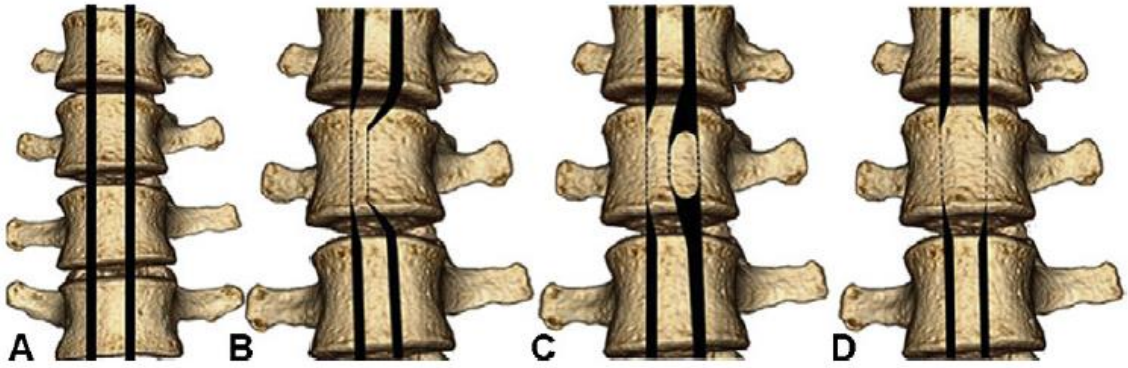
IMAGING OF SPINE TUMORS

Laszlo Mechtler, MD, FAAN, FASN

SUMMARY



Historic classification of spine tumors based on computed tomography myelopgraphy. (A) Normal, (B) extradural extramedullary, (C) intradural extramedullary, and (D) intradural intramedullary

INTRAMEDULLARY LESION

Tumors

- 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

Ependymomas:

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 syrinx 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 tumor from spinal cord. The World Health Organization (WHO) recognizes five histological variants of ependymoma, which include cellular, papillary, epithelial, and tanycytic and myxopapillary subtypes. Ependymomas are also commonly divided into typical, WHO grade II, or anaplastic WHO grade III varieties. In addition, two 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 are 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].

MRI of the spine has reduced the average duration from symptom onset to diagnosis from 24 to 36 months to 14 months and as a consequence, the incidence 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. This is attributed to the location of spinal ependymomas around the central canal; the symmetric expansion of the central canal causes an interruption of the crossing spinalthalamic tracts (central cord syndrome). When pain and numbness are in a radicular pattern involving the legs, the underlying tumors usually are myxopapillary ependymomas predominantly involving the cauda equina. Spinal ependymomas also have a tendency of causing micro hemorrhages 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[19,20]. This is an autosomal dominant disease 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 MISME (Multiple Inherited Schwannomas, Meningioma and Ependymoma). The frequency of polar tumoral cysts that are seen rostral or caudal to the tumor is about 50 to 90%.[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 occur in about 20 to 64% of cord ependymomas. STIR sequences show hyperintensity, while 80% of these cases on post contrast T1-weight images enhance homogeneously. Minimal or no enhancement is actually relatively rare. Diffusion tensor imaging (DTI) may show the tumor displace the fiber tracts rather than interrupt them, as shown in figure 2.[16,17,21-24]

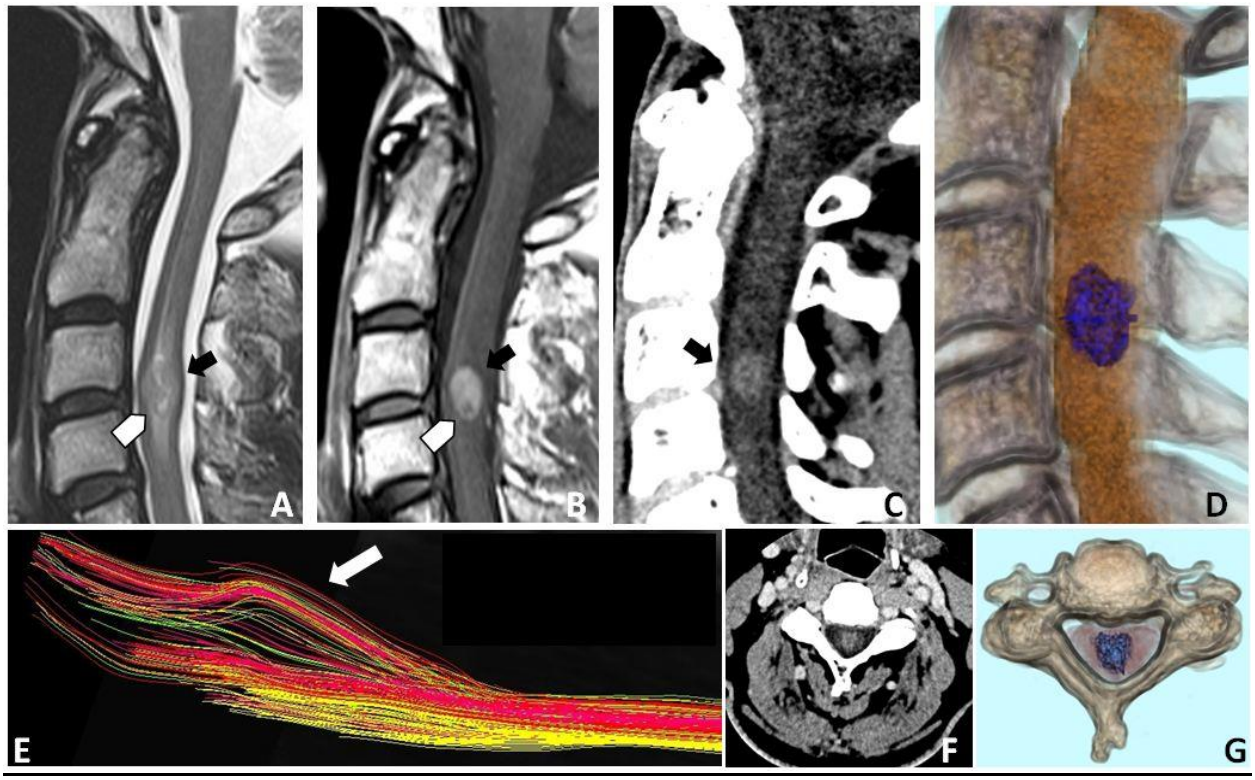


Figure 2: MRI and CT images of a spinal intramedullary ependymoma

Legend: Patient is a 55 year old male who presented with progressive one year history of shawl-like dissociated sensory loss in the upper extremities as well as weakness, typical of a central cord syndrome. MS work up was negative. (A) T2W sagittal image shows a central cord mass (black arrow) with mild edema, with a rostral and a caudal (white arrow head) small polar cysts . On T1W sagittal with contrast, there is diffuse tumor enhancement. The polar cyst (white arrow head) does not enhance with contrast. Diffusion tensor imaging /tractography (E) confirms the non-infiltrative nature of this mass with fibers being displaced (white arrow). Post contrast images obtained on a 320-slice CT (C, F) and 3-D reconstruction in the sagittal (D)and axial (G)planes elaborates the bony structures surrounding this well demarcated enhancing ovoid (blue) spinal cord mass that was consistent with a cellular ependymoma.

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 GFAP/S100 positivity. They make up about 1/3 of all ependymomas and 90% of filum terminale tumors. . They appear as isointense to hypointense masses 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 figure 3, and they usually fill the entire lumbar sacral thecal sac. There may be posterior vertebral scalloping, as well as intravertebral foraminal widening. At times onT1 and T2-weighted images they may be hyperintense due to accumulation of mucin. On T2-weighted images they may also be hypointense due to tumor margin 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:

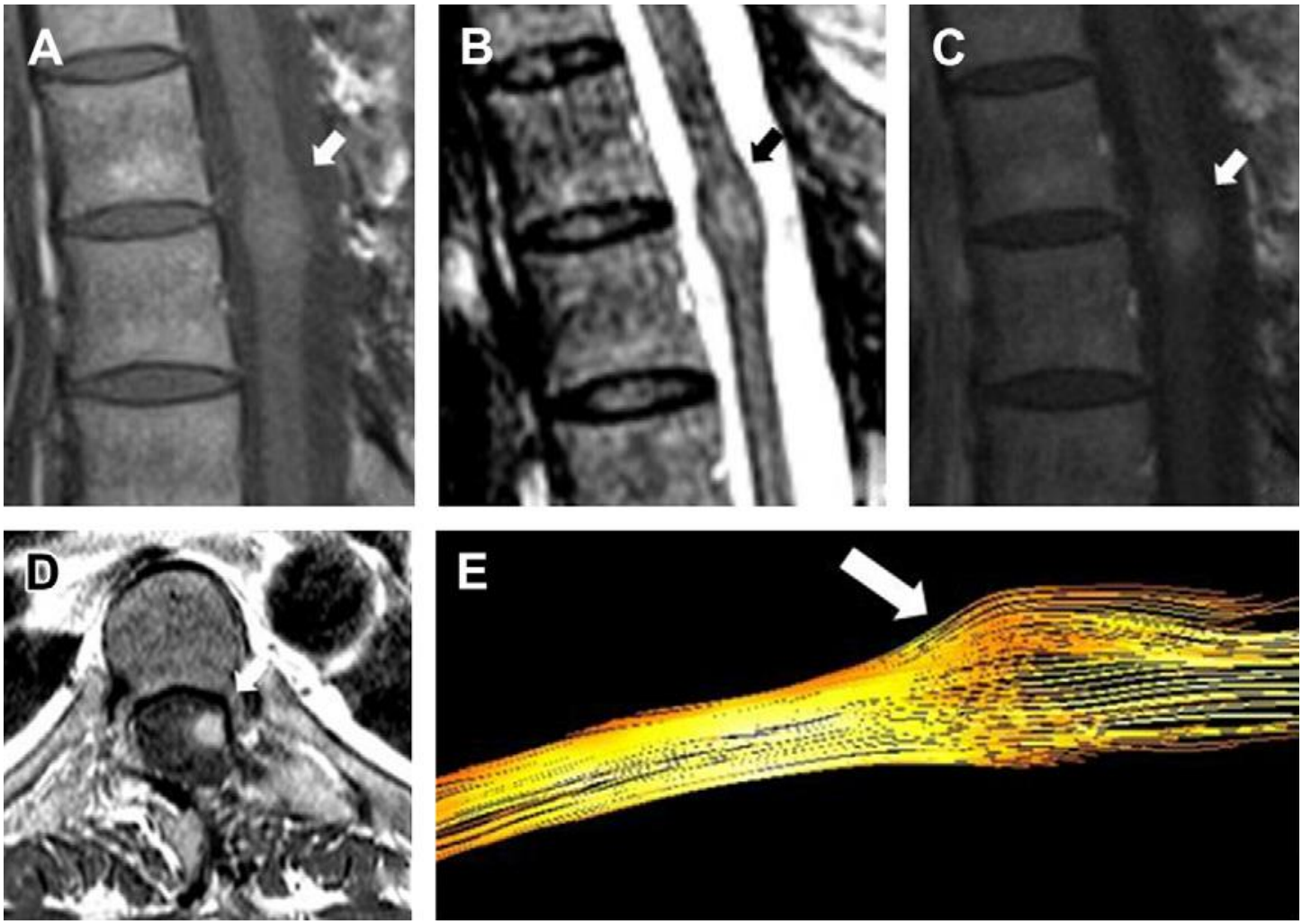
Intramedullary spinal astrocytomas account for 3 to 4% of all CNS astrocytomas. In adults, they comprise about 30 to 35% of all intramedullary spinal cord tumors. They are more common in children, comprising 90% of all primary spinal cord tumors in those less than 10 years of age and up to 60% of primary 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. Tumor spanning the entire spinal cord called holocord tumors can occur, but is 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)[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. 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, while glioblastoma multiforme occurs in 0.2-1.5% of all cord astrocytomas[28,29]. 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 10 fold 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 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[30].

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[31] Axial MRI images show an asymmetric expansion of the cord. . In fact the frequency of non-enhancing spinal cord astrocytoma is 18%[16,17]. MRI appearance of an intramedullary astrocytoma with diffusion tractography is shown in figure 4. Spinal astrocytomas and ependymomas often demonstrate associated cysts. There are 3 distinct types of cysts associated with these intramedullary spine tumors:

a) Tumoral cyst
b) Rostral or caudal cysts (polar cysts)[32]
c) Reactive dilatation of the central canal (syringomyelia)

The cysts located rostral or caudal to the tumor are typically nonneoplastic, 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 post contrast MRI and in fact are a form of a syringohydromyelia. On the contrary, 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 where 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[33]. A syrinx was more likely to be found above than below the tumor level. Hemangioblastomas were the most common tumor type to be associated with syrinx. The higher the spinal level, the more likely a syrinx was encountered[34,35].



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 agofor 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 Q28fibers 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.

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

Primary CNS Lymphoma

Intramedullary lymphomas are highly aggressive tumors, with poor prognosis. About 90% of the spinal lymphomas arise from large B cells, whereas the rest are T-cell lymphomas[71]. 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[72]. They comprise only 1%–2% of primary CNS lymphoma patients. Immunocompetent patients tend to be middle-aged or older, with a median age of 62.5 years[72], whereas immunocompromised patients are usually younger in 30's to 40's. A slight male preponderance is seen. The most commonly known risk factor is immunosuppression, either due to HIV, or post-organ transplant treatment. A rare case of CNS EBV infection causing spinal lymphoma has been reported in literature[72]. Most common initial presentations include, back pain as the presenting complain in about 30% of the newly diagnosed patients[72], progressive myelopathy, and radiculopathy. Occasionally, symptoms may precede MR appearance[73]. Spine lymphoma favors cervical segment over the throaco-lumbar segments[74]. The tumor tends to contact the subarachnoid space[75]. The tumor size is usually greater than 15mm in diameter[75]. Multifocality is a characteristic of intramedullary spinal lymphoma. Over 50% of spinal lymphomas are multifocal, including intracranial lesions[72].

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[42]. 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 are helpful in identification of the cells of origin. One of the major pitfalls with establishing the diagnosis is that the tumor may shrink or vanish following steroids administration, compromising 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 iso-to hypo-intense on T1-weighted images[76], hypointense on T2-weighted images with surrounding hyperintense signal from vasogenic edema[77]. It is homogeneously enhancing on the post contrast images[76], with restricted diffusion due to hypercellularity, DWI images. The MRI appearance of an intramedullary spinal lymphoma is shown in figure 7. Mulifocal 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 due to hemorrhage or calcifications. About 10% of tumors show leptomeningeal involvement[74]. FDG-PET is further helpful in establishing diagnosis, and may show lesion hypermetabolism. The major differential includes multiple sclerosis, neuromyelitis optica, neurosarcoidosis, transverse myelitis, and immune-mediated paraneoplastic myelopathy syndromes.

Survival typically is less than a year without chemotherapy, and less than 6 months in immunocomprised patients. Treatment is initiated at diagnosis due to aggressive nature of the tumor. Corticosteroids, and methotrexate-based chemotherapy 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[78], and may help with prognostication. The prognosis is generally poor, with a 2-year survival of about 36%[72].

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

Hemangioblastoma:

Hemangioblastomas are benign, WHO grade 1 tumors. Their annual incidence is about 0.02 per 100,000 people. They comprise about 2 to 8% of all intramedullary spinal cord tumors[4]. The cell of origin is uncertain, likely vascular endothelial growth factor (VEGF) secreting cells[36] of undifferentiated mesenchymal origin[37]. They occur sporadically in about 75%, and associated with von Hippel-Lindau disease in the remaining 25%[38]. Mutations on short arm of chromosome 3p25 are seen in VHL patients with hemagioblastomas[39]. Cervical and thoracic segments are commonly involved, with a predilection for dorsolateral cord surface. The tumor can be single or multiple and tend to be smaller than 10 mm in diameter in patients with von Hippel-Lindau disease[40]. With sporadic spinal hemangioblastomas, the tumors can get bigger up to 6 cm in diameter[40]. Grossly, they are well demarcated with a capsule, and have characteristic abnormally dilated tortuous vessels on the surface[41]. Microscopic pathology shows gliosis and Rosenthal fibers, with prominent small capillaries and venous vessels[42]. The tumor's mitotic activity, measured as KI-67 activity, is less than 1% for intra-medullary tumors, compared to up to 25% for tumors which extend both into intra and extra-medullary space[43]. These tumors are isointense on T1-weighted images, and hyperintense on T2 weighted images[40]. They may have mixed heterogenicity if intralesional hemorrhage is present. Contrast enhancement is usually homogenous and well demarcated, with superficial heterogenous enhancement within the flow voids, as seen in figure 5. Surrounding vasogenic edema is usually mild. Flow voids are more common in tumors greater than 15 mm in size[40]. Because of 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 30-60%[40,41,44] of patients with hemagioblastoma, may help differentiate the two. A spinal cyst with an enhancing mural nodule and non-enhancing cyst rim is another characteristic feature of a hemagioblastoma. Spinal angiography may demonstrate enlarged feeding arteries, intense nodular stains, and early draining veins[45]. 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[38]. For this reason, follow-up monitoring with serial imaging at regular intervals is recommended. The first-line treatment is microsurgical resection using techniques of feeder vessels coagulation[44] or temporary arterial occlusion[46]. A CSF fistula is a complication of surgery in less than 5% patients[44]. Presence of multiple tumors may necessitate more aggressive approach with stereotactic radiosurgery[47]. 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[48]. The prognosis in usually excellent[49], although the tumor recurrence is common in patients with von Hippel-Lindau disease.

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

RARE SPINAL INTRAMEDULLARY TUMORS

Gangliogliomas:

Gangliogliomas are mostly Benign WHO grade 1 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[50]. These tumors comprise of ganglion cells as well as neoplastic glial elements. They constitute roughly about 1% of intramedullary spinal cord tumors[51]. They predominantly occur in the pediatric age group, with three-fourths of the patient's being younger than 16 years of age at diagnosis[52]. There is a male preponderance with a sex ratio of 1.7:1[52]. There are case reports of these tumors being found in patients with NF1[53], NF2[54], Floating-Harbor syndrome[55], and Peutz-Jeghers syndromes[56]. There are no known definite genetic associations.

In a large case series[52], the cervicothoracic segment was most commonly involved in about 37.5%, thoracic in 28.5%, cervicomedullary in 14%, cervical in 12.5%, and conus in 7% of patients with intramedullary spinal ganglioglioma. These tumors favor eccentric location[57]. They are elongated tumors that extend over an average of 8 vertebral bodies length, compared to about 4 vertebral bodies length in intra-medullary astrocytomas and ependymomas[57]. Microscopically, they consist of clusters of large ganglion cells, fibrosis, desmoplasia and calcifications[58]. Anti-synatophysin antibody marker for neoplastic neurons is helpful in confirming pathological diagnosis[58].

On a 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[57]. They tend to be hyperintense on T2 weighted images[59], although roughly about 40% appear heterogenous on T2 as well as on contrast enhanced images[57]. 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[57]. Surrounding vasogenic edema is uncommon, and seen in less than 10% of tumors[57]. To differentiate a high-grade anaplastic ganglioglioma from a benign tumor, a pre-operative FDG-PET or a ^{201}Tl-SPECT scan can be helpful[60]. Tumoral cysts are seen in about 40% of the patient's. These tumors are commonly associated with bony erosions and with 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[50]. The 5-year survival rates are close to 90%, whereas the 10-year survival rates are about 80%[52,61]. Tumor recurrence following surgery occur in about 30% of patients[52], 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, while anaplastic oligodendroglioma are WHO grade III[27]. Sixty percent of patients are older than age 18, with a slight male predominance. The most common site of involvement is the thoracic cord[24]. On MRI, oligodendrogliomas are isointense to the spinal cord on T1-weighted images, hyperintense on T2-weighted images, and show heterogenous contrast enhancement. As in the brain, hemorrhages and calcifications are relatively common findings[24,62].

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, 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 paragangliomas 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 T-1 weighted images. that is relatively well delineated round/ovoid/lobulated mass with prominent flow voids. On T2 weighted images, there is iso to hyperintensity with a possible hemosiderin rim as well as tumoral cyst formation..[63] Angiography may be indicated for preoperative embolization. Surgical excision is usually curative[24].

Melanocytoma:

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

Lipoma:

Lipomas are benign intra-medullary tumors. There are believed to arise from premature disjunction of neural ectoderm from cutaneous ectoderm during embryonic neurulation prior to neural tube closure, which allows mesenchymal access to the neural groove, and subsequent development into fat that is indistinguishable from normal body fat[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[66]. They are slow growing tumors, and become symptomatic due to 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[67]. They tend to favor the cervical segment over the thoracolumbar cord, and have a predilection for dorsal location[68]. On gross and microscopic pathology the tumor resembles normal adipose tissue as found elsewhere in the body[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 SWI images. MR images of an intramedullary spinal lipoma are shown in figure 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 intermingling of neural and fibro-fatty tissue at the periphery of the tumor makes total tumor removal extremely difficult[69]. Based on limited published data, improvement of neurological 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 to only 35% at 10 years for partial resection and debulking procedures[70]. Other than the immediate postoperative morbidity, the long-term survival is usually excellent.

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

Type	Frequency (%)
Neurilemomas (schwannomas)	29.0
Meningioma	25.5
Glioma (astrocytoma, ependymoma)	22.0
“Sarcoma” (lipomas, fibrosarcoma, chondromas, lymphomas)	11.9
Vascular tumors	6.2
Chordoma	4.0
Epidermoid, dermoid, teratomas	1.4

Source: Modified with permission from JL Sloof, JW Kernohan, CS MacCarty. Primary Intramedullary Tumors of the Spinal Cord and Filum Terminale. Philadelphia: Saunders, 1964.

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.

Standard MRI Sequences for the Evaluation of Spinal Tumors [2]

T1-weighted image (T1WI) Spin echo	Excellent morphologic detail, especially cord size; dark CSF; important information about cysts, fat, blood
T2-weighted image (T2WI) Fast spin echo	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
Gradient echo (GRE)	Sensitive to magnetic susceptibility artifact from hemorrhage; often used in axial plane in cervical spine instead of FSE T2 to reduce CSF pulsation artifact
T1-weighted + gadolinium	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

Special MRI Sequences in the Evaluation of Spinal Tumors [2]

FLAIR	CSF-suppressed T2-weighted sequence; intramedullary lesions may be less conspicuous on FLAIR than on FSE T2; CSF pulsation artifact accentuated
STIR	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
DWI	Currently limited in spine because of motion, spatial resolution, and susceptibility; in vivo application has been performed in spinal cord infarcts and MS
DTI	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
MRS	Demonstrates spectrum of metabolites in region of interest; currently limited by spatial resolution and susceptibility artifacts and cannot yet be performed adequately in spine

Table 3: Differential Diagnosis of Spinal Cord Enlargement
Intramedullary tumor • Ependymoma • Astrocytoma • Hemangioblastoma
Demyelinating disease • Multiple Sclerosis • Devic's Disease • Transverse Myelitis • Acute Disseminated Encephalomyelitis
Granulomatosis Disease • Sarcoid
Vascular Lesions • Acute Infarction • Arteriovenous Malformation • Cavernous Malformation • Hemorrhage, post traumatic • Venous Hypertension
Infection • Tuberculosis • Toxoplasmosis • Syphilis • Cytomegalic virus infection

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 visualization of the cord and identification of areas of gross enlargement but does not provide good resolution of internal structure[110,111]. High-resolution positron emission tomography (PET) is also capable of allowing clinicians to evaluate spinal cord lesions and tumors anatomically as well as metabolically[112].

The advantages of the MRI are its multi-plane 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. This 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. Magnetic resonance 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 hyper-vascular spinal tumors. MRI appearance of different intramedullary spinal tumors is summarized as a schematic diagram in figure 9.

The 3-Tesla MR scanner is currently considered the state of the art imaging modality for spinal cord disease. Signal-to-noise ratio increases approximately by two-fold compared to MR imaging using 1.5T. Using techniques such as parallel imaging, increased signal-to-noise ratio can improve resolution and reduction in the

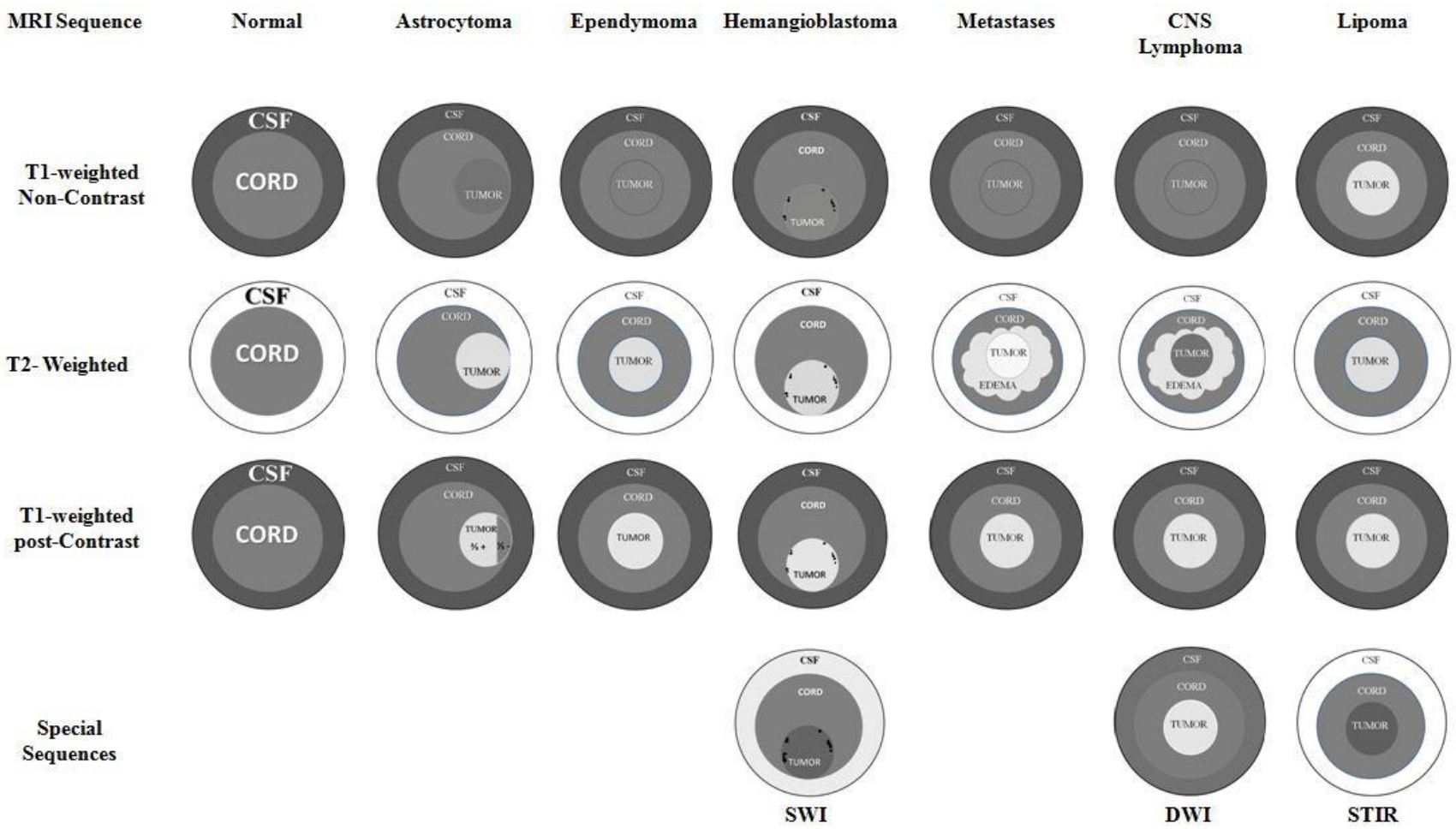
acquisition time. In parallel imaging, different elements in the receiver coil array simultaneously sample the MR signal from the same anatomy; these geometric views are used to reduce the amount of repetitions normally required to produce a desired resolution. The major advantage of the 3-Tesla MRI is improved quality of high-end imaging, such as diffusion-weighted images , diffuse-tensor tractography, susceptibility-weighted imaging, perfusion-weighted imaging and magnetic resonance spectroscopy[1]. 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 is especially true in patients who have hemangioblastomas, paragangliomas, and vascular malformations[113].

Molecular mobility is an essential contrast mechanism exploited in diffusion-weighted imaging (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. Diffusion-weighted images are an excellent sequence in the study of acute ischemic infarctions. There have been publications of spinal cord infarctions with restricted diffusion. In addition, DWI as well as ADC may be a marker for hypercellularity, especially in tumors of the spinal cord that include lymphoma and primitive neuroectodermal tumors (PNETs)[1]. In these so-called "blue cell" tumors, the ADC is lower than in other tumors due to its hypercellularity, which may help in the differential diagnosis of enhancing spinal cord masses[114]. DWI sequences have been adapted to perform diffusion tensor imaging (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 brain and spine. Diffusion tensor imaging can be used to provide maps of white matter fiber tracts (tractography) adjacent to spinal cord tumors [57]. *DTI tractography* maps of desired white matter tracts (i.e. corticospinal 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.. This can in turn decrease surgical morbidity[21,115].

Susceptibility-weighted imaging (SWI) is a relatively novel technique that helps in the detection of calcification, iron content, and deoxygenated hemoglobin (deoxy-Hb) with higher sensitivity than other MR techniques. SWI can increase the visibility of hemorrhagic, calcified and vascular tumors, and may reflect tumor grade and improve the differential diagnosis. Iron and calcium can be discriminated on the basis of their paramagnetic versus diamagnetic behaviors on SWI. This may help identify tumors that are more prone to calcify such as oligodendroglioma. Aggressive tumors tend to have rapidly growing vasculature and many micro-hemorrhages. Hence, the ability to detect these changes in the tumor could lead to better determination of the tumor's biological 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 [1,116]. Magnetic resonance spectroscopy (MRS) is a noninvasive imaging technique that offers metabolic information on spine tumor biology that is not available from anatomic imaging. However, due to technical challenges, MRS has been rarely applied to spinal cord tumors. MR spectroscopy may be used preoperatively and to differentiating between neoplastic from nonneoplastic disease, and expand the differential diagnosis. Elevation of choline indicates increased cellular turnover and therefore, can serve as a marker of neoplastic disease[117]. MR perfusion-weighted imaging (PWI) has enjoyed great clinical and research success in assessment of cerebrovascular reserve and as an adjunct for assessing biologic behavior of cerebral neoplasms. PWI use 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 biological markers of malignancy, grading, and prognosis, particularly in gliomas[118]. Intraoperative MRI surgical suites have been in operation for more than 15 years. Field strength for these intraoperative MRI system ranges from 0.1 to 3 Tesla. The main advantages of intraoperative MRI are its excellent soft tissue discrimination and 3-dimensional visualization of the operative site and it's 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[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 biological 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 be depend on the incorporation of anatomic and functional imaging with high-field MRI to diagnose patients sooner and more

accurately, when patient's performance status is minimally affected. Post-operative prognosis is dependent on pre-operative neurologic morbidity, tumor histology and postoperative residual disease. The majority of 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, and patients should be followed closely with the same imaging modalities, that was instrumental in the initial diagnosis.



BENIGN BONE LESIONS OF THE SPINE

LESION	LOCATION	INCIDENCE	AGE	IMAGING	CLINICAL
Hemangioma	Vertebral body (T, L>C)	Most common benign spinal neoplasm	All Peak 4th-6th decade	CT:"polka dot" body MR:"white spot" on T1WI	Not painful, rarely can fracture
Osteoid Osteoma	Neural arch (L, C>T)	Common (10%) in spine	10 to 20 years	Dense sclerosis lucent <2 cm	Painful, ASA sensitive
Osteoblastoma	Neural arch C>L, T; sacrum	Uncommon (40% in spine)	<30 years	Expansile lytic mass; +/-matrix mineralization	Scoliosis
Giant cell tumor	Vertebral body (sacrum >> vertebrae)	Uncommon	20s to 40s	Lytic, expansile, destructive, highly vascular	Malignant transformation
Osteochondroma	Spinous, Transverse Processes (10% to 12% multiple)	Common (rare in spine)	5 to 30 years	Pedunculated/sessile lesion; periosteum, cortex, marrow in continuity with host bone; cartilaginous CAP +/- Ca	Rarely symptomatic
Aneurysmal bone cyst	Posterior elements (C, T most common)	Rare (20% in spine)	80%< 20 year	Multiloculated, expansile; eggshell-like rims; blood products with fluid-level; highly vascular	Recurrence following resection is common. Can expand quickly
Eosinophilic granuloma		Uncommon	1st or 2nd decade	Vertebral body collapse (vertebra plana)	Fever; lung involvement
Epidural Lipomatosis	T-Spine	Rare		Fat in epidural space	Weakness; back pain; cortico-steroids

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% heperintense 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 formina
        - 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

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