Chapter

Surgical Treatment of Benign Spinal Cord Tumors

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Abstract

Benign spinal cord tumors (SCTs) are uncommon neoplasms that can arise within or adjacent to the spinal cord. Depending on their anatomical location, benign SCTs can be categorized as intramedullary, intradural-extramedullary, and extradural. The three most common benign SCTs are meningioma, nerve sheath tumors, and ependymoma. Both meningioma and nerve sheath tumors develop in the intradural-extramedullary compartment, while ependymoma occurs in the intramedullary space. Spinal meningiomas derive from arachnoidal cells and most commonly occur within the thoracic segment of the spine. Nerve sheath tumors, including schwannomas and neurofibromas, are closely associated with spinal nerves. Half of the spinal cord ependymomas arise in the lumbosacral segment or the filum terminale. Surgical treatment of large or symptomatic benign SCTs concentrates on total or subtotal resection of the tumors, which should be cautiously individualized based on the tumor location and histopathology. A curable complete resection should be achieved if possible while preserving the nervous function of the spinal cord and minimizing potential complications. Thoracic spinal roots may be sacrificed to acquire a total resection, yet cervical and lumbar nerve roots should be preserved prudently. Due to the vulnerable and complex anatomic nature of the spinal cord, maximal resection of the tumors can be achieved with the aid of appropriate intraoperative neural monitoring and meanwhile preserve nervous function.

Keywords: benign spinal cord tumors, surgical treatment, pathology of benign spinal cord tumors, CSF leakage

1. Benign spinal cord tumors

Spinal cord tumors are abnormal mass of tissue that could occur within or adjacent to the spinal cord. They can be benign or malignant. Benign spinal cord tumors are usually rare primary tumors originating in the spinal or spinal cord. Based on their location, they can be categorized as intramedullary, intradural-extramedullary, and extradural (**Figure 1**).

Intramedullary tumors arise inside the spinal cord itself, typically derived from glial or ependymal cells. Astrocytoma and ependymoma are the two most common types, and they usually occur in the cervical segments. Intradural-extramedullary spinal cord tumors arise within the dura but outside of the spinal cord. The most common types are meningiomas, nerve sheath tumors including schwannomas and

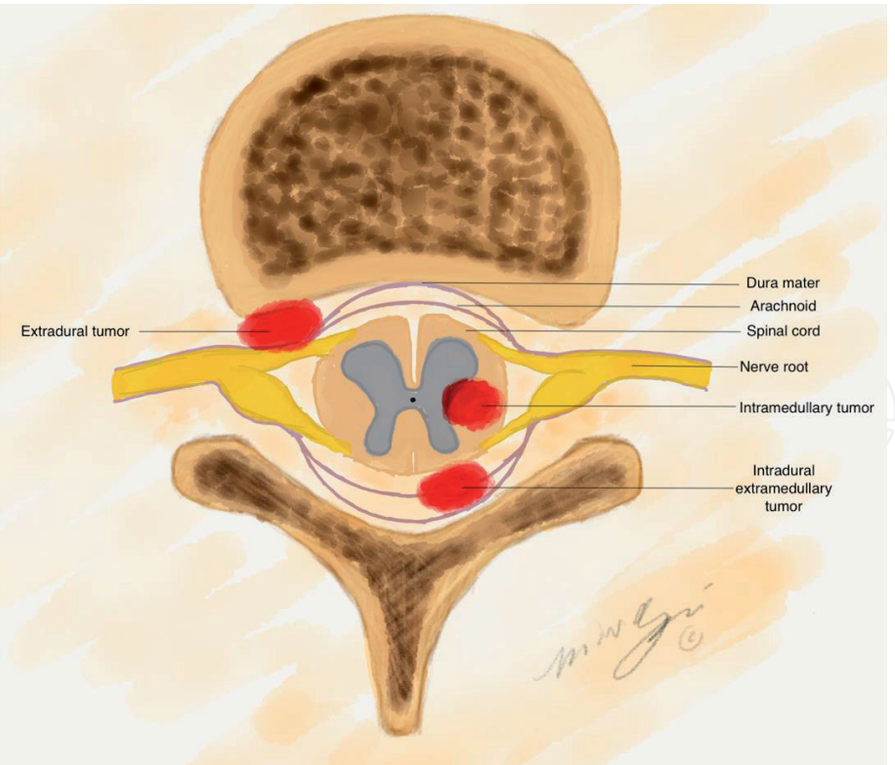

Figure 1.
Illustration of spinal cord tumor locations: intramedullary, intradural-extramedullary, and extradural.

neurofibromas, and myxopapillary ependymomas that occur on the filum terminalis and the conus medullaris. Extradural spinal cord tumors are mostly metastatic and malignant, which is not covered here.

2. Symptoms

Early symptoms of spinal cord neoplasms are often nonspecific. Gradually worsening back pain is the initial feature of spinal cord neoplastic disease in about 90% of adult patients. Spinal cord compression can have a subtle presentation. Pain often precedes other symptoms associated with spinal cord compression and causes nocturnal awakening. Discomfort may be radicular, localized to the back, or both. Patients often describe this pain as a gnawing and unremitting. Radicular pain suggests nerve root impingement and may provide an indication of the location of the tumor. Neurologic dysfunction distal to the lesion is due to interruption of ascending and descending spinal cord pathways. The most common sequelae are sensory dysesthesias and muscular weakness, especially of the iliopsoas musculature. Once symptoms other than pain appear, they may progress rapidly. Tumors intrinsic or extrinsic to the spinal cord can cause symptoms through disruption of normal neural elements and pathways, producing both local and distal effects. Sensory or motor symptoms that may be referred to the cord include limb paresthesia and weakness. Paraplegia and bowel or bladder disturbances (e.g., constipation, urinary hesitancy, retention, incontinence) are usually late findings except in conus medullaris syndrome, in which sphincter dysfunction and saddle anesthesia may emerge early in the course. Although neurologic manifestations may begin unilaterally, they can progress to involve both sides of the spinal cord and thereby produce bilateral symptoms and signs.

3. Physical examination

Findings on physical examination could define a probable site of tumor, document preoperative neurologic deficits, and determine progressive neurologic deterioration. They usually correspond to the location of the tumor, degree of cord impingement, and duration. Early in the course of spinal cord compression, spasticity, hyperreflexia, and loss of pinprick, temperature, position, and vibratory sensation may occur, while the Babinski may be absent. Tenderness over the affected spinal region can present. Late in the course of spinal cord compression, weakness, clear sensory loss, bilateral Babinski signs, and decreased anal sphincter tone, hyperreflexia and Babinski can be present. Lax rectal sphincter tone is a late sign of spinal cord dysfunction. Lhermitte's sign suggests irritation of the meningeal irritation. Brown-Sequard syndrome is caused by lateral spinal cord compression. Cauda equina syndrome and conus medullaris syndrome can be present as a result of compression of the spinal cord and nerve roots arising from L1–L5 levels.

4. Pathology

4.1 Intramedullary tumors

The majority of intramedullary primary spinal cord tumors are gliomas. Due to the relative paucity of glial tissue in the spinal cord, spinal cord gliomas are rare compared to their cerebral counterparts. The major types of spinal glial tumors are ependymomas and astrocytomas.

4.2 Ependymomas

Ependymomas are intramedullary tumors that may be located anywhere along the spinal cord. Over 50% occurs in the filum terminale; the other 50% can occur anywhere in the cervical or thoracic spinal cord [1]. In the World Health Organization (WHO) classification of brain tumors, ependymal tumors are divided into four major groups: sub-ependymoma (WHO Grade I), myxopapillary ependymoma (WHO Grade I), ependymoma (WHO Grade II), and anaplastic ependymoma (WHO Grade III).

4.3 Ependymoma

Ependymomas are more common in adults, with a peak age at presentation between 30 and 40 years. Histologically, they can be categorized to papillary, cellular, epithelial, or mixed. The cellular subtype is most common. Clinically, patients often have localized pain for months to years prior to developing other symptoms leading to diagnosis. Physical exam findings include lower extremity spasticity, loss of pain and temperature sensation, lower extremity and truncal sensory diminution to light touch and vibration, as well as gait ataxia. Ependymomas tend to arise centrally within the cord and expand symmetrically as they grow. Cystic degeneration occurs in about 46% of the cases [2, 3]. They are usually encapsulated and minimally vascular. These lesions generally enhance intensely on MRI. Optimal management consists of gross total resection. Although these are infiltrative tumors, a total or near-total resection can frequently be achieved without causing further neurologic deficits.

4.4 Myxopapillary ependymoma

Myxopapillary ependymomas are biologically and morphologically distinct from other ependymomas (**Figures 2** and **3**). These tumors most commonly arise in the conus medullaris and the filum terminale. At this anatomic location, ganglioglioma and lipoma are the second and third most commonly seen tumors separately following myxopapillary ependymoma. Myxopapillary ependymomas are WHO Grade I and usually solitary. They are papillary with microcystic vacuoles. Myxopapillary ependymomas are slow-growing glial tumors, sometimes with an indolent course for long periods of time. They typically are found in young male, with a median age at diagnosis from 35 to 37 years, and a male to female ratio ranging from 1.4 to 2.5 to 1 [4, 5]. Myxopapillary ependymomas generally present with low back pain, with or without radicular features. The vast majority of these tumors are located in the lumbosacral or thoracolumbar spine. Initial management of these tumors consists of laminectomy with attempted surgical resection. These tumors oftentimes can be totally resected, and many patients are cured following gross total resection. Subtotal resection deems necessary in particular with unencapsulated tumors. As postoperative radiotherapy tends to improve local control and prolong the recurrence-free interval, it may be considered in patients who have undergone subtotal resection or biopsy of a myxopapillary ependymoma. However, radiotherapy is still controversial since its effect on overall survival is unclear.

4.5 Astrocytomas

Astrocytomas occur throughout the spinal cord with the thoracic segment being the most common site. Approximately 50% of spinal cord astrocytomas is pilocytic, and 50% is infiltrative astrocytomas. Pilocytic astrocytomas are well circumscribed and low grade with nonaggressive clinical behavior. On MRI these tumors enhance intensely with gadolinium. Low-grade astrocytomas are shown as hypointense to

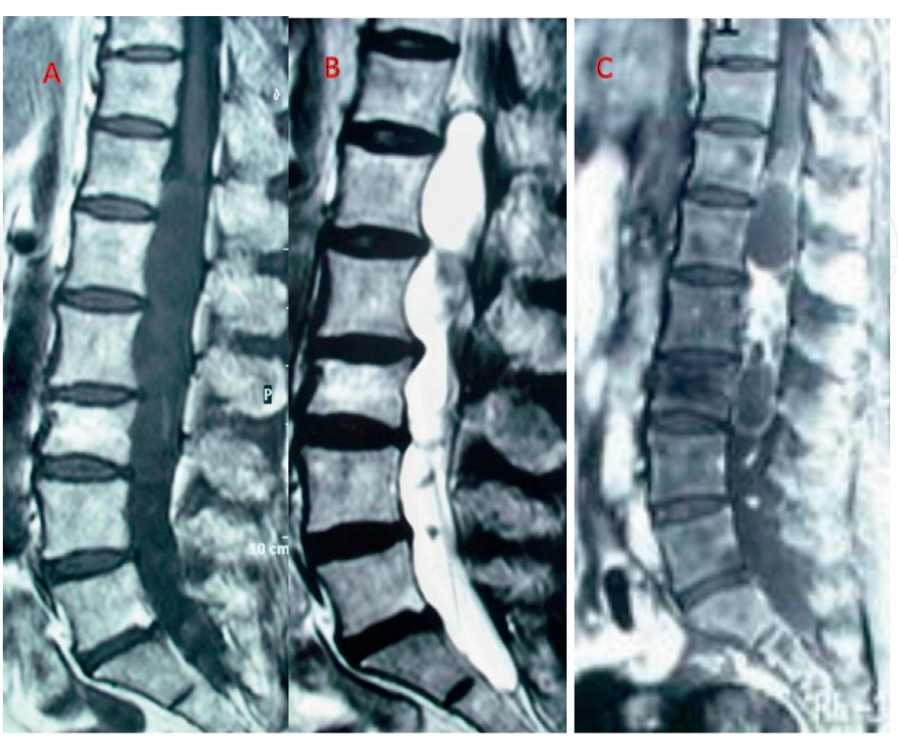

Figure 2.
Encapsulated myxopapillary ependymoma: (A) T1WI shows isointense mass, (B) T2WI shows slightly hyperintense mass with capsule, and (C) T1 with contrast shows enhancement of the mass.

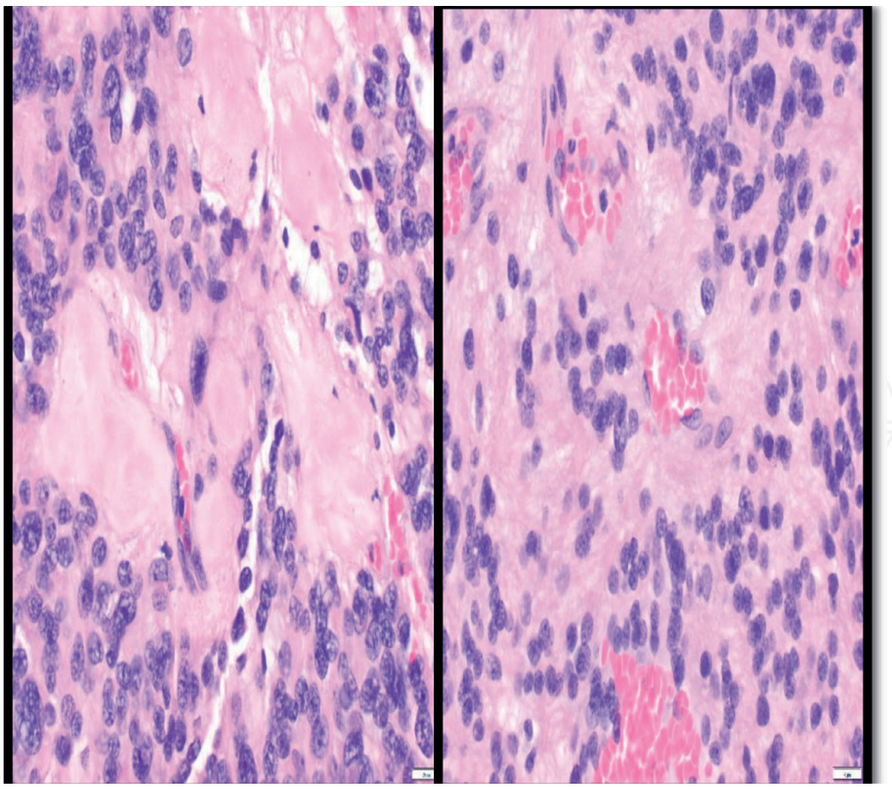

Figure 3.
Focal hyalinized vessels (left) and perivascular pseudorosettes (right) are characteristic histological features of WHO Grade I myxopapillary ependymoma.

isointense signal on T1-weighted images and hyperintense signal on T2-weighted images [6]. Diffuse fibrillary astrocytomas of the spinal cord usually appear as nonencapsulated lesions that enhance minimally or heterogeneously on MRI with gadolinium. Peak diagnosis ranging from the third to the fifth decade, with a median age 35 years. Male to female ratios are about 1.5 to 1. The most important factor associated with a better prognosis is low tumor grade (WHO Grade I). Other factors associated with a better prognosis include tumor location other than the cervical region, limited extent of tumor involvement along the spinal cord, and longer (>180 days) duration of symptoms. Postoperative radiotherapy does not affect outcomes in patients with pilocytic astrocytomas. The initial step in the management of a patient with a symptomatic or enlarging presumed primary intramedullary spinal cord tumor is a surgical procedure for tissue diagnosis and resection to the maximum extent possible. Pilocytic astrocytomas can often be completely or near-completely resected without causing further neurologic deficits. Diffuse fibrillary astrocytomas are more infiltrative, and meaningful resection is often precluded by the lack of clear tissue planes and high risk of neurologic morbidity, in which case an internal debulking procedure would be performed.

5. Intradural-extramedullary tumors

Both meningiomas and nerve sheath tumors (schwannomas and neurofibromas) can develop in the intradural-extramedullary spinal compartment.

5.1 Meningioma

Meningiomas can arise from arachnoidal cap cells anywhere along the neuraxis. Spinal meningiomas most commonly arise within the thoracic spine. Over three

fourths occur in women. The tumors are frequently adherent to the spinal dura, requiring dural resection for complete removal. The tumors can be intradural, extradural, and a mixture of intradural and extradural. Psammomatous meningiomas are the most common histological subtypes of spinal meningioma (**Figure 4**). Spinal meningiomas are typically slowly growing, invasive lesions and may remodel or erode bone. Pathologically, spinal meningiomas demonstrate the same features seen with intracranial lesions. Calcifications may be suggestive of the histologic diagnosis of meningioma. Local or radicular pain is the most common symptom associated with spinal meningiomas, followed by motor deficits and sensory symptoms. On MRI, meningiomas are iso- to hypointense on T1 and slightly hyperintense on T2, with a strong and homogeneous enhancement with gadolinium (**Figure 5**). The usual treatment for spinal meningiomas is resection, and complete resection can often be achieved. The dural origin is generally cauterized and occasionally resected. Thoracic spinal roots may be sacrificed as necessary to achieve a complete resection; cervical and lumbar nerve roots are preserved whenever possible. Recurrence rate with complete excision is 7% [7]. Subtotally resected lesions are generally followed expectantly for regrowth. Symptomatic recurrences are generally treated with further surgery.

5.2 Nerve sheath tumors

Nerve sheath tumors constitute about 25% of tumors arising from the dorsal sensory root near the edge of its exit from the spinal canal in the intradural-extramedullary space. Majority of nerve sheath tumors are schwannomas (**Figure 6A**), and most of the remainder are neurofibromas. Nuclear palisading (Verocay bodies) is a typical feature in schwannomas, with spindle cells arranged in short, intersecting fascicles. Neurofibromas grow as fusiform expansions of the involved nerve. They are less compact and less cellular than schwannomas. Spindle-shaped tumor cells with a wavier or buckled nuclear profile are typical to neurofibromas. Schwannomas and neurofibromas typically are slow growing. Patients generally present with local pain initially, which typically worsens at night or in the morning and resolves during the day. Neurologic deficits develop late in the course of the disease when they fill a significant volume of the spinal canal. As the tumor grows, it extends to the epidural space through the narrowest portion of the course of the nerve root, forming a "dumbbell-shaped" tumor (**Figure 6B**), which is rather radiographically typical. Small, asymptomatic tumors are best observed with serial imaging before committing to definitive surgical therapy. Large or symptomatic tumors are best treated with surgeries. The goal of the surgery is to achieve gross total resection of the benign

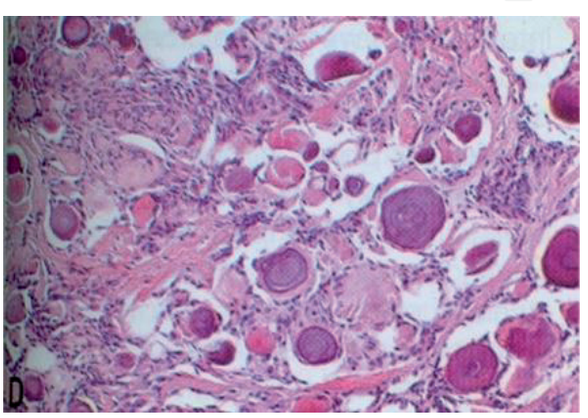

Figure 4.
WHO Grade I psammomatous meningioma, a predominant subtype of meningioma in the spinal region.

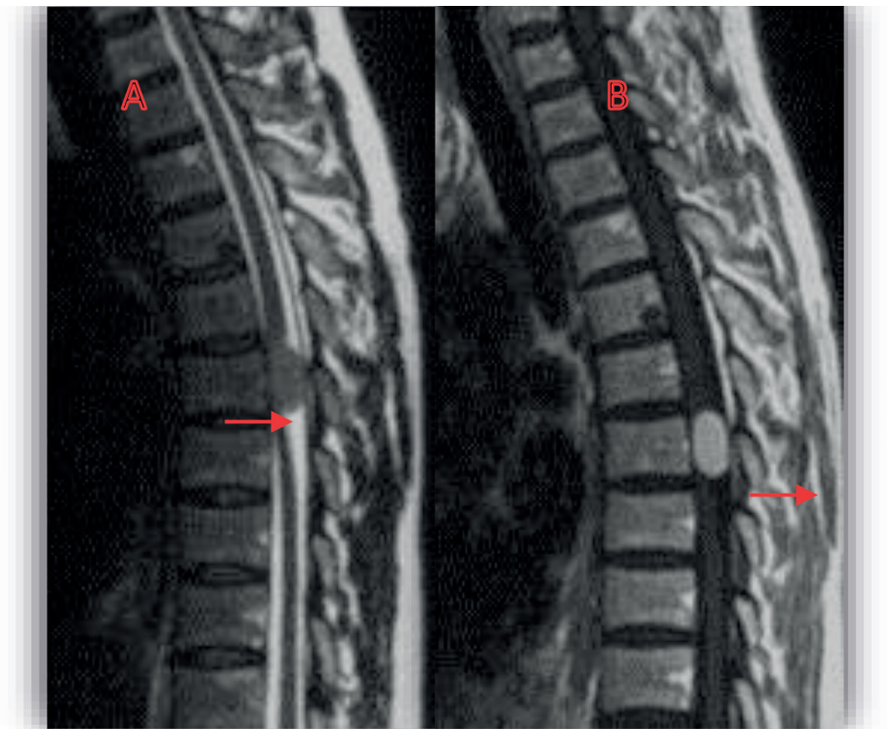

Figure 5.
(A) T2WI, a round slightly hyperintense mass is seen in the intradural space. (B) MRI contrast image shows homogeneous enhancement.

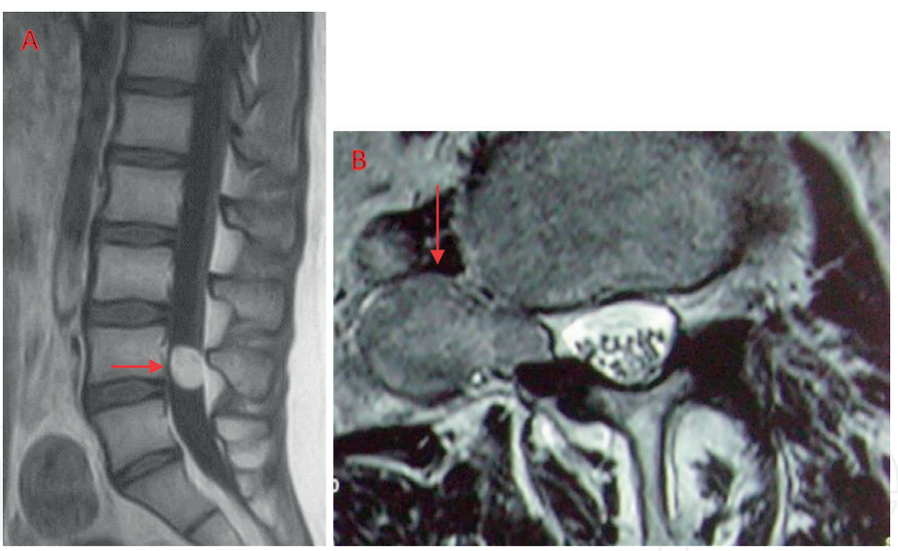

Figure 6.
(A) T1 with contrast: Schwannoma shows enhancement and (B) T2WI shows a "dumbbell-shaped" schwannoma.

tumors, yet a subtotal resection should be obtained to spare neurological function impairment as most of the tumors are benign and slow growing.

6. Surgical treatment

6.1 Surgical anatomy

The adult spine consists of 33 individual vertebrae, which are divided into the cervical, thoracic, lumbar, sacral, and coccygeal vertebrae. The vertebrae are joined

by cartilaginous interbody joints, synovial facet joints, spinal ligaments, and overlying muscles and fasciae. The vertebral foramina constitute the vertebral canal, which contains the spinal cord, nerve roots, meninges, and vasculatures. Adjacent vertebrae form the intervertebral foramina laterally, where the spinal nerves and vessels go through. The posterior portion of the vertebra is called the vertebral arch, which consists of a pair of pedicles and a pair of laminae supporting articular processes, transverse processes, and the spinous process. Reconstruction of the vertebral arch is critical in a surgical treatment of spinal tumors via a posterior surgical approach (**Figure** 7).

The spinal cord runs within the superior two thirds of the vertebral canal from the medulla oblongata to the conus medullaris. The anterior median fissure extends along the whole ventral surface and runs deeper caudally. The posterior median sulcus is shallower, from which a posterior median septum penetrates more than halfway in to the spinal cord. The septum diminishes caudally as the canal becomes more dorsally placed. Lateral to each side of the posterior median sulcus lies the posterolateral sulcus, along which the dorsal roots of spinal nerves enter the cord. Between the posterolateral sulcus and anterior median fissure is the anterolateral funiculus, where the ventral spinal rootlets pass through.

The paired dorsal and ventral roots of the spinal nerves are continuous with the spinal cord. They unite in or close to their correspondent intervertebral foramina to form the spinal nerves. There are 31 pairs of spinal nerves branching off the spinal cord. The section of spinal cord associated with the emergence of a pair of nerves is named a spinal segment.

The conus medullaris is the tapered, lower end of the spinal cord near L1 or L2 vertebra. The upper conus medullaris is usually not well defined. The level at which the spinal cord ends variates in population. The vertebra column elongates more rapidly than the spinal cord during development, hence the discrepancy between the anatomical level of spinal cord segments and their corresponding vertebrae. The spinal nerves continue to branch out after the conus medullaris, forming the cauda equina, which is gathered round the filum terminale. The pia mater surrounding

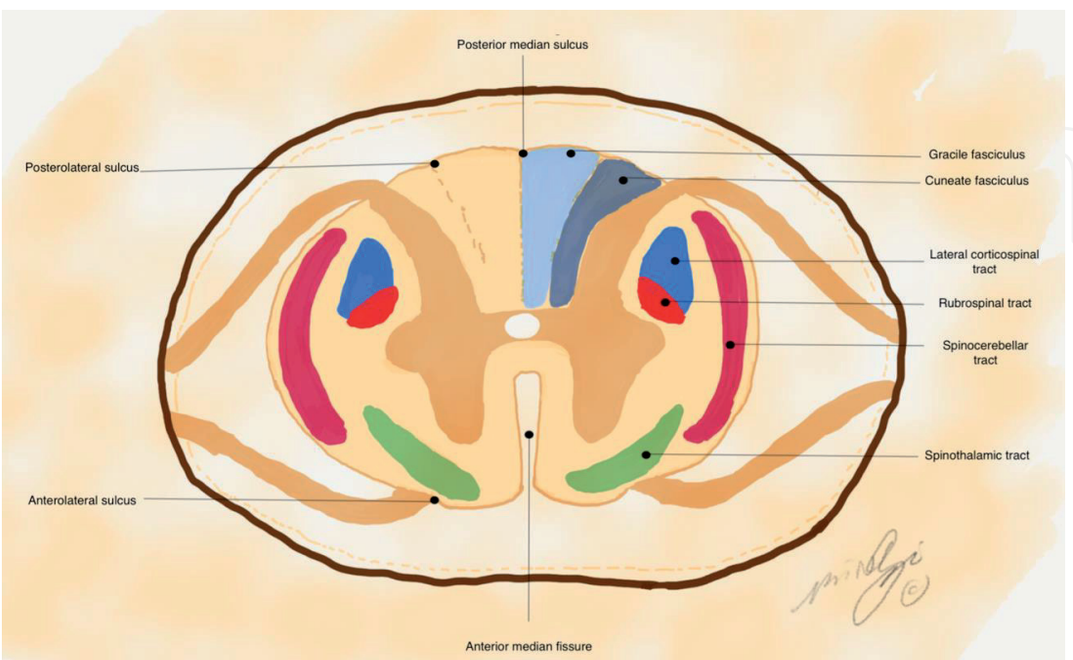

Figure 7.
Illustration of a cross-section anatomy of the spinal cord showing deep anterior median fissure, shallow posterior median sulcus, and shallow grooves of anterolateral or posterolateral sulcus.

the spinal cord projects directly downward, forming the filum terminale. The filum terminale, descending from the apex of the conus medullaris, is continued within extensions of the dural and arachnoid meninges and reaches the caudal border of the second sacral vertebra, stabilizing the entire spinal cord.

The spinal cord is covered by the meninges. The outermost membrane is the spinal dura mater which forms a tube. The spinal cord is directly covered by the thin, translucent membrane of the pia mater, which itself comprises an inner membranous layer, the intima pia, and a more superficial epipial layer. The intima pia, adherent to the underlying nervous tissue, follows its contours closely. The epipial layer is formed by a mesh network of collagenous fiber bundles continuous with the arachnoid trabeculae, as what we call an intermediate leptomeningeal. The blood vessels of the spinal cord lie within this epipial layer. This intermediate leptomeningeal layer is closely applied to the innermost aspect of the arachnoid membrane; it reflects to form the dorsal septum and arborizes over the dorsal surface of the spinal cord, resulting in the formation of the epipial layer. The anterior spinal arteries and veins are arborized over by a dense epipial layer. The spinal cord is attached to the dura mater by a series of lateral, flattened bands of epipial tissue known as the dentate ligaments. The spinal dura mater extends around the spinal roots and nerves as they pass through the vertebral canal and the intervertebral foramina. These prolongations of spinal dura mater are called spinal nerve sheaths or root sheaths. The arachnoid within the sheaths does not extend as far as their dural coverings. Limited prolongation of the arachnoid demonstrates the nerve sleeves.

7. Surgical treatment

The posterior midline approach is most frequently used to remove tumors. Even ventrally located lesions can be safely resected via posterior approach. Dentate ligament resection allows for general mobilization of the spinal cord. Posterior roots can be sacrificed from C2 to C4 and throughout the thoracic region. Lower cervical and lumbosacral posterior roots should be preserved whenever possible. If it becomes necessary to sacrifice the sensory nerve root, it should be resected proximally to the ganglion to minimize postoperative neuralgia. Intracapsular decompression could be required for larger tumors. In a dumbbell-shaped tumor, the intradural portion should be resected first to minimize spinal cord manipulation during the excision of the extradural component. The dura must be closed in a watertight fashion. In cases where a meningioma required resection of dura, a dural graft should be utilized for a watertight closure of the dura to prevent CSF leakage.

7.1 Intramedullary tumors

Surgery is the treatment of choice or the only effective treatment for intramedullary spinal cord tumors. Most patients experience some loss of posterior column function following surgery due to the performance of the myelotomy through the posterior median septum. Due to the indolent feature of benign intramedullary tumors, it is important to optimize both the timing and the performance of surgery in these patients. The goals of surgical treatment are to preserve neurologic function and to maximize surgical removal. These goals are generally compatible, but the preservation of neurologic function should always come first. For patients with an incidental finding of asymptomatic intramedullary tumor, serial imaging and clinical follow-up are recommended. Once symptoms commence, then surgery is offered, before the onset of any substantial neurologic deficit, because surgery is usually not effective in reversing neurologic deficits.

Cysts are frequently found at both ends of a tumor, which serve as landmarks in the dissection. The true tumor-cord interface needs to be carefully exposed, especially in possible cases of benign encapsulated tumors, with minimal damage to the spinal cord parenchyma. It is crucial to identify tumor-cord interface. When a clear tumor-cord interface is difficult or the intraoperative appearance of the tumor suggests an anaplastic nature, further tumor removal is not warranted. Majority of intramedullary ependymomas can be totally resected with preservation of neurologic function, as they usually have a clear plane of dissection. Resection of low-grade astrocytomas should be continued until the interface with the spinal cord is recognized. The interface is not always distinguishable. Surgical resection of more malignant astrocytomas is still controversial, as improvement of neurologic function is still unclear. Hemangioblastomas are well circumscribed and encapsulated neoplasms, so gross total resection can be achieved in nearly all cases. However, they are highly vascular, and vascular supply should be totally interrupted before the removal of the tumor. In general, assessment of the tumor-spinal cord interface under the operating microscope is the most important factor in determining the specific surgical objective for each patient with a benign intramedullary lesion, irrespective of tumor histology.

7.2 Extramedullary tumors

The goal of management for patients with extramedullary spinal cord tumors is either long-term tumor control or cure with preservation of neurologic function. Surgery is clearly indicated in patients with symptomatic tumors particularly those with large tumors producing significant compression of the spinal cord or cauda equina. For patients with smaller tumors or those with minimal subjective symptoms, it may be considered to follow them both over time. For small and asymptomatic tumors, regular radiographic surveillance can also be recommended. However, midline filum/cauda equina tumors are usually ependymomas in nature, which can disseminate through CSF; therefore, an early total resection of these lesions is recommended. The vast majority of intradural-extramedullary tumors can be safely accessed and removed through a standard posterior laminectomy. Even most ventrally located tumors can be accessed posteriorly because lateral spinal cord displacement or rotation enables a safe corridor to debulk and remove most ventrally located tumors. However, pure ventral lesions may require a more lateral or, rarely, an anterior approach. Intraoperative ultrasound can be used to identify the location of the tumor levels. Dumbbell tumors with epidural extension into the neural foramen usually require a unilateral facetectomy to allow access to foramina, followed by instrumented fusion extending one level above and below the facetectomy. Whenever possible, it is preferable to remove the tumor through a single operative exposure to reduce morbidity and preserve surgical options. Debulking is recommended when the tumor is large. As the tumor is mobilized, the nerve stimulator is used to identify motor roots. Once the root or rootlet of origin has been identified, it is sectioned both proximally and distally, and the tumor is removed. If the tumor extends into the extradural space, motor stimulation is essential to determine whether there is motor root involvement. If there is no motor root stimulation, the entire root can be sacrificed. However, a functional motor root involved by tumor should be spared to avoid a significant postoperative neurologic deficit, even though this produces a subtotal resection.

8. Technical advances and adjunctive options

Ultrasonic surgical aspiration: this device consists of a hollow tube that vibrates at high frequencies and physically emulsifies the tumor while irrigating and

aspirating the field. It improves the debulking of spinal tumors. When placing the aspirator tip in contact with the tumor, the surgeon can achieve a relatively atraumatic resection of the tumor, without manipulation of the adjacent spinal cord. Additionally, the ultrasonic aspirator allows preservation of blood flow in adjacent tissue.

8.1 Intraoperative ultrasonography

With an ultrasonic transmitter placed over the spinal cord, intraoperative ultrasonography can help identify the location of the tumor, existence of intramedullary cysts, and the relationship between the spinal cord and the surrounding structures. Prior to dural opening, bony exposure can be adjusted, which could reduce the possibility of further bone removal after dural opening and minimize the risk of direct injury of the exposed neural structures. The integration of intraoperative ultrasonography and microscope allows for a better visualization of the surgical field and to facilitate tumor resection. It can also assist with identifying any residual tumor tissue after resection. A color flow Doppler ultrasound can be utilized for a vascular tumor like hemangioblastoma or in a case where major vasculature structure has been involved. By allowing the evaluation of the anatomy underneath surgical field surface, intraoperative ultrasonography can help in refining the surgical strategy.

8.2 Intraoperative neurophysiological monitoring

Intraoperative neurophysiological monitoring has gained popularity with surgeons when it comes to a surgical resection of intramedullary tumor. Somatosensory evoked potential (SSEP) and transcranial motor evoked potential (MEP) are the most commonly used techniques which continuously monitor sensory and motor potentials individually during surgery for intramedullary tumors. With transcranial MEP, motor pathways are stimulated centrally, and responses can be recorded directly from needle electrodes placed in the extremities' muscles. Myogenic MEP waveforms recorded from muscles can be categorized into three patterns: polyphasic, biphasic, and absent. An electrophysiologist will view and record waveforms and their changes and report any possible adverse reactions to the descending motor pathways related to the surgery. Intraoperative neurophysiological monitoring is not absolutely reliable, as a change in potential may not present until up to 1 minute after the occurrence of the injury [8]. Due to the proximity of the corticospinal and spinothalamic tracts, as well as the dorsal columns, intraoperative injury to the motor pathways can be reflected in changes in sensory evoked potentials. MEP monitoring can be used to avoid excessive spinal cord manipulation and improve the surgical technique during resection of the tumor. Amplitude changes in MEP have been examined to be strongly correlated with postoperative neurologic function [9, 10].

9. Outcome of treatment

9.1 Intramedullary tumors

With aggressive surgical resection as the treatment of choice, postoperative neurologic outcome is closely related to the patient's preoperative neurologic status. In general, better postoperative neurologic outcome occurs with lesser preoperative neurologic deficits [11]. It has been argued that postoperative deterioration of neurologic function, regardless of being transient or permanent, is attributed to

direct surgical insult to either the spinal parenchyma or the spinal cord circulation. When a posterior median sulcus approach is used, patients may present posterior column dysfunction early after surgery, including abnormalities of discriminative touch sensation, proprioception, or gait [12]. These symptoms may or may not be permanent. Neuropathic pain syndrome can present after surgery when syringomyelia is associated with the lesion.

When low-grade astrocytoma is associated with a cyst, a clear interface can be identified between the tumor and the spinal cord; a gross total resection of the lesion is optimal. This will halt the clinical and radiological progression of the tumor for many months. Due to the infiltrative nature of high-grade astrocytoma, radical resection of the lesion is not feasible without damaging the normal spinal cord tissue. Progression of low-grade astrocytoma into high-grade tumor can occur, which then further affects the outcome. For patients with ependymomas, long-term survival is expected, especially as total resection of the tumor is widely adopted. In comparison to astrocytoma, the outcomes of ependymomas do not appear to be related to histologic grades of the tumor. Although rare, CSF dissemination of ependymoma does occur.

9.2 Extramedullary tumors

Regardless of tumor histology, location, and extent of lamina resection, the surgical outcomes of extramedullary tumors are optimal in general [13, 14]. However, an early surgical intervention is recommended for symptomatic lesions, as it is associated with a greater postoperative improvement [13]. Neurologic complications are uncommon, and even if they do occur, improvement could be expected in majority of the cases. Improvement of initial neurologic deficits can be expected for months and up to a year after tumor resection. Provided that a gross resection has been obtained, recurrence rarely occurs [15]. In the case where recurrence does occur, reoperation is usually not required instantly and largely contingent on the patient's neurologic status, age, and tumor growth rate captured with a series of radiologic images.

10. Complications

10.1 CSF leakage

The incidence of CSF leakage remains high after spinal cord tumor surgeries involving opening of the dura mater. It is more commonly seen in the upper thoracic region. Radiation therapy prior to the surgery is a risk factor for patient to develop a CSF leak. Improper treatment of CSF leakage can potentially give rise to other complications including CSF fistula, meningitis, abscess, and even neurological deficits [16].

Management of CSF leakage entails two aspects based on CSF dynamics [17]: to prevent CSF leak with direct watertight closure of the dura mater and to retard CSF leak by reducing the subarachnoid CSF pressure and/or increasing the epidural space pressure. Prevention is of great importance in managing CSF leakage complication. A watertight closure of the dura mater is crucial, and a direct suture with adjuvant dural closure material has gained popularity among spinal surgeons owing to its high successful rate in watertight closure [18, 19]. At times the involved dura has been inevitably excised, and this renders a primary closure impossible. In this case, an augmented closure with the aid of an adipose tissue, muscle tissue, or fascial graft would be indicated. The graft would be layered over the defect of

dura mater, and prolonged bed rest with a wound drainage would be warranted to avoid a CSF leakage [20–22]. In the event of CSF leakage development, techniques reducing the subarachnoid fluid pressure would be exploited. This includes inhibiting the formation of CSF with medications such as acetazolamide, adjusting patient's position, and CSF shunting with a lumbar drain placement [16, 23]. These approaches have been proven effective, although complications do occur pertinent to the treatment [24, 25].

CSF leakage is a vexing problem and usually requires prolonged postoperative treatment. Should CSF leakage persist, surgical exploration of proper dura closure may deem necessary and should not be delayed.

10.2 Postoperative instability

Due to the generally optimal neurological outcome of extramedullary spinal tumors, a rising attention has been turned to the long-term outcome after tumor resection involving a spine procedure. Postoperative iatrogenic instability has been recognized throughout different spine segments, including cervical kyphosis after laminectomies, thoracic instability after laminoforaminotomy-facet resections, and spondylolisthesis after lumbar laminectomies [26, 27]. This has been attributed to the alteration in spine biomechanics as a result of extensive laminectomies with or without facetectomies [28]. Postoperative instability is associated with preoperative instability, extent of facetectomy, level of spine segments involved, and disruption of ligamentous structures. Stabilization is warranted in patient demonstrating preexisting spine instability. An increasing number of levels involved entail more disruptions of structural components during the procedure, which results in a higher risk of postoperative instability [29]. A biomechanical model study has shown that removing the medial one third to one half of the facet joint as well as the posterior ligaments destabilizes the spine by significantly increasing spinal flexion by nearly 12° [30]. Instrumented fusion that extends one level above and below the facetectomy is usually performed. If instability happens, it should be identified early, and a stabilization procedure should be performed to arrest the progression. In patients who are treated with cervical region tumors involving extensive laminectomies, stabilization is routinely applied. Post-laminectomy kyphosis is exceedingly difficult to treat; thus, surgical stabilization is imperative to preempt this [31].

Minimal invasive procedures have prevailed among spinal surgeons; however, their indications are largely contingent on each individual case, and their efficacies in preventing instability have yet to be determined.

11. Summary

Substantial advancement of neuroradiology and its wide adoption in clinical settings have improved the recognition of spinal cord tumors. Many lesions have now been identified on MRI before they become symptomatic clinically. Early recognition has offered physicians the advantage of managing and treating these tumors in the early course of the disease. General refinement of surgical techniques and adjunctive technologies has undeniably improved the outcome of the disease while minimizing neurologic deficits.

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