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REVIEW

Minimally invasive approaches to intramedullary spinal cord tumors: a systematic review of techniques and outcomes

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Abstract

Purpose To systematically review the published literature on minimally invasive spine surgery (MISS) approaches for intramedullary spinal cord tumor (IMSCT) resection and summarize surgical techniques, perioperative outcomes, neurological results, and complications.

Methods A PRISMA-guided search of PubMed, CINAHL, Cochrane Trials, and Scopus was performed from inception through November 19, 2025. Studies reporting MISS techniques for IMSCT resection with operative details and perioperative outcomes were included.

Results Out of a total of 482 studies identified, 11 were included that reported on a total of 222 patients (Age range: 11-72; 52.9% male population). 64% of included studies (n=7 of 11) were retrospective case series whereas 36% (n=4 of 11) were case reports. Posterior tubular retractor-based approaches were most commonly reported, with fewer studies describing non-tubular, muscle- and bone-preserving laminotomy techniques. Tumors most frequently involved the cervical (33.2%; n=74 of the 223 tumors), and thoracic spine segments (30.9%; n=69 of the 223 tumors). Ependymoma (41.3%; n=92 of the 223 tumors), astrocytoma (32.3%; n=72 of the 223 or tumors), and hemangioblastoma (16.6%; n=37 of the 223 or tumors) were the most common histologies. Estimated blood loss was reported in 7 of 11 studies (63.6%) and was uniformly low (under 200 mL); length of hospital stay was reported in 7 of 11 studies (63.6%) and was generally short (3 to 6 days); and extent of resection was reported in all included studies (11/11, 100%), with high rates of gross total resection (87.4%; n=195 of the 223 tumors). Postoperative neurological outcomes were most often stable or improved relative to baseline. Complications and recurrences were uncommon, though follow-up duration was variable.

Conclusion MISS approaches for IMSCT resection are feasible in select cases and can be performed using posterior muscle- and bone-sparing techniques, with generally minimal complications and stable or improved postoperative neurological function. Favorable outcomes likely reflect both technical advantages and selection of tumors with anatomical and histological characteristics suited to MISS. Such variables should be controlled for in future comparative studies.

Keywords Intramedullary spinal cord tumors, surgical strategy, minimally invasive surgery, neurosurgical procedures, systematic review

Introduction

Intramedullary spinal cord tumors (IMSCTs) are rare neoplasms, representing 2–5% of all spinal tumors, compared with extradural and intradural-extramedullary spinal cord tumors [1]. These tumors arise from within the spinal cord and damage the surrounding gray and white matter, leading to the slow and progressive development of non-specific symptoms such as back pain, radiculopathy, weakness, and gait disturbances, which can delay diagnosis [2]. In severe cases, due to the tumor's mass effect, Brown-Sequard syndrome, paralysis, syrinx formation, and other serious neurological complications may occur [1–3]. The majority of IMSCTs are of glial origin, with ependymomas and astrocytomas being most commonly reported [4]. Other types of

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IMSCTs include hemangioblastomas, glioblastomas, and metastases, among others [1, 5].

While prognosis largely depends on tumor histology and patient functionality, microsurgical resection via open laminectomy has become the gold-standard treatment approach, with the goal being gross total resection (GTR) of the neoplasm [6–8]. Adjunct to GTR, or when only subtotal resection (STR) can be achieved, targeted chemotherapy and radiotherapy can be employed, although they are associated with adverse side effects and poor prognoses [9, 10]. Even when resection is successful, however, 9–34% of patients experience acute postoperative neurological deterioration, and only 25–41% regain preoperative levels of neurological functionality within 6 months of surgery [4]. In addition to tumor-related factors, surgical variables such as the extent of cord manipulation and commonality of surgical complications, including dural leaks and wound infections, may further negatively impact postoperative morbidity [4, 11, 12].

In this context, minimally invasive spine surgery (MISS) has emerged as a novel surgical strategy to mitigate the aforementioned surgical risks while also limiting disruption to the paraspinal musculature and operative stress on the spinal cord [13, 14]. While MISS has been thoroughly researched for more common spinal pathologies such as stenosis, disc herniation, and extradural and intradural extramedullary spinal tumors, its application to IMSCTs is less explored due to the rarity of these lesions. Thus, the majority of available evidence of the technique's feasibility for IMSCTs is limited to retrospective case series and case reports. The goal of this review is to synthesize all the available literature on MISS approaches for IMSCT resection to better understand the field's current outlook regarding surgical techniques, perioperative outcomes, neurological results, and complications.

Methods

Search strategy

The search strategy for this review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [15]. A literature search was conducted across PubMed, CINAHL, Cochrane Trials, and Scopus from inception up to November 19, 2025. A combination of appropriate MeSH terms and keywords was adapted to the indexing system of each database, including terms related to intramedullary spinal pathology (e.g., *intramedullary*, *spinal cord*), tumor histology (e.g., *ependymoma*, *astrocytoma*, *hemangioblastoma*), and surgical approach (e.g., *minimally invasive*, *endoscopy*). The full search queries used are provided in **Supplementary Table 1**. Two authors (N.A. and D.M.) reviewed each title and abstract and subsequently conducted full-text screenings using Rayyan (Rayyan Systems Inc., Cambridge, MA) to allow for collaborative efforts between authors. The protocol for this study was not registered in PROSPERO or any other registry.

Eligibility criteria

The primary outcomes of this review were the characterization of MISS approaches for IMSCT resection and assessment of feasibility and safety, as reflected by extent of surgical resection and postoperative neurological outcomes. Secondary outcomes included operation duration, estimated blood loss (EBL), length of hospital stay (LOS), recurrence, and reported survival outcomes.

MISS was operationally defined in this review as surgical approaches intended to minimize disruption to posterior stabilizing structures, paraspinal musculature, and surgical exposure relative to traditional open laminectomy approaches. According to this definition, tubular retractor-based techniques, muscle-sparing laminotomies, split laminotomy approaches, and other posterior bone- or muscle-preserving techniques were considered minimally invasive approaches.

Studies were eligible for inclusion if they: (1) reported the use of a MISS technique for the resection of IMSCTs; (2) provided data on the prespecified primary outcomes and at least one secondary outcome of interest; and (3) were clinical studies of any design, including randomized controlled trials, prospective or retrospective cohort studies, case series, or case reports. Studies were excluded if they: (1) did not involve true neoplastic intramedullary pathology (e.g., arachnoid cysts, arteriovenous malformations, or other non-tumor lesions); (2) were non-human or cadaveric studies; (3) were narrative reviews, editorials, technical notes without patient-level data, or conference abstracts without full-text availability; or (4) lacked sufficient operative or clinical outcome data to permit meaningful assessment.

Data extraction and analysis

Data extraction was independently performed by two authors (N.A. and D.M.) using a standardized Microsoft Excel table. The variables collected included: study characteristics, patient demographics, tumor histology and location, surgical approach and minimally invasive technique, extent of resection, operative time, estimated blood loss (EBL), use of intraoperative neuromonitoring, baseline and

postoperative neurological outcomes, complications, length of hospital stay (LOS), and duration of follow-up. Total sample size and proportions of tumor types, patient sex distribution, and extents of tumor resections were calculated using basic descriptive equations in Microsoft Excel. Given the heterogeneity in study design, populations, and reported outcomes, results were synthesized descriptively rather than through formal meta-analysis.

Risk of bias assessment

The quality of the included studies was independently assessed by two authors (N.A. and D.M.) using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Case Reports and the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Case Series [16, 17].

Results

Study selection

The literature search yielded 802 studies across the four databases. After the removal of 320 duplicates, 482 studies underwent title and abstract screening. Full-text screening was conducted for 22 studies. Of those, 11 were included in this study [18–28]. A PRISMA flow diagram outlining this process in detail is provided in Fig. 1. Baseline study characteristics and outcomes are reported in Table 1.

Study quality assessment

Quality assessment demonstrated favorable methodological quality among the included studies. All seven case series satisfied at least 9 of the 10 JBI quality appraisal domains, with the most common limitation being incomplete reporting of presenting site demographic information (Q9) (**Supplementary Table 2**). Among the four included case reports, all studies satisfying at least 6 of 8 JBI criteria (**Supplementary Table 3**). The most frequently unmet criterion was reporting of adverse or unanticipated events (Q7).

Patient and tumor characteristics

A total of 222 patients with IMSCTs were included in the analysis. Sex was reported for 221 patients, of whom 117 (52.9%) were male. The age range of the pooled cohort was 11–72 years, representing a predominantly adult population. For studies reporting mean ages [19, 22, 23, 25], values generally remained in the 40s and 50s. In total, 223 tumors were reported, as one patient presented with two lesions.

Ependymoma was the most frequently treated tumor type, comprising 92 of 223 tumors (41.3%), followed by astrocytoma (72 tumors, 32.3%) and hemangioblastoma (37 tumors, 16.6%) (Table 2). Less common pathologies included cavernous hemangioma ($n=9$, 4.0%), schwannoma ($n=3$, 1.3%), and hamartoma ($n=3$, 1.3%). Single cases were observed for meningioma, lipoma, primitive neuroectodermal tumor, ganglioma, neuroma, intradural teratoma, and intramedullary inclusion tumor (each $n=1$, 0.4%). The cervical spine was the most common tumor location (74 of 223 tumors, 33.2%), followed by the thoracic region (69 tumors, 30.9%), the cervicothoracic junction (39 tumors, 17.5%), and the lumbosacral region (36 tumors, 16.1%) (Table 2). Thoracolumbar ($n=3$, 1.3%) and lumbar-only ($n=2$, 0.9%) involvement were rare.

Surgical approaches

Across the included studies, the most common method for IMSCT resection was a posterior tubular retractor-based approach (Table 1; Fig. 2A) [18–22, 25–27]. Both fixed, non-expandable tubular retractors [18, 21, 22], most commonly the METRx system (Medtronic, Minneapolis, MN, USA), and expandable tubular systems [19, 21, 24, 25], commonly the MAST QUADRANT retractor (Medtronic, Memphis, TN), were used to establish the surgical window. Retractors were placed through a small paramedian or midline skin incision following serial dilation and docked over the target lamina or interlaminar space. The MISS exposure typically involved a limited hemilaminectomy [18–20, 22, 25–27] or laminotomy [21] under microscopic visualization, followed by a linear durotomy performed within the confines of the tubular corridor. Tumor resections were done using standard microsurgical techniques, with bipolar coagulation and suction typically used for hemostasis [18, 22, 26]. Adjunctive hemostatic agents were employed at the surgeons' discretion [18]. Dural closures were done in a watertight fashion, most commonly using interrupted [18] or running [25, 26] fine nonabsorbable sutures, with dural sealants generally applied [18, 20, 22, 25, 26]. Skin incisions were systematically reported to be less than 4 centimeters in length [20–22, 25, 27].

Three studies utilized non-tubular retractor techniques. Two of these described posterior approaches that preserve muscular structures via a midline or paramedian spinous process-splitting laminotomy. In the midline laminotomy technique (Fig. 2B) described by Banczerowski et al. (2008), the spinous processes were divided longitudinally using Cloward-type retractors [28]. The intramedullary lesions were addressed through a midline durotomy under

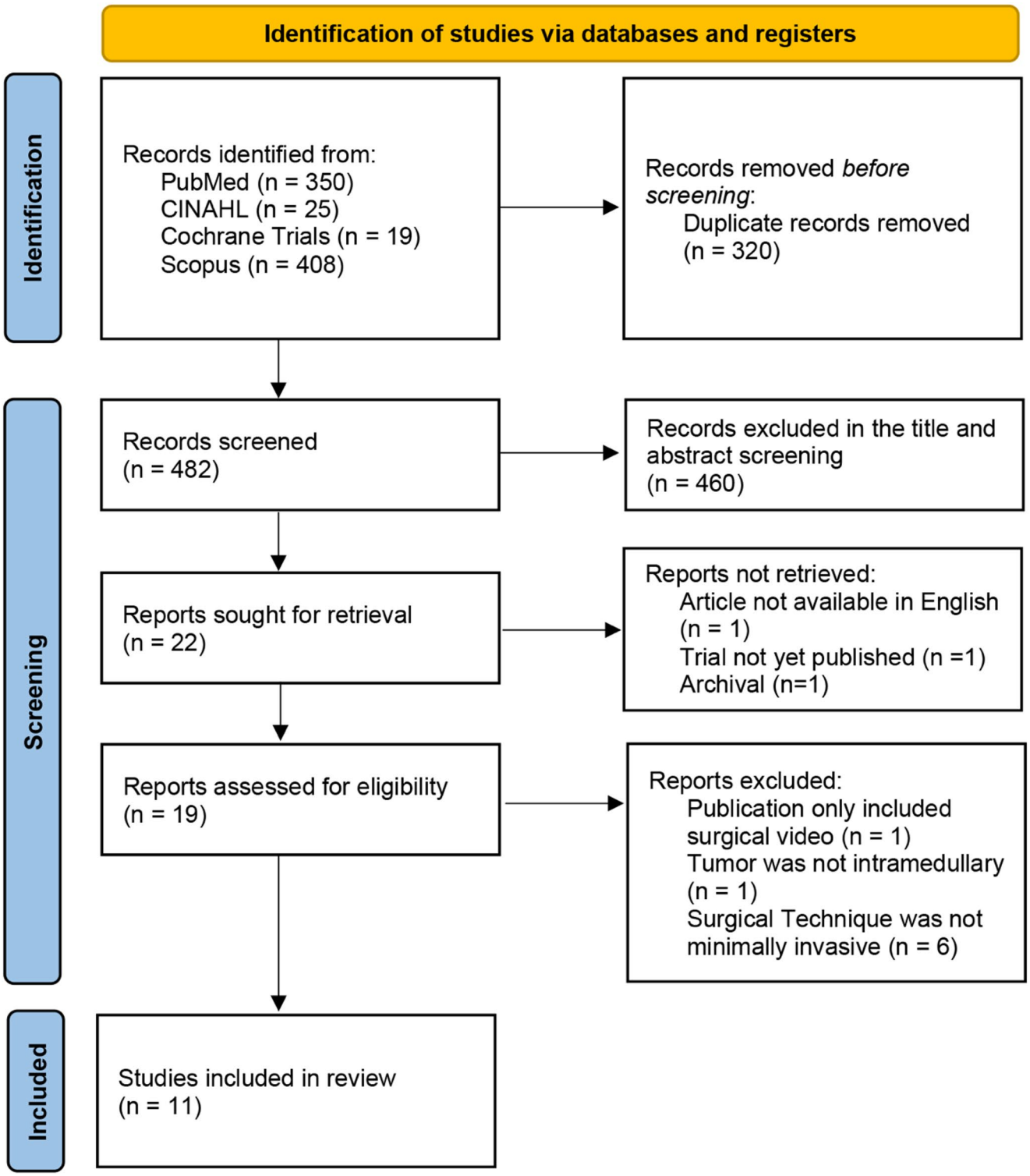

Fig. 1 PRISMA flow diagram detailing the study identification, screening, eligibility, and inclusion process for studies reporting minimally invasive approaches to intramedullary spinal cord tumors

microscopic visualization. The split laminae were either rejoined directly or maintained in a distracted position using iliac crest autografts to increase canal diameter. In the para-split laminotomy technique (Fig. 2C) described by Padányi et al. (2011), the spinal canal was opened in the parasagittal plane using a similar distraction technique to create an operating window [23]. Li et al. (2013) described a posterior minimally invasive hemilaminectomy, performed similarly

Table 1 Baseline study characteristics and outcomes for studies reporting minimally invasive resection of IMSCTs

Study	Study Type	Sample Size (*N*)	Male (*N*)	Age (years)[a]	Tumor Histology	Tumor Level	Approach	Complications	Baseline Neurological Status[b]	Postoperative Neurological Status	Tumor Recurrence
Tarabay et al., 2022 [18]	Case report	1	1	42	Ependymoma (1)	Cervical (1)	Tubular / Non-expandable	None	Progressive gait imbalance, impaired hand prehension, bilateral intrinsic and flexor digitorum profundus weakness (2/5), mild lower-extremity spasticity; modified McCormick grade IV	Continued neurological recovery without residual deficits or cervicothoracic kyphosis	None
Yüce et al., 2021 [19]	Retrospective case series	168	91	43 (11–67)	Ependymoma (79); Astrocytoma (61); Hemangioblastoma (19); Cavernoma (4); Hamartoma (3); Ganglioma (1); Neuroma (1)	Cervical (43); Cervicothoracic (32); Thoracic (57); Lumbosacral (36)	Tubular / Quadrant	Wound infection (2)	McCormick grade I (63), II (78), III (20), IV (6), V (1); presenting symptoms: radicular pain (119), back pain (101), paresis (72), sensory deficit (67), bladder dysfunction (23)	McCormick grade I (149), II (13), III (6); neurological deterioration in 7 patients at a mean follow-up of 37 ± 29 months; better outcomes in cervical vs. thoracic tumors and increased worsening in tumors involving > 3 spinal segments	None
Yaghi et al., 2021 [20]	Case report	1	1	26	Lipoma (1)	Thoracic (1)	Tubular / Quadrant retractor	Expected postoperative pseudomeningocele (1)	Chronic low back pain with subacute ascending bilateral sensory loss to the waist and fingers; no bowel or bladder dysfunction; exam notable for sensory deficits below the waist with preserved strength, hyperreflexia, and EMG/NCS consistent with sensory polyneuropathy	Marked sensory improvement postoperatively with complete resolution of numbness by 2 weeks and full resolution of sensory symptoms and gait disturbance by 3 months	NR
Soriano Sánchez et al., 2020 [21]	Retrospective case series	2	0	60; 59	Hemangioblastoma (1); Astrocytoma (1)	Cervical (1); Thoracic (1)	Tubular / Non-expandable ("keyhole")	NR	Hemangioblastoma (Frankel grade A); Astrocytoma (Frankel grade B); Astrocytoma (Frankel grade C)	Hemangioblastoma (Frankel grade B); Astrocytoma (Frankel grade C)	NR
Krüger et al., 2019 [22] [c]	Retrospective case series	15	6	44.7 (20.0–72.4)	Hemangioblastoma (16)	Cervical (12); Thoracic (4)	Tubular / Quadrant retractor	None	McCormick grade I (7); II (3); III (4); IV (1)	McCormick grade I (7); II (5); III (1); IV (2)	NR
Padanyi et al., 2014 [23]	Retrospective case series	5	2	54 (48–64)	Ependymoma (2); Astrocytoma grade II (2); Primitive neuroectodermal tumor (PNET) (1)	Cervical (2); Cervicothoracic (3)	Split / para-split laminotomy	None	McCormick grade I (2); II (3)	McCormick grade I (2); II (3)	NR

Table 1 (continued)

Study	Study Type	Sample Size (*N*)	Male (*N*)	Age (years)[a]	Tumor Histology	Tumor Level	Approach	Complications	Baseline Neurological Status[b]	Postoperative Neurological Status	Tumor Recurrence
Li et al., 2013 [24]	Case report	1	NR	42	Schwannoma (1)	Thoracic (1)	Minimally invasive hemilaminectomy	NR	Progressive right-sided thoracic sensory disturbance with bilateral lower-extremity weakness and numbness for 1.5 years, followed by acute dysuria and paralysis for 1 week; examination revealed impaired superficial sensation, muscle strength grade 2, and a positive Babinski sign	Complete resolution of thoracic sensory symptoms by 6 months with partial improvement of lower-extremity weakness and numbness; bowel and bladder function fully recovered by 18 months	No radiographic recurrence on MRI at 3, 6, 12, and 18 months
Kwak et al., 2012 [25]	Retrospective case series	8	3	50.3 (32–65)	Schwannoma (2); Astrocytoma (1); Ependymoma (1); Meningioma (1); Cavernous hemangioma (3)	Cervical (8)	Tubular / Quadrant retractor	NR	McCormick scale: 2.1 ± 0.4 (1–3)	McCormick scale: 1.5 ± 0.8 (1–3).	NR
Haji et al., 2011 [26]	Retrospective case series	2	2	72; 54	Intradural teratoma (1); Intramedullary inclusion tumor (1)	Lumbar (2)	Tubular / Quadrant retractor	None	Intradural teratoma: severe back and bilateral leg pain; wheelchair-dependent paraparesis with distal weakness and sensory loss. Intramedullary inclusion tumor: back and left leg pain; cane-dependent spastic paraparesis with distal sensory deficits	Intradural teratoma: improved strength with cane-assisted ambulation; persistent back and right leg pain with left foot paralysis. Intramedullary inclusion tumor: minimal buttock pain, mild spastic paraparesis, and independent ambulation.	Intradural teratoma: Symptomatic recurrence requiring open reoperation; Intramedullary inclusion tumor: none

Table 1 (continued)

Study	Study Type	Sample Size (*N*)	Male (*N*)	Age (years)[a]	Tumor Histology	Tumor Level	Approach	Complications	Baseline Neurological Status[b]	Postoperative Neurological Status	Tumor Recurrence
Ogden and Fessler, 2009 [27]	Case report	1	1	46	Ependymoma (1)	Thoracic (1)	Tubular / Unspecified	None	History of mild upper back pain; involved in motor vehicle accident prompting ER presentation	mild T5 sensory level; Ambulated on postoperative day 1.	No
Banczerowski et al., 2008 [28] [d]	Retrospective case series	18	10	48 (32–64)	Astrocytoma (7; Grade I (1), Grade II (4), Grade III (2)); Ependymoma (8); Cavernous hemangioma (2); Hemangioblastoma (1)	Cervical (7); Cervicothoracic (4); Thoracic (4); Thoracolumbar (3)	Split laminotomy	Iliac crest wound pain (2), dural tear (1)	McCormick grade I (7); II (9); III (2)	McCormick grade I (10); II (4); III (4)	NR

[a] Age was reported heterogeneously across studies. For case reports or case series with only 2 patients, singular age values are reported. For larger series, values are represented as means with range

[b] Neurological status was assessed using standardized functional scales when available (e.g., McCormick or Frankel classifications) or descriptive clinical reporting when standardized scales were not provided

[c] In Krüger et al. (2019), a total of 16 tumors were treated in 15 patients, as one patient presented with two intramedullary hemangioblastomas. Tumor counts, rather than patient counts, are reported where applicable

[d] In Banczerowski et al. (2008), one patient with a dural arteriovenous malformation (AVM) was excluded from tumor-specific outcome analyses. However, age was reported as an aggregate value for the entire cohort

Table 2 Pooled tumor characteristics and surgical resection outcomes for studies reporting minimally invasive resection of IMSCTs

Category	Variable	n (%) [$n=223$]
Tumor Histology	Ependymoma	92 (41.3)
	Astrocytoma	72 (32.3)
	Hemangioblastoma	37 (16.6)
	Cavernous hemangioma	9 (4.0)
	Schwannoma	3 (1.3)
	Hamartoma	3 (1.3)
	Other rare histologies[a]	4 (1.8)
Tumor Location	Cervical spine	74 (33.2)
	Thoracic spine	69 (30.9)
	Cervicothoracic junction	39 (17.5)
	Lumbosacral region	36 (16.1)
	Thoracolumbar	3 (1.3)
	Lumbar only	2 (0.9)
Extent of Resection	Gross total resection (GTR)	195 (87.4)
	Subtotal resection (STR)	19 (8.5)
	Partial resection	9 (4.0)

Values represent pooled tumor-level data aggregated across all included studies

[a] Other rare histologies include meningioma, lipoma, primitive neuroectodermal tumor, ganglioma, neuroma, intradural teratoma, and intramedullary inclusion tumor (each $n=1$)

to the tubular retractor-based approach [24]. Tumor resection was performed microscopically through a 2 × 2-centimeter bone window.

Operative and perioperative outcomes

Across 223 tumors, gross total resection (GTR) was achieved in 195 cases (87.4%), subtotal resection (STR) in 19 cases (8.5%), and partial resection in 9 cases (4.0%) (Table 2). Seven studies reported operative duration [18, 21–23, 25, 26, 28]. Five of these studies were tubular retractor-based, with the shortest operation being 150 min (Haji et al., 2011) and the longest being 300 min (Tarabay et al., 2022). Non-tubular studies reported similar operation times. Seven studies reported blood loss and uniformly indicated low intraoperative blood loss [18, 21–23, 25, 26, 28]. For tubular retractor-based approaches, EBL remained under 200 mL for all studies, with the minimum reported value being 60 mL (Haji et al. (2011); Kwak et al. (2012) range 60–80 mL). The maximum value seen (442 mL) was in a non-tubular approach, which was an outlier in the Banczerowski et al. (2008) series.

Eight studies reported LOS, with a range of 2–14 days across studies [18–22, 26–28]. Postoperative analgesic requirements were infrequently reported [18, 26, 27]. Ogden and Fessler (2009) noted minimal initial narcotic requirements, with complete discontinuation by postoperative day 2. In contrast, Haji et al. (2011) reported higher opioid requirements in a two-patient case series, including one patient with pre-existing chronic opioid use who required substantially greater postoperative opioid dosing, while the second patient required more modest analgesic support. Among the 8 studies that reported complication data, 5 reported no perioperative complications [18–20, 22, 23, 26–28]. Of the three studies that documented complications, two used tubular retractor-based approaches [19, 20]. Yüce et al. (2021) reported wound infection in 2 of 168 patients (1.2%), and Yaghi et al. (2021) observed an expected postoperative pseudomeningocele in their one patient without further sequelae. In the non-tubular paper that mentioned complications, Banczerowski et al. (2008) reported iliac crest donor-site pain in 2 of 18 patients (11.1%) and a single dural tear in 1 patient (5.6%). A summary of operative and perioperative outcomes is provided in Table 3.

Patient outcomes

Preoperative and postoperative neurological function was reported across all included studies, although assessment methods varied (Table 1). Larger case series primarily used the McCormick scale, a standardized neurological grading scale for spinal cord tumors that ranges from McCormick grades range from Grade I (neurologically intact or mild deficits with full independence) to Grade V (severe disability with paraplegia or quadriplegia and complete dependence) [29]. In contrast, smaller series and case reports relied on descriptive neurological assessments [20, 24, 26, 27]. Studies employing the McCormick scale demonstrated a broad spectrum of baseline neurological severity [18, 19, 22, 23, 25, 28]. In the largest tubular retractor-based cohort, Yüce et al. (2021) documented preoperative McCormick grades ranging from I to V, with common presenting symptoms such as radicular pain, back pain, paresis, sensory deficits, and bladder dysfunction.

In terms of postoperative neurological outcomes, Yüce et al. (2021) reported a significant shift toward lower McCormick grades, with most patients classified as grade I or II. Neurological deterioration was observed in 7 patients (4.2%) at long-term follow-up, particularly in cases involving thoracic lesions and tumors spanning more than three spinal segments. Kwak et al. (2012) documented a reduction in the mean McCormick score from 2.1 ± 0.4 preoperatively to 1.5 ± 0.8 postoperatively. Similar distributions were observed in non-tubular retractor studies as well, with Padányi et al. (2014) and Banczerowski et al. (2008) also reporting postoperative neurological grades mostly around McCormick grades I-II.

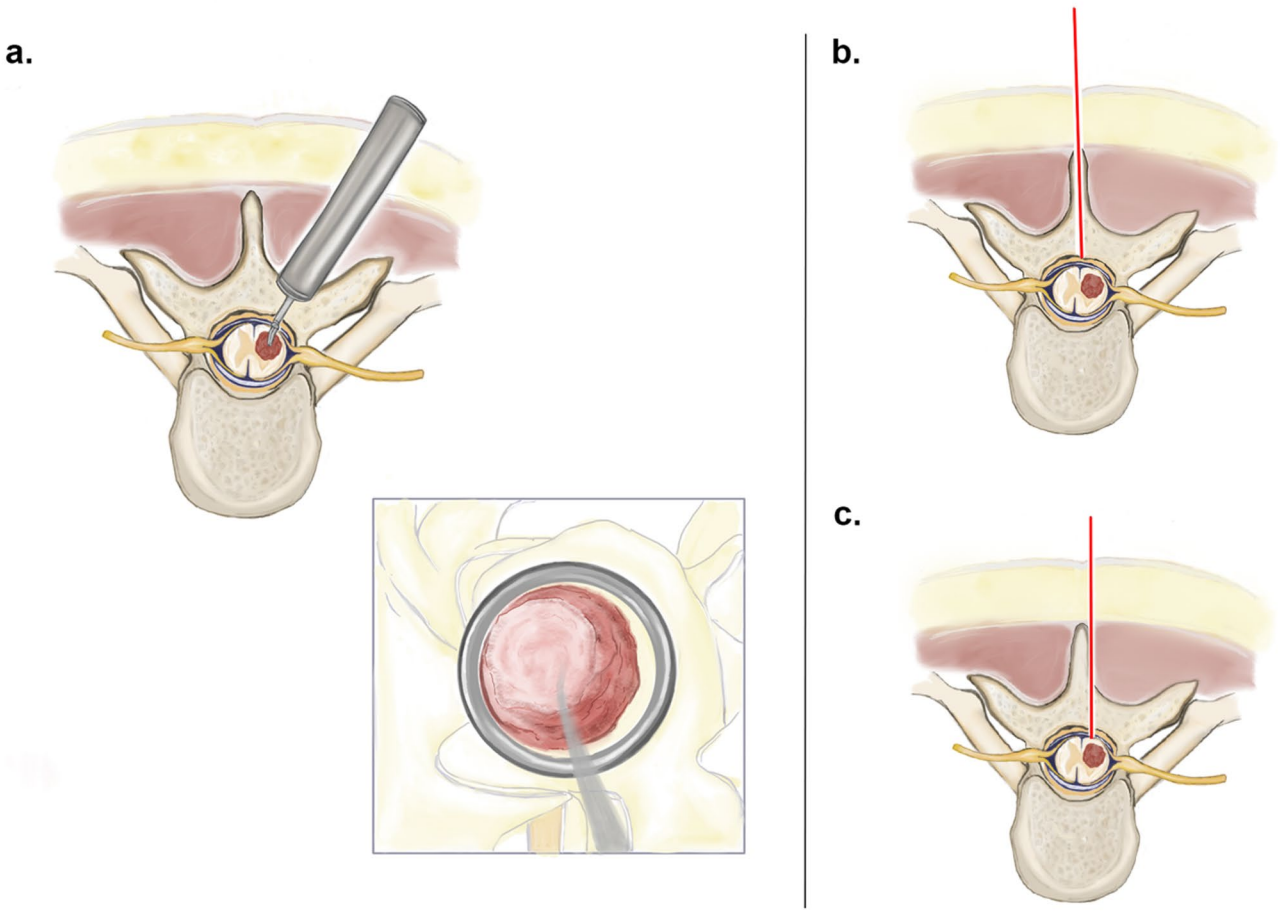

Fig. 2 Minimally invasive surgical approaches for intramedullary spinal cord tumors. **(a)** Posterior tubular retractor-based approach. **(b)** Trajectory of non-tubular midline split laminotomy. **(c)** Trajectory of non-tubular para-split laminotomy. Created with Procreate (Savage Interactive)

Recurrence and survival

Of the 5 studies that addressed recurrence, only one documented a recurrence (Table 3) [19, 20, 24, 26, 27]. Haji et al. (2011) described symptomatic recurrence in 1 of 2 patients, characterized by recurrent lower-extremity pain and a substantial residual lesion (approximately 75%) on postoperative MRI at 18 months, necessitating reoperation through an open approach. Only Yüce et al. (2021) presented survival data, indicating no mortality at 30 days (0/168; 0%). No studies reported long-term progression-free survival (PFS) or overall survival (OS) outcomes.

Discussion

In this systematic review of 11 studies, MISS approaches for the resection of IMSCTs were synthesized and described across the available literature. Tubular retractor-based approaches were the most common approach, with fewer reports of non-tubular laminotomies. The data suggest that these posterior minimally invasive techniques are feasible and can be applied to a variety of tumor types, lesion levels, and patient demographics. The MISS approaches described in the current study were generally associated with limited blood loss, hospital stay, and complications. GTR was often achieved, and recurrence was uncommon, although follow-up durations were generally minimal.

Conventional open approaches have historically been used for their ability to provide a wide visualization of the spinal cord and spinal anatomy [29–32]. However, this exposure comes at the cost of extensive paraspinal muscle

Table 3 Summary of minimally invasive surgical approaches and reported perioperative and clinical outcomes for studies reporting minimally invasive resection of IMSCTs

Category	Outcome Variable	Summary of Findings	Total Tumors or Total Cases assessed	Studies Reporting (*n*/*N*)
Surgical Approach	Posterior tubular retractor-based	Most frequently reported approach (fixed or expandable tubular systems)	199 tumors	8/11
	Non-tubular laminotomy techniques	Split or para-split laminotomy; minimally invasive hemilaminectomy	24 tumors	3/11
Operative / Perioperative Outcomes	Operative time	Reported range: 150–300 min	52 patients	7/11
	Estimated blood loss	Reported range: 60–442 mL; Typically < 200 mL	52 patients	7/11
	Length of hospital stay	Reported range: 2–14 days	209 patients	7/11
Complications	No complications reported	No perioperative complications described	25 patients	5/11
	Wound infection	2 cases (1.2%)	168 patients	1/11
	CSF-related complications	1 pseudomeningocele	1 patient	1/11
Recurrence & Survival	Tumor recurrence	1 documented recurrence requiring reoperation	172 tumors	5/11
	Survival outcomes	No 30-day mortality reported	168 patients	1/11

dissection and bony removal, which disrupts the posterior stabilizing structures of the spine [33, 34]. Disruption of these structures can increase the risk of postoperative kyphosis, which necessitates the need to discuss arthrodesis and future surgery postoperatively with the patient [32, 35]. Still, not every patient is a surgical candidate for minimally invasive removal of an IMSCT, and because surgery remains the mainstay treatment for IMSCTs [36], determining which tumors are suitable for MISS (and which are better approached traditionally) becomes an important topic of discussion.

Determining MISS compatibility for IMSCTs

Based on the literature included in this review, determining whether an IMSCT is amenable to a MISS approach largely begins with careful evaluation of tumor location, size, and longitudinal extent. Most MISS studies included tumors that were small (generally < 20 mm in length), were dorsally located, and involved less than three spinal levels. The combination of these features favors complete visualization and resection of a lesion through a small dorsal or dorsolateral corridor (i.e. a tube or boney window). And although applicable to all IMSCT surgical approaches, MRI evaluation supported a MISS approach when lesions had well-defined margins that permitted microsurgical resection. Histologically, tumors with these characteristics are those that are often well-circumscribed and non-infiltrative [1]. For example, ependymomas tend to have a capsule allowing for an easier removal, and hemangioblastomas are discretely nodular and generally a few centimeters in size [37, 38]. Notably, these tumors were of the most included among studies and are associated with high rates of GTR [39, 40]. On the other hand, glioblastomas, for example, are much more challenging to resect because of their highly infiltrative nature and are associated with poor survival outcomes [41].

A conceptual clinical framework derived from the patterns observed in the current systematic review regarding favorability of MISS versus open surgery is provided in Fig. 3. Current data does not define clear tumor size cutoffs and histological criteria that determine suitability for MISS. These features are reported descriptively across studies, and selection remains individualized based on a combination of tumor characteristics and surgical judgement. Future studies are needed to establish standardized size thresholds and histological predictors that can guide surgical approach selection.

Existing literature on IMSCTs commonly report average sizes to be between 30 mm and 50 mm in length, and ependymomas and astrocytomas typically span three to six spinal levels [1, 42, 43]. This data supports that preferential selection of a specific tumor characteristics is necessary to produce the outcomes reported in the included MISS studies. Longer-segment IMSCTs are also more often reported to be more vascular and invasive [44]. Generally, tumors such as these require great manipulation of the spinal cord and broad exposure to safely perform myelotomy and manage bleeding or tumor adherence, making traditional open surgical approaches preferred in most IMSCT cases [45]. The limited visualization afforded by MISS in long-segment cases may also increase the likelihood of residual tumor burden, which can negatively impact recurrence, progression-free survival, and overall survival. In one of the largest available surgical series of IMSCTs, 253 patients undergoing traditional microsurgical resection demonstrated 10-year

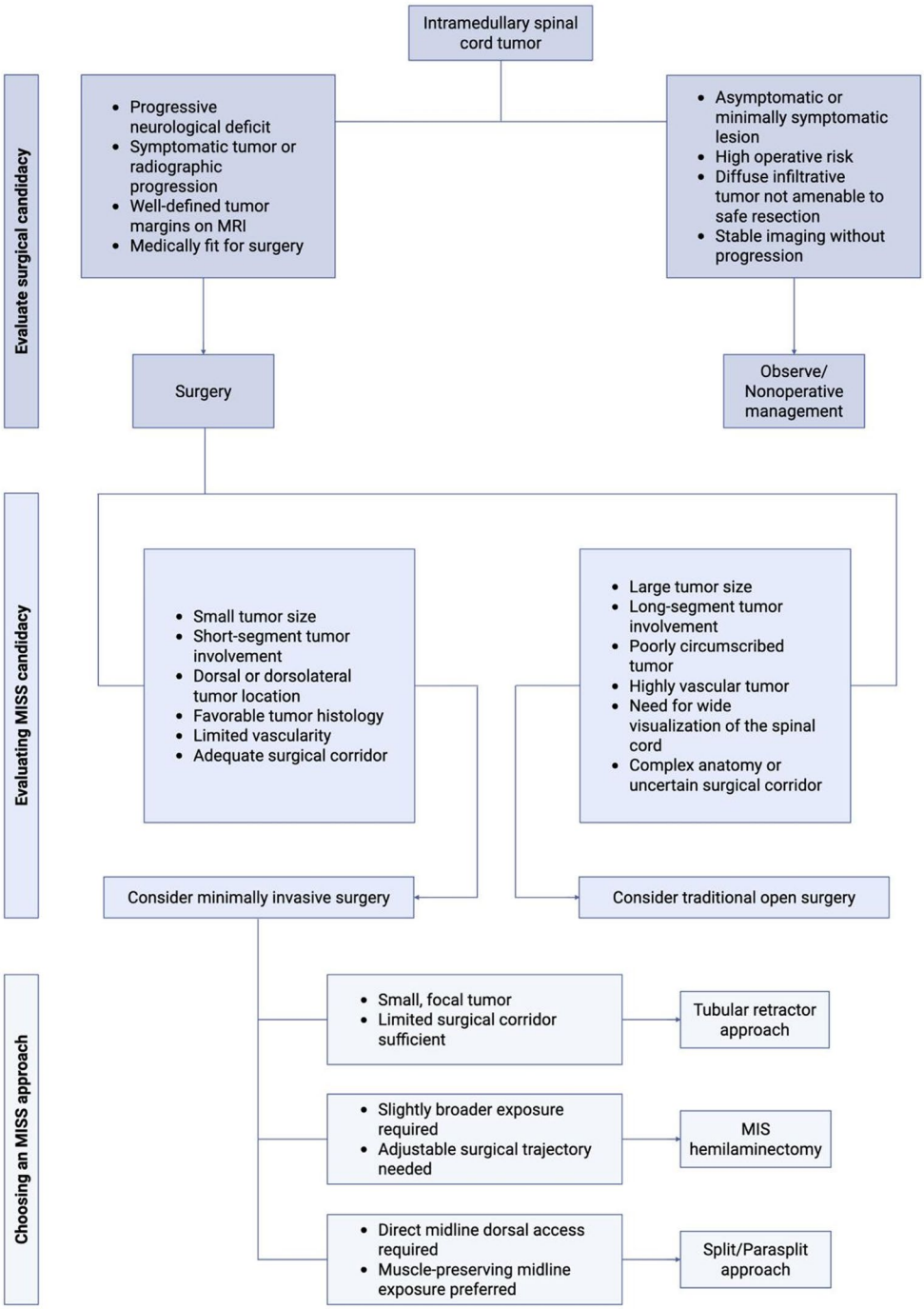

Fig. 3 Proposed framework for selecting minimally invasive spine surgery for intramedullary spinal cord tumors. This schematic summarizes factors identified in the included studies that may guide selection of MISS versus open approaches and is intended as conceptual guidance rather than a definitive clinical guideline Created in BioRender. Al-Saidi, N. (2026) https://BioRender.com/a397afz.

overall survival rate of 84.7% for low-grade tumors and 21.9% high-grade tumors [46]. However, data evaluating the impact of MISS on these outcomes remain unavailable.

Notably, in papers reporting on traditional surgical outcomes for IMSCT resection, longer segment involvement, higher tumor grade, and longer tumor length are all negative predictors of outcomes and GTR [19, 43, 47]. If future comparative studies between MISS and traditional approaches do not control for these variables, it will be difficult to determine whether reported outcomes reflect the benefits of MISS or simply more favorable tumor characteristics. Of all the studies included in this review, only Kwak et al. (2012) included a comparator cohort of patients who underwent open laminotomy. Skin incision size, blood loss, and muscle atrophy rate at two-year follow-up were found to be significantly smaller in the MISS group, and no statistical analysis was done for extent of resection and postoperative

outcomes because controlling for the aforementioned tumor characteristics was not possible given the sample size [25].

Determining MISS surgical approach for IMSCTs

The use of a specific MISS technique may be advantageous in certain clinical scenarios (Fig. 3). Still, surgeon experience and technical comfort arguably play the most important role in the selection of a surgical approach. MISS techniques require great skill and often introduce steep learning curves for surgeons [48, 49]. Although studies have not specifically evaluated the learning curve of MISS for IMSCT surgery, MISS studies often report that completing > 30 high-complexity MISS cases is needed before reaching a plateau in efficiency and complications. In addition to procedural familiarity, institutional resources and surgeon preference are likely to influence the adoption of these techniques. Looking forward, novel technological advancements in virtual reality-based preoperative planning, intraoperative use of augmented reality, and artificial intelligence may help reduce the MISS learning curve for IMSCT surgery [50–52].

Limitations

Several limitations should be considered when interpreting the findings of this review. The rarity of the condition resulted in evidence primarily from retrospective case series and case reports with small sample sizes, rendering the data susceptible to selection bias, reporting bias, and uncontrolled confounding. The absence of a standardized definition for minimally invasive surgical techniques created variability in operative techniques among the included studies. When screening the literature, each manuscript required detailed evaluation to determine whether the described technique met inclusion criteria for a minimally invasive approach, which introduces potential misclassification bias. For this study, minimally invasive surgery was understood broadly as procedures aimed at minimizing disruption to posterior stabilizing structures, which necessitated the inclusion of muscle- and bone-preserving non-tubular approaches such as those described by Banczerowski et al. (2008), Padányi et al. (2014), and Li et al. (2013) for completion. Heterogeneous neurological assessment methods and variable or inadequately reported follow-up are important limitations to note, which restricted comparisons and assessment of long-term neurological, structural, and oncologic outcomes between studies.

Conclusion

The findings of our study suggest that MISS approaches for IMSCT resection are feasible in select cases and can be performed using a range of posterior muscle- and bone-sparing techniques. Across the retrospective case studies and series, MISS approaches were generally associated with minimal complications and stable or improved postoperative neurological function. Favorable outcomes reported in MISS studies likely reflect both technical advantages and underlying selection of tumors with anatomical and histological characteristics that favor a successful MISS approach. However, while MISS may reduce tissue disruption and perioperative morbidity, its adoption remains influenced by surgeon experience and skill. Direct comparison to traditional open procedures is limited and should be explored in future studies.

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Author contributions Rafael De la Garza Ramos, Nadir Al-Saidi, and Ali Haider Bangash contributed to the study conception and design. Nadir Al-Saidi and Dina Mohammed conducted the literature search. Material preparation, data collection, and analyses were performed by Nadir Al-Saidi, Dina Mohammed, and Zainab Fatima. The first draft of the manuscript was written by Nadir Al-Saidi and Dina Mohammed. Zainab Fatima illustrated the artwork accompanying the manuscript. All authors commented on and provided edits to previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interests Dr. De la Garza Ramos reports research support to his institution from CarboFix Spine. None of the other authors have any relevant conflict of interest.

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