

Minimally Invasive Surgery for Intradural Extramedullary Spinal Tumors: A Comprehensive Review with Illustrative Clinical Cases

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ABSTRACT

Intradural extramedullary spinal tumors have recently been successfully treated via minimally invasive surgical approaches. Many studies have shown good results with benefits over traditional open surgery. The authors reviewed the literature to find all studies involving minimally invasive resection of intradural extramedullary spinal tumors through the use of a tubular retractor system. Nine studies were found for a total of 114 patients with reported mean ages from 46.5 to 63.8 years and follow-up times from 1.5 months to 24 months. Studies reported their gross-total resection rates (range, 75-100%), mean operative time (range, 184.9-256.3 min), mean estimated blood loss (range, 56-238.8 ml), and hospital length of stays (range, 2.4-6.9 days). The most common surgery-related complication was CSF leak or pseudomeningocele in 6 patients (5.3%) of which 4 patients (3.5%) required a reoperation. Minimally invasive surgery for the resection of intradural extramedullary tumors is safe and effective, and offers a reduction in operative blood loss, lower risk of cerebrospinal fluid leak, and shorter hospital stay for select patients.

KEY WORDS: Intradural extramedullary spine tumors, MIS, minimally invasive spine surgery, spinal neoplasms

INTRODUCTION

Intradural extramedullary tumors are rare, affecting about 5 to 10 for every 100,000 people (12,25,37,48,64). The most common histology of these tumors are benign, typically meningiomas and nerve sheath tumors such as schwannomas and neurofibromas (59). Excellent outcomes have been demonstrated following complete surgical resection, which is a primary goal in treatment (28).

Historically, these tumors have been resected using a traditional midline incision for posterior bilateral laminectomies or hemilaminectomies. Recently, minimally invasive surgery (MIS) techniques with expandable or nonexpandable tubular retractors have been explored for spinal tumor excision for the purposes of reducing blood loss, soft-tissue injury, and hospital stays. Compared to traditional open spine surgery, MIS techniques are generally

performed through paramedian approaches, and they spare the midline ligaments and the contralateral paraspinal muscles with decreased disruption of ipsilateral paraspinal muscles. The resultant decreased in soft tissue void is believed to decrease bleeding, infection, and cerebrospinal fluid leak risks.

In this article, we present 2 illustrative cases from our institution demonstrating surgical resection of intradural extramedullary tumors via a minimally invasive tubular approach along with a comprehensive review of the literature on MIS approaches for the management of this pathology.

MATERIALS AND METHODS

We conducted a comprehensive review of the English medical literature reported through PubMed (from 1967 to August 16, 2015) to find all clinical studies involving

the use of MIS approaches for the resection of intradural extramedullary spinal tumors. Specifically, we defined “minimally invasive” in this article as surgery through the use of an expandable or nonexpandable tubular retractor system. In addition, the reference lists of these articles were subsequently reviewed to identify further English-language studies which may have not been returned on the initial electronic review. Isolated case reports or video reports were excluded. We also excluded any study which described a “minimally invasive” approach for the resection of spinal tumors that did not include use of a tubular retractor system. For example, some studies described open hemilaminectomy or use of a microscope as minimally invasive, which did not fit our definition for this article (19,67). This search protocol was conducted by two reviewers (M.H.P. and K.E.C.).

Articles which met search criteria were further examined for the following parameters: study design, number of patients, age, sex, follow-up time, diagnoses treated, spinal level of pathology treated, type of minimally invasive approach, gross-total resection (GTR) rate, operative time, estimated blood loss (EBL), hospital length of stay (LOS), and all reported surgery-related complications or adverse events with specific attention to cerebrospinal fluid (CSF) leak, wound infection, and reoperation rate.

RESULTS

Nine studies were identified which described the surgical resection of intradural extramedullary spinal tumors via an MIS tubular access corridor (Table 1). Some articles described the MIS approach for the resection of a variety of different spinal tumors inclusive of extradural foraminal

tumors or intramedullary spinal neoplasms (18,29,38); in those cases, the raw data was extracted from their tables to account for only their intradural extramedullary tumor experience. Three articles directly compared their experiences with MIS approach vs. traditional open surgery for the resection of these tumors (Table 2). Published studies ranged in publication year from 2006 to 2015 and all were retrospective reviews. There were a total of 114 patients (58 male, 56 female) who underwent MIS approach resection with reported mean ages from 46.5 years to 63.8 years. Reported mean follow-up time was from 1.5 months to 24 months. Of the 9 studies, 6 described using a unilateral angled hemilaminectomy approach while 3 described use of a midline transspinous orthogonal approach.

The majority of tumors surgically resected were nerve sheath tumors (56 patients), followed by meningiomas (29 patients), ependymomas (15 patients), and other pathologies (18 patients) (Table 3). The location of these tumors was cervical in 7 patients (6.1%), thoracic in 41 patients (36.0%), thoracolumbar in 7 patients (6.1%), lumbar in 61 patients (53.5%), and lumbosacral in 2 patients (1.8%).

Eight of 9 series reported rates of GTR after surgical resection, which ranged from 75% to 100% (Table 4). All articles reported their experience with mean operative time (range, 184.9-256.3 min) and mean EBL (range, 56-238.8 ml), while only 8 of 9 articles discussed their hospital LOS after surgery (range, 2.4-6.9 days). Of the entire aggregate of 114 patients over 9 studies, surgery-related complications after MIS approach for the resection of these spinal tumors were reported as either CSF leak or pseudomeningocele in

Table 1: Studies which utilized minimally invasive surgical approaches with tubular retractor systems for the resection of intradural extramedullary spinal tumors

Study	# Patients (Male/ Female)	Mean Age (Years)	Mean Follow-Up (Months)	Surgical Approach
Tredway et al., 2006 ⁶⁰	6 (4/2)	47	11.3	Unilateral hemilaminectomy
Lu et al., 2010 ³⁰	2 (1/1)	53.5	12	Midline transspinous
Haji et al., 2011 ¹⁸	12 (6/6)	58.2	at least 1.5	Unilateral hemilaminectomy
Lu et al., 2011 ²⁹	18 (6/12)	48	16	Midline transspinous
Mannion et al., 2011 ³¹	11 (7/4)	46.5	15	Unilateral hemilaminectomy
Dahlberg et al., 2012 ⁸	9 (3/6)	63.8	9 to 38	Unilateral hemilaminectomy
Nzokou et al., 2013 ³⁸	4 (2/2)	56	23.3	Unilateral hemilaminectomy
Raygor et al., 2015 ⁴⁸	25 (13/12)	51.3	24	Midline transspinous
Wong et al., 2015 ⁶⁴	27 (16/11)	50.3	16	Unilateral hemilaminectomy

Table 2: Studies directly comparing traditional open vs. minimally invasive surgery techniques, with demographics and data for open cohorts here

Study	# Patients (Male/Female)	# Meningioma	# Nerve sheath tumor	# Ependymoma	# Other	Mean GTR	Mean Op Time (min)	Mean EBL (ml)	Mean LOS (days)
Lu et al., 2011 ²⁹	9 (5/4)	4	2	0	1 epidermoid, 1 hemangioblastoma	100%	273.3	372.2	8.2
Raygor et al., 2015 ⁴⁸	26 (11/15)	6	10	6	4 other	88.5%	218.6	320	7.2
Wong et al., 2015 ⁶⁴	18 (9/9)	5	12	0	1 congenital	94%	241.1	558.8	6.1

GTR = gross-total resection, Op = operative, EBL = estimated blood loss, LOS = length of stay as inpatient hospital setting.

Table 3: Histology and location of intradural extramedullary spinal tumors

Study	# Meningioma	# Nerve sheath tumor	# Ependymoma	# Other	C	T	TL	L	LS
Tredway et al., 2006 ⁶⁰	0	5	1	0	1	1	0	4	0
Lu et al., 2010 ³⁰	2	0	0	0	0	2	0	0	0
Haji et al., 2011 ¹⁸	7	5	1	1 teratoma	2	5	1	6	0
Lu et al., 2011 ²⁹	5	5	3	1 breast metastasis, 1 lipoma, 2 paraganglioma, 1 glioblastoma	0	9	1	8	0
Mannion et al., 2011 ³¹	2	9	2	0	1	6	0	6	0
Dahlberg et al., 2012 ⁸	1	5	3	0	1	1	1	6	0
Nzokou et al., 2013 ³⁸	1	1	0	1 metastasis, 1 plasmacytoma	0	2	0	2	0
Raygor et al., 2015 ⁴⁸	6	10	5	4 other	0	8	4	12	1
Wong et al., 2015 ⁶⁴	5	16	0	2 congenital, 1 paraganglioma, 3 other	2	7	0	17	1

C = cervical, T = thoracic, TL = thoracolumbar, L = lumbar, LS = lumbosacral.

Table 4: Surgical resection, operative characteristics, and hospital length of stay

Study	Mean GTR	Mean Op Time (min)	Mean EBL (ml)	Mean LOS (days)
Tredway et al., 2006 ⁶⁰	100%	247	56	2.4
Lu et al., 2010 ³⁰	100%	225	150	6.5
Haji et al., 2011 ¹⁸	75%	184.9	238.8	3.2
Lu et al., 2011 ²⁹	94%	239	153	4.9
Mannion et al., 2011 ³¹	NR	150	155	3.1
Dahlberg et al., 2012 ⁸	100%	126	222	NR
Nzokou et al., 2013 ³⁸	100%	193.8	181.2	4
Raygor et al., 2015 ⁴⁸	92%	188.9	142	6.9
Wong et al., 2015 ⁶⁴	92.6%	256.3	133.7	3.9

GTR = gross-total resection, Op = operative, EBL = estimated blood loss, LOS = length of stay as inpatient hospital setting, NR = not reported.

6 patients (5.3%), wound infection in 1 patient (0.9%), or wrong-level exposure in 2 patients (1.8%) (Table 5). Of these complications, 4 patients (3.5%) required a reoperation for treatment.

CASE ILLUSTRATIONS

CASE 1

Presentation. A 35-year-old man without any significant past medical history presented with progressive back pain. On subsequent workup with magnetic resonance

imaging (MRI) studies, he was found to have an intradural extramedullary lesion spanning the L1-2 interspace (Figure 1). Neurologically, he otherwise had an intact exam.

Surgery. Proceeding with an MIS approach, a 2.5 cm incision was marked out over the left L1-2 region under fluoroscopic guidance approximately 1.5 cm lateral to the midline to avoid colliding with the spinous process. After skin incision, the fascia was opened sharply. Serial dilators were then placed under fluoroscopic guidance to dilate and

Table 5: Surgery-related complications reported in minimally invasive or open surgery for intradural extramedullary spinal tumors.

Study	Operative Approach		Complication Rate	Reoperation Rate
	MIS	Open		
Tredway et al., 2006 ⁶⁰	None		0%	0%
Lu et al., 2010 ³⁰	None		0%	0%
Haji et al., 2011 ¹⁸	1 CSF leak requiring reoperation		8.3%	8.3%
Lu et al., 2011 ²⁹	1 pseudomeningocele requiring reoperation		5.6%	5.6%
		None	0%	0%
Mannion et al., 2011 ³¹	2 wrong-level exposure (thoracic spine), 1 pseudomeningocele with CSF leak and wound infection treated conservatively, 1 pseudomeningocele		36.4%	0%
Dahlberg et al., 2012 ⁸	None		0%	0%
Nzokou et al., 2013 ³⁸	None		0%	0%
Raygor et al., 2015 ⁴⁸	1 pseudomeningocele requiring reoperation		4.0%	4.0%
		3 CSF leaks (resolving with lumbar drain), 1 wound infection requiring reoperation, 1 epidural hematoma requiring reoperation	19.2%	7.7%
Wong et al., 2015 ⁶⁴	1 CSF leak requiring reoperation		3.7%	3.7%
		1 CSF leak (resolving with lumbar drain), 2 CSF leaks requiring reoperation	16.7%	11.1%

MIS = minimally invasive surgery; CSF = cerebrospinal fluid.

dock them over the left L1 inferior lamina (Figure 2A). Once in good position, the final expandable retractor (Quadrant, Medtronic) was placed and the microscope was subsequently brought in for better visualization (Figure 2B). The remainder of soft tissue and muscle was removed with electrocautery

to expose the base of the L1 spinous process to the upper half of the L2 spinous process. A high-speed drill was then used to perform the ipsilateral hemilaminectomies. Due to the medial angle of the retractor tubing, the contralateral lamina was also decompressed at the inner cortex using

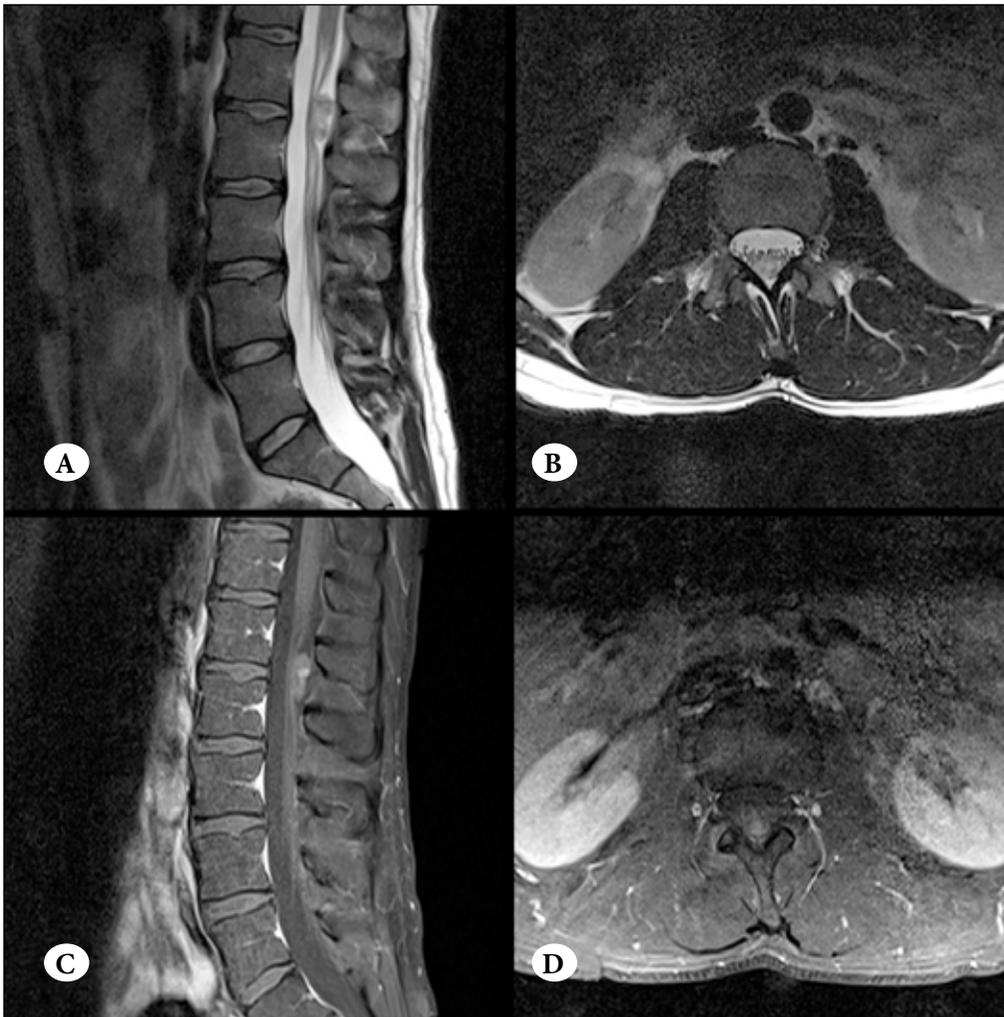


Figure 1: Preoperative T2-weighted MRI in both sagittal (A) and axial (B) dimensions as well as a T1-weighted post-contrast MRI in sagittal (C) and axial (D) dimensions demonstrating the L1-2 intradural extramedullary tumor.

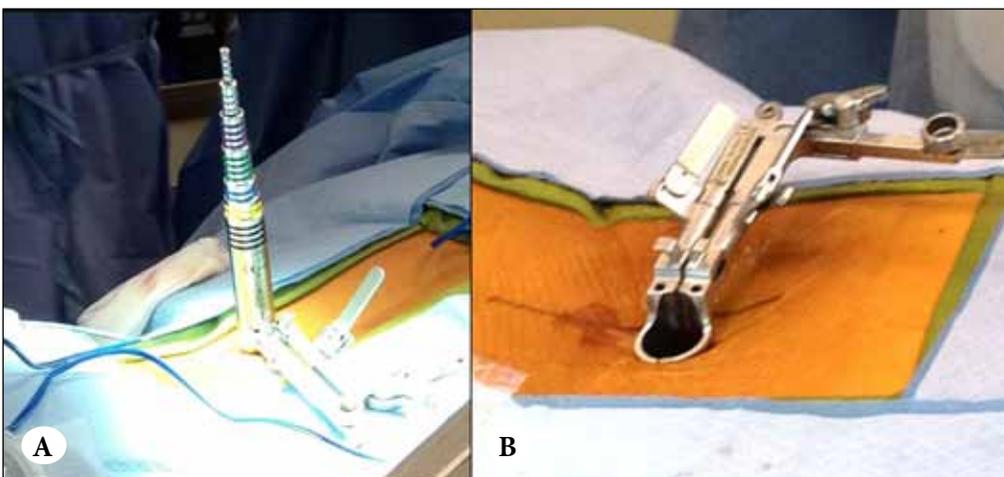


Figure 2: (A) Serial dilators are placed under fluoroscopic guidance and docked on the left L1 inferior lamina. Note the expandable retractor that has been placed around the dilators already as well. (B) Serial dilators removed with a view of the expandable retractor system.

the drill and Kerrison rongeurs to reach the contralateral pedicle for full visualization of the spinal canal. The dura was opened with a long-handled no. 15 blade scalpel over the midline and tacked up with 4-0 Nurolon sutures. The tumor was visualized at this time as a lesion consistent with an intradural extramedullary lesion attached only to a single nerve root with a distinguishable border. Using a combination of microinstruments, the tumor was dissected and removed with standard microsurgical techniques in en bloc fashion (Figure 3). After hemostasis and irrigation, the dura was closed with a 6-0 running Prolene running suture. Watertight closure was confirmed with a Valsalva to 40 mm Hg. A small piece of Duragen regeneration matrix was placed over the dural exposure along with Tisseel fibrin sealant to reinforce the dural closure. The fascia was then closed with absorbable 0 Vicryl suture and the subcutaneous tissue was closed with absorbable 2-0 Vicryl suture. Skin closure consisted of a running subcuticular absorbable 4-0 Monocryl suture followed by a topical layer of Dermabond skin adhesive (Figure 4). Estimated blood loss was 50 cc and operative time was 225 minutes.

Pathology. Examination of the en bloc spinal tumor specimen found its pathology to be consistent with a myxopapillary ependymoma (WHO Grade 1).

Postoperative Course. The patient woke up from surgery neurologically intact and was transferred from anesthesia recovery to a regular medical/surgical floor room. With the exception of meals, he was kept flat in bed for 2 days. An MRI study on postoperative day 1 demonstrated gross-total resection of the tumor (Figure 5A and 5B). He was subsequently mobilized out of bed on postoperative day 2, cleared by physical therapy, and discharged home that day. There were no immediate or delayed postoperative complications. At last clinical and radiographic follow-up 3 years after surgery, he remains neurological intact and disease free (Figure 5C and 5D).

CASE 2

Presentation. A 32-year-old woman without any significant past medical history presented to clinic with progressive back pain and leg weakness and recently some urinary incontinence. Neurologically, she was found to have bilateral weakness in her lower extremities with a muscle grade of 4+/5 with decreased sensation and diminished proprioception. She had a left-sided upgoing toe. Review of her imaging demonstrated a large thoracic intradural

spinal tumor (Figure 6). Due to her signs of progressive myelopathy and bladder symptoms and severe radiographic cord compression, she was admitted to the hospital for urgent treatment. Her admission status was to the intensive care unit (ICU) for serial neurologic examinations, mean arterial pressure (MAP) goals with induced hypertension if needed, and intravenous dexamethasone.



Figure 3: View of the resected tumor. Due to the well-demarcated plane, the tumor was able to be resected en bloc. The pathology of this tumor was consistent with a myxopapillary ependymoma.



Figure 4: Skin closure at the conclusion of the MIS approach resection of this tumor. The incision measures 2.5 cm.

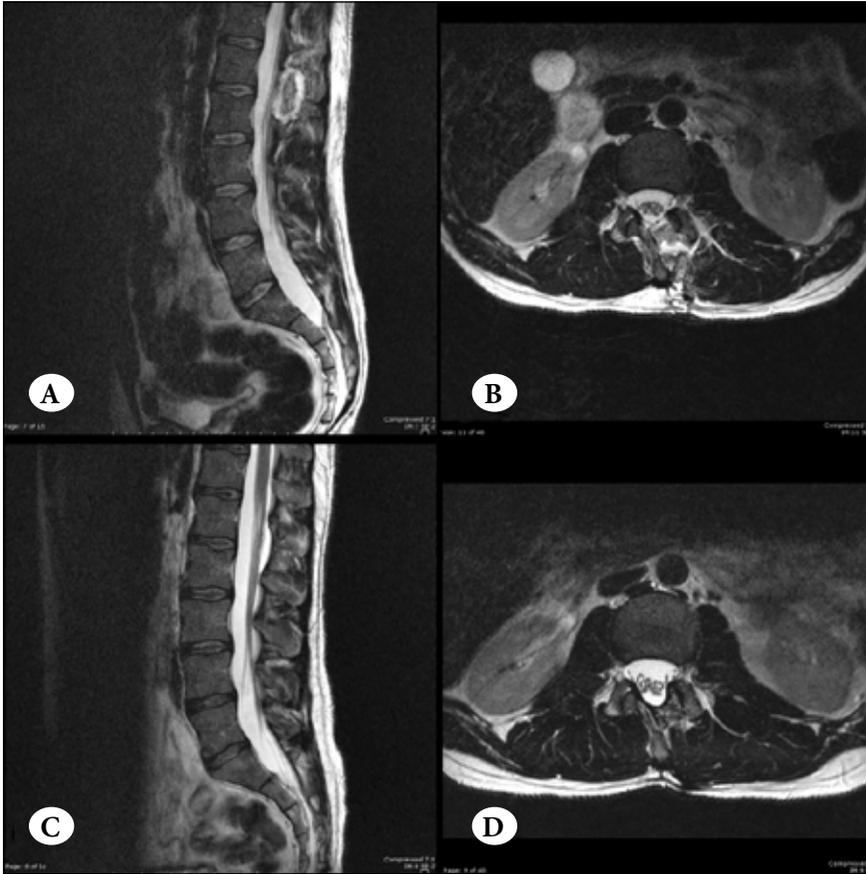


Figure 5: Postoperative T2-weighted MRI in both sagittal (A) and axial (B) dimensions on postoperative day 1 showing gross-total resection of tumor. At 3 years radiographic follow-up, a repeat postoperative T2-weighted MRI in both sagittal (C) and axial (D) dimensions continues to show no residual disease.

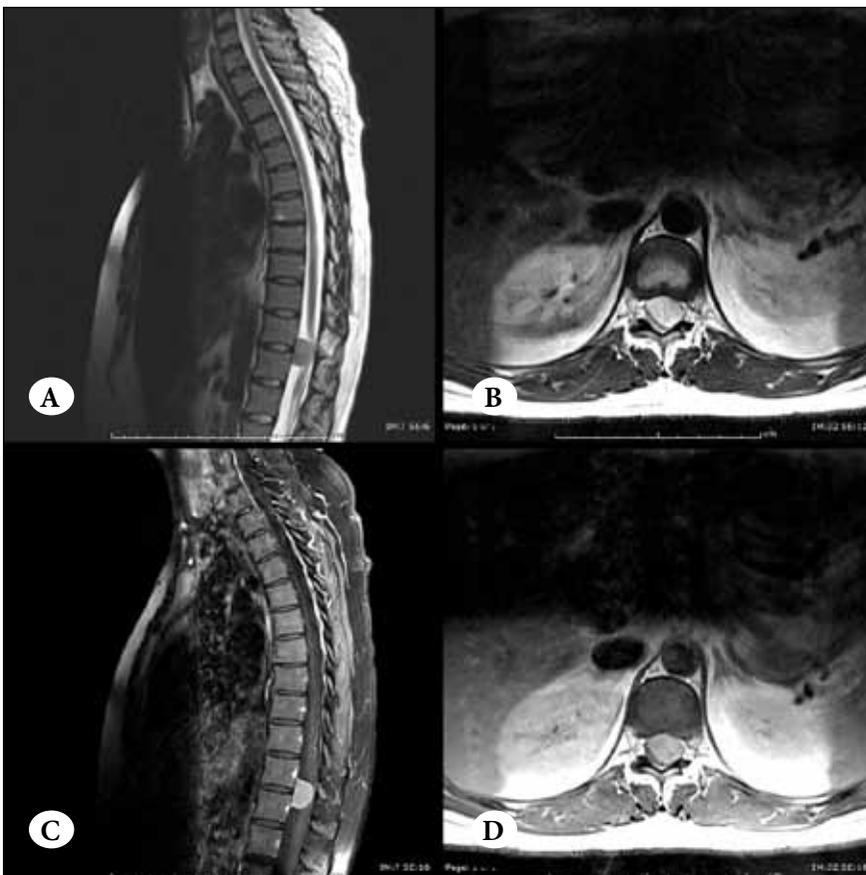


Figure 6: Preoperative T2-weighted MRI in both sagittal (A) and axial (B) dimensions as well as a T1-weighted post-contrast MRI in sagittal (C) and axial (D) dimensions demonstrating significant cord compression caused by the intradural extramedullary tumor. Note the flattened spinal cord in the axial dimensions (B and D) being pushed posterolaterally by the tumor.

Surgery. An MIS approach surgery was planned for this patient. Due to the potential fluoroscopic localization difficulty of the T11-12 level, we utilized our O-arm (Medtronic Sofamor Danek, Memphis, TN) intraoperative computed tomography (CT) scanner to mark out the appropriate level under stereotactic navigational guidance and later again to confirm the appropriate level after exposure. A 3 cm incision was marked out approximately 2 cm to the right of midline. Surgical technique for exposure, tumor removal, and subsequent closure occurred in a similar fashion as described above in Case 1. The only exceptional differences were that this tumor was removed in piecemeal fashion with standard microsurgical technique instead of en bloc. Estimated blood loss was 100 cc and operative time was 272 minutes.

Pathology. Examination of this tumor specimen found its pathology to be consistent with an atypical meningioma (WHO Grade 2).

Postoperative Course. The patient woke up from surgery neurologically stable and was transferred back to her intensive care unit room. A neurologic examination later that day on postoperative day 0 showed that her muscle strength had improved to 5/5. With the exception of meals, she was kept flat in bed for 1 day. An MRI study on postoperative day 1 demonstrated gross-total resection of her tumor. On postoperative day 2, her MAP goals and dexamethasone were weaned off and she was transferred to a regular medical/surgical floor room. She was mobilized out of bed that day and worked with physical therapy. She was subsequently discharged on postoperative day 3. At last clinical and radiographic follow-up at our institution 7 months after surgery, her sensory and motor neurologic examination had improved to intact with complete resolution of her bladder symptoms (Figure 7). She subsequently moved out of state and is followed by neuro-oncology in her new city of residence. Per their correspondence, she has a normal



Figure 7: Postoperative T2-weighted MRI in both sagittal (A) and axial (B) dimensions as well as a T1-weighted post-contrast MRI in sagittal (C) and axial (D) dimensions 7 months after surgery. There is no residual tumor and both spinal cord and canal have been significant decompressed. Noted is a small asymptomatic pseudomeningocele (B).

neurological exam and no evidence of tumor recurrence at 15 months.

DISCUSSION

MINIMALLY INVASIVE APPROACH

Traditional surgical approaches for intradural extramedullary tumors have consisted of a lengthy midline incision, subperiosteal dissection of the paraspinal musculature off the bony spine, wide bilateral laminectomies above and below the tumor, and subsequent intradural tumor resection. Multiple series have shown this approach to be successful with high rates of gross-total resection and minimal postoperative neurologic deficits (28,51,64). This approach has evolved over the years from bilateral laminectomies to more limited and less invasive hemilaminectomies in an effort to reduce postoperative pain and potential spinal instability (38,51,66).

Over the past decade, MIS approaches to the spine using tubular retractors have increasingly been explored to reduce the extensive soft-tissue dissection and disruption of midline structures typically associated with traditional open approaches (56). MIS approaches have allowed for quicker recovery and return to daily activities, lower hospitalization costs and stays, and equivalent outcomes in the degenerative disc disease population (11,21,38,55,62).

Tredway et al. was the first to report a small series of 6 patients who underwent resection of their intradural extramedullary spinal tumors through a small paramedian incision with the use of a tubular retractor system (60). Several years later, Lu et al. then reported another small series of 3 total patients (2 of which had intradural extramedullary tumors) who underwent resection via a midline transspinous approach using an expandable tubular retractor system (30). Exclusive of isolated case or video reports, there are now a total of 114 patients reported in the literature who have undergone an MIS approach via tubular retractor systems for resection of intradural extramedullary spinal tumors. The majority of these patients underwent tumor resection via a unilateral hemilaminectomy, although 3 articles did discuss the midline transspinous approach as their surgical preference. While a unilateral hemilaminectomy exposure is familiar for many surgeons and appropriate for eccentrically located tumors, a midline transspinous MIS approach offers an orthogonal pedicle to pedicle view for direct access to dorsally located neoplasms. Good results were reported for both types of approaches (8,18,29-31,38,48,60,64). At our

institution, we typically utilize a unilateral approach with an expandable tubular retractor system as demonstrated in our 2 case illustrations above. Although the surgical corridor is angled medially, decompression of the contralateral lamina through removal of the inner cortical bone can still provide an exceptional view of the entire canal with visualization to the contralateral pedicle as well.

Recently, Kwak et al. described the removal of intradural cervical tumors by combining a split-spinous laminectomy technique with the use of an expandable tubular retractor system²⁶. After splitting of the spinous process with all its muscular attachments still intact, the expandable retractor was then brought in for the total laminectomy and tumor resection. This technique was carried out in 8 patients with intradural cervical pathologies (schwannomas, astrocytoma, ependymoma, meningioma, cavernous hemangioma) with complete resection in 7 patients. In comparison to their traditional open cervical laminectomy group, they found significant differences in skin incision size, estimated blood loss, and muscle atrophy rate at 2 years. Due to the preservation of the cervical paraspinal muscles, they pointed to future studies to evaluate benefits with regard to postoperative cervical alignment and a reduction in postoperative kyphosis.

Highlighting the potential disadvantages of MIS approaches, Mannion et al. described 2 patients in which the wrong spinal level was exposed³¹. Both of these cases occurred in the mid- to upper thoracic spine. Although the true extent of wrong level surgery in open surgical technique is difficult to know because one can always “extend” a dural opening or laminectomy rostrally or caudally, identification of the correct pathological level in MIS surgery is of the utmost importance because of a limited ability to extend the exposure. Surgeons evaluating patients with mid- to upper thoracic tumors for MIS approach surgery should have clear intraoperative localization plans in mind to minimize these types of errors. At our institution, if there is any question that fluoroscopic guidance may be difficult, we utilize our intraoperative CT scanner for stereotactic navigational localization as demonstrated in our Case 2 illustration above.

SURGICAL RESECTION AND OPERATIVE CHARACTERISTICS

Complete resection of a typically benign intradural extramedullary tumor is a primary surgical goal and the mainstay of treatment for benign intradural extramedullary

tumors (6,38,51). The literature demonstrates good results with gross-total resection in open approaches, with series reporting rates from 74% to 92% (1,17,22,32-34,36,53,57,64). Our review for MIS approaches shows similar rates ranging from 75% to 100%. Three articles directly compared traditional open approaches with MIS tubular techniques for the resection of intradural extramedullary tumors (29,48,64). These groups also found similar results in gross-total resection rates between the two techniques, with 92-94% in the MIS cohorts vs. 88.5-100% in their open cohorts. All series reported improvements in postoperative neurologic exams either through American Spinal Injury Association (ASIA) score assessments, functional improvements, or resolution of presenting symptoms (8,18,29-31,38,48,60,64).

One benefit for the use of MIS tubular approaches for spinal tumor resection is a reduction in operative estimated blood loss (EBL). Mean reported EBL in MIS approach groups for intradural extramedullary spinal tumors ranged from 56 ml to 238.8 ml. Series comparing MIS vs. open approaches found significant differences in the EBL of both groups, with the MIS approaches ranging from 133.7 to 153 ml versus open approaches resulting in EBL of 320 to 558.8 ml (29,48,64). This difference is likely due to the minimal muscle-splitting approach used in MIS techniques which limits blood loss from soft tissue dissection. The tubular retractors also assist to tamponade bleeding around the entire surgical corridor. Smaller incisions also decrease overall tissue injury, exposure, and bleeding. Wong et al. noted that 2 patients (11.1%) in their open surgery group required a blood transfusion whereas none in their MIS group needed to be transfused (64). Similarly, Raygor et al. reported that 3 patients in their open cohort required a blood transfusion as opposed to 1 in their MIS cohort (48). While larger sample sizes will be needed to better establish this clinical benefit, the potential for a reduction in the need for blood transfusions helps to obviate the already low risk associated with that treatment.

Operative times have been found to be similar between MIS and open surgery for small intradural tumors. Our review found overall mean operative times for MIS resection to be between 184.9 min to 256.3 min. Recently, both Wong et al. and Raygor et al. compared traditional open and MIS approaches and both found similar operative times in their open groups (241.1 minutes and 218.6 minutes, respectively) as compared to their MIS groups (256.3 minutes and 188.9 minutes, respectively) whose differences did not meet

statistical significance (48,64). Both of their retrospective reviews are the largest comparison studies to date.

SURGICAL SITE INFECTION

Surgical site infections (SSIs) can be a source of significant morbidity that itself can lead to further major complications and worse outcomes (4,7,39,40,44,50,63). The treatment of these complications can require long-term antibiotic therapy, additional procedures or operations, and prolonged hospitalizations. MIS approaches involve a less traumatic approach with tubular retractors to temporarily expand a surgical corridor through the soft tissue which then falls back in place at the completion of the operation, closing dead space to prevent postoperative hematomas or seromas that may lead to infection (39). The use of a tubular retractor for an MIS approach for spinal tumor resection minimizes tissue injury and ensures that deeper tissues are less exposed to potential pathologic organisms as a result of the restricted surgical field (9,39,54). There is also a reduction in the disturbance of the skin and skin flora because they are guarded by fixed tubes. The incidence of SSI in MIS surgery for the spine has been established to be very low in the degenerative patient population, reported to be in the 0.2-1.3% range and as low as 0.1% for simple decompression procedures (10,39,42,54).

SSIs are of particular significance to spinal tumor surgery where there is an increased risk of 5.9 times for SSI as opposed to patients without a resection of tumor (40). Omeis et al. addressed the issue of postoperative surgical site infection after spinal tumor surgery in a large retrospective review of 678 patients (41). They found an incidence of SSIs in 8.89% for primary nonbony spinal tumors inclusive of intradural extramedullary tumors, 9.5% for metastatic spinal tumors, and 13.78% for primary bony spinal tumors. Our review of published reports on MIS approach surgery specifically for intradural extramedullary tumors only found 1 patient (0.9%) out of 114 that developed an SSI that was treated conservatively with antibiotic therapy. This would suggest a lower rate of SSI in MIS surgery when compared to the published open literature on spinal tumor resection, but further prospective comparison studies are needed to better describe this benefit.

CEREBROSPINAL FLUID LEAK

Meticulous dural closure is a key component for spinal tumor surgery to minimize the risks of postoperative CSF leak that can further lead to postural headaches,

pseudomeningocele, wound infection, meningitis, or remote intracranial complications of subdural or cerebellar hemorrhage (3,5,14,20,23,24,43,45,58). MIS approaches are typically protective against CSF leak due to the re-expansion of the paraspinal musculature after removal of the tubular retractors which creates a physical barrier to the hydrostatic pressure of the intradural space, closing off dead space and tamponading CSF egress. This guards against the development of a large pseudomeningocele or symptomatic CSF leak, especially those that may require intervention with a blood patch or lumbar drain. Multiple studies have shown that MIS techniques have lower rates of postoperative symptomatic CSF leaks when compared with open approaches (2,13,16,21,27,47,49,61,65).

Literature on open techniques report a CSF leak anywhere from 0% to 9% (18,28,29,35,51,60). When reviewing CSF leaks in the degenerative population, comparative studies between MIS and open surgery have found that open surgical groups were two to four times as likely to have a postoperative CSF leak (52,65). Our review of MIS tubular approaches for the resection of intradural extramedullary tumors found 6 patients (5.3%) of a total 114 patients who developed either a pseudomeningocele or CSF leak, of which 4 patients (3.5%) required a reoperation for repair. Wong et al. found a significant difference in the occurrence of postoperative CSF leak when comparing their intradural extramedullary tumors that had undergone either MIS approach resection versus traditional open resection (1 patient in MIS group vs. 3 patients in open group, $p=0.03$) (64). Raygor et al. found a trend for patients in their MIS group to have fewer postoperative adverse events as compared to their open group (8% in MIS group vs. 19% in open surgery group, $p=0.24$), but did not specifically analyze their CSF complication subgroup of which 1 patient in their MIS cohort had a pseudomeningocele and 3 patients in their open cohort had CSF leaks (48).

HOSPITAL LENGTH OF STAY

A reported benefit of MIS approaches is a decrease in hospital LOS likely due to smaller incisions with decreased soft tissue disruption resulting in less postoperative pain and faster immediate postoperative recovery (11,15,18,19,21,29,38,46,60,64,65). Shorter hospital LOS for MIS approach surgery has been demonstrated throughout the degenerative disc disease population when compared to traditional open surgery (52,65). Our review of series reporting MIS resection of intradural extramedullary spinal

tumors showed average hospital LOS from 2.4-6.9 days. Lu et al. compared their average hospital stays between their MIS and open surgery groups and found shorter hospital stays for those undergoing MIS resection (4.9 days vs. 8.2 days, $p=0.003$) (29). Likewise, Wong et al. found a statistically significant difference in their average postoperative hospital stay with their MIS cohort staying 3.9 days as compared with 6.1 days for the open cohort ($p<0.01$) (64). Raygor et al., however, found equivalent postoperative hospital stays in their MIS and open surgery groups with 6.2 vs. 6.0 days ($p=0.78$), respectively (48). They acknowledged that their average hospital LOS for MIS groups was approximately 3 days longer in most other studies (18,31,38,60), and believed that it was likely due to the prolonged management of postoperative pain.

With an increasing emphasis on the cost-effectiveness of the healthcare system, greater attention is being paid to practice patterns that may help mitigate the escalating costs of spine surgery especially as it applies to reducing hospital stays (52).

CONCLUSION

Minimally invasive surgery for the operative resection of intradural extramedullary spinal tumors through tubular retractors is safe and effective. Gross-total resection rates are similar when compared with traditional open surgery with equivalent neurologic outcomes. For appropriately selected patients, advantages of the minimally invasive approach include a reduction in operative blood loss, a lower risk of cerebrospinal fluid leak, and a shorter hospital stay. Future prospective randomized trials directly comparing minimally invasive and open surgery would be invaluable for further elucidation of cost-effectiveness and long-term clinical benefits.

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