

Surgical Techniques for Managing Intradural Spinal Tumors: An Overview and Update

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ABSTRACT

Background: Over the past decades, significant progress has been made in our understanding of the basics and techniques of surgical treatment for intradural tumors. However, the management which is most ideal for these lesions has remained a controversial topic.

Objectives: To review previous work on the available operative options for intradural tumors with focus on both the advantages and disadvantages in each case, the outcomes and also highlight on the current trends in this aspect of spine surgery.

Materials and methods: A systematic literature review of previous publications on the various techniques employed in the surgical treatment of intradural tumors. We discuss their presentation, basic concepts and practical aspects of their management with emphasis on the techniques of operative treatment.

Results: Different outcomes following the application of various techniques in the surgical management of intradural spinal tumors have been well-documented in the literature. However, there are currently no algorithms to guide the surgeon on surgical care for intradural spinal tumors. The choice of which surgery to do in each case is a function of each surgeon's philosophy, knowledge and cumulative experience as well as a clear understanding of the anatomy of the lesion in each patient, the available facilities and equipment.

Keywords: Hemilaminectomy, Intradural extramedullary, Intradural Intramedullary, Laminectomy, Laminoplasty, Laminotomy.

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INTRODUCTION

A spinal tumor has been defined as a growth of cells or mass of cells within or surrounding the spinal cord.⁴¹ Those which are intradural in location are subdivided into intradural extramedullary and intramedullary tumors.

Intradural extramedullary (IDEM) tumors form about 40% of all spinal tumors with schwannomas, meningiomas and ependymomas forming the majority.^{2,4,11,25,60} These are defined as tumors whose location is external to both the arachnoid and pia membrane layers of the meninges, but internal in relation to the dura (i.e. within the dural sheath).^{4,27} On the other hand, intradural intramedullary (IDIM) tumors are lesions that arise directly from the parenchymal tissue of the spinal cord.³⁶

In this article, we briefly discuss the management strategy for intradural spinal tumors and then review the literature on the various operative techniques, their advantages and disadvantages.

METHODS AND SELECTION CRITERIA

A literature search on surgical treatment and operative techniques for intradural spinal tumors was performed with the keywords 'intradural extramedullary' and 'intradural intramedullary'. Clinical papers on the surgical management of intradural spinal tumors that included treatment options and outcome analysis on follow-up were eligible for evaluation. Reference lists in these articles were also examined for any further relevant material.

Articles were included if they contained either qualitative information or quantitative data on outcome, complications after surgical treatment of intradural spinal tumors, advantages and disadvantages of the technique employed.

Information was carefully extracted from eligible studies based on the following variables: the type of tumor, its histological features, its location, technique or approach used at surgery, instrumentation, age and gender of the patients, functional outcome, complications and benefits from the surgery as well as any adjuvant therapies.

RESULTS

Our literature search revealed that majority of intradural extramedullary tumors were benign lesions, and they commonly exhibited non-specific symptoms of radicular pain as well as worsening sensory and motor loss.⁶⁰ The most common type among them was schwannoma (Table 1), closely followed by meningioma.^{2,4,23,27} Spinal meningiomas constituted approximately about 25 to 46% of all spinal tumors, were mostly located in the thoracic

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portion of the vertebral column, predominantly lateral in position, occurred more in elderly people than in younger individuals and were more common in females, where they are thought to occur probably due to the influence of female hormones.^{2,4,12,15,23,25,43,45,49} Meningiomas were reported as slow growing benign tumors with tendency to produce indolent neurological deficits, which were often reversible following excision.^{45,46} The schwannomas on the other hand, occurred in 73 to 50% of cases.^{2,11} These tumors were also frequently located in the thoracic but also in cervical and lumbar regions, and presented as dumbbell-shaped in 10 to 15% of cases.^{4,11,12,59} Schwannomas had tendency to occur in the 30 to 60 years age group.²³ Most were firm, encapsulated neoplasms composed principally of neoplastic Schwann cells and microscopically, were characterized by high cellularity with presence of Antoni A and Antoni B cell patterns.^{23,58} They were commonly restricted to one region of the spine and usually extended over only two or three spinal segments.⁵⁸ Depending on their location, the schwannomas frequently presented with back pain, radiculopathy, myelopathy, motor weakness and voiding difficulty.¹¹ Next in frequency of occurrence after schwannoma and meningioma was myxopapillary ependymoma.²³ Other intradural extramedullary lesions in the literature included neurofibroma, lipoma, teratoma (Table 1) as well as seeding of systemic cancer which is uncommon, accounting for only 5 to 6% of spinal metastases.^{14,23,32,52} Intradural extramedullary spinal metastasis is a rare manifestation of systemic cancer which also presents with pain and weakness in majority of cases.¹⁴ They involved mostly the thoracolumbar area of the spine with the most frequent primary lesion being adenocarcinoma of the lung.¹⁴

Our review showed that intradural intramedullary tumors make up 2 to 4% of all central nervous system tumors and constituted approximately 5% of all spinal tumors.^{4,11,16,29,36} The common ones were gliomas which included the astrocytomas and ependymomas, followed by hemangioblastoma.^{12,24,29,36,47} Intramedullary spinal metastasis was reported to be extremely rare, often occurred in the cervical region and was mostly due to lung cancer.²⁹ Occurrence of meningiomas and schwannomas as intramedullary lesions have also been previously reported.²⁹ In contrast to the extramedullary lesions, most patients with intramedullary tumors tended to be young and these tumors were commonly located in cervical and lumbar spines, which are the regions where patients are prone to complicate with postoperative deformity and instability of spine.^{16,53} Their rare incidence often leads to misdiagnosis and improper workup.³⁶ These lesions tend to have a myriad of clinical signs and symptoms that makes their diagnosis difficult. They commonly

presented with either local dull pain or radicular pain, often associated with some level of numbness in the lower limbs.^{12,24,47} The local back pain typically tended to occur when lying flat in bed (hence, the classical complaint of nocturnal pain) and this is highly suggestive, particularly if the pain wakes the patient from sleep.^{11,24,47} Unfortunately, these alerting symptoms are often absent.³⁶ Muscle weakness was also common and usually presented much later following pain or sensory disturbances.^{12,29,36} Brown-Sequard syndrome, hemiparesis ipsilateral to the lesion with loss of pain and temperature sensation on the contralateral side as well as urinary retention and fecal incontinence were also reported in some of these patients.^{12,29,36} However, sphincteric dysfunction was the least common of the symptoms.¹² In some cases, they were associated with syringomyelia, especially in the cervical spine.^{12,29,36}

MANAGEMENT OF INTRADURAL SPINAL TUMORS

A thorough neurological examination is the key to the assessment of these spinal tumors.¹⁵ The use of spinal magnetic resonance imaging (MRI), especially those of high resolution with extremely accurate details, provides the most useful and dependent diagnostic tool.^{4,11,12,15,29,60} Hence, any patient with signs of new or inexplicable myelopathy, such as spasticity, hyperreflexia, incoordination, or gait disturbance should ideally have MRI of the spine as part of the evaluation.^{36,45} In case the patient cannot have MR imaging, CT myelography is a useful alternative investigation.^{4,12,29} Following confirmation of diagnosis, the best treatment that can be offered in most cases is surgery.^{12,36,60} The goal of treatment for the intradural extramedullary lesions is to achieve complete surgical resection as much as possible under microscopic magnification while preserving spinal stability, to reduce pain and to improve the quality of life.^{4,6,15,19,23,25,31,33,40,45,60} Their total resection positively affects the outcomes and the recovery time varies with preoperative status.^{6,11,23,31} For spinal meningiomas in particular, the surgical strategy usually consists of laminectomy, initial tumor debulking, identification of the interface between tumor and spinal cord, early interruption of the broad based attachment to the dura, resection of the dura including the matrix of the tumor and duroplasty.^{4,9} Even among the elderly, surgery is still the preferred treatment of choice with the neurologic outcome following surgery being favorable in the vast majority of patients, and with less mortality or morbidity.^{40,60} An exception to this rule is intradural extramedullary metastasis with diffuse leptomeningeal involvement, in which case other means of treatment other than surgery should be considered



Table 1: Previous series on the various surgical techniques for intradural spinal tumors and outcomes. Note the contrast of outcomes following hemilaminectomy compared to other methods

Authors and year	No. of patients studied	Age range (in years)	Sex distribution (M:F)	Surgical technique evaluated	Surgical outcome/complications	No. of spinal levels operated	Tumor location	Maximum/mean follow-up	Histology
Sun et al (2011)	45	30–72 (mean of 48.2 years)	19:26	Unilateral hemilaminectomy	2 cases of epidural hydrops; 1 postoperative bacterial fever; no spinal deformity or instability; 93.3% neurologic improvement	N/A	21 cervical, 12 thoracic, 10 lumbar, 2 multiple	94 months	15 meningiomas and 30 neurinomas
Yeo et al (2011)	24	12–81 (mean of 51 years)	14:10	Unilateral hemilaminectomy	1 temporary dysesthesia; no spinal instability; 95.8% improved neurologic status	1–2.5	4 cervical, 9 thoracic, 12 lumbar (*1 patient had two lesions)	21.5 months	12 schwannomas, 6 ependymomas, 3 meningiomas, 1 hemangioblastoma, 1 cavernous hemangioma and 2 carcinoid tumors
Liu et al (2009)	24	18–61 (mean of 36.2 years)	15:9	Laminoplasty	1 CSF leak, 1 tumor recurrence, No spinal instability; only unilateral fusion in 7 patients; bilateral fusion in remaining 17 patients	2–4	12 thoracic, 7 lumbar, 5 thoracolumbar junction	26.5–41 months (average of 34.2 months)	13 neurofibromas, 6 ependymomas, 2 lipomas and 3 teratomas
Sim et al (2008)	7	19–83 (mean of 53.7 years)	4:3	Unilateral limited laminectomy	No complications	N/A	4 cervical, 2 thoracolumbar and 1 lumbar	12 months	6 schwannomas and 1 meningioma
Ruggeri et al (2012)	40	19–69 (mean of 41 years)	N/A	Laminotomy	Kyphosis in 3 patients; chronic pain in 12 patients	1–6 (average of 2)	N/A	52 months	8 astrocytomas, 11 ependymomas, 2 hemangioblastomas and 5 schwannomas
Canbay et al (2012)	15	29–65 years	5:10	Laminectomy and hemilaminectomy	No complications	N/A	2 thoracic, 9 lumbar, 4 thoracolumbar junction	48 months	All 15 were schwannomas
Naganawa et al (2011)	19	14–74 (mean of 42.3 years)	10:9	Hemilaminectomy	1 asymptomatic C1/C2 subluxation, intracranial hypotension from CSF leak in 1 patient, 1 vesicorectal disorder after thoracic neurinoma resection. 16 patients improved neurologically	1–4 (average of 2.9)	9 cervical, 1 cervicothoracic junction, 5 thoracic, 5 lumbar	85 months	13 neurinomas, 2 neurofibromas, 1 meningioma, 1 ependymoma and 3 arachnoid cysts

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Authors and year	No. of patients studied	Age range (in years)	Sex distribution (M:F)	Surgical technique evaluated	Surgical outcome/complications	No. of spinal levels operated	Tumor location	Maximum/mean follow-up	Histology
Ahn et al (2009)	10	32-72 (mean of 57 years)	3:7	Laminectomy (with posterior spinal fusion in only 5 cases)	1 radiologic asymptomatic instability proximal to instrumented segment, 1 pseudomeningocele and 1 tumor recurrence	N/A	1 cervical, 2 thoracic, 4 lumbar and 2 thoracolumbar junction (*1 patient had 2 lesions)	12-72 months (mean of 35.2 months)	8 schwannomas, 2 meningiomas and 1 ependymoma
Matsumoto et al (2009)	21	15-57 (mean of 37 years)	10:11	Osteoplastic laminotomy	Worsened instability in 2 patients, neurologic deterioration in 1 patient, improved in 16 patients and unchanged in 4	1-4 (average of 1.3)	13 thoracic lumbar and 8 lumbar	12-108 months (mean of 43 months)	18 neurinomas, 1 epidermoid cyst, 2 neurofibromas and 1 malignant peripheral nerve sheath tumor
Hossain et al (2009)	17	26-60 years	40:60%	Laminectomy	2 CSF leaks. 70% (12 patients) had complete recovery; 24% (4) with partial recovery; 6% (1) had no recovery	N/A	6 cervical, 10 thoracic and 1 lumbar	2-17 months	8 schwannomas, 2 meningiomas, 1 ependymoma and 1 thyroid metastasis
Zong et al (2013)	110	23-75 (mean of 46.7 years)	52:58	Laminectomy, hemilaminectomy and laminectomy with pedicle screw fixation	Laminectomy = 1 case of CSF leak, hemilaminectomy = no complication at all, laminectomy with pedicle screw fixation = 1 CSF leak; 1 case of paraplegia, 1 wound infection and 1 extradural hematoma	N/A	36 cervical, 37 thoracic and 37 lumbar	12-78 months (mean of 34.6 months)	All 110 were schwannomas

N/A: Information not available; M: Male; F: Female; *This patient was a 59-year-old man who had both T4 and L2 epidural carcinoid tumors.



after confirmation with contrast-enhanced MRI and cytology using samples of cerebrospinal fluid.¹⁴ Additionally, the use of the intraoperative C-arm X-ray equipment is extremely beneficial, allowing for exact localization of the lesion.^{4,15,53}

However, for the intramedullary tumors, the surgical care considered to be most ideal has been a controversial topic.^{12,16} The options include total excision, subtotal resection or just biopsy for tissue diagnosis but with an additional aim of providing adequate decompression of the spinal cord to halt further progression of neurological compromise.³⁶ However, as a result of need to reduce postoperative morbidity, the most widely accepted management protocol for intramedullary spinal cord tumors is partial resection followed by radiotherapy, since these lesions tend to be highly infiltrative.^{12,16} Exceptions to surgical treatment for intradural intramedullary lesions include diffuse inoperable tumors, those with known incomplete resection, significant residual disease in the conus, recurrent tumors, particularly in patients with short intervals between tumor recurrences of less than 12 months, those who could not tolerate surgery or have such a poor prognosis from their primary disease process that surgery would be an ineffective intervention.^{16,36} In these cases, external beam radiation can be done as the treatment for these patients.^{12,16,36} In addition, chemotherapy may be effective in the treatment of malignant astrocytomas of the spinal cord and for patients with progression of disease following surgery and radiotherapy with no other treatment options.^{12,16,36} For the low grade gliomas, Constantini et al demonstrated in their study that just radical excision alone is superior to the conventional partial resection and adjuvant radiotherapy.^{12,16} The main determining factor for outcomes in terms of long-term patient survival is the histologic composition of the tumor, especially for the gliomas.¹⁶

SURGICAL TECHNIQUES FOR INTRADURAL SPINAL TUMOR EXCISION

The first successful excision of an intradural extramedullary lesion was carried out in 1888 by Sir Victor Alexander Haden Horsely.^{2,4,45} Laminectomy is the surgical procedure commonly employed in the removal of IDEM spinal cord tumors.^{7,25,28,31,33,34,41,49,53,55,59} Total laminectomy has been defined as piecemeal removal of the vertebral arch starting from the base of the laminae without any final reconstruction.^{34,44} The first successful laminectomy was done by Alban Smith in 1829 and was later described in detail by Love.⁵⁷ The anatomical structures removed usually include the spinous process, the laminae, part of the facet complex, the interspinous and supraspinous ligaments, and the ligamentum flavum.⁵³ It was later

developed as a standard procedure by Mixter and Barr in 1934.³⁴ However, postoperative complications often develop after the removal of these lesions by laminectomy, such as kyphosis, spinal instability requiring fusion or other forms of stabilization, significant blood loss, epidural fibrosis, progressive myelopathy, prolonged hospital stay and persistent back pain.^{11,18,26,28,31,33,34,37,41,49,53,55,60} These complications commonly arise as a result of extensive soft tissue dissection, paraspinal muscle devascularization, damage to musculoligamentous structures particularly the ligamentum flavum and interspinous ligaments, and to the posterior bony elements during total laminectomy.^{34,37,49,53} The symptomatology of the deformity and occurrence or progression of the spinal instability commonly observed after laminectomy seems to be due to resection of the posterior spinal elements rather than the intervertebral disk.²⁶ Additional use of pedicle screw fixation has been clearly demonstrated to help in avoiding spinal postoperative instability.^{36,60}

Progressive neurological deficit and pain after laminectomy on the other hand, is mainly due to compression of either the spinal cord or nerve roots but also partly due to epidural scarring.^{32,49} Other complications observed from total laminectomy commonly include progressive myelopathy as well as stripping, dissection and denervation of the paraspinal muscles, lack of bony protection over the spinal cord, less protection in the event of a hematoma, possible constriction of the dura by epidural scarring and fibrosis as well as difficulty if a second surgery is required.^{25,49}

Due to these disadvantages, one surgical technique which has been widely used in place of laminectomy for the removal of intradural extramedullary tumor is hemilaminectomy or unilateral laminectomy.^{11,25,31,41,49,57,60} This technique was first introduced by Yarsargil and co-workers in 1991, and was later popularized by Eggert and Chiou.^{13,17,53,57,59} Since then, the procedure has been extensively described in detail.^{25,31,41,42,49,53,59} In this technique, resection of bone and ligaments is restricted to the side of the tumor.^{25,31,41,42,53} Hemilaminectomy is also the technique of choice if the tumor does not extend beyond the midline.³⁸ Advantages from this alternative technique over laminectomy includes reduction of postoperative pain, prevention of instability, elimination of the need for external bracing, and early mobilization of the patient.^{49,57} Several studies involving use of limited unilateral laminectomy for removal of intradural extramedullary tumors with the aim of preserving musculoligamentous attachments and posterior bony elements as much as possible, and with the patients having no form of spinal instability or spinal disability months after the surgery, suggest limited unilateral laminectomy to be a safe and

efficient technique for removal of these tumors.^{42,49,53,61} Technically, however, the main difficulty experienced by most surgeons is too little working space for the needle during dural closure compared to total laminectomy which created more access and visibility.^{25,31,49,55,59,60,61} This is probably the main reason explaining why this procedure is still not so widely accepted in spite of all the above mentioned advantages.⁵⁹ Since after its introduction by Yasargil, results of managing intradural extramedullary tumors with unilateral hemilaminectomy compared to laminectomy has been well documented in various studies.^{9,25,41,57,59,61} Sim et al, in treating 7 patients with intradural extramedullary tumors, demonstrated that it is possible to completely resect these tumors safely by this technique with reduction in postoperative back pain, instability, degenerative changes and operative blood loss, but highlighted on possibility of technical difficulty with the view in the operation field being too narrow in a unilateral laminectomy, such that it is not easy to handle instruments as well as exposure of the lesion being incomplete, leading to damage of normal nerves or even difficulty removing the lesion completely.⁴⁹ Yeo et al expressed the same opinion in their own report and declared that this was particularly so in the thoracic region of the spine.⁵⁹ Naganawa et al, in their experience of treating 20 patients for spinal tumors with unilateral hemilaminectomy confirmed this assumption to be true.⁴¹ As a result, unilateral drilling extending up to the facets may be required.⁴⁹ Iacoangeli et al, further suggested that this disadvantage could in turn increase the risk of dural tearing, nerve root damage, or incomplete tumor removal.²⁵ Other challenges with this technique include intradural extramedullary tumors that involve the contralateral recess, bilateral lesions, huge neoplasms with scalloping of vertebrae, easily bleeding tumors spreading to both sides, lesions with unclear borders, and intramedullary neoplasms.²⁵ A slight modification of the hemilaminectomy technique is unilateral partial hemilaminectomy.^{7,53} This technique is, however, rarely used for spine tumor surgery.⁷

Other techniques have been tried for the excision of intradural extramedullary tumors apart from laminectomy and hemilaminectomy.^{25,31} One of such techniques is laminotomy.^{19,25,31,44} The procedure of laminotomy has been well described in both adults and children.^{19,34,44,55} It is defined as *en bloc* surgical division of the vertebral arch at the base of the laminae with subsequent repositioning at the end of the procedure.⁴⁴ It could be either unilateral or bi-segmental bilateral.⁵⁵ Generally, both forms of laminotomy are neither associated with any increased rate of postoperative nerve deficits nor a higher rate of other complications compared with laminectomy.⁵⁵

Laminotomy is generally preferred in children, especially at the cervical level.¹⁰ Compared to laminectomy, it is said to have lower risk of epidural scarring, a less time-consuming procedure, less intraoperative hemorrhage due to the shorter period of bone work and lower risk of spinal trauma due to less tendency of blows from the surgeon's instruments.⁴⁴ It is also a less invasive procedure and generally requires shorter surgical incisions, thus making room for better cosmesis.^{34,55} However, though laminotomy has been widely used as an approach to resect spinal tumors, it is not yet recognized as the standard approach for pathologies of the spine and spinal cord not requiring bony decompression.⁴⁴ This is probably because in spite of its advantages, some who tried laminotomy as an option have also experienced similar complication of postoperative kyphotic deformities as in laminectomy as well as postoperative segmental instability from failure of fusion of the operated lamina.^{19,37,44} This complication, however, commonly turns out to be asymptomatic and self-limiting, requiring no treatment in some cases.⁴⁴ Laminotomy also tends to be more technically demanding than laminectomy.^{31,55} In the descriptive work by Ruggeri et al, on the technique of laminotomy in 40 patients over a period of 4 years, they acknowledged that a standardized procedure for the technique does not yet exist because of the various methods described in the literature and stated that laminotomy is not yet a standard approach to pathologies of the spine despite their observation of satisfactory fusion of the osteoligamentous flap with the spine.⁴⁴ Osteoplastic laminotomy is one modification of the technique which has been used by some authors to achieve anatomic reconstruction of the posterior arch after excision of these spinal tumors with the aim of preventing postoperative kyphosis.^{1,15,31,37,53} Osteoblastic laminotomy has also been used in surgery for intradural spinal tumors.⁵³ One study comparing laminotomy with laminectomy using radiologic evaluation clearly demonstrated that both laminectomy and laminotomy have about the same degree of postoperative listhesis as a complication.⁵⁴ Apart from application in management of intradural spinal tumors, other studies exist in the literature on exclusive comparisons between just laminectomy and laminotomy alone. Mahadewa et al carried out a 3-year retrospective comparative study between bilateral laminotomy and laminectomy with fusion as techniques of surgical decompression in management of lumbar canal stenosis in 105 patients, and observed that both were equally effective over a short period of follow-up.³⁴ Similarly, according to another study by Thomas et al, on radiographic comparison between laminectomy and laminotomy for 26 patients with lumbar canal stenosis, laminotomy has the same degree of postoperative listhesis as laminectomy.⁵⁴



Thomé et al, in comparing both bilateral and unilateral laminotomy with laminectomy in 120 patients found out that outcomes after unilateral laminotomy were quite comparable with that after laminectomy, with bilateral laminotomy being more superior in outcomes to both unilateral laminotomy and laminectomy.⁵⁵ They demonstrated that the benefits of stability appear to be significantly higher if the laminotomy is bilateral instead of unilateral, despite slightly longer duration of surgery and more blood loss associated with bilateral surgery.⁵⁵ Asazuma et al studied postoperative changes following laminectomy, laminotomy and hemilaminectomy in 51 patients but that evaluation focused only on tumors in the cervical region of the spine and reviewed all types of spinal tumors in general, and not intradural extramedullary tumors in particular.⁵ Matsumoto et al evaluated the outcomes of osteoplastic type of laminotomy as a technique for surgical management of intradural spinal tumors in 21 patients but had no comparison with laminectomy or any other technique.³⁷ In a descriptive work by Ruggeri et al, on the technique of laminotomy in 40 patients over a period of 4 years, they acknowledged that a standardized procedure for the technique does not exist because of the various methods described in the literature and stated that laminotomy is not yet a standard approach to pathologies of the spine despite their observation of satisfactory fusion of the osteoligamentous flap with the spine.⁴⁴ Compared with laminectomy previously carried out in another set of 40 patients, their experience of postoperative kyphosis was far less than it was with the 40 patients who had laminectomy.⁴⁴ Their work, however, included other pathologies of the spine apart from spine tumors.⁴⁴ Matsumoto et al, clearly demonstrated from their work that osteoplastic laminotomy preserves the structures that could be important for spinal stability.³⁷ Furtado et al, reported similar findings on children who underwent laminotomy and tumor excision for benign cervical intradural extramedullary tumors.¹⁹

Laminoplasty is yet another technique also thought to have advantage of maintaining the postoperative stability of the spine following excision of these tumors.^{25,31,32} It can preserve the posterior arch of the spine, makes for reconstruction without any need for fusion, protects the paraspinal muscles and prevents postoperative instability, epidural adhesion and kyphotic deformities.^{18,31,32} The re-attached laminae provides effective primary stability after fibrous healing not only between the incision lines in the laminae, but also among the interfaces of the paraspinal musculature, laminae and spinous processes.³² In addition, considering that intradural extramedullary tumors can recur after initial excision, the technique of laminoplasty makes revision surgery much easier, as

it is safer to expose the dura after this type of surgery than after traditional laminectomy, because it preserves a relatively normal posterior bony structure and causes no epidural scar.³² It also reduces postoperative pain.¹⁸ It is, however, also not widely considered as an alternative to laminectomy in the management of intradural extramedullary tumors because laminoplasty can still disrupt the posterior ligamentous structures on the dorsal spine.^{31,32,59} In addition, after laminoplasty, external fixation for an extended period of time is necessary, which prolongs the period of bed rest and prevents the patients from undergoing early mobilization and rehabilitation.³² Furthermore, laminoplasty is difficult to apply in the thoracic and lumbar spine because the pedicles have a tendency to fracture as a result of their anatomy in those regions of the spine.³¹ Unilateral hemilaminectomy is in fact thought to surpass laminoplasty in the aspect of the dynamic stability of the spine since it not only avoids damage to the supraspinous and interspinous ligaments but also leaves the paravertebral muscle on the opposite side completely intact.^{31,59} Finally, additional instrumentation may be required if more than three levels are involved in the laminoplasty.³²

The location of intradural extramedullary tumors can be posterior, posterolateral, lateral, anterolateral or anterior.^{4,15,53} 31% of the intradural extramedullary tumors are located anterior (i.e. ventral) to the spinal cord.² Posterior or lateral tumor position in the spinal canal tends to have better prognosis than those in ventral locations.⁴⁶ Apart from that, evidence has shown that recurrence rates tend to be relatively high for tumors located anteriorly rather than laterally.⁶ This is partly because some macroscopic tumor located at this site is more likely to be left behind, and also because management of attachment to the dura mater in such cases tends to be technically difficult.⁶ Surgical routes to intradural extramedullary tumors should be chosen based on the location of the tumor, its spread, and the region in which it is localized.^{4,52} It had earlier been suggested that either an extreme lateral or posterolateral approach involving removal of the pedicle with or without costotransversectomy, or even an anterior approach will be necessary for the complete removal of tumors in ventral locations, particularly ventral thoracic lesions with extraforaminal tumor extensions.^{2,4,52} Unfortunately, extreme lateral approaches invariably require spinal fusion to avoid the development of postoperative instability due to the removal of both the laminae and the facet joints, while the anterior approaches are technically difficult to carry out as a result of the associated epidural venous bleeding, the limited range of exposure and access, as well as the need to remove several vertebral bodies to achieve adequate access to the tumor.² However,

recent experience and evidence has clearly shown that practically no difficulties are really encountered in removing tumors which are ventral to the spinal cord with these various posterior approaches and so, either extreme lateral or anterior approaches may not be necessary for the removal of such tumors.^{2,3,25,27,56} This is particularly made possible by the discrete anatomical barrier formed by the arachnoid and pia between the dura and the spinal cord.^{27,56}

Regarding the resection of intramedullary tumors, the technique involves the exposure and decompression of the spinal cord, usually through a multilevel laminectomy followed by a midline dorsal dural opening.³⁶ Alternatively, with microsurgical techniques, unilateral partial hemilaminectomy has also been shown to be a safe and effective approach both by protecting the posterior elements and by giving the surgeon space to manipulate the intradural contralateral side easily.⁷ Opening of the spinal cord in order to access the spinal tumor is commonly done parallel to the long tracts through a longitudinal, midline incision. This is done to avoid transection of the white matter tracts of the dorsal columns and avoid disturbing motor and cerebellar long tracts found laterally and ventrally in the spinal cord.³⁶ The presence of a visualized plane between the tumor and the tissue of the spinal cord greatly improves the extent of the resection, neurological outcome and overall survival.^{20,29,36} In addition, the presence of a syrinx that is continuous with the tumor plane also improves overall neurological outcome.³⁶ Just as with intradural extramedullary lesions, osteoplastic laminoplasty or internal spinal fixation with fusion has effectively been used to prevent long-term spinal deformity from the surgery, even in children.^{19,39,50} Both Chiou et al, and Yasargil et al reported removal of intramedullary tumors via hemilaminectomy or partial hemilaminectomy, including extensive lesions.^{13,57}

Finally, a few other techniques have been well described for surgical management of intradural lesions. These include unilateral multilevel interlaminar fenestration as an alternative surgical approach instead of the conventional laminectomy, hemilaminectomy or any of the other techniques already described.^{28,53} It has also been referred to as 'multiple spinal key hole surgery'.²⁸ In their experience with this technique in managing 78 patients having various spinal tumors, Koch-Wiewrodt et al, reported complete extirpation of the lesion in most cases with no postoperative spinal instabilities observed in all the patients up to 8 years after surgery.²⁸ They described the approach as an effective technique that interferes with spinal stability to a much lesser extent than the other conventional techniques by significantly reducing the need for bone removal.²⁸ Banczerowski et al

used a hemi-semi-laminectomy approach combined with the supraforaminal burr hole technique in seven adult patients with neuroma extending inside the foramen in the region of the cervical spine.⁸

MANAGEMENT OF DURAL ATTACHMENT

Another crucial aspect regarding operative care for intradural spinal tumors is on the best and most appropriate management of dural attachment, particularly for meningiomas.²⁵ This is particularly an important issue both for young patients and for cases where malignancy is suspected, in which case aggressive treatment of the dura mater overlying the anterior aspect of the spinal cord in such cases has been recommended.⁶ In their report, Iacoangeli et al, utilized a previously described technique which involved separation of the dura into an outer and inner layer, with removal of the inner layer together with the tumor followed by primary dural closure with the outer layer.²⁵ The preserved outer dural layer is used to close the dura in a watertight fashion and the closure is then reinforced with fibrin glue and fat.²⁵ For the 10 patients treated by Ahn et al, closure of the dura mater was simply done with only prolene 7-0 in the first few cases, while prolene 6-0 reinforced with fibrin glue was used for the remaining surgeries, together with use of negative pressure drainage in all 10 patients.² Yet, duroplasty using an iliotibial band was performed in one patient from the same set of 10 patients reported by Ahn et al, following development of a pseudomeningocele as a complication.² Haque et al, in another report of two illustrative cases, described a different method for primary repair of the spinal dura during minimally invasive spine surgery for excision of intradural spinal lesions.²² In that method, a size 4-0 Surgilon braided nylon with a CV-20 taper 1/2 circle, 10 mm diameter needle is used for continuous primary dural closure through a retractor system with no postoperative cerebrospinal fluid leakage observed.²² Others, such as Lee et al, simply coagulated the site of dural attachments to the tumor to avoid both the additional risks of CSF leakage after removal of dura and the risk of spinal cord damage following dural excision at the site of the tumor's origin.³¹ Interestingly, these ideas appear quite comparable to Simpson's work on dealing with dural attachment in the prevention of recurrence after excision of intracranial meningiomas.^{25,51}

CURRENT ADVANCES IN SURGICAL TECHNIQUES FOR MANAGING INTRADURAL SPINAL TUMORS

Despite good curative outcomes with these open conventional approaches, several associated complications still exist, such as more intraoperative blood loss as well



as a higher risk of injury to the spinal cord or nerve roots.⁶⁰ With the introduction of minimal access surgical techniques, one can avoid these problems as much as possible.^{9,60} Current evidence regarding management of intradural spinal tumors has shown that blood loss and hospital stay durations are significantly reduced with less invasive surgical techniques.⁶⁰ Minimally invasive spine surgery was initially developed for carrying out lumbar spinal decompression but presently has an increasing role in the treatment of intradural spinal tumors.^{9,22,60} In an attempt to further minimize the problems associated with bone removal, Koch-Wiewrodt et al, used multilevel interlaminar fenestration, also called 'multiple spinal keyhole surgery, to remove intramedullary extramedullary lesions, and even some lesions that extended over several spine segments.^{28,53} This more limited approach requires an endoscope or endoscopic assistance in a few cases.^{28,53} Even for extramedullary lesions, such as meningiomas, favorable clinical results as well as low recurrence rates have been reported following less invasive surgical techniques.⁹ Higher resolution MRI together with these improved surgical techniques has helped to significantly improve resection and enhance the overall neurological outcome. Image-merged guided minimally invasive spine surgery for tumor removal in patients with intradural extramedullary lesions employing merged preoperative MRI and intraoperative 3D fluoroscopy using merging software has been recently demonstrated not only to be feasible and safe, but also to have relatively good outcomes.³³ Intraoperative ultrasound may at times be useful to evaluate intraoperative extent of lesion and radicality of surgery.⁴

For the intramedullary variety, results have also shown reduced postoperative mortality, better recovery of the disturbed functions of the spinal cord, as well as prolonged postoperative remission and survival with minimally invasive surgery.⁶⁰ The employment of the operative microscope as well as cavitron ultrasonic surgical aspiration devices during the exposure and resection of intramedullary tumors, active neuromonitoring during the surgery, such as with combined use of somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs) to provide feedback to the surgeon during intramedullary tumor resection, LASER (light amplification for the stimulated emission of radiation) and intraoperative ultrasound have all been shown to reduce surgical morbidity.^{4,16,29,36} Intraoperative monitoring especially with SSEPs and MEPs has become a major determinant in making the critical decision about the extent of the resection, in which case the tumor excision can continue as long as MEPs are maintained at more than 50% of their original amplitude.¹⁶

In spite of its wide application in management of various pathologies involving the spine, the use of stereotactic radiosurgery in the management of both intradural extramedullary and intramedullary lesions especially metastasis remains controversial.⁴⁸ However, findings have shown it to be an effective and safe method of treating patients with these lesions, especially in cases of recurrent or unresectable tumors.^{12,48}

AN ADDITIONAL NOTE: LONG SEGMENT INTRADURAL TUMORS

Surgical extirpation of midline ventral long segment intradural tumors in particular can be quite formidable and can have potentially serious morbidity.³⁵ Regarding the intramedullary tumors, a retrospective review by Constantini et al, on radical treatment of gliomas revealed that the majority of longer segment lesions were low grade.¹⁶ Experience and literature on the subject of surgical considerations in the case of intradural extramedullary tumors spanning multiple spinal segments is scarce.³⁵ Probably as result of how rare intradural extramedullary tumors are, it has not been easy to organize a significantly large study population in order to objectively assess a surgical procedure for treating these long-segment tumors.² An appropriate surgical approach and strategy needs to be outlined to achieve a good outcome following operative treatment of such lesions.³⁵ It has been suggested that posterolateral approach is more suitable for such long-segment spinal tumors since a wider exposure would be required to achieve total control while removing the tumor.³⁵ Generally, bone opening is limited to one level above and one level below the solid portion of intradural extramedullary tumors but for very extensive tumors, requiring extensive laminectomy or laminotomy, for children as well as for adults, leaving in place one posterior arch after every five to six levels has been recommended.¹⁰ These extensive tumors have previously been approached via either laminectomy or laminotomy.¹⁰ A review by Kumar and Singh revealed that intradural extramedullary lesions with a long segment involvement have a good outcome following a good microsurgical excision.³⁰ In a report on successful excision of a ventral long-segment schwannoma extending from C2 to D3 by Mahore et al, they used the technique of laminotomy and concluded from their experience that posterolateral approach is feasible in ventrally-located large sized tumors spanning over multiple spinal segments.³⁵ However, in another similar report by Yeh et al, of a 63-year-old man with acute spinal cord compression caused by a long segment of intradural extramedullary schwannoma, laminectomy

instead was performed from thoracic vertebrae T7 to T12 level with subtotal excision.⁵⁸ In yet another report by Gardner et al, of a long segment intradural extramedullary lesion extending from T2 to T7 in a 27-year-old lady, a T2-T8 laminoplasty was performed.²¹ Interestingly, none of these three reports involving the three different techniques made mention of any findings of instability during follow-up.^{21,35,58}

CONCLUSION

Surgical treatment of intradural spinal tumors has changed over the years with advances in neuroradiology, neurosurgery, neuro-oncology and neuropathology all contributing substantially to improving outcomes for patients.²⁵ Yasargil and co-workers suggested that total laminectomy, laminoplasty and laminotomy all require different degrees of bone removal and involve surgical stripping and denervation of posterior muscular and ligamentous structures that are essential for maintaining spinal stability.⁵⁷ However, others have described the advantages of laminoplasty or laminotomy in maintaining postoperative stability and preventing epidural scarring.⁴² Several studies have clearly demonstrated excellent outcomes following the application of each of these various techniques in the surgical management of intradural spinal tumors.^{22,53} However, there are currently no algorithms to guide the surgeon on surgical care for intradural spinal tumors. The choice of which surgery to do in each case is largely dependent on each surgeon's philosophy, knowledge and experience as well as patient-related factors, a clear understanding of the involved anatomy of the lesion in each patient, as well as the available facilities and equipment. It is important to always remember that neurological outcome following surgery is also highly dependent on the extent of already existing preoperative deficits.³⁶ In addition, choice of optimal surgical route mostly depends on the location and size of the tumor, but also on patient status and surgeon preference.^{4,25} Ideally, after detailed clinical, neurologic and radiologic assessment, the chosen operative approach should be properly planned before the procedure.⁴ The cumulative experience of the surgeon and team which develops over time also goes a long way to help in further improving outcomes.

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