International Journal of Multiphysics
Volume 18, No. 3, 2024
ISSN: 1750-9548

Surgical Outcomes of Microsurgical Resection for Intradural Spinal Cord Tumors: Review Article

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Abstract:

Intradural spinal cord tumors comprise a heterogeneous group of neoplasms classified as intradural extramedullary or intramedullary according to their anatomical relationship to the spinal cord. These lesions may cause progressive pain, motor weakness, sensory disturbance, and sphincter dysfunction because of spinal cord or nerve-root compression. Magnetic resonance imaging is the principal diagnostic modality and plays a major role in surgical planning. Microsurgical resection remains the cornerstone of treatment, with gross total resection offering the best chance of long-term tumor control in well-circumscribed lesions such as schwannomas, meningiomas, ependymomas, and hemangioblastomas. Advances in operative microscopy, microsurgical instruments, intraoperative neurophysiological monitoring, imaging, and safe myelotomy techniques have improved the extent of tumor removal while reducing neurological morbidity. Nevertheless, surgical outcomes depend on tumor histology, anatomical location, presence of a clear tumor–spinal cord interface, preoperative neurological status, and the ability to preserve functional neural tissue. This review highlights the role of microsurgical management in improving neurological and oncological outcomes in patients with intradural spinal cord tumors.

Keywords: Intradural spinal cord tumors; Microsurgery; Intramedullary tumors; Extramedullary tumors; Gross total resection; Intraoperative neurophysiological monitoring; Neurological outcome.

Introduction:

The term microsurgery encompasses techniques that require optical magnification and specialized micro-instruments to successfully operate on small anatomical structures, such as small vessels. These methods are employed across various surgical fields. In plastic surgery, microsurgical techniques are a crucial part of the reconstructive surgical spectrum and serve as the foundation for free autologous tissue transfer, peripheral nerve reconstruction, replantation and lymphatic surgery. The historical development of modern microsurgery is closely tied to advancements in microscopes and micro-instruments. In the 1950s and 1960s, with the introduction of coaxial illumination and motorized zoom, microsurgery was first clinically applied to perform limb replantation procedures via anastomosis of small-caliber arteries, veins, and peripheral nerves **(1)**.

Today, the size of the structures no longer appears to be a limiting factor for further advances. In the last decade, supermicrosurgical techniques have been refined to perform anastomosis of lymphatics and blood vessels with diameters below 0.5 mm. These techniques enable even more minimally invasive tissue transfer and a specific, tailored inset of tissue to suit the defect **(2)**.

Performing supermicrosurgery requires special instruments, such as forceps with tip diameters of 0.1 mm and suture material sized 11-0 or 12-0. Utilizing these instruments demands specially trained motor skills and frequent practice to avoid unnecessary increases in operating time or severe complications **(3)**.

Robotic Microsurgery:

Since successful microsurgery depends on high-precision instruments in combination with fine motor skills, it is inevitable that robotics will play a dominant role in this field in the future. Currently, the main benefit of robotic-assisted surgery lies in the ability to operate on deep anatomical structures through small incisions. This has led to the routine integration of human-controlled semi-autonomous robots, such as the da Vinci system, in many clinics worldwide. Although plastic surgery primarily concerns superficial regions and open surgical approaches, there have been successful reports of intra-abdominal DIEP flap dissection for breast reconstruction using the da Vinci system. The greatest potential lies in the application of robots in microsurgery, particularly lymphatic surgery **(3)**.

For selected indications, AI-powered autonomous robots are already considered superior to even highly trained surgeons in terms of tremor reduction and movement scaling, leading to a greater range of motion with increased precision. Additionally, the surgeon can operate in an ergonomic position while viewing a 3D screen, which is an important factor during long, complex procedures **(4)**.

Microsurgery of Spinal Tumors:

Tumors of the spine can be divided into primary and metastatic tumors, with the latter being the most common presentation. The standard classification divides spinal tumors, based on their anatomical location, in relation to the spinal cord into extradural and intradural tumors, and then into extramedullary spinal cord tumors (EMSCTs), and intramedullary spinal cord tumors (IMSCTs). This classification dramatically influences the surgical approach to the lesion in terms of surgical removal, vertebral stability, and final outcome of the patients **(5)**.

Among spinal tumors which occur extradurally, schwannomas (29%), meningiomas (25%), and exophytic ependymomas (13%) are the most common neoplasms, while ependymomas (55%) and astrocytomas (30%) are the most common intradural intramedullary tumors statistically reported . Metastases are the most common extradural extramedullary tumors, and they typically involve bony structures. MRI is considered the state of the art to diagnose intradural spinal tumors whereas in some cases, CT scans, angiography, CSF analyses, and neurophysiological examination could add a valuable help in diagnosis **(6)**.

The preoperative management of these lesions is focused either on the suspected histopathological diagnosis and on the clinical presentation and the anatomical location. Although intramedullary lesions are rarer and harder to manage, a well-planned treatment could lead to an excellent outcome without treatment-related deficits. Technical advances in imaging, neuromonitoring, minimally invasive approaches, and radiotherapy have improved the outcome of intradural spinal tumors. However, the outcome remains poor in malignant intramedullary tumors**(5)**.

Gross total resection is the gold standard therapy for spinal tumors and may be curative for well-circumscribed lesions (this is particularly true for EMSCTs and low-grade IMSCTs). However, adjuvant radiation and chemotherapy can be indicated for patients that would experience increased morbidity from an iatrogenic damage. Intraoperative tools are systematically used in spinal tumor surgery in order to improve the surgical removal and to increase the neurological outcome. As well as with lesions occurring in eloquent regions of the brain, intraoperative neurophysiological monitoring (IONM) of spinal cord lesions has been proven to be safe and effective: SSEP, MEP, and D-wave monitoring are the most used and useful tools for this kind of surgery. While surgery is the mainstay treatment for many of these lesions, radiation and chemotherapy are of growing importance in recurrent and multifocal disease **(5)**.

Extramedullary intradural spinal cord tumors (EMSCTs):

Extramedullary intradural spinal cord tumors are rare variants of SCTs, characterized by their extraaxial location, accounting for about 40–45% of all spinal tumors. The first case of a resected EMSCT in the literature was reported by Sir Victor Alexander Haden Horsley in 1888 which described the resection of a “fibromyxoma” in a 42-year-old patient **(7)**.

Meningiomas are the most common primary extramedullary tumors (25%), most likely to occur in the thoracic spine, in the posterolateral side of the spinal canal and in female patients.

Nerve sheath tumors, spinal schwannomas, or neurofibromas account for 10–15% of all the EMSCTs, and they usually originate from the sensory dorsal rootlets: typical schwannomas are intradural (10–15%) but it is not unusual to find “dumbbell” tumors with an intraextradural growth (10%). Dumbbell schwannomas were considered in some series, to be at an higher risk to be malignant, particularly in young patients **(8)**.

Among ependymomas, about 40% occurs within the filum terminalis being mostly myxopapillary, WHO grade I. In filum terminale ependymomas surgery, the role of the tumor capsule plays a fundamental role to reduce the risk of local recurrence: an en bloc resection of both the tumor and the capsule itself is a predictor of the best surgical outcome. Intradural extramedullary tumors typically compress and displace the spinal cord, nerve roots and, occasionally, surrounding structures.

The main goal of EMSCTs tumors is to control the origin and the extent of the lesion: a posterior durotomy could give a direct control of posterior or posterolateral located lesion. For highly vascularized tumors of those that are partly calcified (e.g., meningioma), the debulking could be more challenging and a preoperative surgical planning is mandatory to achieve the GTR without any functional damage. Schwannomas nearly exclusively originate from the posterior sensory root. A T-shaped dural opening with a root-sparing surgery is safe and recommended **(9)**.

Intramedullary Spinal Cord Tumors (Imscts):

Intradural spinal cord tumors account for 10–20% of primary CNS tumors, with extramedullary tumors (EMSCT) accounting for up to two-thirds of this group and one-third are intramedullary tumors (IMSCTs). Among them, ependymomas are considered the most common, representing about 40–60% of all intramedullary tumors, where astrocytomas being the second in-line accounting for about 30%. Hemangioblastoma is the third reported lesion, representing 3–8% of IMSCTs **(10)**.

Surgery for IMSCTs has been introduced in 1911 with the Elsberg and Beer's two-stage procedure which revolutionized the management of this surgery. From then, evidence-based guidelines recommend some technical tips to achieve the best surgical outcome with the best functional and neurological outcome. The combination of a posterior myelotomy and the intraoperative monitoring of SSEP, mMEP, and eMEP (d-wave) are considered the best predictors for the postoperative neurological outcome **(11)**.

The myelotomy is the key step in the IMSCT surgery: this is the moment in which surgeons, technicals, and anesthesiologists should discuss every relevant change in IONM variables (amplitude and latency) in order to rule out eventual changes in medication and adjust anesthetic drugs, mean arterial pressure, body temperature, or oxygenation. SSEP is a highly sensitive parameter but it is limited in specificity: reduction of SSEP amplitude by 50% or an increase in latency by 10% of baseline after myelotomy indicates the need of a watchful waiting and a release of any local cord compression; a permanent intraoperative SSEP loss is considered in line with a new postoperative neurological deficit in 50–75%.

Different safe entry zones and myelotomy techniques have been proposed over the years: the standard posterior midline myelotomy—between the posterior columns—remains the mainstay for approaching IMSCTs. Mapping the posterior columns might help to identify the physiological midline sulcus for myelotomy in case of asymmetrically filocalized IMSCTs. To avoid the division of posterior large vessels coursing the mid surface of the spinal cord and the somatosensory related deficits, some authors proposed a discontinuous myelotomy technique in order to preserve the integrity of these main vessels **(12)**.

A posterolateral sulcus (PLS) myelotomy might be feasible in cases of lateralized IMSCTs posterior to the level of the attachment of the dentate ligament (dorsal root entry zone), particularly if the lesion is associated with moderate to severe local pain symptoms **(13)**.

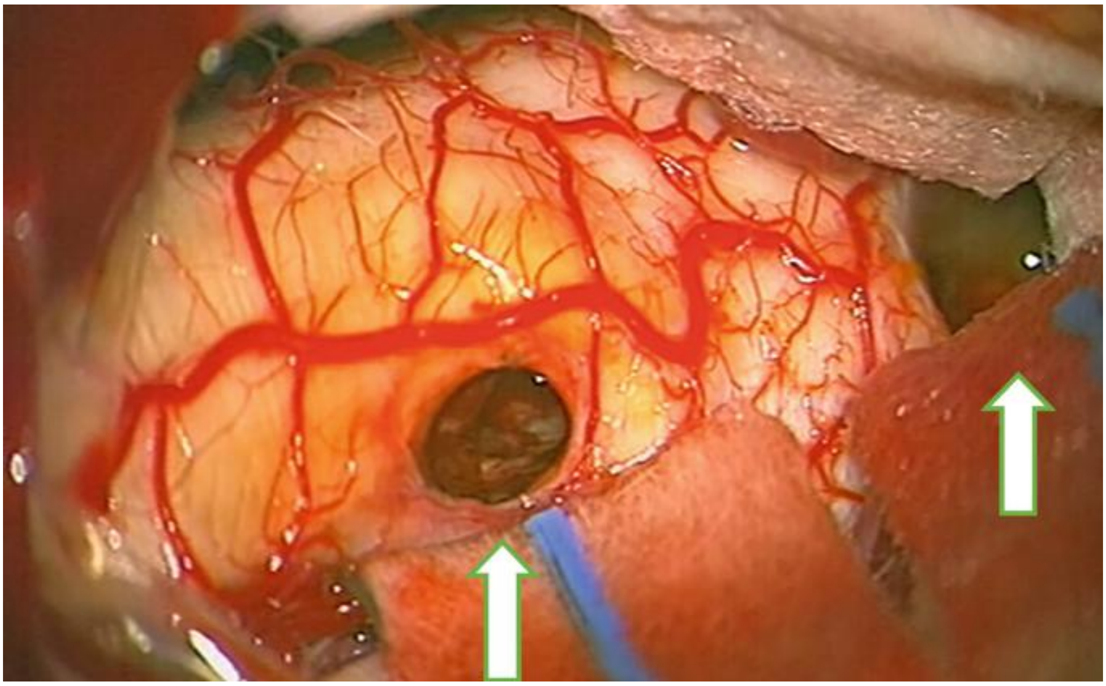

Figure (1): Discontinuous myelotomy, personal case **(5)**.

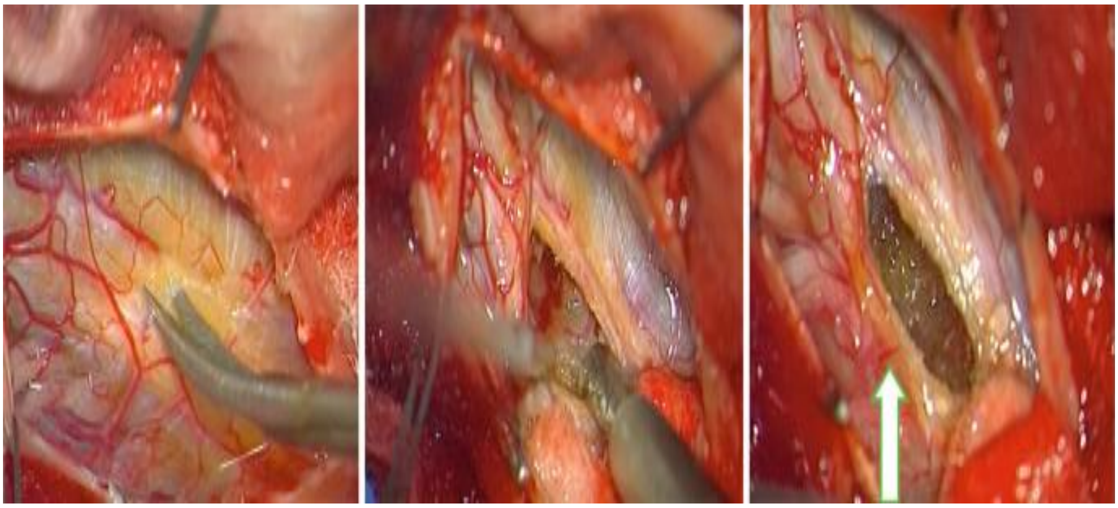

Figure (2): Intraoperative pictures showing a dorsolateral myelotomy, at the root entry zone for lateral tumors **(5)**.

Anterior or anterolateral approaches, even if very rare, were also described and should be considered in case of ventral intradural tumors with a paramedian anterior myelotomy **(14)**.

The main goals of IMSTCs surgery are achieving the gross total resection with the best postoperative neurological outcome: the identification of tumor margins and the tumor-spinal cord interface should be mandatory in the first stages of the surgery in order to gain the early control of the tumor extension in all the lateral and craniocaudal directions. The decision of looking forward a gross total removal of the lesion should count mainly on two factors: the histology and the presence of a plan of dissection with the spinal cord are considered the most important predictors of neurological outcome in terms of "resectability" and recurrence **(15)**.

This is particularly true for ependymomas and hemangioblastomas, whose benign histology and easy dissection plan encourage a GTR with a good neurological outcome.

On the contrary, in case of malignant histologies (astrocytomas, higher-grade gliomas, or ependymomas) or the absence of a clear spinal cord-tumor interface leads to subtotal resections or biopsy in order to avoid neurological impairments. Moreover, astrocytic tumors with an unclear cleavage plane were not associated with an improved progression free survival even after a gross total resection . In summary, primary goals for astrocytic tumors, in case of an absent tumor-spinal cord interface, should be based also on patient's involvement, surgeon experience, and intraoperative changes of IONM variables **(16)**.

Figure (3): Preoperative MRI showing the intramedullary nature of the lesion and the high intensity after contrast administration **(5)**.

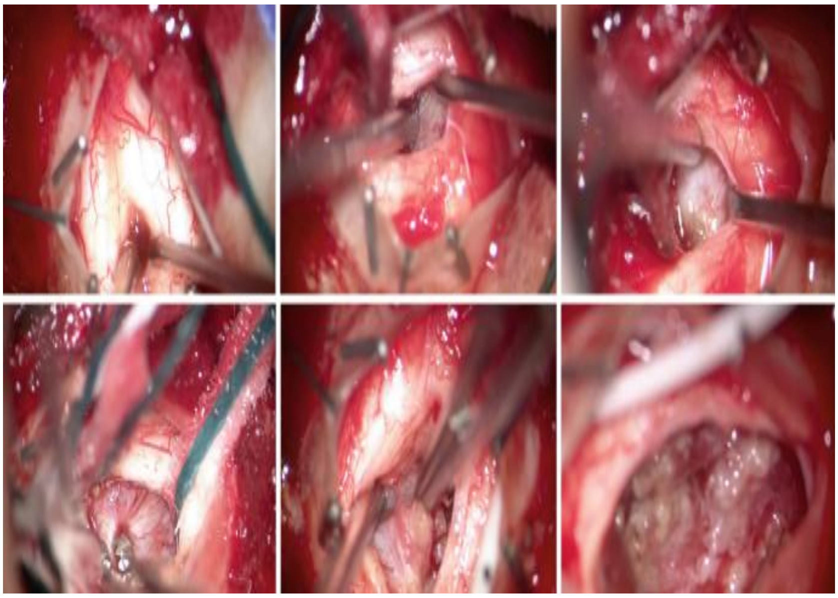

Figure (4): Intraoperative pictures showing the removal of the lesion. The patient underwent a posterior bilateral C4–C5 hemilaminectomy and microscopic exeresis of the cervical lesion **(5)**.

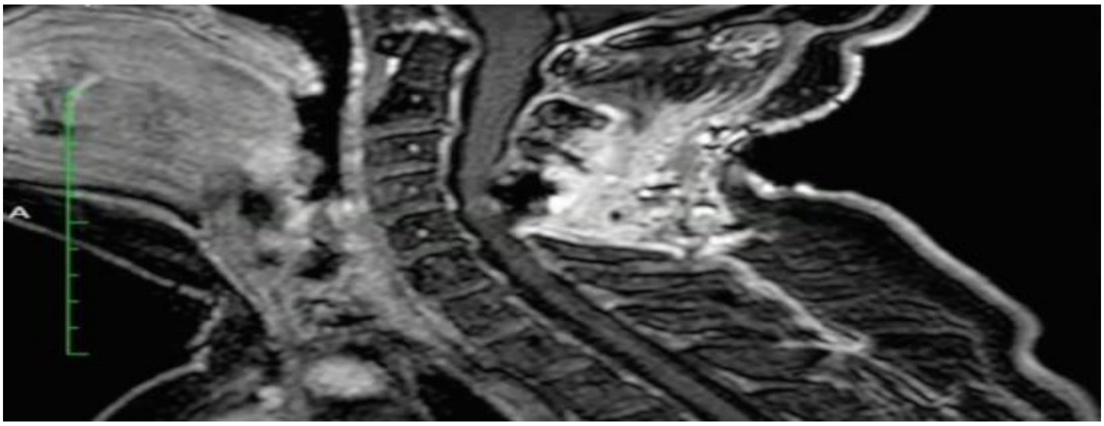

Figure (5): Six months postoperative MRI **(5)**.

Figure (6): (**a**) Preoperative sagittal image showing a huge intramedullary mass coursing along the cervicodorsal region. (**b**) Postoperative MRI **(5)**.

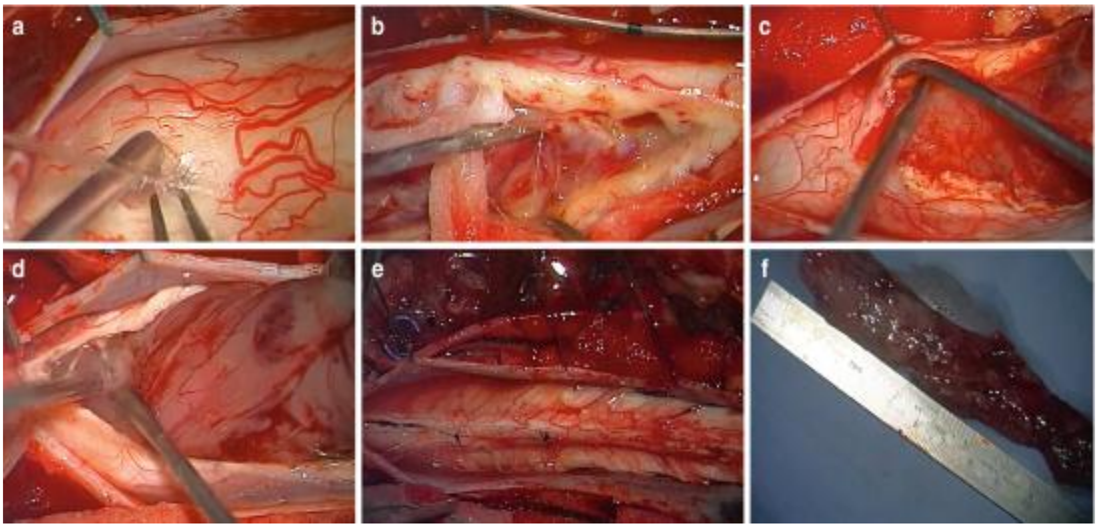

Figure (7): Intraoperative pictures showing the removal of the lesion. (**a**) Midline myelotomy. (**b–d**) Microsurgical anatomical dissection. Identifying the interface tumor-intact shell of the spinal cord dissecting from the side of the tumor. (**e**) Suture of pia mater allowing anatomical reconstruction. (**f**) Tumor specimen after microsurgical removal (length 12 cm) **(5)**.

References:

1. Tamai, S. (2009). History of microsurgery. Plastic and Reconstructive Surgery, 124(6S), e282–e294.
2. Yamamoto, T. (2019). Onco-reconstructive supermicrosurgery. European Journal of Surgical Oncology, 45(7), 1146–1151.
3. Thamm, O. C., Eschborn, J., Schäfer, R. C., & Schmidt, J. (2024). Advances in modern microsurgery. Journal of Clinical Medicine, 13(17), 5284.
4. Shademan, A., Decker, R. S., Opfermann, J. D., Leonard, S., Krieger, A., & Kim, P. C. W. (2016). Supervised autonomous robotic soft tissue surgery. Science Translational Medicine, 8(337), 337ra64-337ra64.
5. Tomasello, F., Garufi, G., & Cardali, S. (2024). Microsurgical Removal of Spinal Tumors. In Neuroanatomy Guidance to Successful Neurosurgical Interventions: The Torch of Neurosurgical Excellence (pp. 731–741). Springer.
6. Tobin, M. K., Geraghty, J. R., Engelhard, H. H., Linninger, A. A., & Mehta, A. I. (2015). Intramedullary spinal cord tumors: a review of current and future treatment strategies. Neurosurgical Focus, 39(2), E14.
7. El-Mahdy, W., Kane, P. J., Powell, M. P., & Crockard, H. A. (1999). Spinal intradural tumours: Part I-extramedullary. British Journal of Neurosurgery, 13(6), 550–557.
8. Ozawa, H., Kokubun, S., Aizawa, T., Hoshikawa, T., & Kawahara, C. (2007). Spinal dumbbell tumors: an analysis of a series of 118 cases. Journal of Neurosurgery: Spine, 7(6), 587–593.
9. Alafaci, C., Grasso, G., Granata, F., Salpietro, F. M., & Tomasello, F. (2016). Ossified spinal meningiomas: clinical and surgical features. Clinical Neurology and Neurosurgery, 142, 93–97.
10. Ardeshiri, A., Chen, B., Hütter, B.-O., Oezkan, N., Wanke, I., Sure, U., & Sandalcioglu, I. E. (2013). Intramedullary spinal cord astrocytomas: the influence of localization and tumor extension on resectability and functional outcome. Acta Neurochirurgica, 155(7), 1203–1207.
11. Nuwer, M. R., & Schrader, L. M. (2019). Spinal cord monitoring. Handbook of Clinical Neurology, 160, 329–344.
12. Cantore, G., Ciappetta, P., Santoro, A., & Paolini, S. (2002). Discontinuous myelotomy: an alternative to standard myelotomy in the surgical treatment of intramedullary spinal cord tumours. Acta Neurochirurgica, 144(4), 373–376.
13. Takami, T., Yamagata, T., & Ohata, K. (2013). Posterolateral sulcus approach for spinal intramedullary tumor of lateral location. Neurologia Medico-Chirurgica, 53(12), 920–927.
14. Angevine, P. D., Kellner, C., Haque, R. M., & McCormick, P. C. (2011). Surgical management of ventral intradural spinal lesions. Journal of Neurosurgery: Spine, 15(1), 28–37.
15. Karikari, I. O., Nimjee, S. M., Hodges, T. R., Cutrell, E., Hughes, B. D., Powers, C. J., Mehta, A. I., Hardin, C., Bagley, C. A., & Isaacs, R. E. (2015). Impact of tumor histology on resectability and neurological outcome in primary intramedullary spinal cord tumors: a single-center experience with 102 patients. Neurosurgery, 76, S4–S13.
16. Garcés-Ambrossi, G. L., McGirt, M. J., Mehta, V. A., Sciubba, D. M., Witham, T. F., Bydon, A., Wolinksy, J.-P., Jallo, G. I., & Gokaslan, Z. L. (2009). Factors associated with progression-free survival and long-term neurological outcome after resection of intramedullary spinal cord tumors: analysis of 101 consecutive cases. Journal of Neurosurgery: Spine, 11(5), 591–599.