J Neurosurg Spine 19:708–715, 2013

Minimally invasive removal of thoracic and lumbar spinal tumors using a nonexpandable tubular retractor

Clinical article

***Andre Nzokou, M.D., Alexander G. Weil, M.D., F.R.C.S.C., and Daniel Shedid, M.D., M.Sc., F.R.C.S.C.**

Department of Surgery, Section of Neurosurgery, Centre Hospitalier de l'Université de Montréal, Hôpital Notre-Dame, Montréal, Quebec, Canada

Object. Resection of spinal tumors traditionally requires bilateral subperiosteal muscle stripping, extensive laminectomy, and, in cases of foraminal extension, partial or radical facetectomy. Fusion is often warranted in cases of facetectomy to prevent deformity, pain, and neurological deterioration. Recent reports have demonstrated safety and efficacy of mini-open removal of these tumors using expandable tubular retractors. The authors report their experience with the minimally invasive removal of extradural foraminal and intradural-extramedullary tumors using the nonexpandable tubular retractor.

Methods. A retrospective chart review of consecutive patients who underwent minimally invasive resection of spinal tumors at Notre Dame Hospital was performed.

Results. Between December 2005 and March 2012, 13 patients underwent minimally invasive removal of spinal tumors at Notre Dame Hospital, Montreal. There were 6 men and 7 women with a mean age of 55 years (range 20–80 years). There were 2 lumbar and 2 thoracic intradural-extramedullary tumors and 7 thoracic and 2 lumbar extradural foraminal tumors. Gross-total resection was achieved in 12 patients. Subtotal resection (90%) was attained in 1 patient because the tumor capsule was adherent to the diaphragm. The average duration of surgery was 189 minutes (range 75–540 minutes), and the average blood loss was 219 ml (range 25–500 ml). There were no major procedure-related complications. Pathological analysis revealed benign schwannoma in 8 patients and meningioma, metastasis, plasmacytoma, osteoid osteoma, and hemangiopericytoma in 1 patient each. The average equivalent dose of postoperative narcotics after surgery was 66.3 mg of morphine. The average length of hospitalization was 66 hours (range 24–144 hours). All working patients returned to normal activities within 4 weeks. The average MRI and clinical follow-up were 13 and 21 months, respectively (range 2–68 months). At last follow-up, 92% of patients had improvement or resolution of pain with a visual analog scale score that improved from 7.8 to 1.2. All patients with neurological impairment improved. The American Spinal Injury Association grade improved in all but 1 patient.

Conclusions. Intradural-extramedullary and extradural tumors can be completely and safely resected through a minimally invasive approach using the nonexpandable tubular retractor. This approach may be associated with even less tissue destruction than mini-open techniques, translating into a quicker functional recovery. In cases of foraminal tumors, by eliminating the need for facetectomy, this minimally invasive approach may decrease the incidence of postoperative deformity and eliminate the need for adjunctive fusion surgery.
(http://thejns.org/doi/abs/10.3171/2013.9.SPINE121061)

Key Words • **intradural tumor** • **extradural tumor** • **oncology** • **minimally invasive surgery** • **schwannoma** • **spinal neoplasm**

Spinal tumors are rare lesions located the majority (two-thirds) of the time outside the spinal cord and are either intradural-extramedullary or extradural. Nerve sheath tumors (for example, schwannoma) and meningiomas make up most of these tumors.[15] The mainstay of treatment of these lesions is gross-total resection (GTR). For extradural spinal tumors, exposure traditionally requires bilateral subperiosteal muscle stripping, hemilaminectomy, or extensive laminectomy, and in cases of foraminal with additional extraforaminal extension (Eden Grade 2 or 3), radical ipsilateral facetectomy has been warranted by some authors for cervical and lumbar dumbbell tumors.[11,13,19] In a report by Ozawa et al., more than half (55%) of lumbar spinal dumbbell tumors resected through a posterior approach required facetectomy

Abbreviations used in this paper: ASIA = American Spinal Injury Association; GTR = gross-total resection; VAS = visual analog scale.

* Drs. Nzokou and Weil contributed equally to this work.

in addition to hemilaminectomy.[19] This was required in all giant extradural foraminal and extraforaminal tumors approached posteriorly (Eden Type 2 or 3).[19] Although the evidence is anecdotal, this may increase the risk of instability, leading to deformity and pain. In a few lumbar cases in the report by Ozawa et al., posterolateral fusion was performed. The approach for resection of intradural tumors has evolved over the years from bilateral laminectomy to a more limited exposure using a less invasive hemilaminectomy in an effort to reduce postoperative pain and instability.[26,34] Recent reports have demonstrated the safety and efficacy of minimally invasive and mini-open removal of these tumors using expandable tubular retractors.[9,12] The minimally invasive approach obviates the need for complete or even partial facetectomy, which is an advantage of this approach. We report our experience with the minimally invasive removal of extradural foraminal and intradural-extramedullary tumors using the 18-mm nonexpandable Spotlight Access System (DePuy Spine). The advantages of this approach are discussed.

Methods

We performed a retrospective chart review of 13 consecutive patients who underwent minimally invasive resection of spinal tumors between December 2005 and March 2012. Approval was obtained from the Centre Hospitalier de l'Université de Montréal Notre-Dame ethics committee. Preoperative evaluation consisted of clinical examination and MRI of the spine. We analyzed intraoperative blood loss, operative time, postoperative time to mobilization, postoperative opiate equivalency use by recording the total number of narcotic doses received by each patient postoperatively (in equivalent potency doses of codeine, morphine, hydromorphone, and oxycodone), and duration of hospitalization. Extent of resection was assessed during surgery and was confirmed using postoperative spinal MRI. Postoperative MRI was not repeated after initial postoperative MRI showed complete resection of a benign tumor, such as a WHO Grade I schwannoma or meningioma. At last follow-up, clinical outcome was assessed using the visual analog scale (VAS) for pain and the American Spinal Injury Association (ASIA) scale for motor/sensory outcome.

Operative Technique

Extradural Tumor Resection. After sedation and endotracheal intubation, the patient was placed prone on the operating table. Anteroposterior and lateral intraoperative fluoroscopy were used to localize the correct level with a K-wire. For extradural tumors, a 20-mm-long paramedian skin incision was made 5 cm from the midline. This paramedian longitudinal incision allowed an adequate angle to access the ipsilateral extraforaminal space. The fascia was incised parallel and slightly medial to the skin incision. A Steinmann pin was docked on the ipsilateral facet complex between the transverse processes of the superior and inferior vertebrae. A series of dilators were introduced to split the paraspinal muscles. A final 18-mm Spotlight Access System was fixed in place with a table-mounted flexible arm, and it was attached to the tube and connected to the light source. Fluoroscopy confirmed the adequate position of the tube retractor between the ipsilateral transverse processes just lateral to the facet complex (Fig. 1C).

The surgical microscope was introduced. For thoracic extradural tumors, the adjacent ribs were observed and, medially, the transverse processes. For thoracic tumors, the transverse process of a part of the costovertebral junction and rib were drilled using the Midas-Rex drill (Medtronic), providing access to the space between the transverse recesses. The intercostal muscles were removed, exposing the tumor capsule. For lumbar extradural tumors, the fascia and intertransverse membrane were opened, allowing access to the tumor capsule. Prior to entry into the tumor capsule, stimulation was performed on the tumor capsule to ensure that there was no nerve root.

Standard microsurgical techniques were used. After coagulation of the tumor capsule, intracapsular debulking was performed using the Cavitron Ultrasonic Surgical Aspirator (CUSA). This allowed us to infold the remaining tumor capsule at the cleavage plane and perform extracapsular dissection between the tumor and the psoas muscle. A dissection plane was maintained with paddies. Intraoperative stimulation was performed throughout to ensure that no viable nervous structures were harmed. After tumor resection, the nerve root was identified and stimulated, confirming its integrity. Hemostasis was performed using standard hemostatic agents and bipolar cautery. The retractor was then removed. The fascia was closed with absorbable sutures, and the 20-mm paramedian skin was closed with 2-0 Vicryl sutures.

Intradural Tumor Resection. For intradural tumors, a 20-mm incision was made 2.5 cm off the midline (Fig. 2). The serial dilators and final tubular retractor were placed over the interlaminar space (for example, T12–L1). Using the surgical microscope, a unilateral laminectomy was done using a 3-mm Maestro drill (Stryker) to expose the ligamentum flavum. The base of the rostral spinous process was drilled to expose the contralateral side. The ligamentum flavum was removed with a Kerrison rongeur to expose the dura mater, which was subsequently opened using a No. 11 blade scalpel and nerve hook. The nerve roots and tumor were identified, and the tumor was removed using standard microsurgical technique, as described above. After tumor removal, the dura was closed with Nurolon 4-0 using a knot pusher. Biological glue (TISSEEL, Baxter) was added, followed by closure.

Results

Between December 2005 and March 2012, 13 patients underwent minimally invasive removal of spinal tumors at Notre Dame Hospital (Table 1). There were 6 men and 7 women with a mean age of 55 years (range 20–80 years). There were 2 lumbar and 2 thoracic intradural-extramedullary tumors and 7 thoracic and 2 lumbar extradural foraminal tumors. Gross-total resection (GTR) was achieved in 12 patients (Table 2). Subtotal resection (90%) was obtained in the remaining patient because the

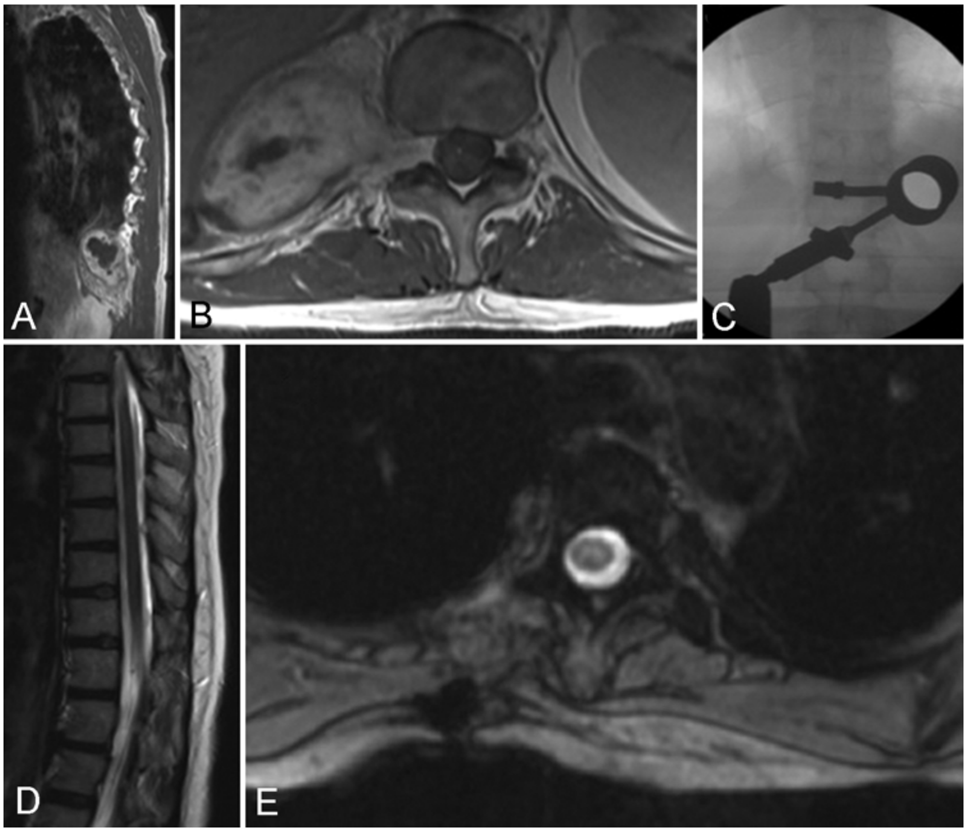

Fig. 1. Case 12. **A and B:** Preoperative sagittal (A) and axial (B) T2-weighted MR images revealing an L3–4 extradural foraminal schwannoma. **C:** Anteroposterior intraoperative radiograph showing placement of the tubular retractor between the L-3 and L-4 transverse processes on the right side. **D and E:** Sagittal (D) and axial (E) postoperative T2-weighted MR images demonstrating GTR.

tumor capsule was adherent to the diaphragm. The average duration of surgery was 189 minutes (range 75–540 minutes), and the mean blood loss was 219 ml (range 25–500 ml). There were no procedure-related complications. Pathology revealed benign schwannomas in 8 patients and meningioma, metastasis, hemangiopericytoma, plasmacytoma, and osteoid osteoma in the remaining 5 patients. The average equivalent dose of postoperative narcotic use was 66.3 mg of morphine. All patients were mobilized at 24 hours, and the mean length of hospital-

TABLE 1: Characteristics of 13 patients undergoing minimally invasive resection of intradural-extramedullary and extradural spinal tumors*

Case No.	Age (yrs), Sex	Tumor Location	VAS Score	Neurological Deficit, ASIA Grade	Duration of Symptoms (mos)
1	64, M	rt T11–12 (ED-IT)	0	dysesthesia T-12, D	11
2	80, F	rt T12–L1 (ID-EM)	10	myelopathy, C	6
3	45, F	rt T6–7 (ED-IT)	0	E	NA
4	53, M	lt L2–3 (ID-EM)	6	E	1
5	20, M	rt T1–2 (ED)	9	E	24
6	42, F	rt T4–5 (ED-IT)	6	E	3
7	68, F	rt T3–4 (ED-IT)	9	E	12
8	44, M	rt L3–S1 (ID-EM)	7	myelopathy, C	6
9	76, F	rt L2–3 (ED)	10	E	12
10	34, M	lt T10–11 (ED)	8	E	9
11	69, M	rt T8–9 (ED-IT)	5	E	9
12	72, F	rt L3–4 (ED)	8	E	12
13	47, F	rt T9–10 (ID-EM)	0	myelopathy, D	NA

* ED = extradural; ID-EM = intradural-extramedullary; IT = intrathoracic; NA = not available.

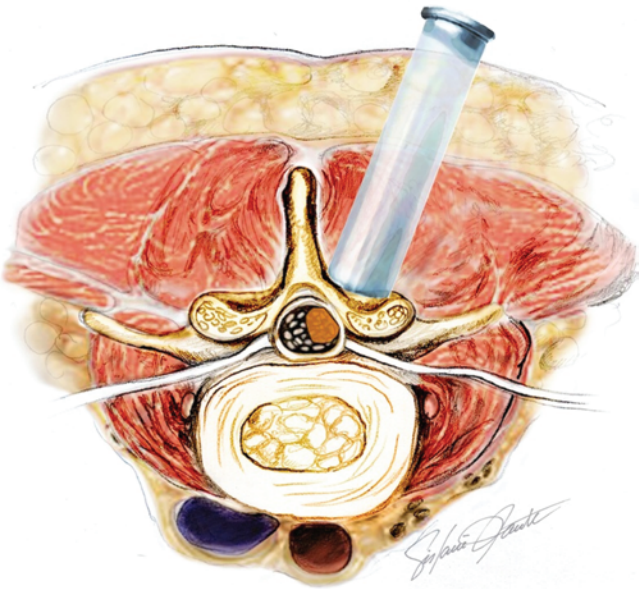

Fig. 2. Illustration depicting the minimally invasive approach using a transmuscular tubular dilator for intradural schwannoma resection. Copyright Andre Nzokou. Published with permission.

ization was 66 hours (range 24–144 hours). All working patients returned to normal activities within 4 weeks. The mean MRI and clinical follow-up were 13 and 21 months, respectively (range 2–68 months). At last follow-up, 92% of patients had improvement or resolution of pain with a VAS score that improved from 7.8 to 1.2. The ASIA grade improved in all patients except 1 (Table 2).

Illustrative Cases

Case 12

A 72-year-old woman with no significant history reported 12 months of lower lumbar pain with progressive right sciatica. There was no history of gait disturbance or bowel or bladder dysfunction. On examination, there were no sensory or motor deficits. The patient underwent lumbar MRI, which revealed an extradural tumor at the L3–4 level with extension through the L3–4 foramen (Fig. 1A and B). The patient underwent minimally invasive resection (Fig. 1C), and postoperative imaging revealed complete resection (Fig. 1D and E). The tumor was revealed to be a schwannoma. At follow-up pain was completely resolved.

Case 2

An 80-year-old woman with no significant history presented with a 10-month history of lumbar pain, right lower-leg paresthesia, and progressive gait disturbance. There was no bowel or bladder dysfunction. On examination, the patient had right foot and great toe dorsiflexion paresis with 3/5 strength. There was no sensory loss. Magnetic resonance imaging revealed an intradural-extramedullary benign schwannoma at the T12–L1 level (Fig. 3A and B). The patient underwent minimally invasive resection (Fig. 3C). Postoperative MRI confirmed complete resection (Fig. 3D and E). During the early postoperative period, the patient developed weakness of the right iliopsoas and quadriceps muscles. At last follow-up, her low-back pain and right leg weakness had improved.

Discussion

Gross-total resection, the mainstay of treatment of extradural and intradural tumors, is attainable in the majority of cases and is associated with long-term remission and excellent functional outcome.[5,27] The classic surgical approach for these lesions involves a long midline skin incision, bilateral subperiosteal muscle stripping from the posterior spinous elements, and laminectomy extending to levels above and below the tumor. Traditionally, partial or radical facetectomy has been required on the side of the foraminal tumor that extends extraforaminally, especially in cases of giant tumors.[5,12,30,32] In the series by Ozawa et al., facetectomy was required in 55% of extradural foraminal/extraforaminal dumbbell tumors approached posteriorly.[19] Postlaminectomy instability and deformity is a major concern, especially after multilevel laminectomy and radical facetectomy.[1,3,4,16,20,25,31,33,35] Fusion surgery has thus been advocated by several authors for some cases of dumbbell tumor removal associated with radical facetectomy.[11,13,19] Mini-open (expandable tubular retractors) and minimally invasive (nonexpandable tubular retractors) approaches have recently been used to resect extradural and intradural spinal tumors through reduced paraspinal tissue destruction.[7,9,14,17,32] Potential advantages include avoidance of fusion surgery; reduced blood loss, surgical time, postoperative pain and narcotic use, and length of stay; and quicker return to daily activities. There is Level III evidence showing that the use of minimally invasive surgery in the treatment of degenerative spinal disease and intradural spinal tumors translates in less blood loss, shorter operative time, shortened hospitalization, and a quicker return to daily activities.[7–10,12,14,17,21–24,28,29,32] Although recent randomized clinical trials comparing minimally invasive and open microdiscectomy have not supported these findings,[2] the advantage of minimally invasive surgery may be more evident when used for more extensive open surgeries such as tumor resection.[24]

To avoid iatrogenic instability, deformity, pain, and fusion surgery, resection of intradural-extramedullary and intradural-intramedullary spinal tumors has been performed through a more limited hemilaminar exposure with unilateral partial facetectomy (up to one-third medial facetectomy).[6,18,25,34] More recently, minimally invasive hemilaminar approaches with expandable tubular retractors have been used to access and successfully resect intradural tumors with reduced tissue destruction, blood loss, and length of hospitalization.[9,14,17,32] Lu et al. recently reported the use of an alternative approach, encompassing midline mini-open access with expandable tubular retractors. The 18 patients who underwent mini-open approaches had reduced blood loss and length of stay compared with the 9 patients who underwent a standard open technique.[12]

Extradural schwannomas have only recently been resected using mini-open approaches through expandable

TABLE 2: Outcome data of patients undergoing minimally invasive resection of intradural-extramedullary and extradural spinal tumors*

Case No.	Location	Pathology	Op Time (mins)	EBL (ml)	EOR (GTR vs STR)	LOS (hrs)	Follow-Up (mos)		VAS Score (preop/follow-up)	ASIA Grade (pre-/postop)	Complication
							Clinical	MRI			
1	rt T11–12 (ED)	schwannoma	540	500	STR	96	24	24	0/0	D/E	no
2	rt T12–L1 (ID-EM)	schwannoma	120	200	GTR	144	21	9	10/0	C/D	no
3	rt T6–7 (ED)	schwannoma	160	200	GTR	72	63	9	0/0	E/E	no
4	lt L2–3 (ID-EM)	metastasis	150	25	GTR	48	3	3	6/0	E/E	no
5	rt T1–2(ED)	osteoma osteoid	205	200	GTR	48	68	68	9/0	E/E	no
6	rt T4–5 (ED)	hemangiopericytoma	185	500	GTR	96	14	12	6/0	E/E	no
7	rt T3–4 (ED)	schwannoma	85	100	GTR	24	8	3	9/0	E/E	no
8	rt L3–S1 (ID-EM)	plasmacytoma	355	300	GTR	96	16	2	7/2	C/D	no
9	rt L2–3 (ED)	schwannoma	180	200	GTR	48	17	13	10/9	E/E	no
10	lt T10–11 (ED)	schwannoma	105	50	GTR	24	2	2	8/0	E/E	no
11	rt T8–9 (ED)	schwannoma	75	50	GTR	24	2	2	5/0	E/E	no
12	rt L3–4 (ED)	schwannoma	150	100	GTR	48	32	19	8/5	E/E	no
13	rt T9–10 (ID-EM)	meningioma	150	200	GTR	96	8	8	0/0	D/E	no
overall	9 ED & 4 ID-EM		mean 189	mean 219	12 GTR, 1 STR	mean 66	mean 21	mean 13	mean 7.8/1.2	92% improved	0%
literature overall	53 ED & 10 ID		mean 215	mean 208	mean 89% GTR	mean 124	mean 12	NA	83–100% improved		8%

* EBL = extent of blood loss; EOR = extent of resection; LOS = length of stay; STR = subtotal resection.

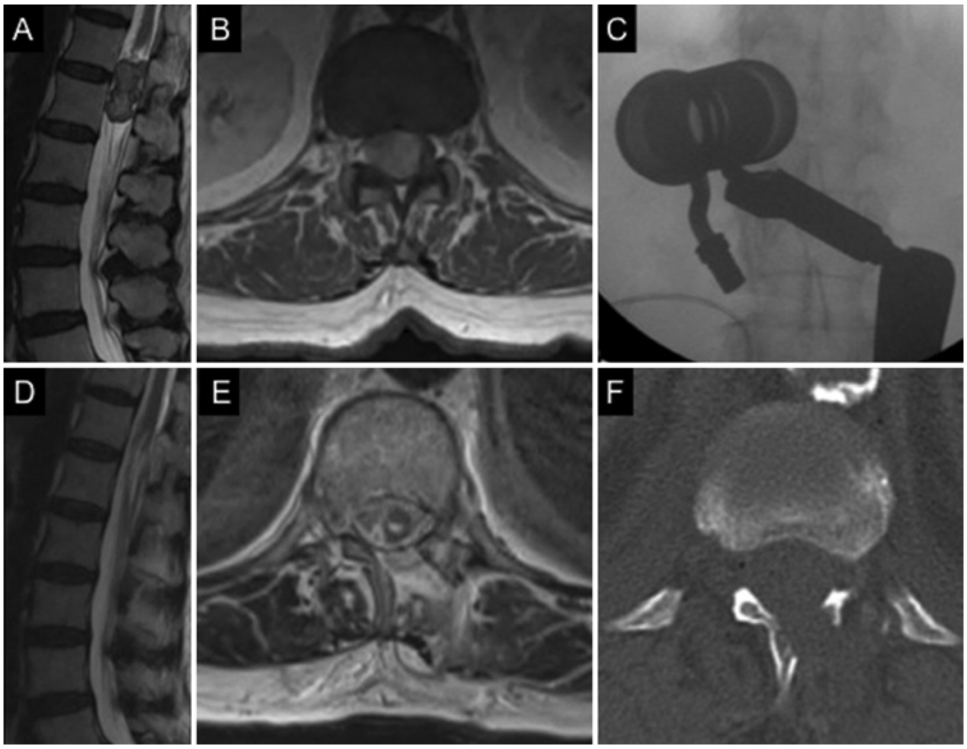

Fig. 3. Case 2. **A and B:** Preoperative sagittal (A) and axial (B) T2-weighted MR images revealing a left T12–L1 intradural schwannoma. **C:** Anteroposterior intraoperative radiograph showing placement of the tubular retractor over the left T-12 and L-1 interlaminar space. **D–F:** Sagittal (D) and axial (E) postoperative T2-weighted MR images demonstrate GTR with a limited left T-12 hemilaminectomy, as shown on the CT scan (F).

tubular retractors. Lu et al. resected extradural lumbar schwannomas in 3 patients through a mini-open approach using an expandable tubular retractor[13] (Table 3). In these patients, of whom 2 had previously undergone surgery (discectomy and fusion surgery), hemilaminectomy and total facetectomy were required to completely visualize the tumor, followed by fusion surgery.[13] The advantages of this approach in these reoperation cases include the use of a lateral approach, eliminating passage through midline scar tissue and simultaneous access for percutaneous instrumentation. Haji et al.[9] recently reported the feasibility and efficacy of resection of intramedullary in addition to intradural-extramedullary and extradural tumors in 22 cases using the METRx MAST Quadrant expandable (22 mm to 52 mm) retractor system (Medtronic). They demonstrated at least comparable rates of GTR, good outcome, complications, and perioperative factors (blood loss, operative time, length of hospitalization, and narcotic equivalent usage) compared with historic controls with standard open techniques (Table 3).

We demonstrate the feasibility and safety of resection of intradural-extramedullary and extradural spinal tumors using a nonexpandable tubular retractor. The efficacy in this series in terms of neurological recovery, pain improvement, and perioperative variables (length of surgery, blood loss, and length of hospitalization) were similar to standard and mini-open techniques.[9,14,17,32] The use of nonexpandable retractors may be associated with even less tissue destruction than mini-open techniques, translating to shorter operative time and hospital stay (Table 2). There are several relative contraindications to this approach, including very extensive extraforaminal tumors, tumors involving 2 or more levels, certain types of tumors that are hemorrhagic, such as paragangliomas or certain metastasis, and morbid obesity because the height of the tube may not be appropriate. Also, there are a number of technical challenges of the minimally invasive approach that must be considered. Fluoroscopy is mandated to ensure the correct level, meticulous hemostasis may be achieved, and dura closure through the tube is challenging but can be done using a Castro needle and knot pusher. Finally, nerve stimulation is essential to increase procedural safety. However, further studies are needed to evaluate the relative safety and efficacy of minimally invasive resection of spinal tumors compared with standard open or newer mini-open techniques.

Conclusions

Intradural extramedullary and extradural tumors can be completely and safely resected through a minimally invasive approach using the nonexpandable tubular retractor. In cases of foraminal tumors, by eliminating the need for facetectomy, this minimally invasive approach may decrease the incidence of postoperative deformity and eliminate the need for adjunctive fusion surgery.

Disclosure

Dr. Shedid is a consultant for DePuy Synthes Spine and Baxano.

TABLE 3: Literature review of previous reports of minimally invasive and mini-open removal of spinal tumors*

Authors & Year	No. of Patients	Tumor Location	Technique†	Fusion (%)	Mean Op Time (mins)	Mean EBL (ml)	GTR (%)	Mean LOS (hrs)	Mean Follow-Up (mos)	Sign/Symptom Improvement (%)	Complication
Tredway et al., 2006	6	ID-EM	X-TUBE	0	247	56	100	57	11	84	0
Ogden & Fessler, 2009	1	ID-IM	X-TUBE	0	NA	NA	100	72	6	NA	0
Mannion et al., 2011	13	ID-EM	X-TUBE/MAST Quadrant	0	180	155	100	72	16	NA	2 wrong level
Haji et al., 2011	22	ID-IM 2, ID-EM 13, ED 7	MAST Quadrant	0	210	428	68	72	6	95	2
Lu et al., 2011	18	ID	Pipeline	0	239	153	100	391	16	100/83	1 pseudomeningocele
Lu et al., 2009	3	ED	Pipeline	100	200	250	66	80	18	100	0
overall	63	53 ID, 10 ED	expandable dilators	5‡	215	208	mean 89% GTR	124	12		8%

* IM = intramedullary.
† X-TUBE is manufactured by Medtronic and Pipeline is manufactured by DePuy.
‡ Percentage is based on 3 of the 63 patients undergoing fusion.

Author contributions to the study and manuscript preparation include the following. Conception and design: Nzokou, Weil. Acquisition of data: Nzokou, Weil. Analysis and interpretation of data: Nzokou, Weil. Drafting the article: Nzokou, Weil. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Shedid. Administrative/technical/material support: Nzokou, Weil. Study supervision: Shedid.

References

1. Alexander E Jr: Postlaminectomy kyphosis, in Wilkins RH, Rengachary SS (eds): **Neurosurgery.** New York: McGraw-Hill, 1985, pp 2293–2297
2. Arts MP, Brand R, van den Akker ME, Koes BW, Bartels RH, Tan WF, et al: Tubular diskectomy vs conventional microdiskectomy for the treatment of lumbar disk herniation: 2-year results of a double-blind randomized controlled trial. **Neurosurgery 69:**135–144, 2011
3. Bresnahan L, Ogden AT, Natarajan RN, Fessler RG: A biomechanical evaluation of graded posterior element removal for treatment of lumbar stenosis: comparison of a minimally invasive approach with two standard laminectomy techniques. **Spine (Phila Pa 1976) 34:**17–23, 2009
4. Caputy AJ, Spence CA, Bejjani GK, Luessenhop AJ: The role of spinal fusion in surgery for lumbar spinal stenosis: a review. **Neurosurg Focus 3(2):**E5, 1997
5. Celli P, Trillò G, Ferrante L: Spinal extradural schwannoma. **J Neurosurg Spine 2:**447–456, 2005
6. Chiou SM, Eggert HR, Laborde G, Seeger W: Microsurgical unilateral approaches for spinal tumour surgery: eight years' experience in 256 primary operated patients. **Acta Neurochir (Wien) 100:**127–133, 1989
7. Fessler RG, Khoo LT: Minimally invasive cervical microendoscopic foraminotomy: an initial clinical experience. **Neurosurgery 51 (5 Suppl):**S37–S45, 2002
8. German JW, Adamo MA, Hoppenot RG, Blossom JH, Nagle HA: Perioperative results following lumbar discectomy: comparison of minimally invasive discectomy and standard microdiscectomy. **Neurosurg Focus 25(2):**E20, 2008
9. Haji FA, Cenic A, Crevier L, Murty N, Reddy K: Minimally invasive approach for the resection of spinal neoplasm. **Spine (Phila Pa 1976) 36:**E1018–E1026, 2011
10. Harrington JF, French P: Open versus minimally invasive lumbar microdiscectomy: comparison of operative times, length of hospital stay, narcotic use and complications. **Minim Invasive Neurosurg 51:**30–35, 2008
11. Jinnai T, Koyama T: Clinical characteristics of spinal nerve sheath tumors: analysis of 149 cases. **Neurosurgery 56:**510–515, 2005
12. Lu DC, Chou D, Mummaneni PV: A comparison of mini-open and open approaches for resection of thoracolumbar intradural spinal tumors. Clinical article. **J Neurosurg Spine 14:**758–764, 2011
13. Lu DC, Dhall SS, Mummaneni PV: Mini-open removal of extradural foraminal tumors of the lumbar spine. Technical note. **J Neurosurg Spine 10:**46–50, 2009
14. Mannion RJ, Nowitzke AM, Efendy J, Wood MJ: Safety and efficacy of intradural extramedullary spinal tumor removal using a minimally invasive approach. **Neurosurgery 68 (1 Suppl Operative):**208–216, 2011
15. Nittner K: Spinal meningiomas, neurinomas and neurofibromas, and hourglass tumors, in Vinken PH, Bruyn GW (eds): **Handbook of Clinical Neurology.** New York: Elsevier, 1976, pp 177–322
16. Ogden AT, Bresnahan L, Smith JS, Natarajan R, Fessler RG: Biomechanical comparison of traditional and minimally invasive intradural tumor exposures using finite element analysis. **Clin Biomech (Bristol, Avon) 24:**143–147, 2009

17. Ogden AT, Fessler RG: Minimally invasive resection of intramedullary ependymoma: case report. **Neurosurgery 65:** E1203–E1204, 2009
18. Oktem IS, Akdemir H, Kurtsoy A, Koç RK, Menkü A, Tucer B: Hemilaminectomy for the removal of the spinal lesions. **Spinal Cord 38:**92–96, 2000
19. Ozawa H, Kokubun S, Aizawa T, Hoshikawa T, Kawahara C: Spinal dumbbell tumors: an analysis of a series of 118 cases. **J Neurosurg Spine 7:**587–593, 2007
20. Papagelopoulos PJ, Peterson HA, Ebersold MJ, Emmanuel PR, Choudhury SN, Quast LM: Spinal column deformity and instability after lumbar or thoracolumbar laminectomy for intraspinal tumors in children and young adults. **Spine (Phila Pa 1976) 22:**442–451, 1997
21. Park P, Foley KT: Minimally invasive transforaminal lumbar interbody fusion with reduction of spondylolisthesis: technique and outcomes after a minimum of 2 years' follow-up. **Neurosurg Focus 25(2):**E16, 2008
22. Park Y, Ha JW: Comparison of one-level posterior lumbar interbody fusion performed with a minimally invasive approach or a traditional open approach. **Spine (Phila Pa 1976) 32:** 537–543, 2007
23. Rahman M, Summers LE, Richter B, Mimran RI, Jacob RP: Comparison of techniques for decompressive lumbar laminectomy: the minimally invasive versus the "classic" open approach. **Minim Invasive Neurosurg 51:**100–105, 2008
24. Ryang YM, Oertel MF, Mayfrank L, Gilsbach JM, Rohde V: Standard open microdiscectomy versus minimal access trocar microdiscectomy: results of a prospective randomized study. **Neurosurgery 62:**174–182, 2008
25. Sario-Glu AC, Hanci M, Bozkuş H, Kaynar MY, Kafadar A: Unilateral hemilaminectomy for the removal of the spinal space-occupying lesions. **Minim Invasive Neurosurg 40:** 74–77, 1997
26. Seppälä MT, Haltia MJ, Sankila RJ, Jääskeläinen JE, Heiskanen O: Long-term outcome after removal of spinal neurofibroma. **J Neurosurg 82:**572–577, 1995
27. Seppälä MT, Haltia MJ, Sankila RJ, Jääskeläinen JE, Heiskanen O: Long-term outcome after removal of spinal schwannoma: a clinicopathological study of 187 cases. **J Neurosurg 83:**621–626, 1995
28. Sim JE, Noh SJ, Song YJ, Kim HD: Removal of intradural-extramedullary spinal cord tumors with unilateral limited laminectomy. **J Korean Neurosurg Soc 43:**232–236, 2008
29. Smith JS, Ogden AT, Fessler RG: Minimally invasive posterior thoracic fusion. **Neurosurg Focus 25(2):**E9, 2008
30. Sridhar K, Ramamurthi R, Vasudevan MC, Ramamurthi B: Giant invasive spinal schwannomas: definition and surgical management. **J Neurosurg 94 (2 Suppl):**210–215, 2001
31. Sridhar K, Ramamurthi R, Vasudevan MC, Ramamurthi B: Limited unilateral approach for extramedullary spinal tumours. **Br J Neurosurg 12:**430–433, 1998
32. Tredway TL, Santiago P, Hrubes MR, Song JK, Christie SD, Fessler RG: Minimally invasive resection of intradural-extramedullary spinal neoplasms. **Neurosurgery 58 (1 Suppl):** ONS52–ONS58, 2006
33. Tuite GF, Doran SE, Stern JD, McGillicuddy JE, Papadopoulos SM, Lundquist CA, et al: Outcome after laminectomy for lumbar spinal stenosis. Part II: Radiographic changes and clinical correlations. **J Neurosurg 81:**707–715, 1994
34. Yaşargil MG, Tranmer BI, Adamson TE, Roth P: Unilateral partial hemi-laminectomy for the removal of extra- and intramedullary tumours and AVMs. **Adv Tech Stand Neurosurg 18:**113–132, 1991
35. Yasuoka S, Peterson HA, MacCarty CS: Incidence of spinal column deformity after multilevel laminectomy in children and adults. **J Neurosurg 57:**441–445, 1982

Manuscript submitted November 21, 2012.

Accepted September 9, 2013.

Please include this information when citing this paper: published online October 18, 2013; DOI: 10.3171/2013.9.SPINE121061.

Address correspondence to: Daniel Shedid, M.D., M.Sc., F.R.C.S.C., Department of Surgery, Division of Neurosurgery, CHUM, Hôpital Notre-Dame, 1560 rue Sherbrooke Est, Montréal, QC, Canada H2L 4M1. email: danielshedid@gmail.com.