Primary spinal cord tumors account for 5% to 10% of all adult spinal tumors and 4.5% of primary central nervous system (CNS) tumors. Approximately 850 to 1700 new adult cases of primary CNS spinal cord tumors are diagnosed each year in the United States. Primary spinal cord tumors unlike intracranial tumors do not show an association between grade and age at diagnosis.

Because tumor origin varies by anatomic site in the spinal cord, primary spinal cord tumors are classified by anatomic sublocation as either intradural intramedullary, intradural extramedullary, or extradural. Intradural intramedullary spinal cord tumors constitute 20% to 30% of all primary spinal cord tumors; the remaining 70% to 80% are intradural extramedullary. Most (90%) intradural intramedullary tumors are either ependymomas (60%–70%) or astrocytomas (30%–40%). For the remaining 10%, hemangioblastomas account for 3% to 8%, of which 15% to 25% are associated with von Hippel-Lindau (VHL) disease. Another 2% of intradural intramedullary spinal cord tumors are metastatic. Intradural extramedullary spinal cord tumors predominantly comprise either meningiomas (30%) or peripheral nerve sheath tumors (30%). Overall, and including the lumbar cistern, the most common intradural extramedullary tumor types are meningiomas (24.4%), ependymomas (23.7%), and schwannomas (21.2%). Anatomically, the sites of primary spinal cord tumors are the spinal cord (70.5%), spinal meninges (24.2%), and cauda equina (5.3%).

The clinical presentation of primary spinal cord tumors is determined partially by the location (Tables 1 and 2). Pain is the most common presenting symptom regardless of location and is manifested as back pain (27%), radicular pain (25%), or central pain (20%). Neurologic deficit is the second most common symptom and can occur in the form of motor (72%), sensory (39%), or sphincter disturbance (15%). Intramedullary tumors usually affect central gray matter and cause
a syringomyelic syndrome characterized by the disassociation between pain/temperature (loss) and tactile (preserved) sensations at affected levels, lower motor nerve dysfunction at the affected level, and upper motor nerve dysfunction caudal to the lesion. No symptoms are pathognomic for spinal cord tumors, although sacral sparing (i.e., maintenance of sensation in the sacral dermatomes) and upper motor deficits are common in intramedullary tumors, whereas a Brown-Séquard–type syndrome (hemisegmental cord dysfunction) is characteristic of extramedullary tumors. Extramedullary tumors mostly present clinically with pain and myelopathic symptoms, such as paraparesis. Schwannomas, in contrast to other tumors, are more prone to cause radicular symptoms.4

### General Considerations

#### Imaging

MRI (with and without contrast) plays an essential role in the diagnosis of primary spinal cord tumors. Currently, no other imaging modality can be used alone to establish a diagnosis. Plain radiographs may show scalloping, foraminal enlargement, bony erosion, and calcification. CT myelography may show spinal cord enlargement in cases of intramedullary tumors, or a filling defect in extramedullary tumors. However, the internal structure of the spinal cord and tumor and the tumor/cord interface cannot be visualized.

The presence of mass effect in the form of spinal cord segmental enlargement, cyst formation, contrast enhancement, and peritumoral edema favors the diagnosis of a neoplastic process. Non-neoplastic lesions that can be interpreted as tumors and are considered part of the differential diagnosis are multiple sclerosis, transverse myelitis, spinal cord ischemia, sarcoid, and CNS angiitis.5,6 Acute demyelination, such as in multiple sclerosis and transverse myelitis, may be associated with spinal cord edema and segmental enlargement, mimicking a tumor.1 Additional studies, such as brain MRI, cerebrospinal fluid (CSF) analysis, and angiography, should be performed in suspected cases to establish the correct diagnosis. In rare cases, when diagnosis cannot be established based on correlative data, patient observation with follow-up imaging in 2 to 3 months is reasonable. Spinal cord edema in non-neoplastic lesions usually regresses on interval MRI.

#### Surgery

Microsurgery is the cornerstone of spinal cord tumor treatment. Tumor type and grade have been shown to be the most important factors affecting outcome (Table 3). Surgery allows tissue sampling, and consequently a pathologic diagnosis with corresponding prognosis, and removes bulk tumor (i.e., cyto-reduction). In most well-defined (circumscribed) low-grade tumors, resective surgery can be curative. With infiltrative tumors, maximal safe resection or biopsy helps provide a diagnosis and define further treatment. Diffusion tension tractography has been shown to be a useful tool that can demonstrate the passage of fibers around or through the tumor, and therefore can be used in preoperative planning.7 Class 3 evidence shows that the extent of resection positively correlates with patient outcome. However, this approach is counterbalanced by the risk of neurologic injury from aggressive surgery. Most postsurgery deficits, however, are transient and improve with time and rehabilitation. The McCormick grading score that is based on patient functional status and limited longitudinal extent are the most important factors for a favorable outcome.8 Delayed postoperative neurologic deterioration may occur from tumor growth (most frequent) or operative complications, such as spinal cord tethering to the dura, spinal instability, and resulting deformity. Spinal instability may be present preoperatively or postoperatively due to neurologic deficits, erosion of bony/ligamentous elements by the tumor, postlaminectomy kyphosis, or radiation injury.

The role of laminoplasty versus laminectomy has been debated, with some studies showing an advantage with laminoplasty in preventing a future deformity, at least in the pediatric population. This effect seems to be less prevalent in the adult group, although laminoplasty facilitates surgical exposure

### Table 1 Intramedullary Spinal Cord Tumor: Topography

<table>
<thead>
<tr>
<th>Topography</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical</td>
<td>30%</td>
</tr>
<tr>
<td>Cervicothoracic</td>
<td>25%</td>
</tr>
<tr>
<td>Thoracic</td>
<td>29%</td>
</tr>
<tr>
<td>Conus</td>
<td>15%</td>
</tr>
</tbody>
</table>

in recurrent cases. Yasargil et al. reported on a series of 100 patients with intraspinal arteriovenous malformations and tumors treated with hemilaminectomy. Although technically challenging, this approach ultimately eliminates the risk of surgery-induced instability.

**Radiation Therapy**

Radiotherapy is an important adjuvant therapy for the treatment of spinal tumors. Radiotherapy is primarily administered for high-grade gliomas and recurrent or residual tumors with confirmed progression when surgical resection is not possible. Radiotherapy-associated side effects are characterized as acute, early delayed, and late delayed. Acute reactions usually reflect secondary inflammatory and transient effects on nearby tissues (in-field effects), especially skin and gastrointestinal tract. Early delayed side effects most often manifest as transient demyelination and posterior column dysfunction (i.e., Lhermitte's sign) that can be seen on T2-weighted images. Surprisingly, a recent series of benign intradural spinal tumors treated with radiosurgery showed that all patients developed radi-
ation-induced myelitis despite having a radiographic margin between the tumor and the spinal cord. Delayed late injuries include secondary malignancies, particularly in the pediatric population and in patients with genetic tumor predisposition disorders.

### Intradural Intramedullary Tumors

#### Ependymoma

Ependymoma is the most common intradural intramedullary tumor type in adults. Myxopapillary ependymoma (WHO grade 1) is a distinct type, predominantly extramedullary and located in the lumbar cistern, and is considered in the intradural extramedullary section. Cellular ependymomas arise from the ependymal lining of the central canal and are classified as WHO grade 2 tumors. Anaplastic ependymomas are rare and considered WHO grade 3 tumors. The most common presentation is pain, followed by neurologic deficit. Rare cases of acute neurologic compromise from tumor hemorrhage have been reported.

Histologically, ependymoma cells are characterized by round to oval nuclei containing finely dispersed chromatin with perivascular and ependymal rosettes. The association between neurofibromatosis type 2 (NF2) and spinal ependymoma is well known. This is an autosomal dominant disease caused by mutation of the merlin or schwannomin gene on chromosome 22, which is a member of the protein 4.1 family.

The most common location of ependymomas is the cervical spine, followed by the cervicothoracic and thoracic spine. Ependymomas are hypointense on T1- and hyperintense on T2-weighted MR images (Figure 1A). Contrast enhancement is usually present. Ependymomas mostly reside centrally in the spinal cord, attributed to the origin of these tumors from the ependymal cells lining the central canal. Reactive syrinx usually occurs at the superior or inferior poles of the tumor, and does not require surgical removal. Cyst presence does not seem to have an effect on overall prognosis. The main factor affecting postoperative morbidity is tumor width in relation to spinal cord and preoperative neurologic status. Tumor length does not have an effect on preoperative neurologic status or morbidity, but longer tumors are associated with postoperative dysesthesias, possibly because of longer myelotomy. A recent study of very long intramedullary spinal cord tumors showed that none of 13 holocord tumors were ependymomas.

Ependymomas mostly follow a benign course, except for malignant histologic subtypes (anaplastic ependymoma; WHO grade 3). Surgery is the most effective treatment for all grades, and the same rate of complete resections can be achieved even for recurrent tumors. Local control rates of 90% to 100% have been reported with total surgical resection, although in a minority of cases complete surgical resection is not achieved. An inverse relationship exists between preoperative symptom duration and tumor resectability. This effect may be explained by the possible development of microadhesions between tumor and normal tissue in longstanding cases. Overall survival increases with complete resection.

Chemotherapy plays a limited role in the management of ependymomas. Data regarding the effect of chemotherapy for patients with recurrent spinal cord ependymoma is extremely sparse. Etoposide and platinoids are generally considered the preferred agents commonly used for recurrent intracranial ependymomas. No evidence shows that temozolomide is effective in ependymomas, notwithstanding its widespread use in other gliomas. Recently, epidermal growth factor inhibitors (particularly lapatinib) and antiangiogenic inhibitors (i.e., bevacizumab) have been shown to be useful in recurrent intracranial ependymoma and may be applicable for recurrent spinal cord ependymoma.

Radiotherapy is an option for incomplete resection and is indicated for malignant grade (external beam radiotherapy at 45 to 54 Gy). However, several studies have shown no benefit in survival or time to recurrence for its use in incompletely resected

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**Table 3: Primary Spinal Cord Tumors: 5-Year Survival**

<table>
<thead>
<tr>
<th>Tumor Type</th>
<th>Grade</th>
<th>5-Year Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astrocytoma</td>
<td>Juvenile pilocytic</td>
<td>&gt; 90%</td>
</tr>
<tr>
<td></td>
<td>Low-grade</td>
<td>&gt; 70%</td>
</tr>
<tr>
<td></td>
<td>High-grade</td>
<td>30%</td>
</tr>
<tr>
<td>Ependymoma</td>
<td>Low-grade</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>Anaplastic</td>
<td>30%</td>
</tr>
<tr>
<td>Myxopapillary</td>
<td></td>
<td>&gt; 95%</td>
</tr>
</tbody>
</table>
low-grade ependymoma. Therefore, because of the slow growth of low-grade ependymomas, observation with sequential MRI can be performed and radiotherapy administered at disease progression. Patients undergoing total resection should also be followed up with serial neurologic examinations and MRI. If no recurrence is present, time between MRIs can be increased and the patient can be followed up neurologically.

Astrocytoma

Astrocytomas are a diverse group of gliomas with differing biological behavior. Histologically, gliomas can be differentiated as pilocytic (WHO grade 1), fibrillary (WHO grade 2), anaplastic (WHO grade 3), and glioblastoma (WHO grade 4). Grade of the glioma is the major prognostic factor with regard to outcome, yet studies have shown that histopathologic distinction between anaplastic astrocytomas and glioblastomas is not of prognostic significance. Astrocytomas are associated with NF1, although the exact mechanism of tumor formation is unknown.

Radiologically, astrocytomas are characterized by heterogenous contrast-enhancement; show isointensity or hypointensity on T1-weighted and hyperintensity on T2-weighted images; and are challenging to differentiate from ependymomas. Contrast enhancement does not, however, predict tumor grade or behavior, because pilocytic astrocytomas commonly have intense and homogenous contrast enhancement but rarely behave aggressively. The likelihood of total surgical resection for pilocytic astrocytomas is higher than for WHO grade 2 through 4 gliomas. Astrocytomas typically occupy an eccentric position in the spinal cord and may be associated with cysts and may not contrast-enhance as much as ependymomas (Figure 1B). WHO grade 2 through 4 astrocytomas lack distinct borders within normal neuronal tissue, reflecting their infiltrative nature.

Microsurgery is an important part of treatment of astrocytomas. Total excision rates are lower than in ependymoma, with a partial resection or biopsy performed in most patients. Some authors have shown that complete resection significantly reduces the risk of disease progression, whereas others suggest no benefit to extensive resection. Although rare, adult pilocytic astrocytomas have a relatively benign course, and total resection can be attempted. However, if intraoperative biopsy confirms the diagnosis of astrocytoma grade 2 or higher, and no clear surgical plane exists between tumor and neuronal tissue, further tumor resection is not recommended.

As with other primary spinal cord tumors, limited data address the role of chemotherapy. Temozolomide has been used with some success in the recurrent setting, but no trials establish a role for its adjuvant use (i.e., up-front). Nonetheless, and as in the management of intracranial gliomas, spinal cord high-grade tumors are commonly treated with concomitant (chemoradiation) and postradiotherapy temozolomide. A recent small case series also suggested that salvage therapy with bevacizumab is of palliative benefit for recurrent spinal cord glioblastoma. Lomustine, carboplatin, and vincristine, and the 8-in-1 chemotherapy protocol have also been used in children.

Adjuvant radiotherapy plays an important role in the management of spinal cord astrocytomas. Because biopsy or partial resection is the surgical result in most patients, radiotherapy is usually administered. Radiotherapy does not confer a survival benefit in patients with WHO grade 2 tumors, but it reduces the risk of disease progression. In high-grade gliomas, the survival benefit of radiotherapy is established (or at least accepted as usual and customary) and commonly applied. In addition, radiotherapy is the preferred treatment for recurrent gliomas not already irradiated. Serial neurologic status assessment and MRI is the usual follow-up strategy to monitor tumor recurrence.

Pilocytic astrocytomas differ by manifesting a low potential for malignant transformation, and therefore radiotherapy is usually deferred notwithstanding incomplete resection. The usual approach involves close follow-up with serial MRI and repeat surgery for recurrence.

Hemangioblastoma

Hemangioblastomas are the third most common primary spinal cord tumor in adults, representing 3% to 8% of all intramedullary tumors. They are seen predominately in men and presentation usually occurs in the fourth decade. Among patients with hemangioblastoma of the spinal cord, 10% to 30% have VHL syndrome, an autosomal dominant disorder caused by deletion of chromosome 3p25. Decreased VHL protein levels induce cell proliferation and increase expression of vascular endothelial
growth factor (VEGF), platelet-derived growth factor, and erythropoietin. Therefore, chemotherapeutic agents targeting VEGF have been shown to be effective in hemangioblastoma.

The origin of hemangioblastomas is unknown. Anatomically, most hemangioblastomas arise from the dorsal portion of the cervical spinal cord, close to the dorsal root entry zone, and can be intramedullary (30%), intramedullary and extramedullary (50%), or extramedullary (20%).

Radiographically, the tumor presents as a homogenously enhancing hypervascular nodule with associated cyst or syrinx and peritumoral edema on MRI. Spinal angiography shows enlarged feeding arteries, intense nodular stains, and early draining veins. These tumors are highly vascular and can present with intramedullary or subarachnoid bleeding. Endovascular embolization can be performed to decrease vascularity of the tumor and facilitate resection. However, usually neither diagnostic angiography nor endovascular embolization is required in managing these tumors.

Understanding the natural history of hemangioblastomas in the setting of VHL is an essential part of treatment, and experts typically recommend that resection of hemangioblastomas be reserved until the onset of the symptoms.

Surgical resection is the main treatment modality. Well-defined margins are usually present, allowing for total resection and cure. Excessive intraoperative bleeding that obscures the operative field can be the limiting factor in subtotal resection. This complication can be avoided through adherence to the technique of circumferential dissection, feeder coagulation, and preservation of draining vein up to the end of the operation.
Radiotherapy has no role in the management of hemangioblastomas, and experience with chemotherapy is limited. Stereotactic radiosurgery is an option for patients with recurrent or unresectable tumors. Individual patients and small case series have shown clinical and radiographic response to SU5416 (semaxanib, a VEGF receptor inhibitor) and bevacizumab (monoclonal antibody against VEGF-A). Follow-up of patients with sporadic hemangioblastoma usually includes serial MRI with increasing time span. If no recurrence is present, the patient may be switched to clinical observation only. However, patients with VHL syndrome should undergo lifelong follow-up with MRI.

Intramedullary Cavernous Malformation

Cavernous malformations are considered a rare disorder representing approximately 5% of all spinal lesions. Familial cases have been reported mostly related to KRIT1/CCM1 gene mutations. CCM2 and CCM3 mutations have been reported as a cause of multiple cerebral but not spinal cavernous malformations. Spinal cavernous malformations have a slight female preponderance, and the peak of incidence is in the fourth decade. Grossly, they have a mulberry-like appearance and are characterized by sinusoidal channels under magnification. Unlike hemangioblastomas, they are not highly vascular lesions because of the lack of feeding arteries.

Despite the relatively small size and low growth potential of cavernous malformations, neurologic deficits are not infrequent. In the largest retrospective series from the French Study Group of Spinal Cord Cavernomas, initial neurological symptoms were acute in 38% of patients, mostly because of hematomyelia (70%), and were progressive in 32% of patients mostly because of compression (75%).

On MRI, cavernous malformations typically have mixed signal intensity with a hemosiderin rim around the lesion on T2-weighted images. The absence of contrast enhancement is a distinguishing feature of hemangioblastomas.

Microsurgery is the mainstay of cavernous malformation treatment. Usually these lesions are approached posteriorly through hemilaminectomy/laminectomy. Lesions are usually well circumscribed and sometimes associated with hematoma cavity, allowing total resection in most cases. Hemosiderin rim of the tumor should be left intact to prevent additional deficit; however, transient new postoperative deficits are seen in half of the patients.

RT and chemotherapy have no role in the management of cavernous malformations. Postoperative MRI should be obtained to confirm resection extent. The presence of a hemosiderin rim after surgery is not a sign of incomplete resection and does not require radiologic follow-up. Follow-up usually requires serial MRI with increasing time span, and if no recurrence is seen, patients can then be followed up with clinical observation.

Intramedullary Spinal Cord Metastasis

With current treatment modalities patients with cancer have longer survival time, and thus the incidence of CNS metastasis is increasing. However, intramedullary spinal cord metastases (ISCMs) are rare and represent fewer than 2% of primary intramedullary spinal cord tumors. Although any malignant tumor can spread into the spinal cord, the most common types are lung cancer, breast cancer, and melanoma. The presence of ISCM should be suspected in patients with known malignancy that have an intramedullary mass. Clinically, these tumors often grow more rapidly than primary spinal cord tumors. Therefore, progression of neurologic symptoms is also rapid, with higher incidence of complete deficits. Consequently, these tumors have worse outcomes than primary spinal cord tumors.

Radiologically, ISCM may be indistinguishable from primary spinal cord tumors, showing contrast enhancement and peritumoral edema formation on T2-weighted images. Treatment for patients with ISCM should be individualized based on tumor localization and size, neurologic deficit, cancer type, extension of metastatic disease, and other medical conditions. A high rate of CSF dissemination is seen with widespread leptomeningeal disease. Therefore, complete brain and whole-spine MRI should be obtained before treatment. Most cases do not require biopsy because these tumors are managed with radiotherapy and steroids, especially in the presence of radiosensitive tumors. However, given the aggressive behavior of these tumors, with 70% to 75% of patients developing complete neurologic deficit in 1 month, surgical intervention may be warranted. Additionally, in select cases, surgery is necessary, as in cancer of unknown origin. Patients treated with surgery may have a better prognosis than those treated only with radiotherapy, although the results are at least partially due to selection bias. Nonetheless, when an ISCM is...
amenable to total removal, vascularity and adhesiveness can impede complete resection, making cytoreduction an alternative approach: Additionally, aggressive surgical treatment does not affect overall survival and is often associated with poor functional outcome. Intraoperative biopsy is important in selected patients, especially in those with no known history of cancer. Systemic chemotherapy has a limited role because these tumors are in a relatively secluded site behind a pharmacologic barrier much like brain parenchymal metastasis. Consequently, radiotherapy is the primary palliative therapy for most patients. Intra–CSF chemotherapy has no role in the treatment of ISCM because it has limited diffusion into spine parenchyma.

Miscellaneous
Other rare primary spinal cord intramedullary tumors include ganglioglioma, lymphoma, germinoma, primitive neuroectodermal tumor, teratoma, dermoid cyst, epidermoid cyst, lipoma, and hamartoma.

Intradural Extramedullary Tumors

Myxopapillary Ependymoma
Myxopapillary ependymoma is a WHO grade 1 ependymal tumor usually found in the conus or filum region from which it arises. Radiologic features are similar to those of cellular ependymomas, with pronounced contrast enhancement. Grossly, these tumors are well circumscribed and encapsulated, but invasive tumors with nerve root encasement and even extravertebral invasion have been reported. Histologically, myxopapillary ependymomas are characterized by myxoid changes in the stroma and papillary organization of tumor cells.

Microsurgery plays an essential role in the treatment of these tumors, given their benign nature and resectability. In cases of filum tumors, the tumor can be removed in en bloc fashion. However, some authors reported that complete resection was more difficult than with cellular ependymomas. Local recurrence and CSF dissemination can occur with piecemeal removal, and even with tumor capsule violation, during surgery.

Similar to WHO grade 2 or 3 spinal ependymomas, sparse literature suggests a role for chemotherapy. Platinum salts and etoposide are the most common agents used for recurrent radiation- and surgery-refractory ependymomas in the intracranial compartment, and a similar strategy has been applied to spinal ependymomas.

Radiotherapy plays a minor role in the treatment of these tumors, because given the benign nature of the tumor, radiotherapy is typically not given in instances of incomplete removal. However, one study showed that adjuvant radiotherapy resulted in better local tumor control in patients who had either gross total or subtotal resections. Remote metastasis can occur in the central nervous system, including the brain, but no compelling evidence currently suggests a benefit from wider neuraxis irradiation.

Follow-up usually includes neurologic monitoring and serial MRI with an increasing time span. Surgery should be considered for recurrence of residual tumor growth.

Schwannomas
Schwannomas are common tumors that usually arise from the posterior (i.e., dorsal) nerve root, although sometimes they can begin in the anterior root. Schwannomas originate from a single fascicle, and the remainder of the nerve root is intact. Because the most common origin is the dorsal nerve root, they usually reside posteriolateral to the spinal cord (Figure 1C). Anatomically, schwannomas are classified as intradural (group 1; 54%), intra- and extradural (group 2; 8%), extradural (group 3; 14%), extradural with extension to the intervertebral foramen (group 4; 17%), and intra- and extradural with extension to the intervertebral foramen (group 5; 6%). Intramedullary schwannomas are rare and believed to arise from the penetrating nerve fibers accompanying the anterior spinal artery, although different theories exist. Most schwannomas are benign encapsulated tumors referred to as WHO grade 1, although malignant subtypes exist (malignant schwannoma). Schwannomas usually present in the fourth through sixth decades.

The association between schwannomas and NF2 is well-known. NF2 is caused by mutation of the merlin gene on chromosome 22q12. This gene is involved in cell membrane stability and motility, and intercellular adhesion. Mutation of the second allele is necessary for tumor formation, and the phenotype correlates with the type of mutation. All spontaneous schwannomas also have merlin gene
Schwannomas are characterized by a biphasic pattern consisting of highly cellular regions with spindle-shaped cells in columns (Antoni type A) and hypocellular regions with large, vacuolated, pleomorphic, stellate cells (Antoni type B). On MRI, schwannomas appear as solid tumors in the dorsal sensory root region, with displacement of the spinal cord, conus medullaris, or filum terminale. They are iso- or hypointense on T1-weighted images and hyperintense on T2-weighted images. Contrast enhancement varies from intense homogeneous to faint enhancement. If contrast enhancement is faint or absent, differential diagnosis from perineural cyst may be difficult. A cyst may be present and is believed to arise from degeneration of Antoni B portion of the tumor. Anatomically, spinal cord nerve sheath tumors are evenly distributed throughout the spinal axis (upper cervical, 16%; cervical, 31%; thoracic, 22%; conus medullaris, 7%; and cauda equina, 24%). Usually only neural foramina are enlarged because of tumor erosion; however, cases of extensive bony destruction have been reported. Hemorrhage is rare, but intratumoral, subdural, subarachnoid, and even intramedullary hemorrhage can be present. When large, these tumors may extend beyond neural foramina and have an hourglass appearance. Schwannoma and neurofibroma have no differentiating features on MRI. Melanocytic schwannomas are distinct and hyperintense on T1-weighted images, and hypointense on T2-weighted images, because of the paramagnetic effect of melanin.

Microsurgery is the primary treatment for schwannomas. The uninvolved nerve root of origin can usually be spared. Because most schwannomas originate from dorsal sensory nerve roots, even amputation of the involved root usually does not cause postoperative deficits. Grossly, schwannomas are tan-colored, globoid masses attached to nerve roots, in contrast to melanocytic schwannomas, which appear as dark masses and may be misinterpreted as melanomas. Surgery is usually curative, with improvement of symptoms and minimal morbidity. Adjuvant therapy is not recommended; incompletely resected tumors should be followed by serial MRI and resected if growth is documented. Stereotactic radiosurgery can be considered for patients who are poor surgical candidates. Malignant schwannomas are treated with radiotherapy, even if total resection was achieved. The role of adjuvant chemotherapy is unclear, but because malignant schwannomas are considered soft tissue sarcomas, sarcoma anthracycline-based chemotherapy protocols are often used.

Follow-up usually requires serial postoperative MRI and neurologic monitoring. Because total resection is achieved in most cases, patients can be followed up with only neurologic observation after several postoperative MRIs. Patients with NF2, however, are usually followed up with MRI for longer times, and brain imaging should also be performed in these patients.

**Neurofibromas**

Neurofibromas are WHO grade 1 tumors that arise from peripheral nerves. Two clinicopathologic types are recognized: solitary and plexiform. Solitary neurofibromas are often discretely localized, small, globular, or fusiform nodules originating from a single sensory nerve. Plexiform neurofibromas are characterized by redundant loops of nerve fiber bundles and tumor tissue intermixed in a disorganized pattern, involving multiple nerves. In contrast to schwannomas, neurofibromas encase nerve roots rather than displacing them, and tend to grow more longitudinally. Neurofibromas arising from brachial and lumbar plexuses can extend into the spinal canal via multiple nerve roots in retrograde fashion. Solitary neurofibromas are often small, isolated, painless nodules that mostly reside in the cutaneous or subcutaneous layer of the skin and can cause cosmetic problems or pain.

Up to 60% of neurofibromas occur in patients with NF1. NF1 is one of the most common autosomal dominant disorders, caused by mutation of the neurofibromin gene on chromosome 17q11.2; however, 50% of cases are caused by de novo mutations. Neurofibromin is a tumor suppressor gene involved in the regulation of multiple pathways, including cellular growth and division. Genetic testing is available, but sensitivity is approximately 70%, requiring clinical diagnosis that is based on National Institutes of Health criteria. Plexiform neurofibromas occur almost exclusively in NF1, and 10% of them eventually progress to malignant peripheral
nerve sheath tumors. Therefore, aggressive treatment should be attempted in patients with NF1 who have a rapidly enlarging mass and worsening pain.

On MRI, neurofibromas typically appear as rounded or fusiform tumors that are isointense on T1-weighted images and hyperintense on T2-weighted images, similar to schwannomas. Intense enhancement is seen postcontrast, and cyst formation is rare, unlike with schwannomas.

The origin of neurofibromas is unknown; however, most authors suggest a mesenchymal source. Histologically, neurofibromas are characterized by bundles of Schwann cells within an abundant matrix of collagen, with intermingling axons passing though the tumor.

Patients with spontaneous neurofibromas have a better prognosis than those with NF1. Surgical resection is the primary treatment for patients with solitary neurofibromas. Complete resection is sometimes achieved through sacrificing the nerve root of origin. Neurologic sequelae are not usually significant. In most cases, the tumor is intradural and spinal stabilization is not needed. Resection of a plexiform neurofibroma is technically challenging, and complete resection is rarely achieved. Malignant peripheral nerve sheath tumors usually have infiltrative character and extraspinal extension. Subtotal resections have a very high rate of recurrence, and therefore total en bloc resection should be the goal whenever possible. However, this technically challenging approach usually requires a multidisciplinary surgical team. Radiotherapy and chemotherapy have no defined roles for benign neurofibromas. Patients with neurofibromatosis are at risk for malignant transformation either spontaneously or after radiotherapy.

Chemotherapy is currently limited to malignant peripheral nerve sheath tumors and is similar to the Adriamycin-based regimen used for other soft tissue sarcomas. The follow-up strategy of these patients is close to that for schwannoma. Benign neurofibromas resected totally are monitored with serial neurologic examinations and radiologic follow-up. Malignant cases require more close observation, followed by radiotherapy for recurrence.

Meningiomas

Meningiomas are dural-based tumors that arise from arachnoid cap cells. They are the most common intradural extramedullary tumor, representing 25% of all primary spinal cord tumors. Similar to intracranial meningiomas, women are affected more often than men; more than 80% of all patients with spinal cord meningiomas are women, in whom the thoracic region is the most common location (80%). In men, meningiomas are equally encountered in the cervical and thoracic segments. Overall, 12% of all meningiomas are located in the spinal canal, with 15% in the cervical, 81% in the thoracic, and 4% in the lumbar regions. Anatomically, cervical meningiomas frequently occupy ventral and ventrolateral positions because of a higher concentration of arachnoid villi containing cap cells around nerve root sleeves. The same factor possibly contributes to the lower incidence of meningioma in the lumbosacral region. Thoracic meningiomas tend to occur more laterally.

Genetic predisposition (NF2) and prior exposure to ionizing radiation are the only known risk factors. Merlin gene inactivation contributes to familial cases, and most spontaneous meningiomas harbor merlin gene mutations.

Meningiomas in the setting of NF2 have more aggressive behavior and are more often multiple than spontaneous types.

Most spinal cord meningiomas are slow-growing WHO grade 1 tumors. Histologically, they are a rather diverse group of neoplasms with numerous subtypes, including meningothelial, fibrocytic, transitional, secretory, psammomatous, and angiomatous variants corresponding to WHO grade 1. Common histologic findings are whorl and psammoma body formation. Higher-grade meningiomas (grades 2 or 3) can also occur in the spine, although incidence is much lower.

On MRI, meningiomas appear as solid, well-circumscribed lesions with broad attachment to the dura. The tumor is iso- or hypointense on T1-weighted and slightly hyperintense on T2-weighted images. Contrast enhancement usually is intense and homogenous. The dural “tail” sign can be present and highly suggestive of meningioma (Figure 1D). Among all spinal cord meningiomas, 94% are intradural and 6% are extradural.

Indications for treatment should be individualized, including age, presence of neurologic deficit, evidence of growth, and general medical condition. Observation might be appropriate in older and asymptomatic patients. If treatment is indicated, microsurgery is the primary modality and can be curative (with 5- and 10-year recurrence rates of 3%.
Extradural Extramedullary Tumors

Most extradural extramedullary tumors in adults are metastases, most often from lung, breast, or prostate cancers, or lymphoma, and may result in epidural spinal cord compression. Primary tumors of the vertebral column can be separated into benign and malignant types. Benign tumors include osteoid osteoma, osteoblastoma, osteochondroma, hemangioma, aneurysmal bone cyst, giant cell tumor, and eosinophilic granuloma. Malignant varieties include chordoma, multiple myeloma, osteosarcoma, chondrosarcoma, Ewing’s sarcoma, lymphoma, soft tissue sarcomas, and plasmacytoma. A complete discussion of these tumor types is outside the scope of this article.

Conclusions

Early recognition of the signs and symptoms of primary spinal cord tumors facilitates early treatment, potentially minimizes neurologic morbidity, and improves outcome. In most series, pain is the predominant symptom and often persists after surgery. Primary treatment is surgery in most spinal cord tumors, and predictors of outcome include preoperative functional status, histologic tumor grade, and extent of surgical resection. Postoperative care after resective spinal cord surgery often mandates a lengthy rehabilitation with delayed return of neurologic function, often requiring a year or more. Symptom management for spinal cord tumors can be challenging, particularly for intramedullary tumors, with quality of life issues involving motor, sensory, and autonomic dysfunction.

References


Adult Intradural Primary Spinal Cord Tumors


