CIs. Meta-analyses were performed using RevMan 5.3.

Results Fifteen studies, comprising a total of 943 patients (488 in the MIS group and 455 in the OS group), met the inclusion criteria. The meta-analysis indicated that MIS significantly reduced estimated blood loss (MD = -76.73, 95% CI -102.56 to -50.91, $P < 0.01$), incision length (MD = -4.09, 95% CI -5.20 to -2.97, $P < 0.01$), VAS score (MD = -0.79, 95% CI -1.48 to -0.11, $P = 0.02$), time to mobilization (MD = -4.27, 95% CI -5.12 to -3.43, $P < 0.01$), length of hospitalization, (MD = -3.94, 95% CI -5.05 to -2.84, $P < 0.01$), and overall complications (RR = 0.40, 95% CI 0.25 to 0.64, $P < 0.01$) compared with OS. No significant differences were observed in surgery duration (MD = -28.67, 95% CI -58.58 to 1.23, $P = 0.06$), gross total resection (RR = 1.00, 95% CI 0.94 to 1.07, $P = 0.92$), blood transfusion (RR = 0.23, 95% CI 0.05 to 1.04, $P = 0.06$), or CSF leakage (RR = 0.50, 95% CI 0.24 to 1.04, $P = 0.07$).

Conclusion Findings from this analysis suggest that MIS offers clinical advantages over OS in reducing blood loss, incision length, pain, time to mobilization, length of hospitalization, and overall complication rates.

Keywords Minimally invasive surgery, Open surgery, Intraspinal tumors, Meta-analysis

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Introduction

Intraspinal tumors, encompassing primary and metastatic growths within the spinal cord, meninges, nerve roots, and adjacent tissues, present a significant concern in spinal surgery. These tumors are classified based on anatomical location as extradural, intradural-extramedullary, or intramedullary. The incidence of intraspinal tumors is approximately 0.96–0.99 per 100,000 individuals, with benign tumors such as schwannomas, meningiomas, and neurofibromas being the most common [1, 2]. Early symptoms may be subtle; however, as the tumors advance, they frequently lead to spinal cord and nerve root compression, resulting in progressive neurological impairments [3, 4].

Surgical resection is the most effective treatment for intraspinal tumors. Traditional approaches, such as laminectomy and modified hemilaminectomy, have long been the standard of care. However, with advancements in precision medicine and minimally invasive surgical techniques, surgeons are increasingly aiming to reduce surgical trauma. In the past decade, minimally invasive surgery (MIS) using tubular retractors has gained popularity for resecting intraspinal tumors [5–7].

Although numerous studies [6, 8–13] have compared the outcomes of MIS with traditional open surgery (OS), findings have often been inconsistent due to clinical heterogeneity, small sample sizes, and limited statistical power. This study aims to synthesize the existing evidence and evaluate the clinical efficacy of MIS versus OS for treating intraspinal tumors.

Materials and methods

Literature search

We systematically searched PubMed, Cochrane Library, EMBASE, Web of Science, China National Knowledge Infrastructure (CNKI), and Wanfang databases for studies published from database inception through March 10, 2024. The search strategy involved combining keywords such as “minimally invasive surgery,” “keyhole surgery,” “tubular retractor,” “traditional open surgery,” and “intra-spinal tumor.” Reference lists of selected studies were also reviewed. When full texts or original data were unavailable, authors were contacted via email. Two independent authors (CX and HL) conducted the search to maintain objectivity, with a third author consulted to resolve any disagreements.

Inclusion and exclusion criteria

Studies were included if they met the following criteria: (i) patients had a confirmed diagnosis of intraspinal tumors; (ii) the study compared MIS with OS; (iii) MIS was defined as using tubular retractors for lesion exposure, followed by laminectomy; (iv) OS involved subperiosteal lamina exposure and laminectomy or

hemilaminectomy; (v) at least one of the following outcomes was reported: surgery duration, estimated blood loss, time to mobilization, length of hospitalization, visual analog scale (VAS) score, gross total resection, blood transfusion, cerebrospinal fluid (CSF) leakage, or overall complications; and (vi) the study included at least five patients per group. Studies lacking full texts or original data, duplicate publications, reviews, commentaries, conference abstracts, case series, or those focusing on biomechanical or cadaveric analyses were excluded.

Literature screening and data extraction

Two authors (CX and HL) independently screened the titles and abstracts to identify eligible studies. Full texts of selected studies were reviewed in detail based on inclusion and exclusion criteria. Extracted data included the first author, publication year, country, study design, tumor type, sample size, and reported outcomes. Discrepancies were resolved by consulting a third author.

Quality assessment

The methodological quality of observational studies was assessed using the Newcastle-Ottawa Scale (NOS), which evaluates selection, comparability, and outcome assessment. Studies scoring 6–9 were considered to be of good quality, while those scoring 0–5 were rated as poor quality. Quality assessment was performed independently by two authors (CX and HL), with a third author consulted to resolve any disagreements.

Sensitivity analysis and publication bias

A sensitivity analysis was conducted by sequentially excluding each study to evaluate the stability of the overall results. Publication bias was assessed using funnel plots, with asymmetry suggesting potential bias.

Statistical analysis

Data were analyzed using RevMan 5.3 software. Heterogeneity was evaluated using I^2 and P -values; if $I^2 \leq 50\%$ and $P \geq 0.1$, a fixed-effect model was applied; otherwise, a random-effect model was used. Continuous variables, including estimated blood loss, surgery duration, time to mobilization, length of hospitalization, visual analog scale (VAS) score, and incision length, were reported as mean differences (MD) with 95% confidence intervals (95% CIs). Dichotomous variables, including gross total resection, blood transfusion, cerebrospinal fluid (CSF) leakage, and overall complications, were reported as relative risks (RR) with 95% CIs. Statistical significance was set at $\alpha = 0.05$ for all tests.

Results

Literature retrieval results

A comprehensive search of six databases yielded 870 relevant articles: 316 from PubMed, 369 from Web of Science, 123 from EMBASE, 1 from the Cochrane Library, 26 from CNKI, and 35 from Wanfang Data. No additional studies were identified through manual reference checks. One study, published in Russian, could not be accessed, and attempts to contact the author via email were unsuccessful. After removing duplicates and screening the titles and abstracts, the remaining articles underwent a full-text evaluation. Ultimately, 15 articles [6, 8–21] met the inclusion criteria and were included in the meta-analysis. The detailed literature screening process is presented in Fig. 1.

Basic characteristics of included studies

Fifteen cohort studies were included, with 11 published in English and 4 in Chinese. In total, 943 participants were involved: 488 patients in the MIS group and 455 in the OS group. Among these, the study by Jiang et al. [18] was a prospective cohort, while the others were retrospective. The studies were conducted across several countries, including China, the United States, South Korea, France, Germany, and Portugal. The study quality evaluation showed that all studies scored at least 6 points, indicating good quality. Detailed characteristics of the included studies are summarized in Table 1.

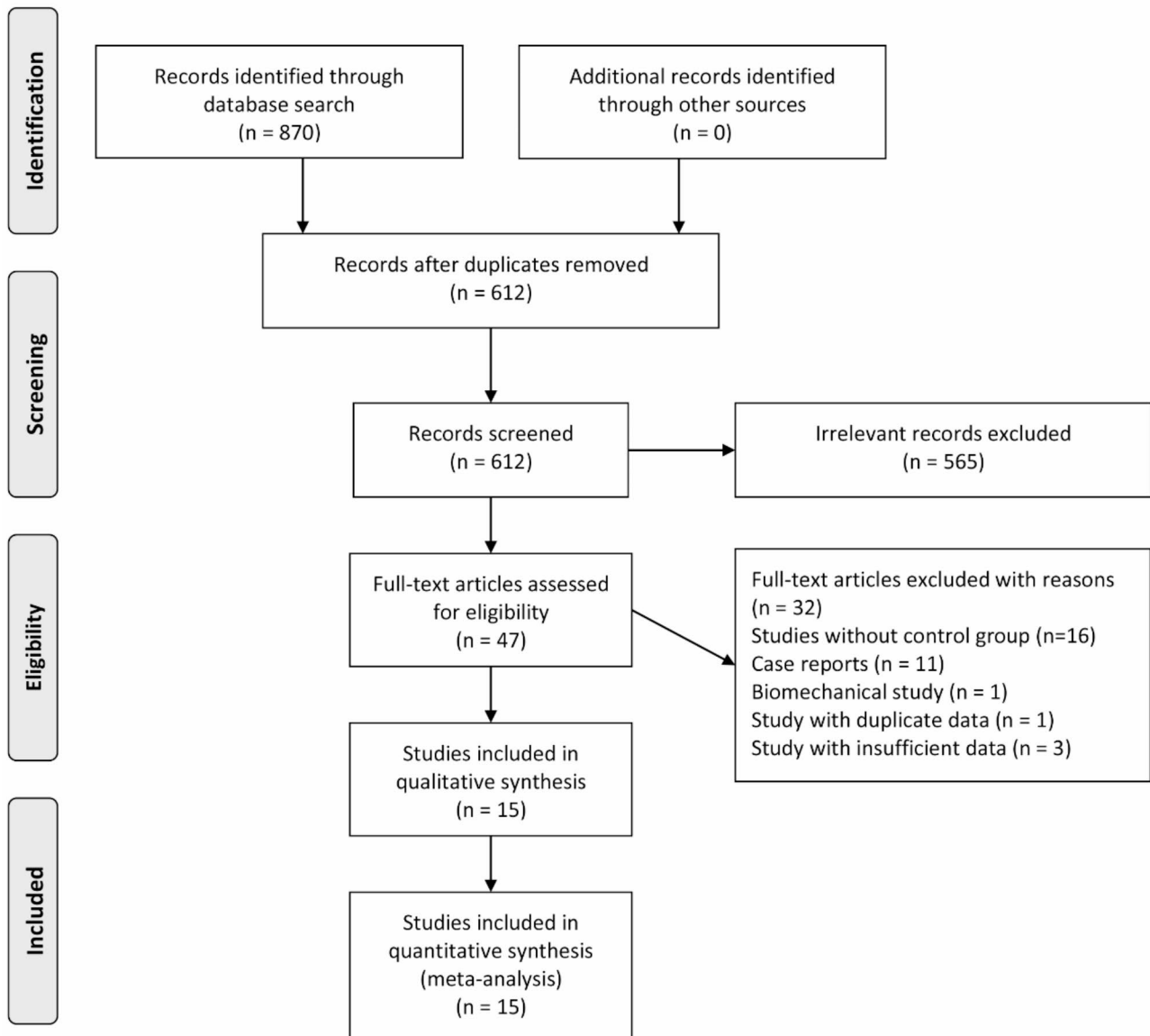


Fig. 1 Flowchart of literature selection

Table 1 Main characteristics of included studies

Author	Year	Country	Publication language	Study design	Tumor type	Sample size	MIS/OS	Outcomes	NOS
Kelly et al.	2022	America	English	RCS	Multiple	21	11/10	①②④⑦⑧	7
He et al.	2022	China	English	RCS	Meningioma, nerve sheath tumor	42	9/33	①②④⑦⑧⑩	7
Dauleac et al.	2022	France	English	RCS	Meningioma	48	18/30	①②③⑦⑧⑩	7
Xie et al.	2020	China	Chinese	RCS	Multiple	69	31/38	①②③④⑦⑧⑨	7
Wang et al.	2020	China	English	RCS	Multiple	125	73/52	②③④⑤	6
Li et al.	2020	China	Chinese	RCS	Multiple	102	50/52	①②④⑤⑥⑨	7
Jiang et al.	2020	China	Chinese	PCS	Nerve sheath tumor	30	15/15	①②④⑧⑨	8
Mende et al.	2017	Germany	English	RCS	Multiple	245	156/89	④⑦⑧	7
Chen et al.	2016	China	Chinese	RCS	Multiple	33	16/17	①②③④⑤⑨	6
Fontes et al.	2016	America	English	RCS	Multiple	35	17/18	⑧⑩	8
Wong et al.	2015	America	English	RCS	Multiple	45	27/18	①②④⑥⑦⑧⑩	7
Raygor et al.	2015	America	English	RCS	Multiple	51	25/26	①②⑥⑦⑧⑩	8
Lee et al.	2015	South Korea	English	RCS	Nerve sheath tumor	24	6/18	①②④⑩	6
Lu et al.	2011	America	English	RCS	Multiple	27	18/9	①②④⑤⑨⑩	7
Kitumba et al.	2023	Portugal	English	RCS	Multiple	46	16/30	②	7

RCS, retrospective cohort study; PCS, prospective cohort study; MIS, minimally invasive surgery; OS, open surgery; ① Estimated blood loss; ② surgery duration; ③ Incision length; ④ Length of hospitalization; ⑤ Time to mobilization; ⑥ Blood transfusion; ⑦ Cerebrospinal fluid leakage; ⑧ Overall complications; ⑨ VAS; ⑩ Gross total resection

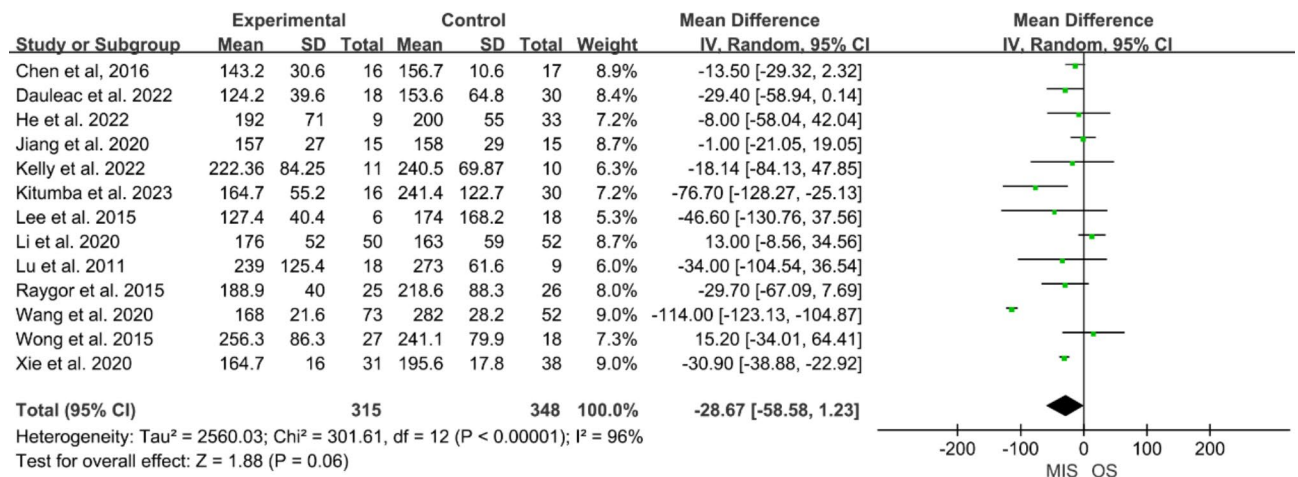


Fig. 2 Forest plot of minimally invasive surgery versus open surgery for surgery duration

Results of meta-analysis

Surgery duration

Thirteen studies [8–15, 17–21] reported surgery duration, involving 315 participants in the MIS group and 348 in the OS group. Significant heterogeneity was noted among these studies (P < 0.01, I² = 96%), necessitating the use of a random-effects model. The pooled data suggested that the MIS group had a shorter surgery duration than the OS group, but the difference was not statistically significant (MD = -28.67, 95% CI -58.58 to 1.23, P = 0.06, Fig. 2).

Estimated blood loss

Eleven studies [8–12, 14, 15, 17–19, 21] reported estimated blood loss, involving 226 participants in the MIS

group and 266 in the OS group. High heterogeneity was present (P < 0.01, I² = 89%), so a random-effects model was applied. The results indicated that the MIS group experienced significantly less blood loss than the OS group (MD = -76.73, 95% CI -102.56 to -50.91, P < 0.01, Fig. 3).

Incision length

Three studies [17, 20, 21] reported incision length, involving 121 participants in the MIS group and 107 in the OS group. Due to substantial heterogeneity (P < 0.01, I² = 82%), a random-effects model was used. The MIS group had significantly shorter incisions than the OS group (MD = -4.09, 95% CI -5.20 to -2.97, P < 0.01).

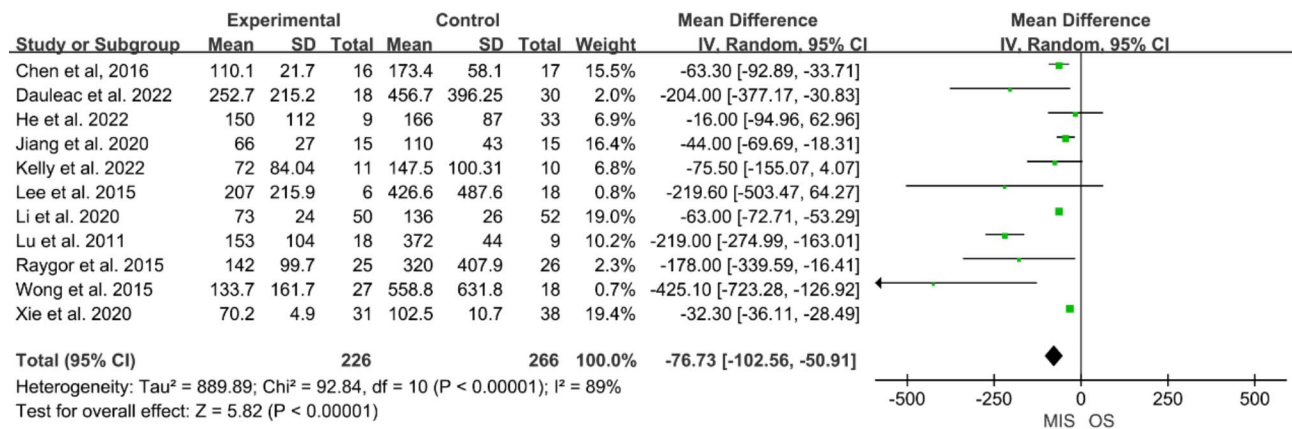


Fig. 3 Forest plot of minimally invasive surgery versus open surgery for estimated blood loss

VAS score

Six studies [14, 17–21] reported VAS pain scores, including 203 participants in the MIS group and 183 in the OS group. The analysis revealed considerable heterogeneity ($P < 0.01$, $I^2 = 89\%$), prompting the use of a random-effects model. The pooled results demonstrated that the MIS group had significantly lower VAS scores than the OS group (MD = -0.79, 95% CI -1.48 to -0.11, $P = 0.02$).

Time to mobilization

Three studies [17, 19, 20] reported the time from surgery to first mobilization, including 139 participants in the MIS group and 121 in the OS group. High heterogeneity was noted ($P < 0.01$, $I^2 = 94\%$), necessitating the use of a random-effects model. The analysis showed that the MIS group had a significantly shorter time to mobilization than the OS group (MD = -4.27, 95% CI -5.12 to -3.43, $P < 0.01$).

Length of hospitalization

Twelve studies [6, 9–12, 14, 15, 17–21] reported the length of hospitalization, involving 430 participants in the MIS group and 381 in the OS group. Considerable heterogeneity across studies was detected ($P < 0.01$, $I^2 = 88\%$), and a random-effects model was applied. The pooled data indicated that the MIS group had a significantly shorter hospital stay than the OS group (MD = -3.76, 95% CI -4.82 to -2.70, $P < 0.01$).

Gross total resection

Seven studies [8–11, 14–16] reported the gross total resection, involving 120 participants in the MIS group and 152 participants in the OS group. No between-study heterogeneity was detected ($P < 0.99$, $I^2 = 0$), and a fixed-effects model was applied. The pooled data indicated that there was no significant difference in the gross total resection rate between two groups (RR = 1.00, 95% CI 0.94 to 1.07, $P = 0.92$).

Blood transfusion

Three studies [8, 9, 19] examined the blood transfusion, including 102 participants in the MIS group and 96 in the OS group. With no observed heterogeneity ($P = 0.88$, $I^2 = 0$), a fixed-effects model was applied. Although the pooled results suggested a lower incidence of blood transfusion in the MIS group, the difference was not statistically significant (RR = 0.23, 95% CI 0.05 to 1.04, $P = 0.06$).

CSF leakage

Seven studies [6, 8–12, 21] reported the incidence of CSF leakage, involving 227 participants in the MIS group and 244 in the OS group. No heterogeneity was observed ($P = 0.67$, $I^2 = 0$), and a fixed-effects model was therefore used. The pooled data indicated a reduced incidence of CSF leakage in the MIS group, though the difference did not reach statistical significance (OR = 0.50, 95% CI 0.24 to 1.04, $P = 0.07$).

Total complications

Ten studies [6, 8–12, 14, 16, 18, 21] reported the overall complication rates, including 327 participants in the MIS group and 286 in the OS group. With no heterogeneity detected ($P = 0.49$, $I^2 = 0$), a fixed-effects model was utilized. The findings revealed a significantly lower overall complication rate in the MIS group than the OS group (RR = 0.49, 95% CI 0.33 to 0.73, $P < 0.01$).

Sensitivity analysis and publication bias

Sensitivity analyses confirmed that most results were stable, supporting their reliability. However, VAS scores proved sensitive to the inclusion of the study by Lu et al. [14], which showed notably larger difference between MIS and OS groups than other studies. Excluding this study led to stabilized VAS results, suggesting it was an outlier impacting the initial findings. Funnel plots for all

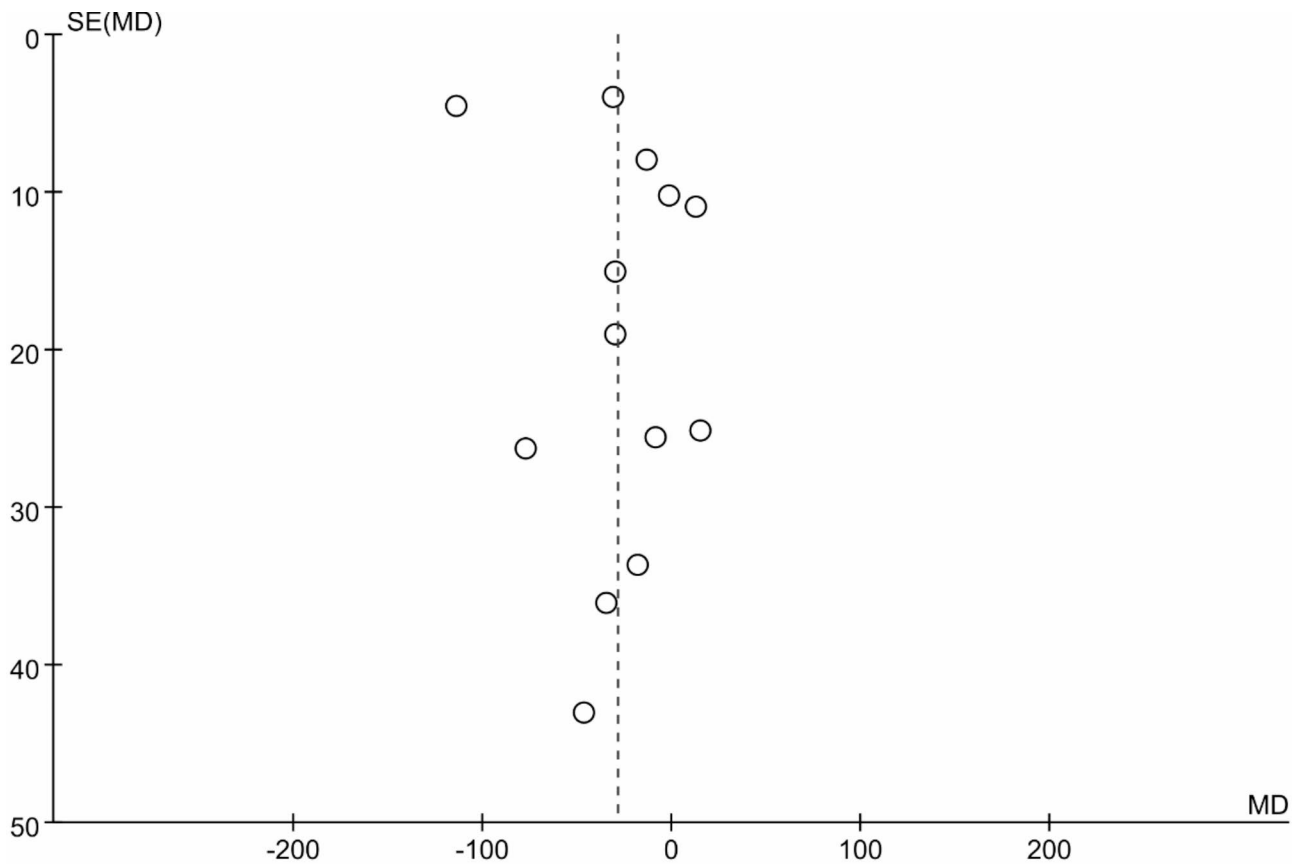


Fig. 4 Funnel plot of minimally invasive surgery versus open surgery for surgery duration

outcomes showed no significant asymmetry, indicating no major publication bias (Fig. 4).

Discussion

Traditional laminectomy for treating intraspinal tumors requires stripping the paraspinal muscles and removing posterior elements such as the lamina, spinous process, and interspinous ligament. This extensive removal can compromise spinal stability, increasing the risk of iatrogenic spinal deformity and often necessitating pedicle screw fixation for stabilization [22, 23]. In contrast, the hemilaminectomy technique, which preserves the interspinous and supraspinous ligaments, intervertebral joints, and paravertebral muscle on the contralateral side, offers enhanced stability and fewer postoperative complications. This approach is particularly suited for unilateral intraspinal tumors [24]. Microscope-assisted hemilaminectomy has further refined the precision of this approach, reducing the risk of complications [25]. However, limitations such as restricted exposure and a narrower surgical field persist, as the ipsilateral muscles are still removed.

Laminoplasty offers an alternative with increased structural resistance to buckling, shear, and rotation. A study by Song et al. [22] found that laminoplasty (replanting

the resected lamina with micro-plate fixation) resulted in shorter operation time, lower blood loss, and reduced incidence of CSF leakage compared to laminectomy. The laminoplasty group also exhibited better neurological function improvement at 12-month follow-up. However, other studies have not demonstrated a consistent benefit in neurological outcomes or reduction in postoperative deformity risks [26]. For instance, Park et al. [27] used hollow screws to reattach the lamina and reconstruct ligaments in 10 patients, achieving favorable outcomes. Despite these improvements, risks remain; for example, the use of a T-saw to cut the lamina carries a risk of damaging the spinal cord or nerve roots, particularly in patients with larger tumors or reduced spinal canal space. A study by Wang et al. [28] on unilateral laminoplasty in 38 patients with cervical intraspinal tumors demonstrated significant neurological improvement, stable cervical curvature, and no severe complications over a 2-year follow-up.

In 2006, Tredway et al. [29] introduced channel-based techniques to facilitate tumor resection, which allow for gross total resection with significant symptom improvement. Lu et al. [14] further compared minimally invasive expandable channels for tumor resection against traditional open surgery. Results indicated that minimally

invasive approaches led to reduced trauma, less blood loss, faster recovery, and fewer complications. Since then, comparative studies of MIS and OS for intraspinal tumors have emerged, although many have small sample sizes and inconsistent findings. Meta-analysis offers a solution to these limitations, combining data from multiple studies to enhance statistical power and reliability.

In this analysis, we reviewed 15 studies from China, South Korea, the United States, France, Portugal, and Germany, comparing MIS and OS for intraspinal tumors. Our findings showed that MIS significantly reduced intraoperative blood loss, incision length, postoperative pain (measured by VAS), length of hospitalization, and complication rates compared to OS. No significant differences were observed in surgical duration, CSF leakage, gross total resection, or blood transfusion. The analyses revealed high heterogeneity in surgery duration, estimated blood loss, incision length, VAS, time to mobilization, and length of hospitalization. This variability likely stems from differences in surgical methods, instrumentation, and inclusion criteria, as well as tumor location, type, size, and surgeon expertise. Due to the limited number and small size of included studies, subgroup analyses based on lesion type, site, and surgical approach were not feasible.

To assess the stability of our findings, we performed sensitivity analyses, which indicated good stability across indices except for the VAS score. Differences in pain assessment timing and baseline pain levels may have contributed to the VAS score variability. The study by Lu et al. [14] emerged as an outlier, showing large preoperative VAS score differences between MIS and OS groups. Excluding this study stabilized the results, indicating that MIS was associated with significantly lower postoperative pain. Variability in VAS score data limits further conclusions, suggesting that pain reduction may be a more consistent measure of procedural differences.

OS remains the standard approach for intraspinal tumor resection, providing wide exposure, clear visualization, and ample space for safe and complete tumor removal with minimized neurological injury risks. However, the removal of the spinal lamina in OS disrupts muscle and ligament attachments, which can compromise spinal stability and potentially lead to deformities [26, 30]. For ventral tumors, OS may involve cutting the dentate ligament and retracting the spinal cord, which heightens the risk of neurological injury. Subchannel resection with precise incision placement and channel adjustment could mitigate some of these risks, though OS is also associated with larger incisions, increased blood loss, greater postoperative pain, and prolonged recovery. In a study by Xie et al. [21], patients undergoing MIS showed lower creatine kinase levels on the first postoperative day than those undergoing OS, suggesting

reduced muscle injury in MIS. Financially, MIS was 24.5% less expensive than OS in the study by Fontes et al. [16], although cost analysis was not performed in this study due to limited data.

MIS is also technically challenging, requiring high skill and a steep learning curve due to the limited field of view and narrow operating space. Additionally, MIS is not suitable for all tumors, particularly those spanning multiple segments. Frequent fluoroscopy during channel establishment can increase radiation exposure for both patients and staff. The constrained space in MIS makes dural suturing challenging and necessitates accurate preoperative and intraoperative tumor localization.

Despite this study systematically reviewed evidence on OS and MIS for intraspinal tumors, several limitations remain to be overcome. First, this meta-analysis lacks of randomized controlled trial studies, and except for one prospective study by Jiang et al. [18], all included studies were retrospective, which might reduce the overall strength of the evidence. Second, all studies were single-center with small sample sizes, which might introduce selection bias. Future studies should prioritize multi-center and large-sample prospective randomized controlled trials to strengthen the findings. Third, the included studies primarily focused on short-term intraoperative outcomes, long-term outcomes such as tumor recurrence and spinal alignment could not be evaluated. Fourth, the literature search was limited to English and Chinese databases, potentially excluding relevant studies in other languages, and incurring potential publication bias. Fifth, heterogeneity in MIS channel selection, record method of blood loss, inclusion/exclusion criteria, and tumor size across studies also influence the pooled outcomes.

Conclusion

MIS for intraspinal tumors offers several advantages over OS, including smaller incisions, reduced trauma and blood loss, shorter hospital stays, faster mobilization, less postoperative pain, and fewer complications. However, MIS is limited in applicability to larger tumors, requires advanced technical skill and equipment, and entails a steep learning curve. Due to the limitations of this meta-analysis, including small sample sizes and retrospective study designs, further multi-center, large-sample prospective randomized controlled trials are essential to validate these findings.

Abbreviations

MIS	Minimally invasive surgery
OS	Open surgery
CNKI	China national knowledge infrastructure
VAS	Visual analog scale
MD	Mean differences
CSF	Cerebrospinal fluid
RR	Risk ratios
CI	Confidence intervals

NOS Newcastle-ottawa scale

Author contributions

Haonan Li, Chuanhui Xun and Weibin Sheng wrote the main manuscript text; Yukun Hu, Shutao Gao, Jianlin Xu and Yanlong Wang prepared Figs. 1, 2, 3 and 4; Ting Wang prepared Table 1. All authors reviewed the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

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