Epidural Metastasis

Epidemiology

Epidural spinal cord compression (ESCC) by metastases is more common than compression by primary spinal tumors. It occurs in 5% of patients who die of cancer, which represents more than 25,000 cases annually of spinal cord compression in the United States. Moreover, prolonged survival time from improved cancer treatment is expected to increase the incidence of ESCC. Approximately one-half of ESCCs in adults are metastases from breast, lung, or prostate cancer; the primary tumor is not identified in 10% of cases (Table 58d.1).

Table 58D1: Types of primary tumors causing metastatic epidural spinal cord compression in men and women

<table>
<thead>
<tr>
<th></th>
<th>Men (%)</th>
<th>Women (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung</td>
<td>53</td>
<td>12</td>
</tr>
<tr>
<td>Breast</td>
<td>0</td>
<td>59</td>
</tr>
<tr>
<td>Prostate</td>
<td>8</td>
<td>---</td>
</tr>
<tr>
<td>Kidney</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Melanoma</td>
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<td>1</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Female reproductive</td>
<td>---</td>
<td>6</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>31</td>
<td>16</td>
</tr>
</tbody>
</table>


Distribution

The overall frequency of metastases to any portion of the spine is a function of length: 70% involve the thoracic spine, 20% the lumbosacral spine, and 10% the cervical spine. Lung and breast carcinomas tend to metastasize to the thoracic spine and color or pelvic tumors to the lumbosacral spine. Approximately 10-38% of epidural metastases involve multiple noncontiguous levels—an important consideration in evaluation and treatment.

The anatomical site of metastasis is an important factor in patient management. Bony lesions occur in more than 90% of patients with spinal metastasis, of which 71% are osteolytic, 8% are osteoblastic, and 21% are mixed. Eighty-five percent of metastases arise in the vertebral body and invade the epidural space anteriorly. Laminectomy can be effective in decompressing the spinal cord but fails to remove the tumor, which arises
from the anterior body of the vertebrae. Metastatic lesions never involve the intravertebral disc or transgress the dura.

Pathogenesis

Metastases cause ESCC by three mechanisms. The first and most common is hematogenous spread to the vertebra, which contains highly vascularized hematopoietic bone marrow and rich growth factors. Second is spread of tumor cells to the vertebral column through the vertebral venous (Batson’s) plexus. Batson’s veins are valveless and have low intraluminal pressure and allows retrograde tumor seeding when intrathoracic or intra-abdominal pressure increases (i.e., through coughing, sneezing, or Valsalva’s maneuver). The third mechanism of direct invasion of tumor through the intravertebral foramina is responsible for approximately 15% of ESCCs. Lymphoma accounts for about 75% of these cases, in which radioisotope studies and radiographs are typically normal.

Clinical Features

Pain, the most common initial feature, occurs in 95% of adults and 80% of children. Pain is usually localized to the site of metastasis and is caused by stretching the pain-sensitive bony periosteum. Radicular pain is less frequent but is also localizing. It is often bilateral in thoracic ESCC and unilateral in cervical and lumbosacral ESCC. Segmental or funicular pain, indicating intrinsic spinal cord damage, is uncommon and is continuous, burning, dull, and diffuse. As degenerative disc disease, Valsalva’s maneuver, straight-leg raising, and neck flexion aggravate back pain. Unlike a herniated disc, ESCC pain is characteristically aggravated by recumbency (which is worse at night). Epidural metastasis is the initial manifestation of malignancy in about 10% of patients. The primary is usually lung cancer, myeloma, lymphoma, or renal cell cancer.

Common clinical features at the time of diagnosis are bilateral weakness (76%), autonomic dysfunction (57%), and sensory complains (51%). Weakness (caused by anterior compressions of the spinal cord) precedes the sensory symptoms. At the time of diagnosis, 50% of patients are ambulatory, 35% are paraparetic, and 15% are paraplegic. As many as one-half of those who are paraplegic at diagnosis, had deteriorated abruptly or within the previous 24- to 48-hour period. Rapid progression is mostly seen in patients with lung cancer, lymphoma, or renal tumors. Autonomic dysfunction is never the presenting symptom. Sensory complains are almost always painful. Lhermitte’s sigh, herpes zoster, gain ataxia, and Brown-Sequard’s syndrome are unusual in ESCC.

Neuroimaging

On plain radiographs of the spine, metastases cause changes in the pedicles, which are compact bone, before the vertebral bodies, which must be 50% destroyed before changes can be identified. Abnormal radiographs at the time of presentation are seen in 85% of patients with ESCCs from epithelial tumors but in only 33% of patients with lymphoma. The most common findings are pedicle erosion (“winking owl” sign), paravertebral soft issue shadow, vertebral collapse, and pathological fracture dislocation. The likelihood of epidural tumor is 87% when vertebral compression is greater than 50%. ESCC is present in only 7% of patients with radiological evidence of vertebral metastases without collapse.

The sensitivity of bone scanning approaches 91%, but its specificity is limited, with a high false-positive rate. Computed tomography (CT) of the spine is more sensitive and specific than plain radiographs or radionuclide scanning for ESCC. The combination of myelography followed by CT was the study of choice but is being replaced by magnetic resonance imaging (MRI). MRI is as sensitive as bone scans for detecting vertebral metastasis and is more specific.

MRI provides detailed anatomical resolution of the vertebrae and surrounding structures and permits direct visualization in multplanar sections along the entire length of the spinal column. Unenhanced T1- weighted sagittal images are obtained first because contrast enhancement might obscure subtle vertebral metastases. This is followed by a T2-weighted or enhanced T1-weighted scan. The characteristic findings on MRI are multiple foci of low signal intensity on T1-weighted images. Collapse and destruction of the vertebral body sparing the
adjacent disc spaces are common. Short T1 inversion recovery, which is a fat-suppression technique, increases the sensitivity of MRI. Although gadolinium enhancement may mask vertebral lesions, it is helpful in the detection and characterization of epidural, intradural, and intramedullary processes. Conventional myelography is preferred to MRI in patients who cannot lie still because of claustrophobia or severe pain and in patients with severe scoliosis, ferromagnetic implants, aneurysm clips, or a cardiac pacemaker. In cases in which MRI does not yield the diagnosis, myelography should be performed.

Prognostic Variables

Severity of weakness at time of diagnosis is the most significant prognostic variable for recovery of neurological function. Ninety percent of patients who are ambulatory at diagnosis remain ambulatory after treatment. After radiation, 75% of paraparetic patients with radiosensitive tumors remain ambulatory, whereas only 34% with radioresistant tumors remain ambulatory. In contrast, only 13% of paraplegic patients with radiosensitive tumors and none with radioresistant tumors become ambulatory. Rate of onset and progression of symptoms correlate better with outcome than does duration. Outcome also depends on the radiosensitivity of the primary tumor. Myeloma, lymphoma, neuroblastoma, and to a lesser degree, breast and prostate cancer, have a more favorable prognosis; non-small cell lung cancer, renal cancer, and melanoma have a poor prognosis. The extent and location of epidural disease also influence the response to treatment. Vertebral collapse and anterior location of the metastasis is less favorable because surgical access is limited, and a partial myelographic block has a more favorable prognosis for neurological recovery than a complete block.

Treatment

ESCC is usually associated with inadequate control of the primary tumor, and survival time is short. Treatment of ESCC is palliative and directed at maintaining ambulation, decreasing tumor bulk, and relieving pain. Patients with advanced cancer and poor performance status are treated conservatively. In those without advanced disease, expeditious diagnosis and treatment should improve or at least maintain neurological function. High-dose corticosteroids are started immediately, followed by radiotherapy and sometimes chemotherapy. Corticosteroids rapidly decrease spinal cord vasogenic edema and promote clinical improvement in relation to dose administered. Dexamethasone, 100 mg intravenously followed by 24 mg every 6 hours, is recommended. The usual maintenance dose is 4 mg every 6 hours. An intravenous bolus of high-dose dexamethasone may cause severe but transitory (5-minute) dysesthesias of the genitalia. Other side effects include hiccoughs, psychosis, hallucinations, hyperglycemia, gastrointestinal bleeding, and drug interaction (phenytoin and Warfarin).

Recommendations conflict for the treatment of ESCC. Historically, decompressive laminectomy had been the most common treatment for ESCC. Improved outcomes have also been obtained with the combination of laminectomy and radiotherapy. Other studies showed no difference between radiotherapy and laminectomy plus radiotherapy. Radiotherapy alone is now the treatment of choice. Patients with radiosensitive tumors (e.g., lymphoma, seminoma, myeloma, Ewing’s sarcoma, and neuroblastoma) respond, but patients with radioresistant tumors (e.g., lung, colon, renal, and melanoma) also respond as well to radiotherapy alone as to combined surgery and radiation. The recommended radiation fields are two normal vertebral bodies above and below the margins of epidural tumor. Because epidural metastasis may occur at multiple levels, the entire spinal cord must be visualized by MRI or myelography. The frequency of local recurrence after initial response, independent of histology, is approximately 10%. Most radiation oncologists recommend 3,000 cGy over 10 fractions. If the irradiated volume is large or if the tumor is highly radiosensitive, a smaller daily dose is usually used.

Decompressive laminectomy is indicated in patients with a posteriorly situated epidural metastasis in the absence of vertebral disease. ESCC in children is often from tumors (e.g., neuroblastoma) that invade the spinal canal through the neural foramen. In this situation, decompressive laminectomy may be effective. Because metastatic tumor is anterior to the cord in 85% of cases, vertebral body resection followed by stabilization offers the best results. The reported surgical morbidity is 9%, but the ambulation rate increased from 28% to 80% postoperatively, and median survival is 16 months. Postoperation radiation therapy is required (Table 58D.2).
Table 58D.2: Indications for surgical intervention in epidural spinal cord compression

- Need for tissue diagnosis
- Spinal instability
- Progressive deterioration during chemotherapy or radiotherapy
- Recurrent disease in previously irradiated site
- Rapidly progressive cord compression by a known radioresistant tumor


With few exceptions, ESCCs do not respond to chemotherapy rapidly enough to prevent neurological deterioration. Systemic chemotherapy can be used to treat chemosensitive tumors with stable or slowly progressive neurological deficits because such epidural tumors are not protected by the blood-brain barrier. The best results have occurred with small cell tumors, such as lymphoma, germ cell tumors, neuroblastoma, or Ewing’s sarcoma. Chemotherapy or hormonal therapy also may be effective in breast and prostate cancer. Some promising results have been achieved with systemic chemotherapy in children with chemosensitive tumors, but further studies are needed.

Overall, tumor type is a more important determinant of the functional outcome that type of treatment. The life expectancy of patients with bronchogenic carcinoma is 87 day; for breast cancer, it is 7 months; and for hematological malignancies, it is 12 months.

Extradural Primary Spinal Neoplasms

Tumors of the vertebral column, unlike tumors of all other bones, are more often malignant that benign. Myeloma is the only common primary tumor of the spine in adults. Neuroblastoma and Ewing’s sarcoma are the main malignant spinal tumors of childhood, and despite substantial morbidity with early treatment, the outcome is often favorable because these tumors are relatively sensitive to radiations and chemotherapy.

Multiple myeloma is a plasma cell neoplasm that accounts for up to 33% of bone tumors. The peak incidence is in the sixth through eighth decades. It is twice as common in African-Americans as in Americans of European ancestry. Polynuropathy is sometimes associated and confused the diagnoses of spinal cord compression. ESCC occurs in 10-15% of people with multiple myeloma. The median age of onset of plasmacytomas is 50 years, and the male-to-female ratio is 3 to 1. Most plasmacytomas evolve into multiple myeloma after 10 years. Radiation and chemotherapy remain the treatments of choice.

Ewing’s sarcoma accounts for nearly 20% of spinal cord compression in children. Osteosarcoma and neuroblastoma are next in frequency. Neuroblastoma is the most common cause of spinal cord compression in children less than 5 years of age. Intensive chemotherapy and radiotherapy are beneficial in the treatment of Ewing’s sarcoma, neuroblastoma, and osteosarcoma. Chordomas arise from notochordal remnants. Their location is the sacrococcygeal area in 50% of cases and the skull base in 35%. Chordomas are the second most common tumors of the spine. Peak incidence is the fifth through seventh decades (the same as that for metastatic cancer). Hematogenous dissemination occurs in 33% of cases. Surgery, the primary therapy, is followed by radiation when resection is incomplete.

INTRADURAL TUMORS

Leptomeningeal Metastasis

Leptomeningeal metastasis (LM) occurs when tumor cells infiltrate the arachnoid and the pia mater (leptomeninges), causing focal or multifocal infiltration. LM develops in approximately 5-8% of patients with non-Hodgkin’s lymphoma and up to 70% of patients with leukemia. Adenocarcinomas are the most common
solid tumors causing LM. Breast cancer is first, followed by lung, melanoma, and gastrointestinal cancers. The prevalence of LM is increased in long-term survivors of melanoma and small cell lung cancer.

Untreated primary central nervous system (CNS) tumors, such as medulloblastoma, ependymoma, and glioma, also have high frequency of LM. CNS prophylaxis has markedly decreased the risk of LM in leukemia. The risk factors for leptomeningeal lymphomatosis in non-Hodgkin’s lymphoma are bone marrow and testicular involvement, extranodal disease, epidural invasion, diffuse histology, Burkitt’s syndrome, and lymphoblastic histology. Most primary CNS lymphomas are parenchymal, often leading to leptomeningeal spread, whereas systemic lymphomas are primary meningeal with secondary parenchymal invasion.

Pathology

The characteristic pathologic features of LM are thin, sheetlike layers of tumor cells, multifocal nodules, infiltration of cranial or spinal nerve roots (or both), and superficial invasion of the brain and spinal cord through the Virchow-Robin spaces. Tumor infiltration is more prominent along the ventral surface of the brain and the dorsal surface of the spinal cord. LM is associated with a high frequency of brain metastasis (42%) and dural metastasis (16-37%). ESCC is seen in 1-5% of patients with LM. Most breast or lung cancers that cause LM have spread directly from vertebral or paravertebral metastasis, whereas gastrointestinal cancer invades through the perineural spaces. Deep CNS parenchymal metastasis occurs through hematogenous spread.

Clinical Features

The clinical features of LM are referable to the cerebrum, cranial nerves, or spinal nerve roots, individually and in combination. The features of cranial nerve involvement, in order of decreasing frequency, are ocular motor palsies, facial weakness, hearing loss, vision loss, facial numbness, and tongue deviation. Headache and encephalopathy are common. Seizures occur in 6% of patients. In the spine, the lumbosacral roots are most commonly involved. This results in a cauda equina syndrome of asymmetrical weakness, dermatomal sensory loss, and paresthesias. Pain is an initial symptom in 25% of patients.

The pathophysiology of clinical symptoms and signs of LM may be due to hydrocephalus, parenchymal invasion, ischemia, metabolic competitions, immune responses, and disruption of the blood-brain barrier.

Examination of the cerebrospinal fluid (CSF) is the most important test for LM. Only 3% of initial lumbar punctures yield normal CSF. The abnormalities, in order of decreasing frequency, are increased protein concentration, lymphocytic pleocytosis, increased CSF pressure, and positive cytology. The glucose concentration is decreased in 31% of patients. Cytological examination is the most specific test. Positive cytology is seen on initial CSF examination in 54% of cases, and the yield increases to above 90% when three separate spinal taps are performed (Table 58D.3). The best yield is obtained when CSF is taken from the symptomatic area. False-negative CSF cytology results are common, but they can be minimized by good technique. This involves withdrawing at least 10.2 ml of CSF for cytological analysis, processing the CSF specimen immediately, obtaining CSF from the site of known leptomeningeal disease, and repeating the procedure at least once after initial cytology is negative (Glantz et al. 1998). CSF markers, such as carcinoembryonic antigen, B-glucuronidase, B2-microglobulin, and lactate dehydrogenase are more useful for following the response to treatment that for initial diagnosis.

Newer techniques for diagnosing LM include flow cytometry and monoclonal antibodies. Polymerase chain reaction techniques have increased the sensitivity in diagnosis of lymphomatous meningitis. This technique is based on detection of clonal rearrangements of immunoglobulin or T-cell receptor genes (Rhodes et al. 1996).

\[\text{Table 58D.3: Leptomeningeal metastases from solid tumors in 90 patients: cerebrospinal fluid (CSF) findings}\]

<table>
<thead>
<tr>
<th>Initial (%)</th>
<th>Subsequent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure &gt;160 mm CSF</td>
<td>50</td>
</tr>
<tr>
<td>Cells &gt;5/ul</td>
<td>57</td>
</tr>
<tr>
<td>Protein &gt;50 mg/dl</td>
<td>81</td>
</tr>
<tr>
<td>Glucose &lt;40 mg/dl</td>
<td>31</td>
</tr>
</tbody>
</table>
### Neuroimaging

Gadolinium-enhanced MRI is the modality of choice and has almost twice the sensitivity of CT myelography. MRI shows thin, linear enhancement on the surface of nerve roots and the spinal cord. Sensitivity may be increased with high-dose contrast studies. Enhanced spinal MRI may detect LM in about one-half of patients who are at high risk of CSF seeding with a negative initial CSF cytology or no spinal symptoms. Treatment should be initiated on the basis of MRI even when CSF cytology is normal, if the clinical setting is supportive of LM (Gomori et al. 1998).

### Treatment

The median survival of untreated patients with LM is 4-6 weeks. Most patients die from progressive neurological dysfunction. Radiotherapy is combined with intrathecal and systemic chemotherapy. Radiation therapy is delivered to the symptomatic site at a dose of 2,000-3,000 cGy in 10-15 fractions. Total cranial-spinal axis radiotherapy is used only for meningeal leukemia because of myelosuppression. Intrathecal therapy is favored because systemic chemotherapy is probably not as effective in treating LM from solid tumors. An intraventricular reservoir is the recommended method to deliver intrathecal chemotherapy because it provides a more uniform distribution of drug in the CSF. It is also allows frequent repetitions of low dosages of chemotherapeutic agents by means of a “concentration x time” regimen, which theoretically improves effectiveness without increasing toxicity. This is especially important when using methotrexate and cytosine arabinoside because they are cell cycle-specific agents and need fairly constant CSF levels to be effective. Methotrexate, 12-20 mg reconstituted in preservative-free sterile normal saline, is the mainstay of intrathecal chemotherapy for solid tumors. Cytosine arabinoside (ara-C), 30-100 mg, is substituted or added to methotrexate in LM from lymphoma or leukemia. Among patients with leukemia and lymphoma, 75-80% show a CSF response or clinical response to intrathecal chemotherapy, but patients with solid tumors, such as breast cancer, have a 40-80% response rate and a median survival of 6-7 months. The overall response rate for non-small cell lung cancer and melanoma is less than 20%.

With radioisotope ventriculography, more than 60% of patients show ventricular outlet, spinal, or convexity blocks due to leptomeningeal seeding. CSF flow blocks, when untreated, increase morbidity by increasing neurotoxicity (high-concentration effect), and increase CSF tumor progression (protective site effect), and increase systemic toxicity (reservoir effect). These flow abnormalities may be corrected with appropriately directed radiotherapy. Intrathecal chemotherapy should be delayed if abnormal flow is documented until appropriate radiotherapy re-establishes normal flow (Chamberlain and Kormanik 1996).

### Intradural Extramedullary Primary Neoplasms

Most primary intradural extramedullary neoplasms are histologically benign tumors, such as meningiomas (25%), nerve sheath tumors (29%), and developmental tumors (epidermoids, dermoids, lipomas, and teratomas) (Table 58D.4).

### Meningiomas

Most meningiomas arise from arachnoid cells. More than 90% are intradural, 6% are both intradural and extradural, and 7% are only extradural. Multiple meningiomas are rare except in patients with neurofibromatosis type 2. The peak incidence of meningiomas is between ages 40 and 70 years; 85% are in
women, and 80% are located in the thoracic spine. Meningiomas in men are commonly located in the cervical spine, tend to grow rapidly, and have an intradural and extradural component.

The initial symptom of spinal meningiomas, like other spinal tumors, is usually pain followed by paraparesis and sensory disturbances. The average duration of symptoms from onset to diagnosis is 23 months. Bone is not often affected, and only 10% have radiographic abnormalities. Myelography shows a characteristic displacement of the spinal cord away from the mass and enlargement of the subarachnoid space above and below the tumor. Meningiomas have a homogeneous appearance on MRI and are usually isointense to spinal cord on T1-weighted and T2-weighted sequences. Surgery is the treatment of choice. The recurrence rate is 13% after 10 years.

Table 58D.4: Mayo Clinic classification of 1,322 primary tumors of the spinal canal

<table>
<thead>
<tr>
<th>Type</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurilemomas (schwannomas)</td>
<td>29.0</td>
</tr>
<tr>
<td>Meningioma</td>
<td>25.5</td>
</tr>
<tr>
<td>Glioma (astrocytoma, ependymoma)</td>
<td>22.0</td>
</tr>
<tr>
<td>“Sarcoma” (lipomas, fibrosarcoma,</td>
<td>11.9</td>
</tr>
<tr>
<td>chondromas, lymphomas)</td>
<td></td>
</tr>
<tr>
<td>Vascular tumors</td>
<td>6.2</td>
</tr>
<tr>
<td>Chordoma</td>
<td>4.0</td>
</tr>
<tr>
<td>Epidermoid, dermoid, teratomas</td>
<td>1.4</td>
</tr>
</tbody>
</table>


**Nerve Sheath Tumors**

Nerve sheath tumors are schwannomas and neurofibromas. Schwannomas (neurilemomas) are composed of Schwann cells and produce an eccentric enlargement of the involved nerve root. Neurofibromas are a mixture of Schwann cells and fibroblasts with abundant collagen fibers and cause diffuse enlargement of the nerve root. Nerve sheath tumors comprise 29% of primary spinal cord tumors.

Nerve sheath tumors are evenly distributed along the spinal axis. Men and women are equally affected. Age at onset is usually between 31 and 60 years; average age is 43.5 year for nerve sheath tumors and 53 years for spinal meningiomas. Two-thirds of tumors are intradural, and of the remainder, one-half are dumbbell-shaped (intra-extradural) and one-half are extradural.

Pain is the initial feature in 75% of patients. It may be axial, radicular, or referred (distant nondermatomal pain). Pain is exacerbated by Valsalva’s maneuver, coughing, sneezing, and recumbency. Mean duration of symptoms before diagnosis averages 1-4 years. Weakness and sensory symptoms predominate at the time of diagnosis; sphincter dysfunction is uncommon. Malignant deterioration of neurofibromas (neurofibrosarcoma) occurs in 3-13% of all cases; one-half of those are people with neurofibromatosis.

Radiographs of the spine are abnormal in 50% of cases. The usual finding is widening of the intervertebral foramen, erosion of the pedicle or vertebral body, and widening of the interpedicular distance. CT, myelography, or MRI provides a definitive image. Intradural schwannomas are usually hypointense on T1-weighted images and hyperintense on T2-weighted images. Ringlike enhancement is considered a sign of cystic degeneration and is more consistent with schwannoma that meningioma.

**Embryonal Tumors**

Embryonal tumors (epidermoid, dermoid cysts, teratomas, and lipomas) comprise 1-2% of primary spinal tumors. They are usually found in the lumbar region and associated with spina bifida occulta, posterior dermal sinuses, syringomyelia, or diastematomyelia. Associated cutaneous abnormalities may be found, including hypertrichosis, pigmented skin, sacral dimple, and cutaneous angiomas. Most lipomas are in the
cervicothoracic region and are intramedullary as well as intradural-extradural. MRI shows high signal-intensity T2-weighted images.

**Intramedullary Spinal Cord Tumors**

Intramedullary spinal cord tumors, both primary and metastatic, account for 2-4% of adult and 10% of pediatric CNS tumors. Glial tumors account for 22% of primary intraspinal tumors, the third most common after schwannomas and meningiomas. Astrocytomas and ependymomas account for 80-90% of all intramedullary tumors at all ages; in adults, ependymomas are more common than astrocytomas, whereas in children, ependymomas are more common than astrocytomas. Pediatric intramedullary astrocytic tumors are usually in the cervical cord, but some tumors extend the entire length of the cord (holocord astrocytomas). The McCormick Clinical and Functional Classification Scheme is used to prognosticate and quantify the results of treatment. (Table 58D.5).

<table>
<thead>
<tr>
<th>Grade</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Neurologically normal; mild focal deficit not significantly affecting function of involved limb; mild spasticity or reflex abnormality; normal gait.</td>
</tr>
<tr>
<td>II</td>
<td>Presence of sensorimotor deficit affecting function of involved limb; mild to moderate gait difficulty; severe pain or dysesthetic syndrome impairing patient’s quality of life; still functions and ambulates independently.</td>
</tr>
<tr>
<td>III</td>
<td>More severe neurological deficit requires cane or brace for ambulation or significant bilateral upper extremity impairment; may or may not function independently.</td>
</tr>
<tr>
<td>IV</td>
<td>Severe deficit; requires wheelchair or cane or brace with bilateral upper extremity impairment; usually not independent.</td>
</tr>
</tbody>
</table>

**Ependymoma**

One-half of all ependymomas are located below the foramen magnum and involve either the spinal cord (55%) or the cauda region (45%), which includes the conus medullaris, filum terminale, and cauda equina. Myxopapillary ependymomas are characteristically seen in the region of the filum terminale and originate from islands of ependymal cells within fibrous band. The male-to-female ratio of spinal ependymomas is 2 to 1, and the median age of onset is 36 years. MRI has reduced the duration from symptom onset to diagnosis from 24-36 months to 14 months, and as a consequence, the frequency of weakness and sphincter involvement has decreased. The main complaint (95%) at the time of diagnosis is back pain. Most patients have dysesthesias without sensory loss. This is attributed to the location of the crossing spinothalamic tracts (central cord syndrome). When pain and numbness occur in a radicular pattern involving the legs, the underlying tumor is usually a myxopapillary ependymoma involving either the filum or the conus. MRI, with and without contrast, is the imaging modality of choice for detecting intramedullary tumors. Ependymomas have a homogeneous enhancement pattern with sharply defined rostral and caudal poles; 30% have rostral-caudal cysts. Hypointensity at the tumor margins on both T1- and T2-weighted images indicates a relatively firm pseudocapsule, which should suggest ependymomas. Transverse T1-weighted gadolinium-enhanced MRI shows symmetric cord enlargement and intense, homogeneous enhancement.
Ependymomas, unlike astrocytomas, have a cleavage plane and tend not to invade normal tissue. Most ependymomas can be debulked with minimal morbidity. Patients with leg weakness usually show significant spinal cord thinning at surgery, which makes further excision hazardous. The common postoperative complications are a temporary increase in dysesthesias and a loss of proprioception. Postoperative radiotherapy is not indicated after total resection but should be done when MRI shows residual tumor or the histology indicates an anaplastic ependymoma. The 10-year survival rate is greater than 90%, with especially good results in patients with myxopapillary tumors.

Astrocytoma

Excluding cauda equina tumors, astrocytoma is the most common intramedullary spinal tumor in all ages; in children, astrocytoma is twice as common as ependymoma. The peak incidence is in the third to fifth decade of life. The average age at onset is 40 years for low-grade astrocytoma and 31 years for malignant astrocytoma. Overall, more than 75% are low-grade gliomas. Malignancy is more common in adults than in children. The distribution of astrocytomas is consistent with the length of cord segments; most are in the thoracic region. Up to 40% of astrocytomas have an associated intratumoral cyst or syringomyelia.

The clinical features of spinal cord astrocytoma are localized back pain initially, followed by progressive weakness. Unlike ependymomas, paresthesias are more common than dysesthesias. The duration of symptoms before diagnosis is 41 months for low-grade astrocytomas and 4-7 months for malignant astrocytomas. Unlike most intracranial low-grade astrocytomas, spinal astrocytomas enhance with gadolinium. MRI shows a patchy, heterogeneous pattern of enhancement consistent with a diffusely infiltrating tumor. Axial MRIs usually show asymmetric expansion of the cord. Astrocytomas are solitary, except in patients with NF-2. Malignant astrocytomas spread through the subarachnoid pathways and seed the leptomeninges. The complete spine and brain must be fully imaged to establish a treatment plan.

Therapy for intramedullary astrocytomas is controversial. Innovations in neurosurgery, such as bipolar coagulating forceps, operating microscopes, intraoperative ultrasonography, and the Cavitron ultrasonic surgical aspirator, have greatly increased the respectability of astrocytomas. However, the small number of cases and the indolent natural history of the tumor make evaluation of treatment efficacy difficult. Postoperative adjuvant therapy is not needed when gross total resection is achieved, but postoperative radiation is recommended after subtotal resection. Tumor recurs in children receiving 4,500 cGy of radiation, which suggests that this dose is not curative. The 5-year survival rate with low-grade astrocytoma is greater than 90%. The mean survival time for anaplastic astrocytoma and glioblastoma multiforme is less than 1 year, despite surgery, radiotherapy, and chemotherapy. Radical surgery is not indicated.

Intramedullary Metastasis

Intramedullary spinal cord metastasis accounts for 6% of myelopathies in cancer patients. The primary cancers responsible for intramedullary metastasis are lung (49%), breast (15%), lymphoma (9%), colorectal (7%), head and neck (6%), and renal (6%). There is a relative tendency for small cell lung carcinoma to metastasize to the spinal cord.

Intramedullary spinal metastases are thought to be arterially disseminated, a notion that is supported by the fact that one-half of patients have brain metastases. The conus medullaris is the most commonly affected segment, with 12.5% of patients having multilevel disease.

Three-fourths of patients develop significant neurological deficits within 1 month. The most common initial features are weakness, sensory deficits, urinary incontinence, and pain. Weakness from intramedullary metastasis is usually asymmetrical, whereas weakness from ESCC is relatively symmetrical. MRI is the investigation of choice. Focal beam radiation is recommended. The prognosis is poor, with 80% expected to die within 3 months.
REFERENCES


# BENIGN BONE LESIONS OF THE SPINE

<table>
<thead>
<tr>
<th>LESION</th>
<th>LOCATION</th>
<th>INCIDENCE</th>
<th>AGE</th>
<th>IMAGING</th>
<th>CLINICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemangioma</td>
<td>Vertebral body (T, L&gt;C)</td>
<td>Most common benign spinal neoplasm</td>
<td>All</td>
<td>CT: “polka dot” body</td>
<td>Not painful Rarely can fracture</td>
</tr>
<tr>
<td>Osteoid Osteoma</td>
<td>Neural arch (L, C&gt;T)</td>
<td>Common (10%) in spine</td>
<td>10 to 20 years</td>
<td>Dense sclerosis, lucent &lt;2 cm</td>
<td>Painful, ASA sensitive</td>
</tr>
<tr>
<td>Osteoblastoma</td>
<td>Neural arch C&gt;L, T; sacrum</td>
<td>Uncommon (40%) in spine</td>
<td>&lt;30 years</td>
<td>Expansile lytic mass; +/-matrix mineralization</td>
<td>Scoliosis</td>
</tr>
<tr>
<td>Giant cell tumor</td>
<td>Vertebral body (sacrum &gt;&gt; vertebrae)</td>
<td>Uncommon</td>
<td>20s to 40s</td>
<td>Lytic, expansile, destructive, highly vascular</td>
<td>Malignant transformation</td>
</tr>
<tr>
<td>Osteochondroma</td>
<td>Spinous, Transverse Processes (10% to 12% multiple)</td>
<td>Common (rare in spine)</td>
<td>5 to 30 years</td>
<td>Pedunculated/ sessile lesion; peristeam, cortex, marrow in continuity with host bone; cartilaginous CAP +/- Ca</td>
<td>Rarely symptomatic</td>
</tr>
<tr>
<td>Aneurysmal bone cyst</td>
<td>Posterior elements (C, T most common)</td>
<td>Rare (20%) in spine</td>
<td>80%&lt; 20 year</td>
<td>Multiloculated, expansile; eggshell-like rims; blood products with fluid-level; highly vascular</td>
<td>Recurrence following resection is common. Can expand quickly</td>
</tr>
<tr>
<td>Eosinophilic granuloma</td>
<td>Uncommon</td>
<td>1st or 2nd decade</td>
<td>Vertebral body collapse (vertebra plana)</td>
<td>Fever; lung involvement</td>
<td></td>
</tr>
<tr>
<td>Epidural Lipomatosis</td>
<td>T-Spine</td>
<td>Rare</td>
<td>Fat in epidural space</td>
<td>Weakness; back pain; cortico-steroids</td>
<td></td>
</tr>
</tbody>
</table>
Cervical Spine

Syringomyelia and Hydromyelia
Congenital syrinx often associated with Chiari malformation and other congenital anomalies (i.e. block vertebrate). Haustrations within cyst are typical of this type.
Can also see a syrinx with trauma or as part of a cervical spine tumor. To exclude tumor, a syrinx should be enhanced with gadolinium

Transverse Myelitis
T2 weighted bright sign in cord not associated with bone compression. Lesions will often enhance. Impossible to distinguish lesion of MS from monophasic transverse myelitis that can follow viremia

B-12 Deficiency
Uncommon but dramatic cause of bright signal within the cord

Radiation Myelopathy
Long segment of hyperintensity with T2 weighting

Rheumatoid Arthritis
Pannus formation involves hypertrophy of ligamentous structures surrounding odontoid
And along with atlanto-axial subluxation can cause narrowing at craniovertebral junction.
Should be suspected in all cases of myelopathy in patients with rheumatoid arthritis.

Malignant Bone Lesions of Spine

Primary
Myeloma
Most common primary malignant bone tumor
Pedicles involved late
Bone scan often negative
Multiple irregular lytic foci – No sclerotic rim
Generalized osteoporosis

Lymphoma
Often associated with little bone destruction
Epidural mass often extends beyond one segment
Can simulate a lateral disc

Chordoma
Arise from intraosseous notochordal remnants
Two types: typical and chondroid chordoma
Any age; incidence is 50-60 years
Preferential location for both ends of axial skeleton
50% sacrum/coccyx
35% skull base
15% vertebral bodies
NECT scans show lytic, destructive lesions; Ca ++ in 30% to 70%; soft tissue mass often associated
Inhomogenous signal on MR; typical Chordomas are often very hyperintense on PD/T2WI
Males > females

Benign versus malignant compression fractures
Benign (osteoporotic) compression fracture
Signal similar to other vertebral bodies (in elderly, marrow is usually high signal on T1WI, low on T2WI
Signal is relatively uniform

Pathologic compression fracture
Lesions often multiple
Signal usually different from other vertebral bodies
Often Hypointense on T1WI, hyperintense on T2WI
Signal usually heterogenous
Pedicle involvement common

Metastatic source
Breast
Lung
Prostate
Lymphoma
Melanoma
Renal Cancer
Myeloma

Statistics
Most common extradural malignant spine tumor
Occur at death in 40% of patients dying of disseminated cancer

Location
Posterior vertebral body – Pedicle
Lower thoracic and lumbar area most common

Imaging Findings
Low Signal T1 (normal fat replaced)
Isointense to bright T2 – depends on amount of necrosis, hemorrhage, fibrosis

Caution: Magnevist can make bone tumors isointense

Intradural Extramedullary Tumors

A. Nerve sheath tumors
Most common intradural extramedullary mass
Types
Schwannoma, neurofibromas; ganglioneuroma, neurofibrosarcoma are rare
Primary seen in middle-aged adults
Variable location
Intradural extramedullary (70% to 75%)
“Dumbbell” (15%)
Extradural (15%)
Intramedullary (<1%)
Multiple lesions common with neurofibromatosis
Clinical symptoms can mimic disk herniation
Imaging findings
Enlarged neural foramen common, Ca ++ rare
75% isointense, 25% hyperintense on T1WI
>95% hyperintense on T2WI (“target” appearance common)
Virtually 100% enhance

B. Spinal meningioma
Most are typical benign meningioma
Second most common cause of spinal tumor
Classic patient is a middle-aged woman
Most common location: thoracic spine
90% are intradural extramedullary
Imaging findings
Bone erosion, Ca ++ rare
Most are isointense with cord on T1 – and T2WI
Moderate contrast enhancement
+/- dural “tail”

C. Other
Epidermoid cyst
Dermoid cyst
Tethered Cord
Low lying conus with or without a lipomas. Exiting nerve roots have a transverse
or uphill course. Fibrous band can sometimes be seen in axial plane.

D. Malignant – Carcinomatous meningitis
Imaging findings
1. Nodular or plaquelike deposits intimately related to the conus and cauda equina
2. Focal, discrete lumbosacral mass lesions
3. Clumping and crowding of diffusely thickened lumbar nerve roots, causing a striated
   myelographic appearance
4. Root sleeve obliteration, sometimes with expansion of the axilla and ganglion caused
   by tumor implants

E. Diffusely thickened nerve roots
Common
Carcinomatous meningitis
Lymphoma
Leukemia
Uncommon
Toxic neuropathy
Neuritis
Multiple nerve root tumors (usually nodular)
Rare
Sarcoidosis
Histiocytosis
**Intramedullary Tumors**

A. Spinal ependymoma  
   Histology and location  
   Cellular ependymoma (anywhere, but usually cervical cord)  
   Myxopapillary ependymoma (exclusively in conus medullaris and cauda equina)  
   Most common spinal cork tumor overall; most common intramedullary tumor of adults  
   Usually in middle-aged patients  
   Conus ependymomas are slow-growing, may become extremely large and erode bone  
   Imaging findings  
   Vertebral body scalloping common with large conus lesions; may enlarge neural foramina  
   Hemorrhage common; cysts also frequent  
   Usually isointense with cord on T1-, hyperintense on T2WI  
   Enhances strongly, somewhat inhomogenously

B. Spinal cord astrocytoma  
   Usually low-grade fibrillary astrocytoma; anaplastic astrocytoma, GBM rare  
   Second most common spinal cord tumor overall; most common cord tumor in children  
   Cause of low pain, pain, painful scoliosis in children  
   Imaging findings  
   Long, multisegment intramedullary mass typical, causes diffuse cord expansion  
   Interpediculate distance widened, pedicles thinned  
   Cysts common, often extensive  
   Virtually 100 % enhance

C. Spinal cord hemangioblastoma

**SUMMARY**

**INTRAMEDULLARY LESION**

- Ependymoma (most common, esp in adults)  
- Astrocytoma (more common in children/Cx location)  
- Medulloblastoma (CSF seeding)  
- Lipoma/Dermoid/Epidermoid - especially in dysraphism  
- Hemangioblastoma (Von Hippel-Lindau syndrome)  
- Metastasis - breast/lung/melanoma  
- Syringomyelia/Hydromyelia  
- Hematoma Inflammation - myelitis  
- AVM-Angioma  
- Cervical - usually glioma or syrinx  
- Thoracic - consider teratoma, dermoid, astrocytoma?

**EXTRAMEDULLARY/INTRADURAL LESION**

Meningioma (most thoracic)
Schwannoma (more common than neurofibroma)
Neurofibroma (erodes bone while extending through neural foramen, usually NF-1)
Drop metastasis - medulloblastoma/ependymoma/pineal dysgerminoma/glioma
Dermoid-Epidermoid (associated with dysraphism ?)
Lipoma - most common location is caudal (also "fatty filum")

COMMENT: Most tumors in this location are benign

EXTRADURAL LESION
Herniated disc (90% at L4-5 and L5-S1)
Osteophyte
Metastasis (Breast-Lung)
Lymphoma
Meningioma
Primary Bone tumor:
  - Chordoma
  - Osteosarcoma/blastoma
  - Myeloma
  - Aneurysmal bone cyst
  - Giant cell tumor
Neurofibroma (often w/intradural component)
Dermoid-Epidermoid/Lipoma

SACRAL EXPANSILE LESION
Sacrococcygeal Teratoma (often presents in newborn)
Epidermoid cyst
Chordoma (bulky, lobulated mass with bone destruction)
Dural ectasia - meningocele
Dermoid
Lipoma
Giant cell tumor
Aneurysmal bone cyst

PEARLS IN THE DIAGNOSIS OF SPINAL ASTROCYTOMA

1. Thoracic location more common than cervical
   a. Astrocytoma is still the most common primary intramedullary malignant neoplasm of the cervical cord
   b. Ependymoma has a propensity for the lower thoracic and lumbar cord or conus
2. Poorly defined
3. Enhancement is variable but usually occurs less than six minutes after contrast administration
4. Hypointense T1 signal and hyperintense T2 signal
5. T2 signal hyperintensity is variable and mild to moderate
6. Lesion is cigar-shaped
7. On T1, patients who have myelitis may have a normal MR other than mild cord enlargement (and T2 is usually posterior lateral without mass effect in myelitis)
8. Patients with astrocytoma usually demonstrate discrete cord signal alteration
9. Myelitis tends to be less focal, more diffuse and more ill-defined than glioma (it may enhance, especially posterolaterally)
10. Gliomas may be extremely difficult to differentiate from glioma (usually there is a long-standing history of neurologic deficit)
11. Gliosis produces nominal to mild enhancement at best and usually associated with syrinx formation, scar formation or focal atrophy

**PEARLS IN THE DIAGNOSIS OF SPINAL LYMPHOMA**

- Bulky
- Relative bone sparing
- Insinuates itself in foramina and small spaces
- Enhancement is not as consistent as in the brain
- Propensity for posterior epidural spinal space
- Homogeneous
- May have adenopathy anteriorly

**SPINE NEOPLASIA & SELECTED MASSES BY CONTRAST ENHANCEMENT**

**Intramedullary**

- Ependymoma: Well-marginated, marked homogeneous enhancement
- Astrocytoma: Patchy, heterogeneous enhancement and more often eccentric compared to ependymoma
- Hemangioblastoma: Enhancement of a rounded nodule with nonenhancing surrounding cyst
- Cavernous hemangioma: No or nominal enhancement initially, delayed central enhancement
- Arteriovenous malformation: Heterogeneous enhancement admixed with flow void

**Extramedullary Intradural**

- Meningioma: Immediate, uniform, persistent enhancement
- Neurinoma: Homogeneous enhancement
- Drop metastases: Multifocal, rounded, nodular, enhancement

**Extradural Lesions**

- Metastases: Variable heterogeneous enhancement
- Arachnoiditis: Nominal to mild heterogeneous multifocal enhancement
- Disc extrusion: Minimal or moderate rimlike enhancement
- Meningocele: No enhancement
- Lymphoma: Homogeneous enhancement
- Abscess: Rim enhancement
- Synovial cyst: Rim enhancement
- Arthropathic pseudotumor: Mild diffuse enhancement
LEPTOMENINGEAL ENHANCEMENT & THICKENING

**Focal**
- Leptomeningeal carcinomatosis (e.g., breast, lung, melanoma): Lumpy
- Lymphoma: Lumpy or smooth
- Meningitis: Smooth
- Postoperative scarring: Smooth
- Subjacent acute infarction (pial collaterals): Smooth

**Diffuse**
- Leptomeningeal carcinomatosis (breast, lung, melanoma): Lumpy
- Meningitis (bacterial [common]; fungal and viral [rare]): Smooth
- Post radiation: Smooth
- Post shunt: Smooth
- Post subarachnoid hemorrhage: Smooth
- Post surgery: Smooth
- Post trauma: Smooth
- Sarcoidosis: Lumpy or smooth

**Standard MRI Sequences for the Evaluation of Spinal Tumors**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1-weighted image (T1WI) Spin echo</td>
<td>Excellent morphologic detail, especially cord size; dark CSF; important information about cysts, fat, blood</td>
</tr>
<tr>
<td>T2-weighted image (T2WI) Fast spin echo</td>
<td>FSE has mostly replaced spin echo T2; sensitive for identification of intramedullary tumor and edema; hyperintense CSF; susceptible to CSF motion artifacts, especially in axial plane in cervical spine</td>
</tr>
<tr>
<td>Gradient echo (GRE)</td>
<td>Sensitive to magnetic susceptibility artifact from hemorrhage; often used in axial plane in cervical spine instead of FSE T2 to reduce CSF pulsation artifact</td>
</tr>
<tr>
<td>T1-weighted + gadolinium</td>
<td>Useful for characterization and accurate assessment of borders of a lesion; distinguishes tumor from adjacent edema, and differentiates solid tumor from tumor cysts and syrinx; fat suppression improves contrast between enhancing lesion and background, distinguishes fat from hemorrhage, and is particularly important in extramedullary lesions</td>
</tr>
</tbody>
</table>

**Special MRI Sequences in the Evaluation of Spinal Tumors**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLAIR</td>
<td>CSF-suppressed T2-weighted sequence; intramedullary lesions may be less conspicuous on</td>
</tr>
<tr>
<td>Sequence</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>FLAIR</td>
<td>FLAIR than on FSE T2; CSF pulsation artifact accentuated</td>
</tr>
<tr>
<td>STIR</td>
<td>Fat-suppressed T2-weighted sequence; intramedullary lesions shown to be more conspicuous; particularly useful in assessment of trauma and infection; lower signal to noise than FSE T2; sensitive to motion</td>
</tr>
<tr>
<td>DWI</td>
<td>Currently limited in spine because of motion, spatial resolution, and susceptibility; in vivo application has been performed in spinal cord infarcts and MS</td>
</tr>
<tr>
<td>DTI</td>
<td>Application of DWI that measures diffusion anisotropy and may be used to trace white matter tracts; potential use in imaging spinal cord tumors, but not yet feasible in the clinical setting</td>
</tr>
<tr>
<td>MRS</td>
<td>Demonstrates spectrum of metabolites in region of interest; currently limited by spatial resolution and susceptibility artifacts and cannot yet be performed adequately in spine</td>
</tr>
<tr>
<td>Tumor</td>
<td>Location</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>Ependymoma</td>
<td>Intramedullary</td>
</tr>
<tr>
<td>Astrocytoma</td>
<td>Intramedullary</td>
</tr>
<tr>
<td>Cavernous malformation</td>
<td>Intramedullary</td>
</tr>
<tr>
<td>Hemangioblastoma</td>
<td>Intramedullary; rarely extramedullary or extradural</td>
</tr>
<tr>
<td>Ganglioglioma</td>
<td>Intramedullary</td>
</tr>
<tr>
<td>Lipoma</td>
<td>Extramedullary, extramedullary, or intramedullary</td>
</tr>
<tr>
<td>Subependymoma</td>
<td>Intramedullary</td>
</tr>
<tr>
<td>Oligodendroglioma</td>
<td>Intramedullary</td>
</tr>
<tr>
<td>Teratoma</td>
<td>Intramedullary</td>
</tr>
<tr>
<td>Metastatic lesions</td>
<td>Extramedullary, rarely intramedullary</td>
</tr>
</tbody>
</table>
Flowchart of spinal tumors according to location.
REFERENCES


Spinal Cord Tumors
New Views and Future Directions

Laszlo L. Mechtler, MDa,b,c,*, Kaveer Nandigam, MDd

INTRODUCTION

Spinal cord tumors are uncommon neoplasms that, without treatment, can cause significant neurologic morbidity and mortality. The historic classification of spine tumors is based on the use of myelography with 3 main groups as schematically depicted in Fig. 1: (1) extramedullary extradural, (2) intradural extramedullary, and (3) intradural intramedullary. Using this scheme, spinal tumors are characterized as either arising inside the dura mater (intradural) or outside (extradural). This article focuses on intramedullary spinal cord tumors, with an emphasis on new diagnostic modalities1 and treatment options. Because of the rarity of these lesions, the

KEYWORDS
• Intramedullary spinal tumors • Ependymoma • Hemangioblastoma • Astrocytoma
• Ganglioglioma • Spine cysts • MRI • DWI • DTI

KEY POINTS
• About 90% of spinal intramedullary tumors are ependymomas or astrocytomas.
• Ependymomas commonly cause central cord syndrome because of their location.
• Myxopapillary ependymomas compose 90% of filum terminale tumors.
• Astrocytomas compose 90% of all primary spinal cord tumors in those less than 10 years of age and up to 60% of primary spinal cord tumors in adolescents.
• Astrocytomas typically present in an asymmetric eccentric location within the cord.
• Contrary to intracranial astrocytomas, low-grade spinal astrocytomas enhance commonly.
• Spinal cord hemangioblastomas are associated with VHL in 25% and typically show flow voids in the periphery of the tumor.

INTRODUCTION

Spinal cord tumors are uncommon neoplasms that, without treatment, can cause significant neurologic morbidity and mortality. The historic classification of spine tumors is based on the use of myelography with 3 main groups as schematically depicted in Fig. 1: (1) extramedullary extradural, (2) intradural extramedullary, and (3) intradural intramedullary. Using this scheme, spinal tumors are characterized as either arising inside the dura mater (intradural) or outside (extradural). This article focuses on intramedullary spinal cord tumors, with an emphasis on new diagnostic modalities1 and treatment options. Because of the rarity of these lesions, the

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heterogeneous clinical presentation, and varied treatment strategies, it is not feasible to perform a prospective randomized study; a multicenter prospective case series or cohort study would require the standardization of treatment and outcomes. Data from national registries and improved imaging capabilities have allowed spine tumor specialists the opportunity to study and treat these unusual and rare tumors with more confidence and better results.

**EPIDEMIOLOGY OF INTRAMEDULLARY SPINE TUMORS**

Intramedullary spinal tumors account for 5% to 10% of all spinal tumors in adults and approximately 35% in children. About 90% of the tumors of the spinal cord are glial tumors, of which most of these neoplasms are ependymomas and astrocytomas. Ependymomas represent about 60% and astrocytomas 30%. Of the remaining 10%, hemangioblastomas account for 2% to 8% and 2% are intramedullary metastases. Intramedullary tumors are more common in children, with extramedullary tumors being more common in adults.

The rarity of these tumors has significant ramifications on potential outcomes because it impacts research allocation and treatment decisions. Most descriptive epidemiologic studies in primary spinal cord tumors include intradural extramedullary tumors, such as meningiomas, and nerve sheath tumors. Some recent studies have focused on the actual frequency of intramedullary tumors. Data from the central registries in the National Program of Cancer Registration and Surveillance, Epidemiology, and End results programs for 2004 to 2007 and 1999 to 2007 were analyzed. This study provided the first comprehensive population-based incidence of primary spinal cord tumors, covering approximately 99.2% of the US population from 2004 to 2007.

Men had higher rates than women for ependymomas, lymphomas, and nerve sheath tumors but lower rates than women for meningiomas. The most common intradural spinal tumors histologically are meningiomas (33%), nerve sheath tumors (27%), and ependymomas (21%). The overall incidence of spinal tumors, malignant and nonmalignant combined, was 0.97 per 100,000. Seventy-eight percent of the primary spinal tumors were nonmalignant, accounting for most incident cases diagnosed between 2004 and 2007. As a result of mandating the collection of nonmalignant primary spinal tumors in conjunction with malignant primary spinal tumors in a 2004 population-based surveillance of cancers, the authors were able to capture the burden of the disease more completely in the US population.

Tumors of the spinal cord are much less frequent than intracranial tumors. Overall prevalence is about 4 intracranial lesions for every 1 spinal tumor, which varies based...
on tumor histology. The intracranial-to-spine ratio for astrocytomas is approximately 10:1, whereas that for ependymomas can range from 2:1 to 3:1, depending on the specific histologic variant. The anatomic distribution of intramedullary spinal cord tumors is proportional to the length of the cord, with thoracic segment having the most (50%–55%), lumbosacral the second most (25%–30%), and the cervical segment the least (15%–25%).

**CLINICAL SYMPTOMS**

In general, a spinal cord lesion may be suspected when there are bilateral motor and sensory signs or symptoms that do not involve the head and face. Several distinct spinal cord syndromes are recognized. These syndromes are used in a clinical evaluation because they often result from distinct pathologic conditions, such as stroke, infectious, demyelinating, trauma, or neoplasms. These spinal cord syndromes are summarized in Table 1.

**Segmental Syndrome**

*Segmental syndrome* or total cord transection syndrome can result from acute trauma as well as subacute/chronic processes, such as transverse myelitis, multiple sclerosis, or neoplasms. Tumors that cause segmental syndrome are usually epidural metastases with compression fractures and are associated with a relatively subacute onset of complete paralysis. The loss of function occurs in all ascending and descending spinal cord pathways and, thus, results in the loss of all types of sensation and loss of movement below the level of the lesion.

**Brown-Séquard Syndrome**

This syndrome occurs when a lesion is on one side of the spinal cord (lateral cord syndrome) affecting contralateral pain and thermal sensation and ipsilateral proprioception and vibratory sensation. The loss of pain and temperature sensation begins 1 or 2 segments below the lesion. Associated motor paralysis on the side of the lesion completes the syndrome. The unilateral involvement of the descending autonomic fibers does not produce bladder symptoms. The most common causes are trauma, demyelination, and rarely disk herniation and infarctions. Extramedullary tumors are

<table>
<thead>
<tr>
<th>Syndrome</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete cord transection</td>
<td>Metastatic epidural disease, pathologic fractures, intramedullary cord metastasis/hemorrhage (ie, melanoma)</td>
</tr>
<tr>
<td>Brown-Séquard syndrome</td>
<td>Astrocytoma, ganglioglioma, meningiomas, nerve sheath tumor, and hemangioblastoma</td>
</tr>
<tr>
<td>Ventral cord syndrome</td>
<td>Usually vascular but also anterior epidural metastatic disease, radiation myelopathy, astrocytoma</td>
</tr>
<tr>
<td>Central cord syndrome</td>
<td>Ependymoma, syringomyelia, lipoma, metastases</td>
</tr>
<tr>
<td>Posterior cord syndrome</td>
<td>Epidural metastases, astrocytoma, hemangioblastoma</td>
</tr>
<tr>
<td>(Lhermitte syndrome)</td>
<td></td>
</tr>
<tr>
<td>Corpus medullaris syndrome</td>
<td>Ependymoma, syringomyelia, lymphoma, astrocytoma</td>
</tr>
<tr>
<td>Cauda equina syndrome</td>
<td>Epidural metastasis, myxopapillary ependymoma, meningioma, nerve sheath tumor, leptomeningeal disease, paraganglioma</td>
</tr>
</tbody>
</table>
the more common neoplastic cause of this syndrome; but intramedullary astrocytomas, gangliogliomas, hemangioblastomas, and metastases\textsuperscript{9} may cause similar findings.

**Ventral Cord Syndrome**

The clinical presentation of ventral spinal cord syndrome includes complete motor paralysis below the level of the lesion caused by the interruption of the corticospinal tracts, with a loss of pain and temperature sensation below the level of the lesion caused by the interruption of the spinothalamic tract. There is sparing of proprioception and vibratory sensation caused by intact dorsal columns. Flaccid anal sphincter, urinary retention, and intestinal obstruction may be associated with anterior cord syndrome. The most common causes of anterior spinal cord syndrome include occlusion or dissection of the anterior spinal artery. An acute disk herniation, cervical spondylosis, vasculitis, and sickle cell disease are also associated with this syndrome. Anterior epidural metastatic disease is the most common neoplastic cause. Rare neuro-oncological causes include radiation myelopathy, and astrocytoma is also in the differential diagnosis.\textsuperscript{10}

**Central Cord Syndrome**

Central cord syndrome occurs when a lesion affects the center of the spinal canal, mainly the central gray matter and adjacent crossing spinothalamic tracts, causing paresis in the upper extremities more than the lower extremities. There is a loss of pain and temperature sensation in a shawl-like distribution over the upper neck, shoulders, and upper trunk, with light touch, position, and vibratory sensation relatively preserved (disassociated sensory loss). There are usually no bladder symptoms. The classic causes of central cord syndrome are slow-growing lesions, such as syringomyelia, or intramedullary tumors, such as ependymomas. However, central cord syndrome is also seen in patients with hyperextension injury and longstanding cervical spondylosis.\textsuperscript{11}

**Dorsal Cord Syndrome**

Dorsal cord syndrome results from bilateral involvement of the dorsal columns, the corticospinal tracts, and descending central autonomic tracts. The main symptoms of dorsal column syndrome include gait ataxia, paresthesias, weakness, and bladder control symptoms. Lhermitte sign often occurs in patients with posterior column involvement, especially in the cervical spine,\textsuperscript{12,13} which is characterized by a sensation of electrical shocks running down the spine and into the limbs, occurring with bending the head forward or backward. The causes of dorsal cord syndrome include multiple sclerosis, tabes dorsalis, subacute combined degeneration, compressive myelopathy caused by cervical spondylitic disease, as well as epidural and intradural extramedullary tumors, and radiation myelopathy.\textsuperscript{10}

**Conus Medullaris Syndrome**

Conus medullaris syndrome in its pure form presents with sphincter disturbances, saddle anesthesia (S3–S5), impotence, and the absence of lower extremity abnormalities. Lower extremity weakness tends to be mild, and spontaneous pain tends to be bilateral and symmetric. The causes of conus medullaris syndrome include disk herniation as well as the following neoplasms: myxopapillary ependymomas, lymphomas, and astrocytomas.
Cauda Equina Syndrome

This syndrome is caused by a loss of function in 2 or more of the 18 nerve roots constituting the cauda equina. Deficits usually affect both legs but are often asymmetric. Low back pain tends to be radicular in nature. Weakness also seems to be associated with the loss of reflexes and is more unilateral compared with the conus medullaris syndrome whereby weakness occurs late and is usually bilateral. The rectal sphincter paralysis usually occurs later, and sensory loss usually occurs in a dermatomal distribution. The multiple causes of cauda equina syndrome include epidural metastases, myxopapillary ependymoma, paraganglioma, leptomeningeal disease, nerve sheath tumors, and meningiomas.14,15

COMMON SPINAL INTRAMEDULLARY TUMORS

Ependymoma

Half of all ependymomas are located below the foramen magnum and involve either the spinal cord (55%) or the cauda equina region (45%). The mean age of presentation is around 40 years, and there is a slight male predominance. Intramedullary ependymomas have a predilection for the cervical spinal cord such that 67% percent of tumors arise from or extend into this region.16,17 Ependymomas of the cord are typically solitary tumors that arise from the ependymal lining of the central canal causing a diffuse enlargement of the cord over several levels and associated with syringo in about 50% of the cases. Spinal cord ependymomas have only a slight tendency to infiltrate the adjacent neural tissue and have a delicate capsule forming a plane of cleavage to separate the tumor from the spinal cord. The World Health Organization (WHO) recognizes 5 histologic variants of ependymoma, which include cellular, papillary, epithelial, tanycytic, and myxopapillary subtypes. Ependymomas are also commonly divided into typical, WHO grade II, or anaplastic WHO grade III varieties. In addition, 2 low-grade (WHO grade I) forms, myxopapillary ependymoma and subependymoma, have also been recognized. Anaplastic ependymomas (WHO grade III) are less common in the spinal cord and have additional pathologic features, such as increased cellularity, mitotic activity, pleomorphic nuclei, vascular hyperplasia, nuclear atypia, and necrosis.18 Anaplastic ependymomas (WHO grade III) have a malignant behavior and have a tendency for progression. Myxopapillary ependymomas of the filum terminale are a histologic variant accounting for about 13% of all ependymomas but more than 80% of all ependymomas that are located in the conus medullaris and filum terminale. Cellular ependymomas occur in the spinal cord more often.18

Magnetic resonance imaging (MRI) of the spine has reduced the average duration from symptom onset to diagnosis from 24 to 36 months to 14 months; as a consequence, the incidences of weakness and sphincter involvement has decreased. The most common complaint (95%) at the time of diagnosis is back pain. Most patients have dysesthesias without sensory loss, which is attributed to the location of the spinal ependymomas around the central canal; the symmetric expansion of the central canal causes an interruption of the crossing spinothalamic tracts (central cord syndrome). When pain and numbness are in a radicular pattern involving the legs, the underlying tumors are usually myxopapillary ependymomas predominantly involving the cauda equina. Spinal ependymomas also have a tendency of causing microhemorrhages, and delayed diagnosis may lead to superficial hemosiderosis with involvement of the caudal cranial nerves. Unexplained superficial hemosiderosis seen on a cranial MRI should prompt a spinal investigation with MRI for the exclusion of spinal ependymoma.
The association between neurofibromatosis type II (NF2) and spinal ependymoma is well known.\textsuperscript{19,20} This disease is autosomal dominant caused by mutation of the merlin or schwannomin gene on chromosome 22 (this is a member of the protein 401 family). NF2 has been described as multiple inherited schwannomas, meningiomas, and ependymomas. The frequency of polar tumoral cysts that are seen rostral or caudal to the tumor is about 50% to 90%.\textsuperscript{11} On T1-weight images, cellular ependymomas tend to be isointense to slightly hyperintense to the spinal cord. On T2-weighted images, they appear hyperintense. Hemosiderin is commonly seen as an area of hypointensity, showing a so-called cap sign, which occurs in about 20% to 64% of cord ependymomas. STIR sequences show hyperintensity, although 80% of these cases on postcontrast T1-weight images enhance homogeneously. Minimal or no enhancement is actually relatively rare. Diffusion tensor imaging (DTI) may show the tumor displacing the fiber tracts rather than interrupting them, as shown in Fig. 2.\textsuperscript{16,17,21–24}

Myxopapillary ependymoma of the conus medullaris and filum terminale are relatively common spinal intradural neoplasms, predominantly seen in children and young adults, although they may be observed at an older age. There is a slight male predominance. This tumor is a WHO grade I with low mitotic activity and glial fibrillary acidic protein (GFAP)/S100 positivity. They make up about one-third of all ependymomas and 90% of filum terminale tumors. They appear as isointense to hypointense masses.

Fig. 2. MRI and computed tomography (CT) images of a spinal intramedullary ependymoma. Patient is a 55-year-old man who presented with progressive 1-year history of shawl-like dissociated sensory loss in the upper extremities as well as weakness typical of a central cord syndrome. MS workup was negative. (A) T2-weighted (W) sagittal image shows a central cord mass (\textit{black arrow}) with mild edema, with a rostral and a caudal (\textit{white arrowhead}) small polar cysts. On T1W sagittal with contrast (B), there is diffuse tumor enhancement. The polar cyst (\textit{white arrowhead}) does not enhance with contrast. Diffusion tensor imaging/tractography (E) confirms the noninfiltrative nature of this mass with fibers being displaced (\textit{white arrow}). Postcontrast images obtained on a 320-slice CT (C, F) and 3-dimensional reconstruction in the sagittal (D) and axial (G) planes elaborates the bony structures surrounding this well-demarcated enhancing ovoid (\textit{blue}) spinal cord mass that was consistent with a cellular ependymoma.
on T1-weighted images and as isointense to hypointense masses on T2-weighted images. They tend to be extramedullary and present as a cauda equina syndrome. They usually span 2 to 4 vertebral segments as seen in Fig. 3, and they usually fill the lumbar sacral thecal sac. There may be posterior vertebral scalloping as well as intravertebral foraminal widening. At times on T1- and T2-weighted images, they may be hyperintense because of the accumulation of mucin. On T2-weighted images, they may also be hypointense because the tumor margin is consistent with hemosiderin. STIR sequences tend to be hyperintense and the contrast enhancement is usually avid. Myxopapillary ependymomas are the most common subtype of ependymomas that are associated with hemorrhage. They may have local seeding or even subarachnoid dissemination.16,18,25,26

Astrocytoma

Intramedullary spinal astrocytomas account for 3% to 4% of all central nervous system (CNS) astrocytomas. In adults, they compose about 30% to 35% of all intramedullary spinal cord tumors. They are more common in children, composing 90% of all primary spinal cord tumors in those less than 10 years of age and up to 60% of primary spinal cord tumors in adolescents. Gender distribution between male and female patients is fairly even. In adults, the average age of onset is 29 years, a presentation that is earlier than that of ependymomas. The tumor arises in the cervical spinal cord in approximately 60% of patients. Tumors spanning the spinal cord, called holocord tumors, can occur but are very rare. Histologically, gliomas can be differentiated as pilocytic (WHO grade I), fibrillary (WHO grade II), anaplastic (WHO grade III), and glioblastoma multiforme (WHO grade IV) (Box 1).27 Fibrillary astrocytomas show wide spread parenchymal infiltration and variable degrees of nuclear atypia and increased cellularity. The presence of mitoses warrants an anaplastic designation.

Fig. 3. MR images and intraoperative gross pathology of a spinal intramedullary myxopapillary ependymoma. A 38-year-old man who presented with radicular pain as well as sexual dysfunction. A large sausagelike mass with scalloping fills the intraspinal canal at L2–L5 (black arrows). On T1-weighted (W) sagittal contrast images (A), it is strongly enhancing with a caudal tumor cyst (white arrow). T2W images (B) confirm a relative hypointense mass that is probably caused by its myxoid pathology or blood products (hemosiderin). Intraoperatively (C), the tumor was found to be gelatinous and originating from the filum terminale. The tumor was completely excised with relative ease (D). Pathology was consistent with a myxopapillary ependymoma. No treatment was recommended. Patient is disease free and asymptomatic since his diagnosis 10 years ago.
Pilocytic astrocytomas tend to displace rather than infiltrate the cord. Statistically, about 85% to 90% of astrocytomas are low grade (either fibrillary or pilocytic), whereas 10% to 15% are high grade (mostly anaplastic). Glioblastoma multiforme occurs in 0.2% to 1.5% of all cord astrocytomas. In general, astrocytomas cause asymmetric enlargement of the cord. The incidence of primary spinal cord astrocytomas is reported to be at 2.5 per 100,000 per year, which is tenfold less frequent than primary astrocytomas.

The initial clinical presentation of spinal cord astrocytomas is often back pain and progressive weakness. Astrocytomas have an affinity to white matter tracts, which topographically are peripheral in the spinal cord. **Hence, the asymmetric presentation is characteristic of these tumors.** Unlike ependymomas, paresthesias are more common than dysesthesias. The average duration of symptoms before diagnosis is

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**Box 1: Classification of intramedullary tumors**

<table>
<thead>
<tr>
<th>Neuroepithelial tumors (90%)</th>
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<tr>
<td>Ependymal cell tumors (60%)</td>
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<tr>
<td>- Ependymoma (WHO grade II)</td>
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<tr>
<td>- Anaplastic ependymoma (WHO grade III)</td>
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<tr>
<td>- Subependymoma (WHO grade I)</td>
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<tr>
<td>- Myxopapillary ependymoma (WHO grade I)</td>
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<tr>
<td>Astrocytic tumors (30%)</td>
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<tr>
<td>- Pilocytic astrocytoma (WHO grade I)</td>
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<tr>
<td>- Fibrillary astrocytoma (WHO grade II)</td>
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<tr>
<td>- Anaplastic astrocytoma (WHO grade III)</td>
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<tr>
<td>- Glioblastoma multiforme (WHO grade IV)</td>
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<tr>
<td>Oligodendroglial tumors</td>
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<tr>
<td>- Oligodendroglioma (WHO grade II)</td>
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<tr>
<td>- Anaplastic oligodendroglioma (WHO grade III)</td>
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<tr>
<td>Mixed neuronal/glial tumors</td>
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<tr>
<td>- Ganglioglioma (WHO grade I)</td>
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<td>- Gangliocytoma (WHO grade I)</td>
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<tr>
<td>Mesenchymal tumors (7%)</td>
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<tr>
<td>- Hemangioblastoma (2%-8%) (WHO grade I)</td>
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<tr>
<td>- Lipoma</td>
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<tr>
<td>- Melanocytoma</td>
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<tr>
<td>Metastatic tumors (2%)</td>
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<tr>
<td>- Hematopoietic tumors</td>
<td></td>
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<tr>
<td>- Primary CNS lymphoma</td>
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<td>- Leukemia</td>
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about 3.5 years for low-grade astrocytomas and about 6 months for malignant astrocytomas. On T1-weighted images, there is cord expansion, usually less than 4 segments. Holocord presentation is exceedingly rare but is histologically most consistent with pilocytic astrocytoma. In general, astrocytomas are T1 hypointense to isointense. On T2-weighted images, they are hyperintense. Blood products occur in a minority of cases. Unlike most intracranial low-grade astrocytomas, spinal astrocytomas enhance with gadolinium. The enhancement pattern is usually mild to moderate and patchy. Contrast enhancement does not predict tumor grade or behavior, especially in pilocytic astrocytomas. Axial MRI images show an asymmetric expansion of the cord. In fact, the frequency of non-enhancing spinal cord astrocytoma is 18%. The MRI appearance of an intramedullary astrocytoma with diffusion tractography is shown in Fig. 4.

Spinal astrocytomas and ependymomas often demonstrate associated cysts. There are 3 distinct types of cysts associated with these intramedullary spine tumors:

1. Tumoral cyst
2. Rostral or caudal cysts (polar cysts)
3. Reactive dilatation of the central canal (syringomyelia)

Fig. 4. MRI appearance of an intramedullary astrocytoma with diffusion tractography. A 48-year-old man with vague back pain and normal examination was operated on 9 years ago for an intramedullary mass. Laminectomy without biopsy was performed. T1-weighted (W) noncontrast (A) and T2W sagittal images (B) show a focal asymmetric enlargement of the left cord that enhances homogenously on T1W sagittal (C) and axial (D) contrast images. The images and clinical history are consistent with a pilocytic astrocytoma. 3 T MRI diffusion tractography confirms typical findings in a noninfiltrative astrocytoma with fanning of the fibers around the tumor. Fluorodeoxyglucose positron emission tomography (not shown) showed hypermetabolism of the tumor, which is also characteristic of pilocytic astrocytomas, despite being WHO grade I. Patient continues to be neurologically intact and asymptomatic and has not had any adjuvant treatment.
The cysts located rostral or caudal to the tumor are typically non-neoplastic with gliotic linings and filled with fluid similar to cerebral spinal fluid. By contrast, those within neoplastic masses are lined by abnormal glial and are xanthochromic or blood filled. The polar cysts have also been described as satellite or reactive cysts. They usually do not enhance with T1-weighted postcontrast MRI and, in fact, are a form of a syringohydromyelia. By contrast, tumoral cysts are associated with a variable surrounding solid component and enhance in most cases. Characterization of the nature of the cysts is important because reactive cysts simply collapse after excision of the solid component, whereas tumoral cysts have to be surgically removed. The third type of cyst seen in association with spinal tumors is secondary reactive dilatation of the central canal most likely related to the partial obstruction of the central canal by the tumor mass. Distinction between rostral/caudal cysts and reactive dilatation of the central canal might be difficult. It is important to differentiate tumoral cysts from the other two types of cysts because intratumoral cysts should be surgically excised along with the tumor given their potential to cause tumor recurrence when not excised. In the surgical series of 100 intramedullary tumors, 45% were associated with a syrinx. A syrinx was more likely to be found above the tumor level than below it. Hemangioblastomas were the most common tumor type to be associated with syrinx. The higher the spinal level, the more likely a syrinx was encountered.

**Hemangioblastoma**

Hemangioblastomas are benign WHO grade I tumors. Their annual incidence is about 0.02 per 100 000 people. They compose about 2% to 8% of all intramedullary spinal cord tumors. The cell of origin is uncertain but likely vascular endothelial growth factor (VEGF)–secreting cells of undifferentiated mesenchymal origin. They occur sporadically in about 75% and are associated with von Hippel-Lindau disease in the remaining 25%. Mutations on the short arm of chromosome 3p25 are seen in patients with VHL with hemangioblastomas. Cervical and thoracic segments are commonly involved, with a predilection for dorsolateral cord surface. The tumors can be single or multiple and tend to be smaller than 10 mm in diameter in patients with von Hippel-Lindau disease. With sporadic spinal hemangioblastomas, the tumors can get bigger, up to 6 cm in diameter. Grossly, they are well demarcated with a capsule and have characteristic abnormally dilated tortuous vessels on the surface. Microscopic pathology shows gliosis and Rosenthal fibers, with prominent small capillaries and venous vessels. The tumor’s mitotic activity, measured as KI-67 activity, is less than 1% for intramedullary tumors compared with up to 25% for tumors that extend into both intramedullary and extramedullary space. These tumors are isointense on T1-weighted images and hyperintense on T2 weighted images. They may have mixed heterogeneity if intralesional hemorrhage is present. Contrast enhancement is usually homogenous and well demarcated, with superficial heterogeneous enhancement within the flow voids, as seen in Fig. 5. The surrounding vasogenic edema is usually mild. Flow voids are more common in tumors greater than 15 mm in size. Because of the presence of dilated vessels, these tumors are often mistaken for a vascular malformation. The presence of a syrinx, which is uncommon with vascular malformations but seen in 30% to 60% of patients with hemangioblastoma, may help differentiate the two. A spinal cyst with an enhancing mural nodule and a nonenhancing cyst rim is another characteristic feature of a hemangioblastoma. Spinal angiography may demonstrate enlarged feeding arteries, intense nodular stains, and early draining veins. In terms of natural history, the cysts associated with the tumors tend to grow faster than the tumor itself. The symptomatic mass effect is predominantly caused by the cysts. The tumor alternates between a growth phase...
and a quiescent phase with no growth. Hence, the tumor may remain of the same size for several years in a quiescent phase. For this reason, follow-up monitoring with serial imaging at regular intervals is recommended. The first-line treatment is microsurgical resection using feeder vessels coagulation or temporary arterial occlusion. A cerebrospinal fluid (CSF) fistula is a complication of surgery in less than 5% patients. The presence of multiple tumors may necessitate a more aggressive approach with stereotactic radiosurgery. There has been growing interest in the use of the VEGF inhibitor, bevacizumab, which has shown to cause tumor regression in a single case study. The prognosis in usually excellent, although the tumor recurrence is common in patients with von Hippel-Lindau disease.

RARE SPINAL INTRAMEDULLARY TUMORS

Ganglioglioma

Gangliogliomas are mostly benign WHO grade I tumors. Rarely, they can transform into more aggressive anaplastic gangliogliomas, which are WHO grade III tumors. Only about 15 cases of anaplastic ganglioglioma are reported in the literature. These tumors are comprised of ganglion cells as well as neoplastic glial elements. They constitute roughly about 1% of intramedullary spinal cord tumors. They predominantly occur in

Fig. 5. MR images of intramedullary hemangioblastoma. A 58-year-old man with human immunodeficiency virus and diabetes presents with left-sided numbness, left partial foot drop, and left upper abdominal pain progressing over a period of 6 months. A T2-weighted (W) sagittal image (A) shows a heterogeneous mass at T-6 (arrow) associated with extensive cord edema. White arrows show a hypointense linear structure consistent with a vessel posterior to the cord. On the contrast sagittal T1W image (B), an enhancing intramedullary bilobulated mass is seen (black arrow). Furthermore, an enhancing engorged vessel is seen posterior and caudal to tumor (white arrows). Axial T1W contrast (C) shows an interesting bilobulated intramedullary and extramedullary snowman appearance (black arrow). T2W axial (D) hyperintensity (white arrow) is consistent with extensive holocord edema that resolved after surgery. The black arrow is a signal void from an abnormal vessel. Pathology was consistent with a hemangioblastoma.
the pediatric age group, with three-fourths of the patient’s being younger than 16 years of age at diagnosis. There is a male preponderance, with a sex ratio of 1.7:1. There are case reports of these tumors being found in patients with NF1, NF2, Floating-Harbor syndrome, and Peutz-Jeghers syndrome. There are no known definite genetic associations.

In a large case series, the cervicothoracic segment was most commonly involved in about 37.5%, thoracic in 28.5%, cervicomedullary in 14.0%, cervical in 12.5%, and conus in 7.0% of patients with intramedullary spinal ganglioglioma. These tumors favor eccentric locations. They are elongated tumors that extend over an average of 8 vertebral bodies length compared with about 4 vertebral bodies length in intramedullary astrocytomas and ependymomas. Microscopically, they consist of clusters of large ganglion cells, fibrosis, desmoplasia, and calcifications. Antisynaptophysin antibody marker for neoplastic neurons is helpful in confirming pathologic diagnosis.

On a computed tomography (CT) scan, gangliogliomas appear hypodense or CSF dense with patchy contrast enhancement despite their solid nature. About 85% of these tumors show mixed signal intensity on the T1-weighted images. They tend to be hyperintense on T2-weighted images, although roughly about 40% appear heterogeneous on T2 as well as on contrast-enhanced images. The enhancement pattern is mostly patchy, along with pial surface enhancement. About 20% of these tumors show focal enhancement, and 15% of them are nonenhancing. Surrounding vasogenic edema is uncommon and seen in less than 10% of tumors. To differentiate a high-grade anaplastic ganglioglioma from a benign tumor, a preoperative fluorodeoxyglucose positron emission tomography (FDG-PET) or a thallium-201 single-photon emission CT (201Tl-SPECT) scan can be helpful. Tumoral cysts are seen in about 40% of patients. These tumors are commonly associated with bony erosions and vertebral column deformities, such as scoliosis. The first-line treatment is gross total resection with laminectomy. Adjuvant radiotherapy and chemotherapy with temozolomide is usually reserved for anaplastic high-grade tumors. The 5-year survival rates are close to 90%, whereas the 10-year survival rates are about 80%. Tumor recurrence following surgery occur in about 30% of patients and, hence, require close follow-up with serial imaging.

**Oligodendroglioma**

Primary spinal oligodendroglioma constitutes 2% of spinal cord tumors. Fewer than 50 cases have been reported in the literature. According to the WHO grading, oligodendrogliomas are WHO grade II, whereas anaplastic oligodendroglioma are WHO grade III. Sixty percent of patients are older than 18 years, with a slight male predominance. The most common site of involvement is the thoracic cord. On MRI, oligodendrogliomas are isointense to the spinal cord on T1-weighted images, hyperintense on T2-weighted images, and show heterogeneous contrast enhancement. As in the brain, hemorrhages and calcifications are relatively common findings.

**Paraganglioma**

Paraganglioma are extra-adrenal pheochromocytomas originating from the chromaffin cells of the autonomic nervous system. They have also been called chemodectomas and glomus tumors, which is terminology based on the anatomic site. Spinal paragangliomas are almost always located in the intradural extramedullary compartment, predominantly within the cauda equina and filum terminale. Paraganglioma are slightly more common in male patients, with a mean age at presentation of about 46 years. Spinal paraganglioma have little or no secretory activity, and the most common symptom is low back pain and radiculopathy. Paraganglioma present as...
a hypointense/isointense signal on T1-weighted images. That is relatively well delineated round/ovoid/lobulated mass with prominent flow voids. On T2-weighted images, there is isointensity to hyperintensity with a possible hemosiderin rim as well as tumoral cyst formation.\textsuperscript{63} Angiography may be indicated for preoperative embolization. Surgical excision is usually curative.\textsuperscript{24}

**Melanocytoma**

Melanocytoma are benign, although at times locally aggressive tumors arising from melanocytes within the leptomeninges along the neural axis. Most of these leptomeningeal tumors are extramedullary, with only about 18 cases of intramedullary melanocytomas reported in the literature. On T1-weighted images, they seem to be isointense to hypointense. The degree of melanization affects signal intensities on MRI, which creates variability in their appearance on neuroimaging.\textsuperscript{64} On T2-weighted images, they are hypointense to the normal cord. On gradient echo images, there is a blooming effect caused by melanin susceptibility artifact. Heterogeneous enhancement is noted on contrast studies. The cervical/thoracic region is the most common location. Complete cervical resection is usually curative. Subtotal resection is usually followed by external beam radiation therapy.\textsuperscript{65}

**Lipoma**

Lipomas are benign intramedullary tumors. They are thought to arise from premature disjunction of the neural ectoderm from the cutaneous ectoderm during embryonic neurulation before neural tube closure, which allows mesenchymal access to the neural groove, and subsequent development into fat that is indistinguishable from normal body fat.\textsuperscript{66} They are commonly seen in the pediatric age group, and occasionally in young adults. Although no syndromic association is known, a single case study reported intramedullary spinal lipoma in a patient with multifocal dysembryoplastic neuroepithelial tumors.\textsuperscript{66} They are slow-growing tumors and become symptomatic because of the mass effect from their size. They can occur as a solitary cord lesion or multiple mass lesions. The common initial presentations include pain, dysesthetic sensory changes, gait difficulties, weakness, and incontinence.\textsuperscript{67} They tend to favor the cervical segment over the thoracolumbar cord and have a predilection for dorsal location.\textsuperscript{68} On gross and microscopic pathology, the tumor resembles normal adipose tissue as found elsewhere in the body.\textsuperscript{42} On a CT scan, they have the appearance of a hypodense mass lesion. On MRI, they are hyperintense on T1- and T2-weighted images and show signal cancellation on fat-suppressed or STIR images. They are nonenhancing on postcontrast MRI. Occasional calcifications may show susceptibility signal change on susceptibility-weighted imaging (SWI). MR images of an intramedullary spinal lipoma are shown in Fig. 6.

The natural history is usually of a slow-growing mass lesion with progressive myelopathic symptoms. Surgical resection is the first line of treatment. Carbon dioxide lasers are occasionally used for debulking procedures. The timing or the need for surgery is controversial. Lack of cleavage plane and the intermingling of neural and fibrofatty tissue at the periphery of the tumor makes total tumor removal extremely difficult.\textsuperscript{69} Based on limited published data, improvement of neurologic symptoms postoperatively is not universal. Total or near-total resection has been shown to produce about 90% of long-term progression-free survival at 16 years compared with only 35% at 10 years for partial resection and debulking procedures.\textsuperscript{70} Other than the immediate postoperative morbidity, the long-term survival is usually excellent.
Primary CNS Lymphoma

Intramedullary lymphomas are highly aggressive tumors with a poor prognosis. About 90% of the spinal lymphomas arise from large B cells, whereas the rest are T-cell lymphomas. These tumors are considered extremely rare, with a published case series reporting an annual incidence of roughly 1 case diagnosed per year at a large academic hospital. They compose only 1% to 2% of patients with primary CNS lymphoma. Patients who are immunocompetent tend to be middle-aged or older, with a median age of 62.5 years, whereas patients who are immunocompromised are usually younger, in their 30s to 40s. A slight male preponderance is seen. The most commonly known risk factor is immunosuppression, either caused by human immunodeficiency virus or postorgan transplant treatment. A rare case of CNS Epstein-Barr virus infection causing spinal lymphoma has been reported in the literature. The most common initial presentations include back pain as the presenting complain in about 30% of the newly diagnosed patients, progressive myelopathy, and radiculopathy. Occasionally, symptoms may precede the MR appearance. Spine lymphoma favors cervical segment over the thoracolumbar segments. The tumor tends to contact the subarachnoid space. The tumor size is usually greater than 15 mm in diameter. Multifocality is a characteristic of intramedullary spinal lymphoma. More than 50% of spinal lymphomas are multifocal, including intracranial lesions.

On gross pathology, it has indistinct margins, with the cut surfaces being gray or brown. The tumor is usually soft to firm, friable, and granular and may contain hemorrhages and necrosis. The tumor diffusely spreads and extends beyond its macroscopic borders, with cells arranged around blood vessels and encircled by reticulin fibers. Immunohistochemical staining with B- and T-cell markers is helpful in the
identification of the cells of origin. One of the major pitfalls with establishing the diag-
nosis is that the tumor may shrink or vanish following steroid administration, compro-
mising the ability to obtain a histologic diagnosis.

The tumor shows high attenuation on a CT scan with homogeneous contrast
enhancement. On MRI, it is usually isointense to hypointense on T1-weighted
images and hypointense on T2-weighted images with surrounding hyperintense
signal from vasogenic edema. It is homogeneously enhancing on the postcontrast
images, with restricted diffusion caused by hypercellularity, diffusion-weighted
imaging (DWI). The MRI appearance of an intramedullary spinal lymphoma is shown in
Fig. 7. Multifocal persistently enhancing lesions in contact with the subarachnoid
space with conus medullaris or cauda equina involvement are characteristic of an
intramedullary spinal lymphoma. There may be foci of susceptibility signal changes
caused by hemorrhage or calcifications. About 10% of tumors show leptomeningeal
involvement. FDG-PET is further helpful in establishing the diagnosis and may
show lesion hypermetabolism. The major differential includes multiple sclerosis, neu-
romyelitis optica, neurosarcoidosis, transverse myelitis, and immune-mediated para-
neoplastic myelopathy syndromes.

Survival typically is less than 1 year without chemotherapy and less than 6 months in
patients who are immunocompromised. Treatment is initiated at diagnosis because of
the aggressive nature of the tumor. Corticosteroids and methotrexate-based chemo-
therapy with or without radiation are the first line of treatment. Systemic side effects
are common. Surgery is not helpful. KI-67 expression is shown to be inversely related
to survival and may help with prognostication. The prognosis is generally poor, with
a 2-year survival of about 36%.

TREATMENT OF PRIMARY INTRAMEDULLARY SPINAL CORD TUMORS

The most important factor in determining long-term neurologic and functional
outcome after surgery for patients with intramedullary spinal cord tumors is patients'

Fig. 7. MR images of spinal intramedullary lymphoma. A 65-year-old woman with a history
of non-Hodgkin B-cell lymphoma diagnosed 6 years ago s/p chemotherapy who underwent
a PET scan (A) for restaging and was found to have a FDG hypermetabolic spinal cord mass
from C-2 to C-7 (arrows). T1-weighted (W) noncontrast (B) sagittal and contrast sagittal (C)
and axial (D) imaging confirms a diffusely enhancing mass with a minimal edema (arrows).
This mass is best seen on T2W axial (E) images. Despite being asymptomatic, patient under-
went external beam radiation with significant MR response. Unfortunately, patient was also
found to have periventricular and corpus callosum enhancement consistent with recurrent
lymphoma in the brain.
preoperative neurologic status.\textsuperscript{2,79} The second most important factor is the tumor histopathology and grading. Furthermore, the presence of syringomyelia or a cystic component seems to be associated with poor neurologic outcome. Advances in microsurgical techniques and intraoperative electrophysiologic monitoring have significantly reduced operative morbidity. The guiding principle of tumor resectability has been the ability to identify a tumor–spinal cord plane of dissection on neuroimaging. Tumors, such as ependymomas and hemangioblastomas, often exhibit a plane of dissection that facilitates the resection. The absence of a tumor-normal spinal cord interface in infiltrative tumors, such as astrocytomas, permits only subtotal resection or biopsy in hopes of preventing neurologic decline. The exception to this rule is pilocytic astrocytomas (WHO grade I).

In a surgical center experience of 102 patients, gross total resection was achieved in 91.0\% of ependymomas, 14.3\% of astrocytomas, and 92.0\% of hemangioblastomas.\textsuperscript{79} When analyzed by tumor location, there was no difference in neurologic outcomes at a mean follow-up of 41.8 months. The incidence of recurrence was 7.3\% for ependymoma and 47.6\% for astrocytomas. No recurrence was noted in hemangioblastomas. A conclusion drawn from the study was that tumor histology is the most important predictor of neurologic outcome following surgical resection because it predicts resectability and recurrence. The treatment of recurrent tumors is largely based on tumor histology and remains controversial. Incompletely resected low-grade astrocytomas are routinely followed by serial MRI for evidence of tumor progression, and radiation therapy is offered to patients with enlarging tumors or recurrence. Secondary resection is offered to patients with recurring ependymomas. Ependymomas are very amenable to safe, complete removal with a low recurrence rate. Radiation may be indicated in the setting of malignant astrocytoma, recurrent ependymoma, or when a significant portion of the tumor cannot be resected.\textsuperscript{80,81}

Intramedullary astrocytomas are typically low-grade tumors treated by surgical resection and monitored for recurrence by clinical and radiographic follow-up. In cases of subtotal resection, some advocate the use of radiation to the residual tumor; this is especially true for fibrillary astrocytomas. At the time of recurrence, radiation therapy should be considered for those tumors not amenable to further surgical intervention.\textsuperscript{81} Pilocytic astrocytomas are more amenable to aggressive surgery. Radiation is not usually recommended for pilocytic astrocytomas and hemangioblastomas.\textsuperscript{32} Malignant astrocytomas of the spinal cord, however, have a poor prognosis; and radical resection results in high morbidity. Therefore, conservative tumor removal or tissue diagnosis followed by radiation therapy is common practice. In historical studies, the recommended dose of radiation therapy for spinal cord gliomas has been reported to be between 45 Gy and 50 Gy in 25 to 30 fractions given over a course of 5 weeks.\textsuperscript{82} Particle beam therapies, such as protons, have been investigated as a means to improve the therapeutic gain of radiotherapy by reducing the integral dose to surrounding normal tissue. Patients with spinal cord gliomas treated with proton beam radiation seem to do significantly worse than their photon-treated counterparts. Stereotactic radiosurgery for intramedullary tumors has been described in small studies with a brief follow-up. A new technique being applied to selected primary spinal cord tumors is CyberKnife, which is an image-guided frameless stereotactic radio-surgery system. In the future, this treatment strategy may prove useful in select cases in which complete surgical excision is not possible or after multiple recurrences.\textsuperscript{83} The spinal cord is sensitive to the effects of radiation. Overdoses must be avoided to reduce the risk of radiation-induced myelopathy, which is reversible to some extent. The accepted spinal cord tolerance level is 5000 to 5500 cGy administered over 5 to 6 weeks using 180 to 200 cGy daily fractions.
Because of the rarity of spinal cord malignant gliomas, there are only a few cases of chemotherapy-treated tumors. Temozolomide may be a viable option as a concurrent treatment with radiotherapy or an adjuvant regimen for malignant intramedullary spinal cord tumors. Based on activity in intracranial glioblastoma multiforme, the antiangiogenic drug bevacizumab, a humanized monoclonal antibody that inhibits VEGF-A, has been used for the treatment of recurrent high-grade intramedullary gliomas.\textsuperscript{84–87} Radiation-induced myelopathy and vascular tumors (hemangioblastomas) may respond to antiangiogenic agents, such as bevacizumab.\textsuperscript{88} Improved imaging capabilities as discussed in this article and data from national registries will allow neuro-oncologists the opportunity to study and treat these unusual and rare tumors with more confidence and improved outcomes.

**Intramedullary Spinal Metastatic Disease**

Intramedullary spinal cord metastasis (ISCM) is a relatively rare sequela of systemic cancer with arguably the worst prognosis of all intramedullary spinal cord tumors. It is diagnosed in less than 1\% of systemic patients with cancer.\textsuperscript{5} Lung and breast cancers are the most frequent source,\textsuperscript{89} although a multitude of different systemic cancers have been associated, including malignant melanoma,\textsuperscript{90} renal cell carcinoma,\textsuperscript{91} colon carcinoma,\textsuperscript{5} papillary thyroid carcinoma,\textsuperscript{92,93} cystic adenocarcinoma,\textsuperscript{83} epithelioid hemangioepithelioma,\textsuperscript{83} prostate adenocarcinoma,\textsuperscript{94} choriocarcinoma,\textsuperscript{95} gastric adenocarcinoma,\textsuperscript{96} ovarian carcinoma,\textsuperscript{97} uterine carcinoma,\textsuperscript{98} squamous cell cervical carcinoma,\textsuperscript{99} mesothelioma,\textsuperscript{100} acute lymphoblastic leukemia,\textsuperscript{101} and gliosarcoma.\textsuperscript{102} Intracranial cancers, such as pituitary carcinoma,\textsuperscript{103} pituitary stalk and hypothalamus germinoma,\textsuperscript{104} and supratentorial glioblastoma,\textsuperscript{105} are also reported to metastasize to the spinal cord. Location of a supratentorial glioblastoma adjacent to CSF space is thought to be a risk factor for leptomeningeal seeding and subsequent cord invasion.\textsuperscript{105}

Motor weakness is the most common presenting symptom, followed by pain and sensory disturbances.\textsuperscript{89} Rarely, they may present with a Brown-Séquard syndrome.\textsuperscript{9} At the time of diagnosis, most patients with ISCM have a known primary cancer often associated with cerebral and other systemic metastases.\textsuperscript{89} In about 3\% of patients, the spinal intramedullary lesion is the initial manifestation of the malignant disease.\textsuperscript{106} About 90\% of patients with ISCM have intracranial metastases, which is 6 times more frequent than those with vertebral metastases.\textsuperscript{107} Cervical, thoracic, and lumbar spinal segments are equally effected.\textsuperscript{89} Size of the tumors range, on average, from 5 mm up to 6 cm.\textsuperscript{83} MRI would typically show an isointense lesion on T1-weighted images and a hyperintense lesion with extensive surrounding edema on a T2-weighted sequence. Postcontrast images would show either a ring-enhancing or a homogenously enhancing lesion. The presence of hemorrhage may produce heterogeneous enhancement. Metastatic tumors that are most likely to present with an intramedullary hemorrhage are choriocarcinoma,\textsuperscript{95} papillary thyroid carcinoma,\textsuperscript{92} and malignant melanomas.\textsuperscript{108} In these cases, the SWI or gradient echo images show hypointense hemorrhagic lesions. MR images of a spinal intramedullary metastatic lesion from a breast cancer are shown in Fig. 8.

There are 3 principal treatment modalities available for ISCM, including radiotherapy, chemotherapy, and microsurgical resection of a focal intramedullary mass. The optimal modality and survival benefit with each modality is unclear at this time. Nevertheless, the prognosis remains poor, with a median survival of 4 to 6 months from the time of diagnosis.\textsuperscript{89} The 6-month survival rate after radiotherapy was reported to be about 36\%.\textsuperscript{107} In a retrospective review, a modest survival benefit with improvement in quality of life was noted following surgery.\textsuperscript{109} A small series of
9 patients showed an improved survival of about 20 months in patients with metastatic intramedullary melanoma compared with less than 3 months for patients with nonmelanoma metastases.\textsuperscript{90} In addition, patients in this series who were ambulatory preoperatively remained ambulatory postoperatively. Hence, surgical resection was thought to help in preserving ambulatory status in symptomatic patients, although its benefit in extending survival is not convincing.\textsuperscript{90} CyberKnife or linac stereotactic radiosurgery for spinal intramedullary metastatic disease is emerging as a safer alternative\textsuperscript{83} and is likely most appropriate for palliative treatment in symptomatic patients. Although several small case series reported different treatment options, a lack of controlled clinical trials, mainly caused by the rarity of these tumors coupled with poor survival from systemic disease burden, makes it difficult to draw reliable conclusions on optimal therapy or prognostic factors.

**NOVEL NEUROIMAGING IN INTRAMEDULLARY SPINE TUMORS**

The introduction of MRI to clinical practice has been one of the most important advances in the care of patients with spine tumors. The characterization of spine tumors by MRI involves determining, in the context of patient’s age and sex, the location of the lesion and whether or not it enhances after gadolinium injection. The fundamental question is whether the mass is intra-axial (intramedullary) or extra-axial (extramedullary). With the exception of MRI, most imaging modalities play a limited role in imaging the spinal cord. Radiographs fail to provide visualization of the cord, although scalloping of the posterior aspect of the vertebral body that occurs in some cases of long-standing intramedullary lesions with substantive cord expansion may be detected. CT and/or CT myelography allows for the visualization of the cord and the identification of areas of gross enlargement but does not provide good resolution of internal structures.\textsuperscript{110,111} High-resolution PET is also capable of allowing clinicians to evaluate spinal cord lesions and tumors anatomically as well as metabolically.\textsuperscript{112}

The advantages of the MRI are its multiplane capabilities, superior contrast agent resolution, and flexible protocols that play an important role in assessing tumor location and extent, in directing biopsy, in planning appropriate therapy, and in evaluating therapeutic results. The mainstay of spinal cord imaging is the T2-weighted axial and
sagittal sequences using fast spin echo, which produces highly detailed T2-weighted sequences in only a few minutes. T1-weighted images should be performed in the axial and sagittal planes with and without gadolinium contrast. Fat suppression studies (STIR) are also particularly sensitive to spinal cord abnormalities as well as to the involvement of adjacent bone marrow. Gradient-echo or susceptibility-weighted sequences are most sensitive to detecting hemorrhage, calcification, and flow voids. MR myelography can generate images that are compatible with those obtained by conventional myelography. Conventional CT myelography is being largely replaced by MR and should be reserved for patients who are not MRI candidates. The role of angiography is mainly limited to diagnose and preoperative embolization of spinal vascular malformation and hypervascular spinal tumors. The MRI appearance of different intramedullary spinal tumors is summarized as a schematic diagram in Fig. 9.

The 3-T MR scanner is currently considered the state-of-the-art imaging modality for spinal cord disease. Signal-to-noise ratio increases approximately by twofold compared with MRI using 1.5 T. Using techniques such as parallel imaging, increased signal-to-noise ratio can improve resolution and reduction in the acquisition time. In parallel imaging, different elements in the receiver coil array simultaneously sample the MR signal from the same anatomy; these geometric views are used to reduce the amount of repetitions normally required to produce a desired resolution. The major advantage of the 3-T MRI is improved quality of high-end imaging, such as DWI, diffuse-tensor tractography, SWI, perfusion-weighted imaging (PWI), and MR spectroscopy (MRS). Visualization of the angio architecture of vascular malformations and cord tumors has been aided by the addition of 3-dimensional contrast-enhanced MR angiography, which is a natural extension of standard MRI and should be used in all cases of suspected vascular-related myelopathy. This point is especially true in patients who have hemangioblastomas, paragangliomas, and vascular malformations.

Molecular mobility is an essential contrast mechanism exploited in DWI, reflecting in a measurement of the apparent diffusion coefficient (ADC). The greater the density of structures impeding water mobility, the lower the ADC. Therefore, ADC is considered a noninvasive indicator of cellularity or cell density. DWI is an excellent sequence in the study of acute ischemic infarctions. There have been publications of spinal cord infarctions with restricted diffusion. In addition, DWI and ADC may be markers for hypercellularity, especially in tumors of the spinal cord that include lymphoma and primitive neuroectodermal tumors. In these so-called blue cell tumors, the ADC is lower than in other tumors because of its hypercellularity, which may help in the differential diagnosis of enhancing spinal cord masses (Box 2). DWI sequences have been adapted to perform DTI by acquiring data in 6 or more directions. A tensor is used to describe diffusion in an anisotropic system. DTI allows us to visualize the location, orientation, and anisotropy of the white matter tracts in the brain and spine. DTI can be used to provide maps of white matter fiber tracts (tractography) adjacent to spinal cord tumors. DTI tractography maps of desired white matter tracts (e, cortico-spinal tract) can be overlaid onto high-resolution anatomic images. DTI has the potential to help differentiate destructive intramedullary tumors from tumors that displace normal tissue, which can, in turn, decrease surgical morbidity.

SWI is a relatively novel technique that helps in the detection of calcification, iron content, and deoxygenated hemoglobin with higher sensitivity than other MR techniques. SWI can increase the visibility of hemorrhagic, calcified, and vascular tumors and may reflect the tumor grade and improve the differential diagnosis. Iron and calcium can be discriminated by their paramagnetic versus diamagnetic behaviors.
Fig. 9. MRI appearance of different intramedullary spinal tumors. Schematic summary of various tumor-related MR imaging findings in intramedullary tumors. Astrocytomas are commonly found in eccentric location within the cord, and about two-thirds of the spinal astrocytomas enhance. Ependymomas are commonly located centrally. Hemangioblastomas show flow voids in the periphery of the tumor and are hypointense on SWI sequence. Lipomas have similar hyperintense appearance on T1-weighted and T2-weighted images and show hypointense signal suppression on STIR images.
on SWI, which may help identify tumors that are more prone to calcify, such as oligodendroglioma. Aggressive tumors tend to have rapidly growing vasculature and many microhemorrhages. Hence, the ability to detect these changes in the tumor could lead to better determination of the tumor’s biologic behavior. SWI imaging of the spinal cord can potentially help in confirming hemosiderin that is often seen with ependymomas and in the evaluation of hemangioblastomas of the spinal cord.\textsuperscript{1,116} MRS is a noninvasive imaging technique that offers metabolic information on spine tumor biology that is not available from anatomic imaging. However, because of technical challenges, MRS has been rarely applied to spinal cord tumors. MRS may be used preoperatively, to differentiate between neoplastic from non-neoplastic disease, and expand the differential diagnosis. Elevation of choline indicates increased cellular turnover and, therefore, can serve as a marker of neoplastic disease.\textsuperscript{117} MR PWI has enjoyed great clinical and research success in the assessment of cerebrovascular reserve and as an adjunct for assessing biologic behavior of cerebral neoplasms. PWI uses rapid data acquisition techniques to generate temporal data series that capture first-pass kinetics of a contrast agent as it passes through a tissue matrix. PWI can measure the degree of tumor angiogenesis and capillary permeability, both of which are important biologic markers of malignancy, grading, and prognosis, particularly in gliomas.\textsuperscript{118} Intraoperative MRI surgical suites have been in operation for more
than 15 years. Field strength for these intraoperative MRI systems ranges from 0.1 to 3 T. The main advantages of intraoperative MRI are its excellent soft tissue discrimination and 3-dimensional visualization of the operative site and its near real-time imaging to evaluate the extent of tumor or hemorrhage. The use of intraoperative MRI has led to advances in the extent of tumor resection.\textsuperscript{119}

Neuroimaging is entering an exciting new era in which we can ask and expect to answer sophisticated questions concerning intramedullary spine tumors. The shift to high-end imaging incorporating DWI, DTI, MRS, PWI, SWI, PET, and intraoperative MRI as part of the mainstream clinical imaging protocol has provided neurologists, neuro-oncologists, and neurosurgeons a window of opportunity to assess the biologic behavior of intramedullary spine neoplasms. These novel approaches may, in the future, be routinely used preoperatively, intraoperatively, and in therapeutic monitoring. The ultimate success of spine surgery will depend on the incorporation of anatomic and functional imaging with high-field MRI to diagnose patients sooner and more accurately, when patients’ performance status is minimally affected. Postoperative prognosis depends preoperative neurologic morbidity, tumor histology, and postoperative residual disease. Most intramedullary tumors are potentially resectable (ependymoma, pilocytic astrocytoma, and hemangioblastoma) and curable without adjuvant treatment. Tumors that are more infiltrative (astrocytoma, ganglioglioma, oligodendroglioma) or malignant (anaplastic ependymoma or astrocytoma, glioblastoma, metastases, lymphoma) need to be treated with the input of a multidisciplinary team consisting of neurosurgeons, neuro-oncologists, neuroimagers, and radiation oncologists; patients should be followed closely with the same imaging modalities that were instrumental in the initial diagnosis.

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REFERENCES


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