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Neurosurg Clin N Am 15 (2004) 381–389

NEUROSURGERY
CLINICS
OF NORTH AMERICA

Radiology of metastatic spine cancer

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Spinal metastases from nonneural cancers are identified in 5% to 10% of cancer patients. Although these may be asymptomatic and incidentally discovered during imaging for other reasons, they are usually discovered during imaging evaluation for symptomatic spinal disease. Imaging plays a crucial role in the pretreatment workup of spinal cancer as well as in the posttreatment assessment of therapy efficacy. A practical approach to performing and interpreting imaging studies to evaluate spinal metastatic cancer patients is discussed in this article.

Imaging techniques

Plain radiography, myelography, computed tomography (CT), nuclear scintigraphy, and magnetic resonance imaging (MRI) all play important roles in the imaging assessment of spinal cancer.

Plain radiography is readily available, easy to perform, and inexpensive, and it provides a detailed assessment of osseous structures. Disadvantages include its planar format, which results in considerable overlapping of adjacent structures, inability to reformat the data in orthogonal planes, and insensitivity to soft tissue abnormalities. Currently, its main utilization is for cost-effective postoperative evaluation of spinal hardware and assessment of dynamic stability using flexion-extension imaging.

Nuclear radiography (scintigraphy) after intravenous injection of technetium (Tc 99m) demonstrates uptake in lesions inducing active bone metabolism. A major advantage of scintigraphy is its cost-effective ability to scan the entire axial and appendicular skeleton at the same time, which is useful to survey for overall metastatic disease burden [1]. Addition of the single photon emission computed tomography (SPECT) technique improves sensitivity for metastatic lesions [2,3]. Positive bone scan findings require correlation to cross-sectional (CT or MRI) or plain radiography to exclude benign entities, such as degenerative disease masquerading as neoplasm. The most important predictors for a positive bone scan are vertebral cortical involvement and lesion size; small lesions, especially those confined to the medullary cavity, may be occult on bone scanning [1].

Myelography is an older imaging technique that requires fluoroscopically guided administration of intrathecal iodinated contrast. Because it is time-intensive and invasive, it is used considerably less frequently since the advent of MRI. Currently, myelography is used most often in conjunction with CT, and its primary advantages include excellent depiction of osseous structures and good contrast resolution between hyperdense cerebrospinal fluid (CSF) and isodense nerve roots and soft tissue. Disadvantages of myelography include ionizing radiation (a relative disadvantage), its invasive nature, and lower contrast resolution than MRI. Current indications include evaluation of patients with absolute MRI contraindications and as an adjunct to nonconclusive MRI.

CT is useful for detailed assessment of osseous structures and assessing hardware status, particularly in cases in which plain radiographs are inconclusive. At our institution, CT is used primarily to characterize ambiguous lesions detected on MRI and to assess pedicle and posterior element integrity and size before surgical resection and reconstruction. Because of its intrinsically lower

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1042-3680/04/$ - see front matter
doi:10.1016/j.nec.2004.04.002

contrast resolution and axial plane–only acquisition, it has been largely supplanted by MRI for soft tissue characterization and definitive detection of the presence and number of lesions. Nevertheless, modern multislice CT scanners reliably provide excellent thin-section axial images that make routine small-volume isovoxel multiplanar reconstruction possible with excellent spatial resolution, albeit still with lower contrast resolution than MRI. CT may also be effectively used for characterization of possible pathologic vertebral fractures when MRI is impossible or contraindicated [1,4].

MRI is currently the state-of-the-art imaging technique for assessing the spinal metastatic cancer patient [5–7] and has several strong advantages over the other commonly available imaging techniques. It combines excellent spatial resolution and superb contrast resolution, is noninvasive, and does not expose patients to ionizing radiation. MRI provides superior depiction of soft tissues, particularly the spinal cord and tumor margins. Disadvantages include relatively long acquisition times, insurmountable safety contraindications in some patients, and lower sensitivity to osseous structural abnormalities. Standard MRI protocols obtain T1-weighted images (T1WIs) without and with intravenous contrast and T2-weighted images (T2WIs) in at least one and usually two orthogonal planes. The sagittal imaging plane is most useful for global assessment of the number and extent of lesions, tumor margins, and spinal cord status. Axial images provide the best assessment of tumor relation to adjacent nonneoplastic structures. In addition, MRI is usually the most useful tool for postoperative tumor bed surveillance.

Finally, although MRI is the single most useful imaging modality for spinal cancer patient assessment, complex problems may be best assessed using a combination of MRI to define soft tissue tumor margins and relation to adjacent soft tissue structures and CT to assess the osseous structures.

Magnetic resonance imaging and computed tomography interpretation

After image acquisition, it is critical to define the tumor margins and tissue characteristics accurately to facilitate construction of a tailored differential list and for efficient preoperative assessment.

A practical MRI approach to spinal cancer begins with review of the sagittal T1WIs and T2WIs to conclude in which compartment(s) (extradural, intradural/extramedullary, or intramedullary) the tumor resides. Correctly classifying tumor location in this way considerably limits the differential diagnosis list. After delimiting location, I assess superior/inferior and anteroposterior tumor extent, with specific attention to position and status of the spinal cord and presence or absence of central osseous canal compromise. Axial images are used to quantify involvement of the central canal and neural foramina and to clarify the exact relation of the tumor to adjacent osseous, neural, and vascular structures. Intravenous contrast administration is essential for initial tumor patient assessment to confirm the diagnosis and determine the extent and number of lesions. Intravenous contrast has a less absolute role in the follow-up of known extradural spinal cancer, particularly if only a qualitative assessment for the presence or absence of cord compression is needed. This point has considerable practical significance; contrast administration frequently adds at least 30 minutes to imaging time for a total spinal survey, which may be too much additional time for an ill patient to hold still and remain acceptably comfortable after 45 minutes of prior imaging time to acquire the unenhanced images. As a general rule, however, contrast administration is helpful for comprehensive postoperative surveillance and is essential in cases with intradural or intramedullary tumor burden.

I approach CT similarly to MRI. Axial CT scans are acquired via a bone and soft tissue algorithm using thin-slice collimation (1–2.5 mm depending on superoinferior distance to be covered) and reviewed similarly to axial MRI scans. Contrast is necessary whenever soft tissue characterization is needed. If only an assessment of osseous integrity is required, just bone algorithm images without contrast are obtained, which shortens examination time and precludes the risk of allergic contrast reaction. With modern multiplanar scanners, sagittal and coronal reformatted images can be constructed on-line at the time of imaging or off-line on a dedicated workstation and provide anatomic information similar to that provided by MRI.

Compartmental approach to spinal cancer imaging

Extradural metastatic spinal cancer

The lumbar spine is more commonly affected by extradural metastatic lesions than the thoracic

or cervical spine, probably because of its larger size and higher proportion of red marrow. The most useful imaging clue for assessing extradural spinal cancer is destruction of the posterior vertebral body cortex and pedicle. This may be visible on plain radiography but is usually much more obvious on CT or MRI. The major limitation of plain radiography for detection of extradural metastases is that it requires 70% or greater bone destruction before it is detectable, particularly in patients with underlying osteoporosis. The most useful plain radiograph imaging signs are a "missing" or sclerotic pedicle on anteroposterior (AP) radiography (Fig. 1) and loss of the posterior cortical line on lateral radiography (Fig. 2).

Nonenhanced CT may detect lesions that are lytic, blastic, or a combination of both. Lytic lesions are hypodense and destructive, with ill-defined margins and, frequently, an adjacent soft tissue mass (Fig. 3). Some malignant tumors may be extremely infiltrative and difficult to detect using CT (Fig. 4). The posterior vertebral body is nearly always involved, and the pedicle is abnormal in many cases as well. Most patients show infiltration of the anterior vertebral body, and a few show involvement of the spinous processes, transverse processes, and laminae. Uncomplicated small vertebral metastases confined to the marrow cavity often appear as rounded lesions producing destruction of osseous trabeculae but respecting cortical margins. Unfortunately, metastases commonly present in the context of symptomatic vertebral compression fractures, which must be discriminated from the more common benign osteoporotic fractures. CT findings that suggest malignant vertebral fractures (Fig. 5) include anterolateral or AP bone destruction, destruction of cancellous bone in the marrow cavity, pedicle destruction, a focal

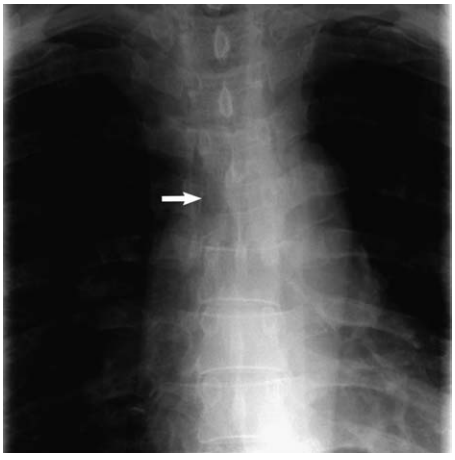

Fig. 1. Anteroposterior plain radiograph shows a "missing" right T5 pedicle (*arrow*) correlating with biopsy-proven renal cell carcinoma metastasis.

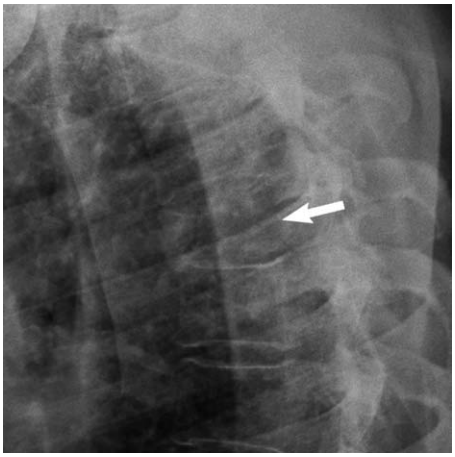

Fig. 2. Lateral plain radiograph (same patient as in Fig. 1) demonstrates lytic change and height loss of the T5 vertebral body, with absence of the posterior cortical line (*arrow*).

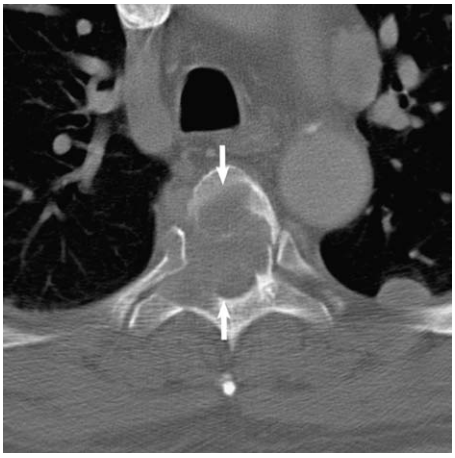

Fig. 3. Axial bone algorithm CT (same patient as in Fig. 1) of the T5 vertebra shows characteristic malignant features, including lytic destruction of the medullary cavity and all three spinal columns, a focal paraspinal soft tissue mass, and epidural extension into the central canal.

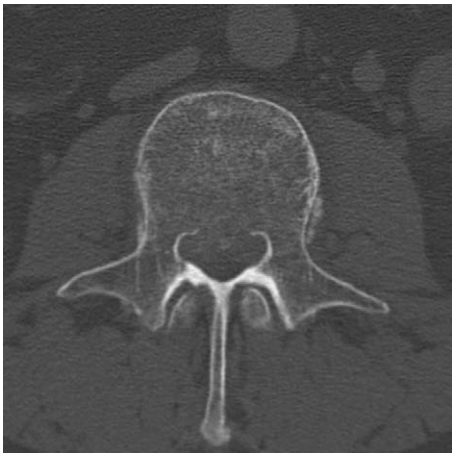

Fig. 4. Axial bone algorithm CT of the L3 vertebra shows subtle disruption of the posterior and lateral cortices with preservation of trabecular architecture in a patient with biopsy-proven metastatic colon cancer.

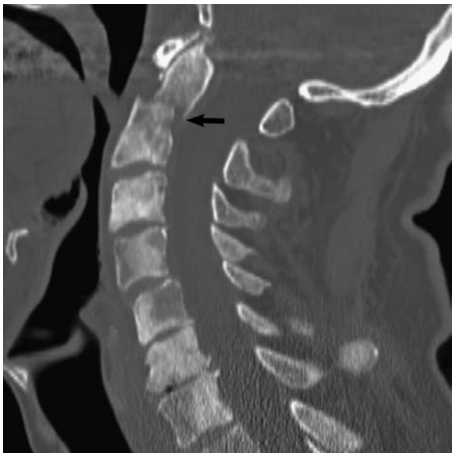

Fig. 6. Sagittal CT reformat shows typical cervical spine blastic metastatic lesions and a pathologic dense fracture (*arrow*) in this patient with prostate cancer, who fell and struck his chin.

paraspinal soft tissue mass, or an epidural mass [4]. It is seldom possible to detect tumor enhancement within a vertebral body, but a paraspinal soft tissue mass may variably enhance. Uncommonly, a lytic lesion may demonstrate a sclerotic rim that erroneously suggests benignity. Blastic extradural metastatic lesions (Fig. 6) show a similar distribution to lytic lesions but demonstrate higher density than the adjacent surrounding marrow cavity. Enhancement is virtually impossible to detect in blastic lesions. Uncommonly, a blastic vertebral tumor shows diffuse sclerosis without obvious destruction ("ivory vertebral body").

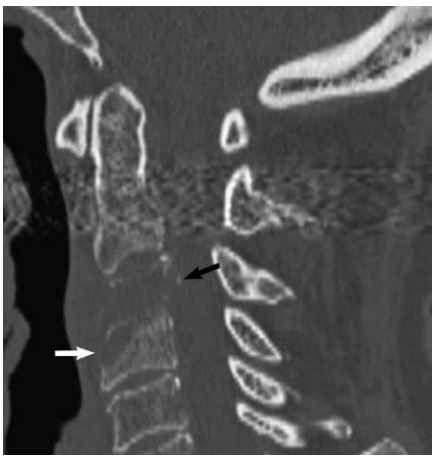

Fig. 5. Sagittal CT reformat shows typical malignant findings, including anterolateral destruction of C4 (*white arrow*) and posterior cortical disruption with cancellous bone destruction of the C3 marrow cavity (*black arrow*).

MRI is useful for assessing impact on the marrow space as well as adjacent bones and soft tissues. The single most useful sequence for detecting extradural spine metastases is the unenhanced sagittal T1WI, which demonstrates a relatively hypointense tumor within a background of higher signal intensity nonneoplastic marrow (Fig. 7). Lesions may be solitary or multiple and may show focal or diffuse fatty marrow replacement. When there is diffuse involvement, it may be more difficult to diagnose metastatic disease, but it is always prudent to search for diffuse reduction of marrow signal resulting in vertebral bodies showing lower T1 signal intensity than disks, which is the opposite of normal (Fig. 8). In extradural metastases, cortical destruction is usually apparent and the disks spared, in contrast to infectious spondylitis, the primary differential diagnostic entity. Contrast administration demonstrates soft tissue extent and helps to distinguish tumor from adjacent epidural venous plexus, disks, or veins. Postenhanced T1WIs are most useful with fat saturation to accentuate tumor conspicuity; failing to use fat saturation may obscure visualization of tumors after contrast (Fig. 9). T2WIs are useful for assessing cord status and degree of canal narrowing but are the least useful sequence for detecting

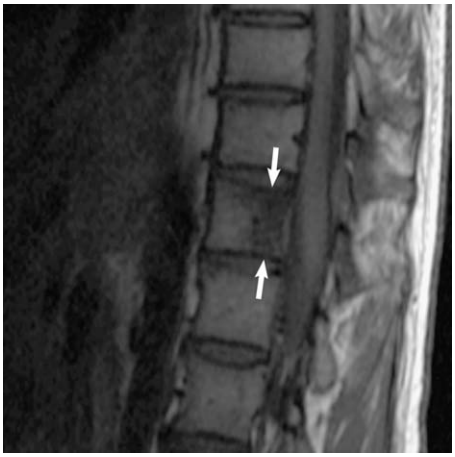

Fig. 7. Sagittal T1-weighted image shows a characteristic hypointense metastatic lesion within the posterior L1 vertebral body (*arrows*), which is easily detected against the brighter background of fatty vertebral body marrow.

vertebral metastases because they are frequently isointense to marrow (Fig. 10). Short tau inversion recovery imaging (STIR) depicts lesions as hyperintense relative to marrow and hypointense relative to CSF.

MRI may be used to determine the benignity or malignancy of a vertebral fracture. Fortunately, it is often possible to discern malignant fractures from the more common benign osteoporotic fractures using MRI. Characteristics reported to be indicative of a malignant fracture include a convex posterior vertebral body, abnormal signal in the pedicle or posterior elements, presence of an epidural mass, presence of a focal paraspinal mass, presence of other spinal metastatic lesions, or detection of fluid signal intensity adjacent to the fracture site [6,7]. Using these criteria, up to 100% sensitivity, 93% specificity, and 95% accuracy have been reported [7]. Diffusion-weighted imaging (DWI) [8–10] has been reported with variable efficacy for discrimination of vertebral metastatic lesions from benign fractures. Ideally, DWI shows an osteoporotic fracture to have iso- to hypointense signal intensity, whereas metastasis reveals hyperintense signal intensity (Fig. 11). Although DWI should be considered a promising technique that has been successfully applied in selected imaging centers, it is not yet accepted for widespread application [8–10].

Fig. 8. Sagittal T1-weighted image in a patient with diffuse metastatic breast cancer. It is difficult to detect the marrow replacement unless one appreciates that the vertebral marrow is darker than the adjacent disks, a finding that is always abnormal.

Nuclear scintigraphy ("bone scan") using Tc 99m is useful for determining practical metastatic tumor burden because it permits cost-effective evaluation of the entire axial and appendicular skeleton in a single study. Positive studies show increased tumor uptake relative to adjacent uninvolved osseous structures (Fig. 12). Detected abnormalities usually require correlation to cross-sectional or plain radiography to exclude degenerative disease or other nonneoplastic lesions masquerading as neoplasm. Lesion size and involvement of the posterior cortex are the primary determinants of tumor visibility on bone scanning [1].

Pertinent differential diagnostic considerations for extradural metastases include hematopoietic malignancies (eg, plasmacytoma, multiple myeloma, lymphoma, leukemia), benign osteoporotic compression fractures (masquerading as malignant fractures), inhomogeneous but otherwise normal marrow, or avascular necrosis.

Intradural/extramedullary metastases

Intradural/extramedullary lesions are quite rare as isolated entities compared with their benign mimics (eg, nerve sheath tumor, meningioma) and usually show involvement of adjacent soft tissue and osseous structures that belies their malignancy. Definitive imaging diagnosis is difficult without demonstrated involvement of the vertebral body or epidural venous structures but

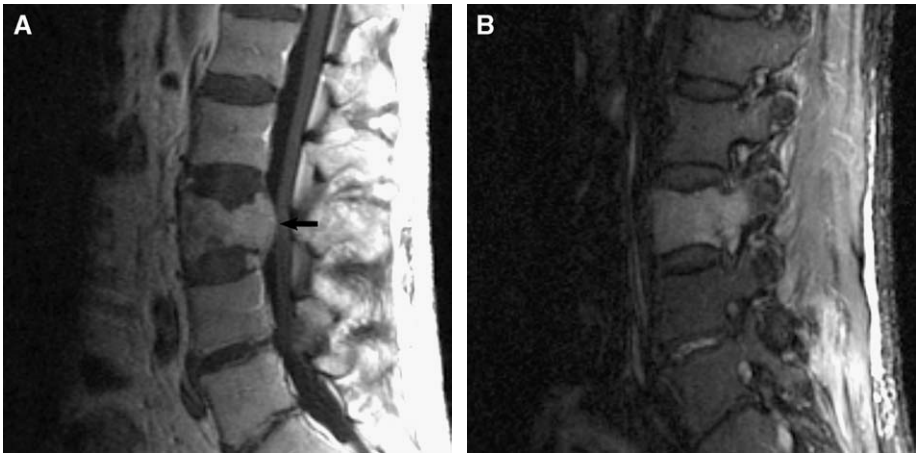

Fig. 9. Sagittal T1-weighted image after intravenous contrast administration without (*A*) and with (*B*) fat saturation demonstrates the utility of fat saturation in a patient with metastatic colon cancer. (*A*) There is rounded displacement of the L3 posterior cortical line (*arrow*) on the image without fat saturation that belies the malignant nature of the lesion, but the tumor signal intensity is indistinguishable from adjacent fatty marrow, a common pitfall. (*B*) Fat saturation darkens the fatty marrow, making the metastatic lesion conspicuous.

would be more likely in the context of lesion multiplicity or a known history of preexisting malignancy.

In adults, intradural metastases are much less common than extradural metastases and most commonly manifest as leptomeningeal disease. Conversely, intradural metastases are more common in children than extradural metastases, a reflection of the higher proportion of brain tumors with a propensity to spread by means of the CSF and the relative rarity of malignant cancers predisposed to bone metastasis within this population compared with adults.

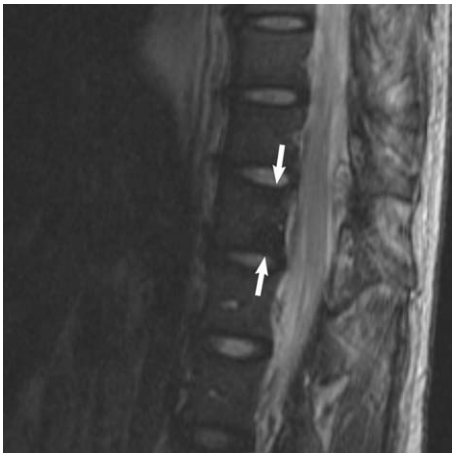

Fig. 10. T2-weighted images (T2WIs) are frequently insensitive for detecting vertebral metastatic lesions because the lesions show similar signal intensity to marrow. The L1 metastasis is barely detectable (*arrows*) on this T2WI but quite visible on a T1-weighted image (see Fig. 7).

Leptomeningeal disease is also known as either ''carcinomatous meningitis'' or ''lymphomatous meningitis'' and results from CSF dissemination of an intracranial neoplasm or systemic spread of a non-central nervous system (CNS) primary tumor. The classic MRI appearance is smooth or nodular enhancement along the spinal cord and nerve roots in a sheet-like distribution (Fig. 13). Nodules along these surfaces are common and are more often found in dependent locations, particularly at the bottom of the thecal sac or between the roots of the cauda equina (Fig. 14). T2WIs may show edema of adjacent spinal cord, but the metastases are often isointense to spinal cord on T1WIs and T2WIs. The CSF may appear ''cloudy,'' and the nerve roots may be blurry or smudged in appearance. Recommended MRI sequences are the same as for extradural metastatic survey, with intravenous contrast essential. CT is considerably less sensitive for intradural metastases than MRI; CT is often normal, even after contrast administration, and osseous destruction is frequently not apparent. Sensitivity for CT is greatly increased by combination with

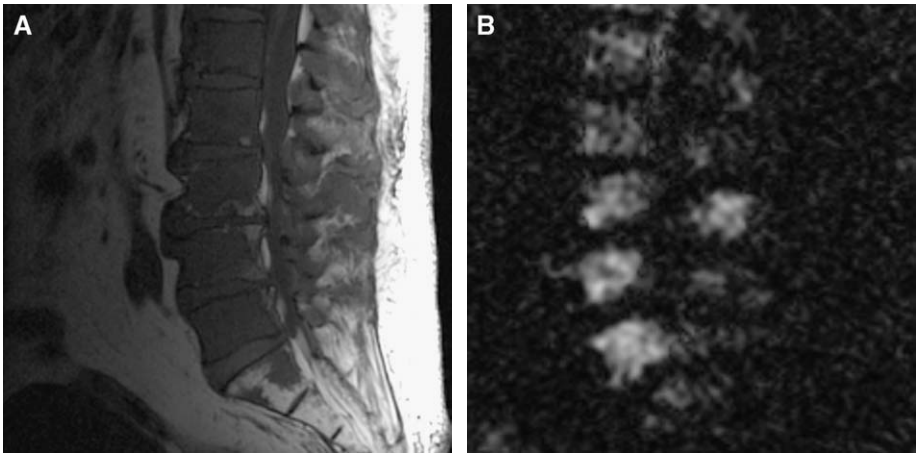

Fig. 11. (*A*) Sagittal T1-weighted image in a prostate cancer patient shows diffuse metastases to all five lumbar and S1 vertebral bodies/posterior elements. (*B*) Sagittal diffusion-weighted imaging displays expected hyperintense signal intensity of the metastases within the affected vertebra.

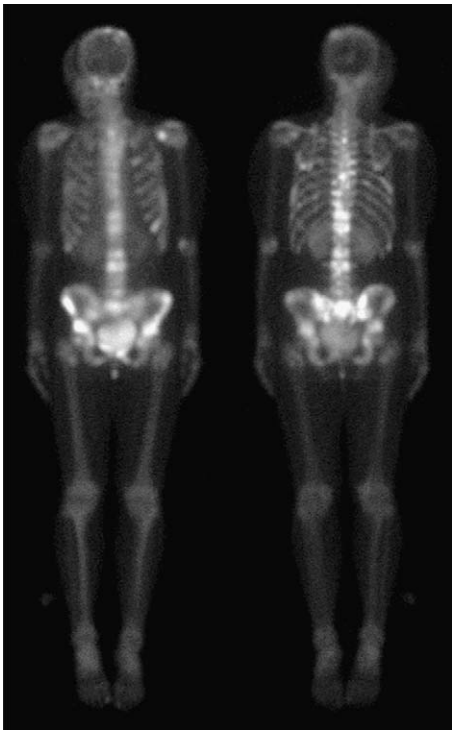

Fig. 12. Anterior and posterior planar whole-body bone scan in a patient with known metastatic breast cancer shows typical increased uptake within the many axial skeleton, calvarial, and rib metastases.

myelography, which shows gray tumor-filling defects within bright CSF. In some cases, nodularity may be difficult to identify on CT myelography, but the cord may appear expanded or the nerve roots diffusely thickened.

Differential diagnostic entities include CSF debris from prior surgery (eg, subarachnoid blood products, adhesions), pyogenic or granulomatous meningitis, sarcoidosis, congenital inherited

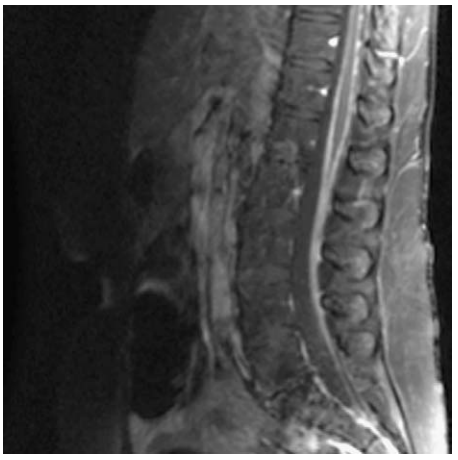

Fig. 13. Sagittal T1-weighted image after intravenous contrast with fat saturation shows thick smooth pial enhancement of the terminal cord and conus correlating with leptomeningeal breast cancer metastasis.

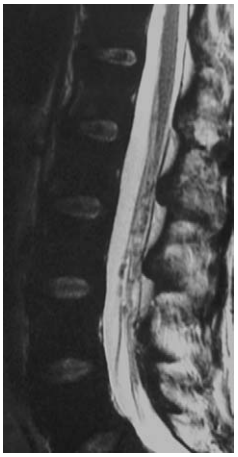

Fig. 14. Sagittal T2-weighted image shows characteristic isointense appearance of leptomeningeal breast cancer nodular metastases residing within the cauda equina.

hypertrophic polyradiculoneuropathies (eg, Charcot-Marie-Tooth disease, Dejerine-Sottas disease), cytomegalovirus polyradiculitis, and chronic immune demyelinating polyneuropathy.

Intramedullary metastases

Spinal cord metastasis is rare. In practice, it is significantly less common than leptomeningeal or extradural metastasis. Intramedullary metastasis usually represents systemic metastasis from a non-CNS primary. Adenocarcinomas, particularly of the breast, lung, or kidney, are the most common type of tumors, but other known causes include lymphoma and leukemia metastasis. MRI is by far the most sensitive imaging modality for detection and reveals a round or ovoid intramedullary nodule that is isointense to spinal cord and surrounded by cord edema (hyperintense on T2WIs, and hypointense on T1WIs), with either solid or ring-like enhancement (Figs. 15 and 16). CT is usually normal unless the tumor is large; enhancement is variably present but helps to make the diagnosis. As with intradural/extramedullary metastasis, myelography increases CT sensitivity by more conspicuously demonstrating focal cord enlargement. There is no significant role for plain radiography.

Differential diagnostic entities to consider include radiation myelitis (in the correct clinical scenario), viral or bacterial myelitis, demyelinating disease (multiple sclerosis or acute disseminated encephalomyelitis), and primary cord neoplasm.

Summary

Radiologic imaging is an essential component of current spinal cancer diagnosis and treatment algorithms and is used for cancer diagnosis, determination of tumor extent for treatment

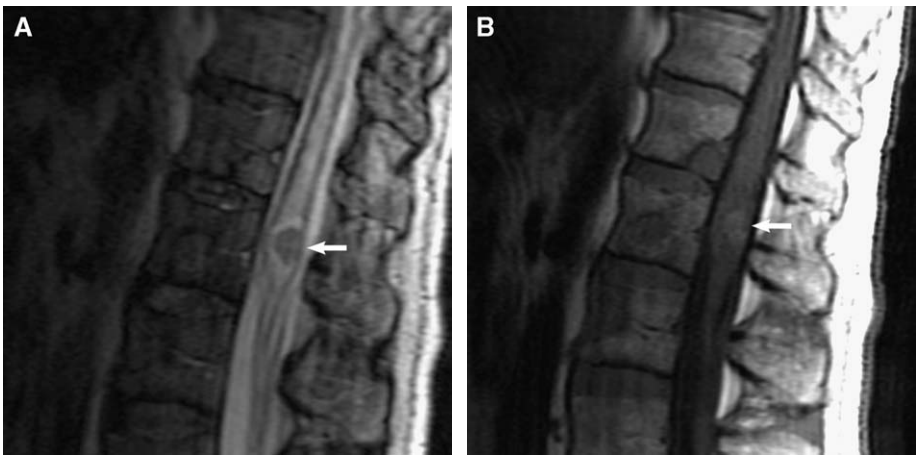

Fig. 15. (*A*) Sagittal T2-weighted image shows an isointense signal intensity rounded intramedullary renal cell carcinoma metastasis in the conus (*arrow*) with surrounding hyperintense edema. (*B*) Sagittal contrast-enhanced T1-weighted image confirms a faintly enhancing intramedullary metastasis (*arrow*).

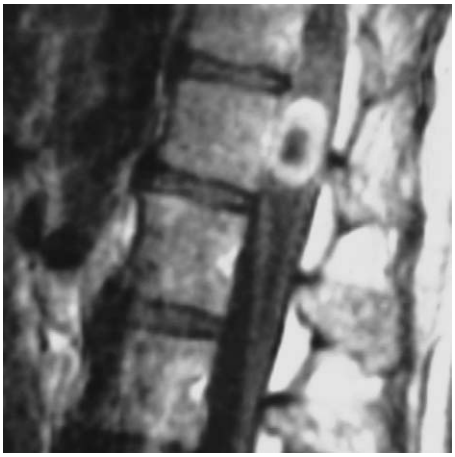

Fig. 16. Sagittal contrast-enhanced T1-weighted image demonstrates strong ring enhancement of an intramedullary melanoma conus metastasis.

planning, and subsequent assessment of therapy efficacy on follow-up.

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