Magnetic Resonance Imaging of Skeletal Neoplasms

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Magnetic resonance imaging plays an important role in the imaging evaluation of patients with primary and secondary neoplasm's involving the skeletal system. The roles of diagnostic imaging in the assessment of skeletal tumors include:

- Detection of the lesion
- Histologic characterization
- Anatomical staging
- Guiding appropriate tissue sampling
- Monitoring therapeutic response

MR shows high sensitivity for detection. MR plays a complementary role with plain film radiography and CT for histologic characterization. MR affords more accurate anatomical staging than any other imaging method. MR is helpful for planning diagnostic biopsy and can be used for biopsy guidance for lesions that can not be visualized on radiographs or CT. The usefulness of MR for monitoring therapeutic response is not as well established.

Technique

The patient should be positioned so that there is minimal pain and minimal tissue compression. Avoid compressing the lesion with the marker, immobilizers and the imaging coil. Compression of overlying soft tissues makes it more difficult to assess depth of penetration of the lesion. We mark the area of palpable abnormality or pain with a pellet placed above and below the lesion or a dab of vaseline.

The study starts with a large FOV fast IR localizer sequence. This sequence is done in a longitudinal plane, typically coronal, which will include the opposite side and the joint proximal to the area being studied. This initial IR sequence detects the lesion, defines its extent, identifies intra-osseous skip metastases, and evaluates the regional lymph nodes. Once the lesion is detected, we switch to the smallest FOV that covers the entire lesion to gain higher spatial resolution. High detail images are necessary for accurate anatomic staging. I often switch to a surface coil partly through the examination if the lesion is small enough to be adequately imaged. Small tumors of the distal extremities may be imaged using a surface coil for the entire study.

All three planes are routinely imaged. Sagittal and coronal planes

depict the longitudinal extent of lesions and better demonstrate the relationship of masses to surrounding joints. The longitudinally oriented fascial compartments are best demonstrated on axial images. We obtain both T1-w and T2-w (FSE with fat sat) images in the axial plane. Axial T1 SE fat-sat post-Gd-DTPA images are obtained if necessary. Gadolinium is useful in distinguishing a homogeneous solid tumor from a fluid-filled mass and in detecting intraarticular or intraspinal invasion by a tumor. I also use Gd-DTPA in post op patients but in my experience, Gd does not reliably differentiate tumor from postoperative alterations. Studies suggest flow rates of Gd enhancement in malignancies are more rapid than in benign lesions and that the pattern of enhancement in malignancy may be unique (e.g. rim enhancement with delayed central filling).

Metastatic Disease

Metastatic disease is the most common bone tumor encountered in all age groups, but particularly in the elderly. Metastasis to bone far outnumbers primary bone malignancy, with a ratio of 50:1 in the elderly patient. The most common primary malignancies to metastasize to the skeleton include carcinoma of the lung, breast, prostate, kidney and thyroid. Metastases to the skeleton can be solitary, disseminated, or diffusely involve the bone marrow. Metastatic disease to bone presents as a solitary lesion in up to 10-15% of patients. The most common pattern of skeletal metastasis is the disseminated pattern, with multiple areas of tumor separated by regions of normal bone marrow. The diffuse pattern involves all the marrow and is more difficult to recognize. MR is more sensitive than scintigraphy but is unable to evaluate the entire skeleton at one setting. The advantage of MR is particularly evident for infiltrative neoplasms such as multiple myeloma and lymphoma, which may have normal scintigrams in the presence of widespread disease.

On MR imaging, metastases appear as low signal within the bone marrow on T1-w images. The signal within a metastasis is typically less than that of the intervertebral disk and muscle on the T1-w images, whereas normal marrow is higher signal than these normal structures. The signal of metastatic disease on T2-w images is more variable and depends upon the nature of the adjacent bony response. Lytic tumors show high signal whereas sclerotic lesions may appear hypointense, hyperintense, or isointense to normal bone marrow, depending on the extent of bone sclerosis. The lesions may disrupt cortex and extend into the soft tissues.

Primary Osseous Neoplasms

Primary bone tumors may be benign or malignant. Benign tumors are much more common than primary bone malignancies, particularly in the young. Multiple myeloma is the most common primary malignant tumor. MR is not particularly helpful for predicting the specific histological type of neoplasm in the majority of cases. The detection of intralesional calcification and ossification are better seen with CT than with MR. The majority of osseous tumors show replacement of normal bone marrow signal with low signal intensity on T1-w sequences. This finding is nonspecific and can be mimicked closely by osteomyelitis, immature infarction, bone marrow edema and other abnormalities. Distinction between benign and malignant neoplasms on MR is often difficult, particularly with low grade malignancies such as chondrosarcoma or early plasmacytoma.

Chondrosarcoma, malignant fibrous histiocytoma and non-Hodgkin's lymphoma are other common primary osseous malignancies in the elderly. Osteosarcoma and Ewing sarcoma are the most frequent primary osseous malignancies in the young. On MR imaging, osteosarcoma typically shows signal heterogeneity due to the mixture of bone sclerosis, active tumor tissue, necrosis, and hemorrhage. Areas of extensive bone sclerosis or tumor mineralization appear as low signal on all imaging sequences. Areas of intralesional hemorrhage, which appear as regions of high signal on the T1 and T2 weighted images, are common in both the osseous and the soft tissue portions of the lesion. Ewing sarcoma permeates the bone and extends into the soft tissues. The disproportionate soft tissue component of Ewing sarcoma is due to the tumor′s ability to rapidly spread through the Haversian canals of the bony cortex without causing macroscopic cortical destruction. The presence of a large soft tissue mass adjacent to a relatively normal appearing cortex is one of the hallmarks of osseous Ewing sarcoma.

Leukemia, lymphoma, and myeloma are primary malignancies arising from the reticuloendothelial elements of the bone. Three patterns of marrow infiltration have been described in patients with leukemia: diffuse uniform, diffuse patchy, and focal. Diffuse infiltrative leukemia is typically associated with the chronic forms of leukemia. While the patchy and focal forms are easily identified on MR images, the diffuse uniform pattern may be difficult to recognize. The appearance of the diffuse uniform pattern has been termed the "flip-flop" sign. On MR images, there is diffuse decrease in the marrow signal intensity on T1-weighted spin echo images, with an increase in signal intensity on T2-weighted spin echo images, a pattern opposite that of normal fatty marrow. The MR changes can be absent or very subtle in early diffuse

leukemia, and marrow abnormalities may not be visible during the early stages of the disease. Even using advanced techniques such as quantitative MR imaging, significant T1 shortening of the bone marrow can be detected in less than half of patients with early stage chronic lymphocytic leukemia.

Primary lymphoma of the musculoskeletal system is much less common than secondary involvement by primary nodal or visceral lymphoma. Secondary musculoskeletal involvement can develop either via hematogenous spread or by contiguous extension of lymphoma from adjacent lymph nodes or viscera. Marrow infiltration by myeloma is difficult to recognize in the infiltrative form of the disease.

With standard SE imaging, 6-34% of multiple myeloma patients have a normal MR examination, even in the presence of widespread marrow disease and pathologic vertebral fractures. Multiple myeloma enhances homogeneously following intravenous gadolinium administration but contrast enhancement does not increase the sensitivity of MR for detection of infiltrative myeloma. The focal nodular form of myeloma is more readily recognized. In this form, multiple larger nodules of myeloma are seen superimposed on a background of normal marrow. Patients with the focal nodular form tend to have lower marrow plasmacytosis and cellularity than patients with the infiltrative pattern. These nodules of malignant cells are dark on the T1 weighted images and increase in signal on T2 weighted or STIR image. The focal nodular form is often difficult to distinguish from metastatic disease solely on the basis of imaging examination.

Histological Characterization of Osseous Tumors

Features to be assessed in order to predict histology include:

1. Longitudinal and transverse location of the lesion.
2. The presence or absence of cortical destruction.

MR imaging shows cortical destruction best on PD or T2 weighted images. CT appears to be more sensitive for subtle cortical erosion.

3. The presence or absence of adjacent bone response or repair.

Periostitis produces a halo or bull's-eye effect on MR. A layer of high signal reactive periostitis surrounds the bone, with a more peripheral layer of low signal representing the elevated fibrous periosteum. Intraosseous sclerosis adjacent to the lesion is easier to visualize with CT.

4. Tumor matrix

Fat can be readily detected with MR. Fat is present in intraosseous lipomas,

mature endochondral ossification in cartilage tumors, within infarcts and within Paget bone. Mineralized cartilage and osseous matrix is easier to assess with CT. Mineralized matrix is often less dark than would be expected on MR based on the sclerosis seen on x-rays. Lesions containing predominantly hyaline cartilage demonstrate a typical appearance on MR. Because of their low cellularity, homogeneous composition and high water content, lesions such as enchondroma and well-differentiated chondrosarcoma both tend to have uniform high intensity on T2-w images. On MR imaging, the lobular growth pattern of cartilage is readily apparent. Multiple rounded areas of cartilage are present within the lesion, and the margin of the enchondroma is very well defined. The signal within the lesion parallels that of hyaline cartilage, with low signal intensity on T1 weighted imaging and high signal on T2 weighted imaging. Mineralization of the lobules can be identified on MR imaging, particularly on gradient echo sequences. The areas of calcification produce a distinctive speckled pattern of low signal within the lesion on T2 weighted images. On high resolution images, the low signal within the areas of calcification can appear clustered at the periphery of the cartilage lobules. If prominent, the cartilage cap of osteochondromas may also demonstrate these characteristics. Fluid-fluid levels also provide information about the matrix of a lesion. Fluid-fluid levels of varying intensity are thought to be secondary to hemorrhage with sedimentation of hemoglobin by-products and serum. MR is more sensitive than CT in detecting these degradation products. Fluid-fluid levels however is a nonspecific finding associated with a variety of tumors including aneurysmal bone cysts, giant cell tumors of bone, telangiectatic osteosarcoma, and even cystic degeneration of fibrous dysplasia.

5. Peritumoral edema

Both benign and malignant tumors can have a large amount of adjacent edema, which can obscure the tumor margins. Peritumoral edema is particularly common with chondroblastoma and osteoid osteoma.

Anatomic Staging

Accurate anatomical staging is necessary to plan appropriate therapy. The development of surgical alternatives to amputation, such as interposition allograft reconstruction and unicompartmental resection requires highly accurate information about tumor extent. Involvement of multiple tissue compartments, invasion of the neurovascular bundle, destruction of normal fascial planes, and involvement of extra-compartmental spaces such as the popliteal fossa and axilla often preclude

limited resection. Staging should optimally be performed prior to biopsy since the edema and hemorrhage caused by the procedure are difficult to differentiate from tumor.

MR affords more accurate anatomical staging than any other imaging method, though some articles suggest that MR and CT are comparable in accuracy. Differentiation between tumor and peritumoral edema is often difficult and may result in overestimation of tumor extent. The 2 most commonly used staging systems in the US are the Surgical Staging System (SSS) developed by Enneking, and the American Joint Committee (AJC) System. The SSS System is widely used by orthopedic surgeons and is applicable to both benign and malignant lesions of both bone and soft tissue. The AJC classification is a modification of the TNM classification widely used by oncologists. It is used primarily for nonoperative staging and is only used for malignant soft tissue neoplasms so it will not be discussed further.

Surgical Staging System: Benign Tumors of Bone and Soft Tissue

Grade	Tumor	Metastases
1 (Inactive)	True capsule	No
2 (Active)	True capsule	No
3 (Aggressive)	Extracapsular	Yes or No

Surgical Staging System: Malignant Tumors of Bone and Soft Tissue

Stage	Grade (Pathology)	Compartmental Anatomy (Radiology)
1A	Low grade	Intracompartmental
1B	Low grade	Extracompartmental
2A	High grade	Intracompartmental
2B	High grade	Extracompartmental
3	Any grade	Metastatic Disease

Tumor follow-up

MR imaging is also used for follow-up of musculoskeletal tumors following surgical excision, radiation therapy, and chemotherapy. Decrease in tumor size and signal are associated with successful therapy. Unfortunately, these changes do not predict tumor necrosis with sufficient accuracy to determine the success of therapy.

Contrast enhancement, quantitative assessment of perfusion, and diffusion weighted imaging may help in increasing the accuracy of staging, particularly following preoperative adjuvant therapy.

References

American Joint Committee. Staging of Musculoskeletal Sarcomas. Cancer 40:1562, 1977.

Enneking WF, et al. Current Concepts Review. The Surgical Staging of Musculoskeletal Sarcoma. JBJS 62A:1027-1035, 1980.

Frank JA, et al. Detection of Malignant Bone Tumors: MR Imaging vs Scintigraphy. AJR 155:1043-1048, 1990.

Lang P et al. Osteogenic sarcoma: Noninvasive in vivo assessment of tumor necrosis with diffusion-weighted MR imaging. Radiology 1998; 206:227-235.

Lecouvet FE et al. Early chronic lymphocytic leukemia: prognostic value of quantitative bone marrow MR. Radiology 1997; 204:813-818.

Lecouvet FE et al. Stage III multiple myeloma: Clinical and prognostic value of spinal bone marrow imaging. Radiology 1998; 209:653-660.

Ma LD, et al. Differentiation of Benign and Malignant Musculoskeletal Tumors: Potential Pitfalls with MR Imaging. Radiographics 15:349-366, 1995.

Ma LD, et al. Benign and Malignant Musculoskeletal Masses: MR Imaging Differentiation with Differential Enhancement Ratios. Radiology 202:739-744, 1997.

Murphey MD et al. Enchondroma versus chondorsarcoma in the appendicular skeleton: Differentiating features. Radiographics 1998; 18:1213-1237.

Panicek DM, et al. CT and MR Imaging in the Local Staging of Primary Malignant Musculoskeletal Neoplasms: Report of the Radiology Diagnostic Oncology Group. Radiology 202:237-246, 1997.

Rahmouni A et al. MR appearance of multiple myeloma of the spine before and after treatment. AJR 1993; 160:1053-1057.

Resnick D, Niwayama G. Chapter 85. Skeletal Metastasis. In Resnick D, Niwayama G (Eds), Diagnosis of Bone and Joint Disorders, 3rd edition. W.B. Saunders, Philadelphia, PA, 1995. p. 3991-4064.

Sundaram M, et al. MR Imaging of Tumor and Tumorlike Lesions of Bone and Soft Tissue. AJR 155:817-824, 1990.

Verstraete KL, et al. Benign and Malignant Musculoskeletal Lesions: Dynamic Contrast-enhanced MR Imaging. Radiology 192:835-843, 1994.