Imaging Evaluation of Musculoskeletal Tumors

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Abstract

In this chapter, we review different imaging modalities, including radiography, computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, and nuclear medicine scintigraphy, and their application to musculoskeletal neoplasm. Advantages and limitations of each modality are reviewed, and suggestions for imaging approach are provided.

Keywords

Radiology · Medical Imaging · X−ray · Radiography · Computed Tomography (CT) · Magnetic Resonance Imaging (MRI) · Ultrasound · Nuclear Medicine

1 Introduction

Imaging evaluation of musculoskeletal tumors often involves a combination of modalities, with each modality serving a specific function in workup. Initial evaluation is typically performed with plain radiography, followed by a more advanced imaging modality, such as computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicine scintigraphy, or ultrasound. Advantages and limitations of each modality are reviewed in this chapter, along with suggestions for imaging approach.

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2 Plain Radiography

Plain radiographs form the basis for initial imaging of suspected bone tumors. Radiography provides excellent resolution, allows for assessment of lesion characteristics, and is often more specific than MRI in generating a reasonable differential diagnosis. Radiography has been the optimal modality in distinguishing nonaggressive from aggressive osseous disease [1, 2]. It should be noted that imaging studies are often able to assess how aggressive a lesion is, but the determination of whether a lesion is benign or malignant is based on pathology. Benign lesions, such as osteomyelitis, may look quite aggressive. If a lesion is pathognomonic for a specific entity, a diagnosis can be made from radiographs alone. In many situations, however, a differential diagnosis is created, and further workup is performed by a combination of advanced imaging modalities [3, 4], and if necessary, tissue sampling. In cases where tissue sampling is necessary, percutaneous biopsy using imaging guidance has been shown to be safe and effective [5]. Soft tissue differentiation is limited at radiography, and evaluation of soft tissue masses primarily involves the identification of fatty or calcified components.

Radiographic evaluation is based on the classification system described by Lodwick, which classifies lesions based on four main groups of characteristics, including destruction of bone, proliferation of bone, mineralization of tumor matrix, and location, size and shape of the tumor [6].

Patterns of bone destruction include geographic, moth-eaten, or permeative. Geographic bone destruction involves loss of bone extending to the transition between tumor and structural bone. A thin sclerotic margin (type IA) is characteristically only seen with geographic lesions, although a geographic lesion can also have a clear nonsclerotic margin (type IB, the so-called "punched out" lesion), or a poorly defined margin, typical of local infiltration (type IC). Moth-eaten bone destruction (type II) is the creation of several smaller confluent holes within the bone. Permeative bone destruction (type III) involves many punctate holes with an ill-defined transition between the involved and uninvolved bone. Moth-eaten and permeative patterns are associated with more aggressive lesions. However, some malignant lesions such as fibrosarcoma and chondrosarcoma can arise within a benign lesion, and as such radiologic-pathologic apparent discordance can arise with an aggressive histology in a benign appearing radiographic lesion [7]. Of note, the fastest margin of tumor growth would be a radiographically invisible permeative lesion, as this involves the widest of margins.

In order for a radiolucent lesion to be appreciable at radiography, there must be destruction of either cortical or cancellous bone. Since the diaphysis of long bones is comprised of primarily cortical bone that envelops a thin internal margin of cancellous bone and the marrow in the central medullary cavity, lesions arising in the medullary space may not be visible at radiography. The term "endosteal scalloping" refers to a tumor that originates in the medullary canal, and as it grows, displaces, or replaces the internal cortical margin rather than the outer surfaces of the bone. This tends to have rounded margins, hence the scalloped appearance.

Endosteal scalloping is not by itself an aggressive finding and can be seen with benign lesions, but does suggest adjacent marrow replacement.

Proliferation of bone includes both encapsulated and unencapsulated patterns, with unencapsulated growth being more aggressive. This feature is particularly characterized by different patterns of periosteal reaction. Broadly speaking, periosteal reaction can be classified as continuous, interrupted, or complex, depending on its morphology. Continuous forms include both nonaggressive and aggressive morphologies, with the terms *smooth* and *continuous* representing examples of nonaggressive periosteal reaction, and *lamellated* or "*onion-skin*" representing examples of an aggressive reaction. Interrupted patterns include the Codman's angle or triangle, which is a focal periosteal elevation, and interrupted spiculated patterns. Complex patterns include a mix of various types [8].

Tumor matrix is reflective of the type of calcification or ossification, if any, that is present within the lesion. Osteoid matrix is often described as solid, cloud-like, or ivory-like, and when in an aggressive lesion can be associated with osteosarcoma. Chondroid matrix is classically described as stippled, flocculent, or "ring and arc" configuration, and when aggressive can be seen in the setting of chondrosarcoma [9]. Fibrous matrix, as seen in fibrous dysplasia, demonstrates a "ground glass" radiographic density as a result of small, abnormally arranged trabeculae of immature woven bone [10]. Many lesions of varying cell types do not show any type of internal matrix, and this is also the case with highly dedifferentiated osteoid or chondroid malignancies.

Location, size, and shape also play a role in the evaluation of a bone tumor. Generally speaking, malignancies tend to be larger and more spherical. Differential diagnosis is aided also by location, as some tumors originate in the diaphyseal, metaphyseal, or epiphyseal location. Age of the patient also aids in formation of a differential diagnosis, as different tumors tend to favor different age groups.

Once the lesion has been assessed radiographically, if there are aggressive features, further imaging evaluation is warranted. This is particularly true in the setting of cortical destruction or suspected extension into the adjacent soft tissues. The degree of soft tissue involvement is more accurately characterized by contrast enhanced CT or MRI [11], which allow better discrimination of the extent of disease. This is often not possible at plain radiography, as both tumor and adjacent normal soft tissues are of the same density and attenuate the X-ray to the same degree (Figs. 1, 2, 3, 4, 5 and 6).

3 Computed Tomography

Computed tomography utilizes X-rays and complex computer algorithms to generate tomographic axial images, which can be reformatted in coronal and sagittal planes to aid interpretation. CT has many advantages over radiography, including allowing lesion characterization in complex regions of osseous overlap, such as the spine or pelvis, allowing determination of extent of soft tissue involvement, and in

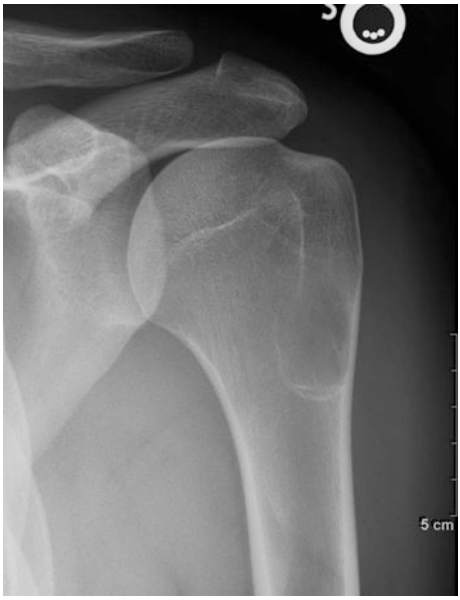

Fig. 1 Unicameral bone cyst. 18 year old man with a Lodwick type IA lesion, with a nonaggressive appearance. This does not require further evaluation

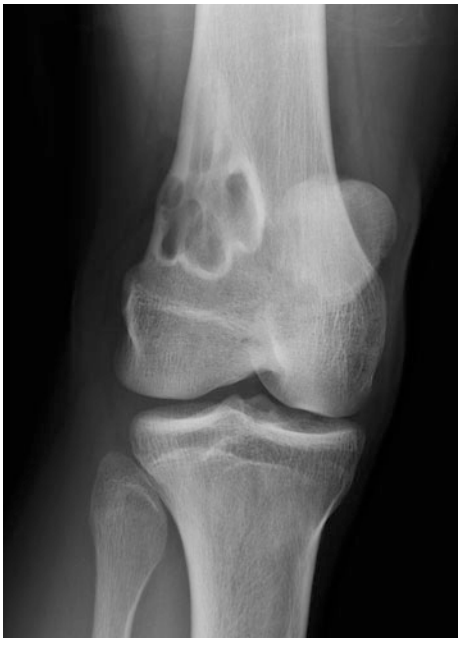

Fig. 2 Nonossifying fibroma. Another lesion typifying a type IA lesion in this 21 year old man, with a nonaggressive appearance

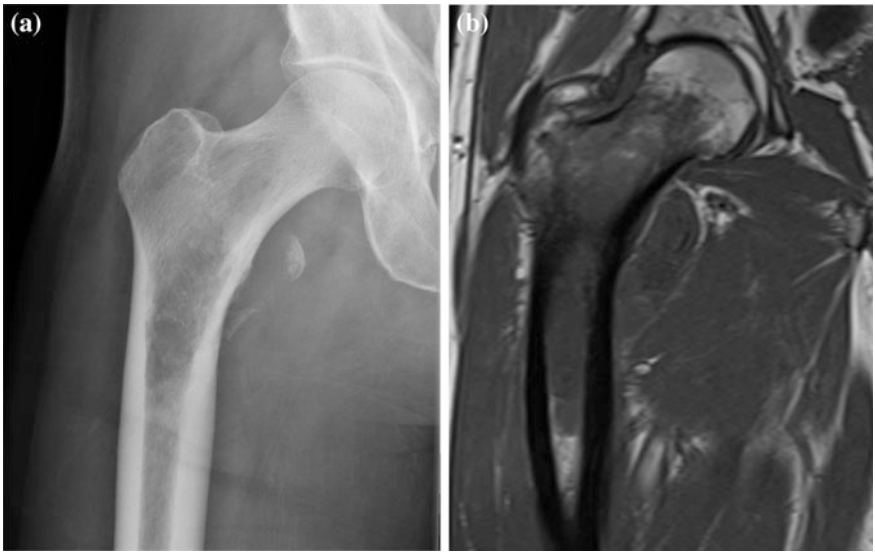

Fig. 3 **a** Dedifferentiated chondrosarcoma. 58 year old man with an aggressive lesion demonstrating ill-defined, permeative type III margins. Because of its dedifferentiation, no chondroid matrix is appreciable. There is a pathologic fracture of the lesser trochanter, a typical location for an underlying lesion. **b** Corresponding coronal T1-weighted MRI demonstrates replacement of the marrow by tumor

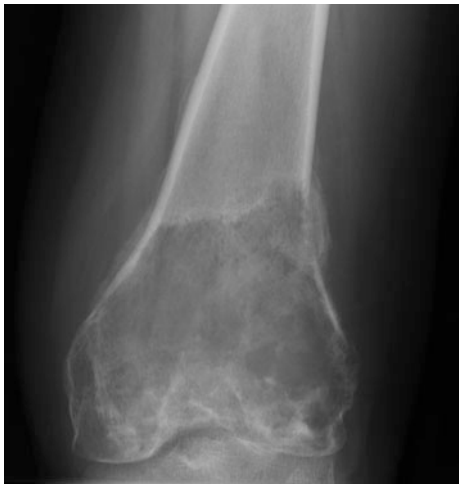

Fig. 4 Osteosarcoma, high grade. This aggressive lesion in this 30 year old woman demonstrates aggressive interrupted lamellated periosteal reaction, with permeative margins and soft tissue extension

some cases, degree of intramedullary involvement. The relatively quick speed with which CT can be acquired is also of benefit in patients who are claustrophobic or unable to hold still, as motion artifact degrades all imaging. Limitations or drawbacks of CT include its inability in many cases to provide a specific histologic

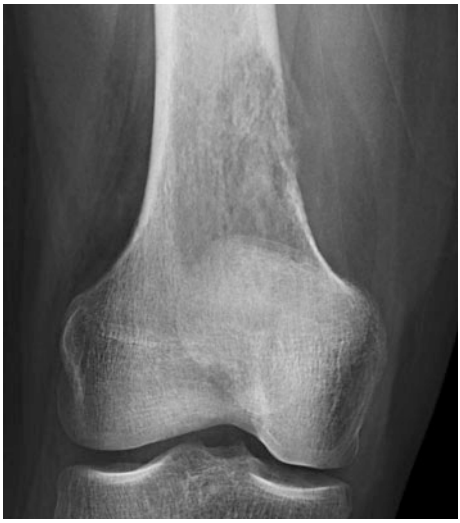

Fig. 5 Osteosarcoma. This aggressive lesion demonstrates periosteal reaction with a Codman's triangle of focal periosteal elevation in this 23 year old man. There is typical "cloud-like" osteoid matrix

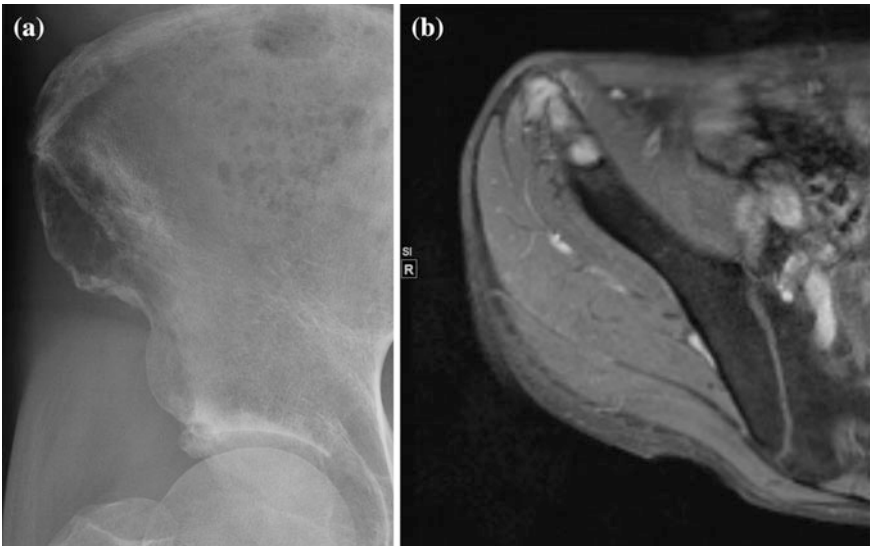

Fig. 6 **a** Multiple myeloma. 52 year old man with an ill defined right anterior iliac wing lesion, with a wide zone of transition. **b** MRI demonstrates better the extent of the lesion, showing that there is no adjacent soft tissue extension. This was subsequently biopsied and shown to be multiple myeloma

diagnosis of soft tissue tumors, and its associated radiation dose, which is particularly relevant for children and pregnant patients.

CT characterizes lesions based on their degree of attenuation of a focused X-ray beam. A specific volume of tissue is assigned a value representing this degree of attenuation, called a Hounsfield unit (HU), named for the inventor of CT, Sir Godfrey Hounsfield. Although not absolute, bone is typically +400 to +1000 HU, soft tissue +40 to +80, water 0, fat −60 to −100, and air is −1000 [12].

Although attenuation values can sometimes be helpful, such as in the setting of a lesion that contains fat or calcification, many times a lesion will be of soft tissue attenuation. This does not aid in providing a specific histologic diagnosis. Some tumors, such as osteosarcoma or chondrosarcoma, demonstrate internal matrix, which can allow for further characterization, although this information is often obtainable via radiography.

Patterns of osseous destruction seen on CT follow those seen on radiography. A slow growing process will demonstrate a narrow zone of transition and geographic margins, and more aggressive processes will have moth-eaten or permeative patterns of destruction. The endosteum is also well evaluated on CT, which can be scalloped or destroyed in the setting of tumor. The degree of marrow replacement is better evaluated on MRI, but an obvious soft tissue mass infiltrating the medullary cavity can be assessed on CT.

CT can also be helpful in identifying areas of reactive cortical destruction. CT allows direct visualization without overlying interfering attenuation from soft tissues. Cortical destruction can be assessed even in areas where several bones are in close proximity to one another or are of complex shape, such as in the spine or pelvis [13]. On X-rays, these areas of destruction can be obscured, as the three dimensional shape is flattened into two dimensions. Cortical destruction may be mistaken for overlap of other anatomic structures [14].

Extension of tumor into the adjacent soft tissues often accompanies aggressive osseous pathology, and CT can provide accurate assessment of the margins of extension. Addition of intravenous contrast can provide additional resolution between pathologic and uninvolved tissues. Despite these advantages with more well-encapsulated lesions, some tumors can be infiltrative, and the exact margin between tumor soft tissue and adjacent muscle may not be possible on CT. MRI may be advantageous in these patients as it offers superior soft tissue contrast when compared to CT, and as a result of its absence of ionizing radiation, has largely supplanted CT for the evaluation of soft tissue extent [15]. Intramedullary involvement is also better assessed on MRI [16], where subtle marrow infiltration may be detected by methods discussed below, but when grossly present may be detectable on CT by noting replacement of the marrow fat with soft tissue attenuation.

Despite the advantages of CT, in many cases, a specific histologic diagnosis of a soft tissue mass cannot be reached, and in these cases a differential diagnosis is generated. Further evaluation with MRI or tissue sampling is then performed.

Other potential limitations or drawbacks of CT include radiation dose, patient motion, and iodinated dye contrast allergy. Radiation dose associated with CT has received considerable media attention, and is particularly relevant for children and pregnant patients. Despite the attention it has received, the actual lifetime risk of developing fatal cancer from abdominopelvic CT has been the subject of a recent publication, and is by conservative estimate erring on the side of overestimation of at most 0.5 per 1,000 individuals. The risk of dying from pedestrian accident, for reference, is 1.6 per 1,000 individuals; from drowning, 0.9 per 1,000 individuals; and the risk of dying from lightning strike 0.013 per 1,000 individuals [17]. This is not to trivialize the possibility of radiation-induced cancer, but serves to provide a frame of reference of the likelihood to allow appropriate risk-benefit stratification. In general, a guiding principle with regards to medical imaging is to achieve the necessary diagnostic information using a radiation dose that is *As Low As Reasonably Achieveable* (ALARA). This can be done through both optimization of imaging protocols to include only the area of interest, and also by using techniques that do not involve ionizing radiation, such as ultrasound or MRI when appropriate. Additionally, newer generations of CT scanners have included features, such as dose modulation or iterative reconstruction, to marked reduce radiation exposures.

Patient motion degrades all imaging, regardless of modality. Although this can be a drawback on CT when a patient cannot hold still, CT is less susceptible to this limitation than is MRI, as imaging times are shorter. Sedation can be considered if the patient is a candidate when motion limits interpretation.

Iodinated contrast allergy is not uncommon. Severe anaphylaxis following contrast administration is rare, but can result in life-threatening complications that require immediate treatment [18]. Most reactions tend to be minor, and premedication regimens with steroids prior to contrast administration have been advocated. Of note, there is no specific cross-reactivity between allergy to iodinated contrast materials and allergy to gadolinium based contrast materials, so that a patient who has a history of severe allergic reaction to iodinated CT contrast material is often a candidate for contrast-enhanced MRI (Figs. 7, 8 and 9).

4 Magnetic Resonance Imaging

Magnetic resonance imaging has traditionally been utilized for staging of bone lesions and as such has been extremely valuable in planning management, but the advent of more advanced pulse sequences allows for some increased lesion characterization as well. Conventional MRI sequences do not usually allow for lesion characterization, as both benign and malignant processes show increased relaxation times on both T1 and T2 sequences. Main strengths of MRI in bone tumor imaging include the ability to assess extent of marrow involvement, to determine the presence of discontinuous, or “skip” lesions within the same bone, and to determine the extent of any soft tissue component extending beyond the

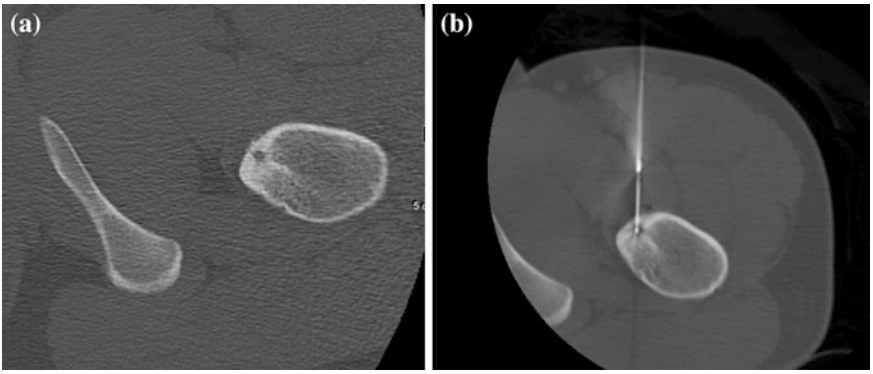

Fig. 7 **a** Osteoid osteoma. CT demonstrates focal cortical thickening with a central lucent nidus in this 19 year old man. **b** Under CT guidance, a radiofrequency ablation probe was directed to the nidus, providing relief of symptoms following ablation

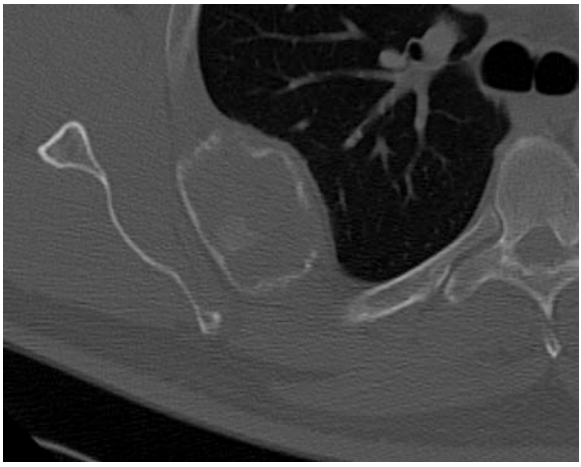

Fig. 8 Fibrous dysplasia. For complex locations such as the ribs, where there is osseous overlap with the adjacent scapula at radiography, CT is helpful in providing additional information. In this 37 year-old man, this lesion demonstrates the typical ground glass matrix of fibrous dysplasia, which was suggested at the initial CT examination. Biopsy was performed because of cortical breakthrough superiorly, and pathology confirmed fibrous dysplasia

cortex. For these reasons, continuous images extending from the joint above the lesion to the joint below are typically obtained. Additionally, MRI carries the advantage of absence of ionizing radiation. However, limitations of MRI include susceptibility artifact from metallic hardware, which is often placed in the surgical treatment of musculoskeletal tumors, and inability to safely image many patients with pacemakers or other metallic devices.

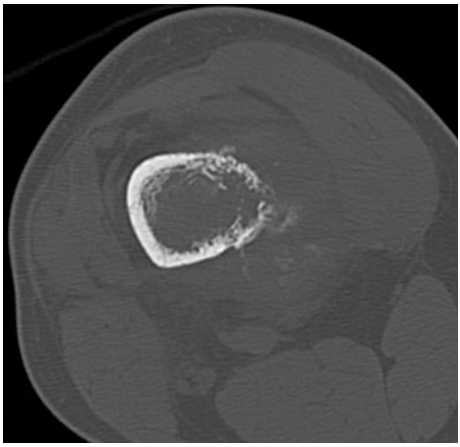

Fig. 9 Osteosarcoma. CT of the same patient as in Fig. 5. The extent of soft tissue involvement is better assessed on CT

For evaluation of marrow infiltration, T1-weighted images are the workhorse sequence. Marrow conversion from red, hematopoietic marrow to yellow, fatty marrow in a normal patient occurs in a predictable distribution with advancing age. This can be appreciated on T1-weighted images as an increase in marrow signal correlating with increased fat content. When an area that should contain yellow marrow loses its bright signal, this may represent either marrow infiltration by a pathologic process or red marrow reconversion in response to increased hematopoietic needs. On T1 images, this can many times be differentiated by assessing the signal intensity with respect to muscle. Red marrow reconversion will typically be hyperintense to skeletal muscle, whereas a pathologic process typically will be isointense to hypointense.

Extent of disease involvement is assessed as areas of T1 hypointensity. This is evaluated both for the primary lesion, which is measured and reported, as well as for the presence of any concurrent lesions within the same bone. T1-weighted images can also suggest a diffuse pattern of marrow replacement, as is often seen in the setting of metastatic disease, myeloma or lymphoma.

Local infiltration of soft tissues adjacent to bone can usually be best characterized on T2-weighted images or T1-weighted images following the administration of intravenous contrast. T1-weighted images without IV contrast may demonstrate loss of fat planes or a demarcation between tumor and normal adjacent muscle if there is a difference in signal intensity, but these findings are often subtle, and small areas of involvement can be easily overlooked.

Pathological conditions are usually more conspicuous on fluid-sensitive sequences, such as T2-weighted imaging or with *short tau inversion recovery* (STIR), since the signal intensities of these areas are brighter than skeletal muscle. Additionally, fluid sensitive sequences are commonly performed with fat saturation. Decreasing the signal from fat further increases the conspicuity of abnormal fluid content within tissues. Thus, T2-weighted images increase the conspicuity of tumor infiltration. Chemically selective fat saturation sequences tend to have higher

spatial resolution but may suffer from areas of inhomogeneous fat suppression or may be more prone to other artifacts. On the other hand, STIR images demonstrate uniform fat suppression over larger fields of view but have poorer spatial resolution and may take longer to perform. T2-weighted images also increase the conspicuity of fluid-fluid levels. Although fluid–fluid levels are not specific, a lesion comprised of a higher percentage of fluid-fluid levels has a higher likelihood of being benign [19].

While the mainstay of MRI has been in assessing the extent of disease, the advent of advanced pulse sequences has allowed for some lesion characterization as well [20]. Chemical shift imaging, diffusion weighted imaging, and post-contrast imaging provide additional information for problem solving.

Chemical shift imaging is also called in and opposed phase imaging. The basic principle behind chemical shift imaging is that when water and fat molecules are located within the same sampled space and imaged while in phase, their signals will be additive, producing bright signal on the image. When imaged during the opposed phase, their signals will cancel one another out, resulting in a signal drop. Yellow marrow contains predominantly fat, and as such, will remain bright in signal on opposed phase imaging. Red marrow contains more hematopoietic elements, and as such is more cellular. With increased cellularity comes increased water content, although there is also usually some fatty marrow in these areas as well [21]. On opposed phase imaging, these signals then cancel, resulting in a signal drop.

Both marrow replacing processes and hematopoietic red marrow may be lower in signal intensity than fatty marrow on a T1-weighted image, and sometimes it can be difficult to distinguish between them simply by using comparison to internal references, such as muscle. This principle of chemical shift imaging can be applied to allow differentiation of an aggressive marrow replacing process from hematopoietic marrow. Marrow replacing processes are unlikely to spare the normal fatty marrow, and as a result, only cellular, water-heavy components are likely to remain. Thus, unlike with red marrow, there will be no signal drop on opposed phase imaging.

The role of diffusion-weighted imaging in the musculoskeletal system is less well defined. Diffusion-weighted sequences have been used extensively in the evaluation of stroke and many other intracranial processes, but have been less extensively studied with regard to bone tumors. Diffusion-weighted sequences are created based on Brownian motion at the microscopic level, and in tumor imaging, increased cellularity results in restricted diffusion. This is displayed on two sets of sequences. One of these is referred to by their *b value*, which is a representation of the diffusion weighting used to generate the image, and the other is called the *apparent diffusion coefficient*, or *ADC map*. Some authors have attempted to classify neoplastic versus normal marrow signal based on absolute ADC values [22]. However, the application of this technique for this usage is early, and absolute cutoffs may vary based on vendor and institution specific techniques used to generate the ADC map.

Although contrast-enhanced imaging is often unnecessary in the setting of a primary osseous tumor [23], contrast-enhanced MRI may provide additional information for the assessment of a suspected soft tissue mass. Additionally, contrast-enhanced imaging may provide additional valuable information when staging for local extent, biopsy planning, tissue characterization, monitoring pre-operative chemotherapy, and detection of recurrence [24]. Musculoskeletal malignancies often demonstrate high T2 signal, which can mimic a ganglion cyst, meniscal cyst, or synovial cyst on unenhanced images. If the lesion demonstrates any internal T1 heterogeneity or septations, further evaluation with contrast-enhanced images are requisite to exclude a solid malignancy mimicking a benign process [25]. Contrast can also be useful for allowing identification of any cystic regions within the mass. When biopsy is performed of a mixed solid and cystic mass, it should be directed toward the solid components.

Recent studies have focused on the utilization of dynamic contrast-enhanced MRI in evaluation of the prognosis of patients with osteosarcoma. Dynamic contrast-enhanced MRI utilizes a bolus of IV gadolinium contrast, with serial images of the tumor after administration allowing assessment of parameters related to tumor vascularity, which may serve as a marker for treatment response. Early results are promising although further studies are needed [26].

MR spectroscopy is an emerging technology for the characterization of musculoskeletal neoplasms. Spectroscopy is a technique that uses MRI to determine the chemical composition of a volume of tissue. A tissue containing a discrete choline peak has been shown to have a sensitivity of 88 % and specificity of 68 % in the detection of malignancy [27]. Limitations include inaccuracy as a result of magnetic field inhomogeneity and difficulties arising from the varying shapes of the musculoskeletal system. Because people are of varied body habitus, different coils need to be used to optimally image different sized extremities, which further complicates analysis.

Ultimately, evaluation of many lesions solely on MRI yields nonspecific results, and studies have shown less than 50 % accuracy in determination of malignancy from benign processes. Correlation with plain radiographs can aid in assessing whether a process is likely to be aggressive, and the need for further evaluation with tissue sampling (Figs. 10, 11, 12, 13, 14 and 15).

5 Nuclear Medicine Scintigraphy

Nuclear medicine scintigraphy is used to look for areas of increased bone turnover, and its power in the diagnosis of musculoskeletal tumors lies in its sensitivity to detect lesions. Bone scintigraphy is typically performed with technetium 99 m methylene diphosphonate (MDP), although a variety of other isotopes are also available for medical imaging. Bone scintigraphy for tumor imaging is best

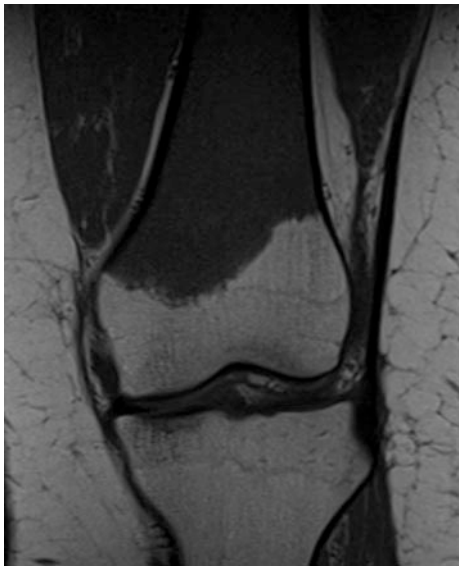

Fig. 10 Lymphoma. T1 coronal MRI demonstrates confluent marrow replacement in the femoral diaphysis in this 30 year-old woman with lymphoma

performed in patients with a known primary tumor, particularly to assess for the presence and extent of metastatic disease [28]. Bone scan is more sensitive than radiography in depicting a reactive process, as approximately 50 % of bone must be lost before a lytic lesion will become radiographically visible.

Multifocal disease will be seen as several discontiguous areas of increased uptake. This will allow detection of both local and remote disease spread, as bone scintigraphy is most commonly acquired as whole body imaging, with spot views of areas of concern for higher magnification. Primary bone lesions uncommonly present with metastatic disease, and bone scan is not initially indicated in the setting of a known primary osseous tumor [29].

Following detection of a lesion with bone scan, radiographic correlation is the appropriate next step to ensure that the lesion does not represent a non-tumor area of osseous pathology, such as an infectious or arthritic process. Particularly in the setting of a solitary lesion in a patient with low grade primary disease, specificity for tumor on bone scan alone is low. Biopsy may be necessary, as even in the setting of known primary malignancy, biopsy may reveal no malignancy or a second malignancy as frequently as 12 % of the time [30].

Positron emission tomography, or PET, is typically performed with a fluorine-18 fluorodeoxyglucose (FDG) tracer. This radiolabeled analog of glucose is injected intravenously and trapped in cells that are metabolically active. As a result, it has a predilection for some tumor cells, which tend to have higher metabolic needs. PET is often performed in combination with CT, with hybrid fused images allowing precise anatomic localization.

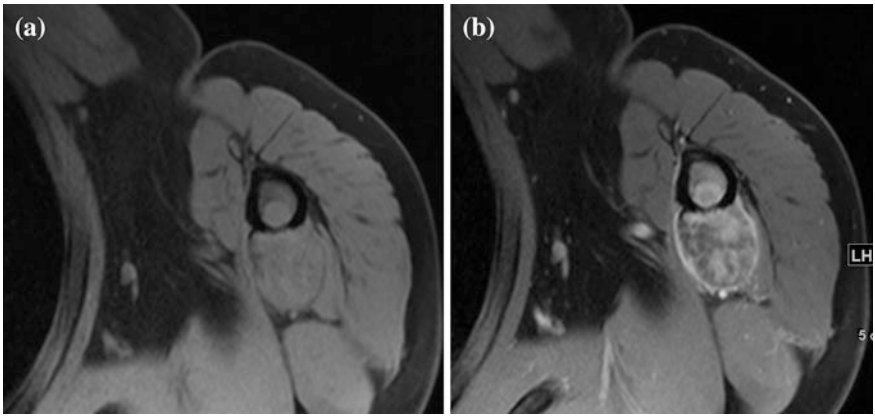

Fig. 11 **a** and b Osteosarcoma. Axial T1 pre and post contrast images demonstrate the added value of contrast in the evaluation of soft tissue extension of tumor in this 48 year old man

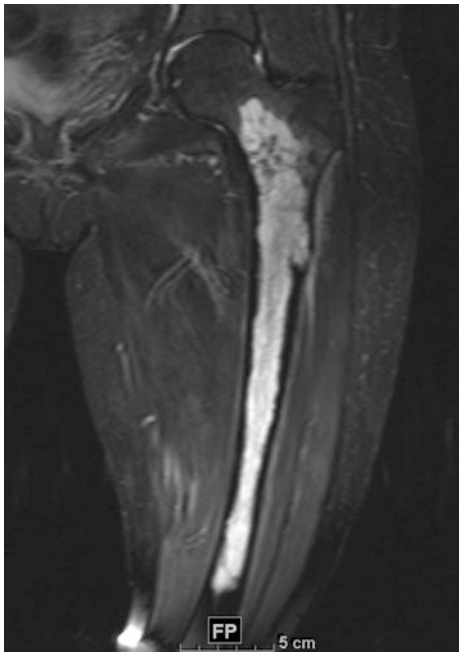

Fig. 12 Chondrosarcoma. Coronal STIR demonstrates diffuse marrow replacement with tumor in this 60 year old woman

FDG PET has shown particular benefit in imaging of patients with sarcomas. Many types of childhood sarcoma, including Ewing's sarcoma, rhabdomyosarcoma, osteosarcoma, and leiomyosarcoma, can be detected both at their primary site and at sites of metastasis as areas of increased metabolism [31]. This has also been shown of value in adult sarcoma as well [32].

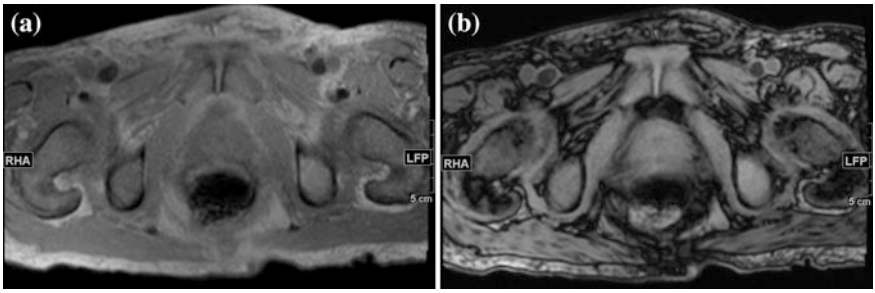

Fig. 13 **a** and **b** Hematopoetic red marrow. In and opposed phase images demonstrate loss of signal on opposed phase images in the intertrochanteric regions, consistent with the presence of both water and fat. This is compatible with hematopoetic red marrow in this 60 year old man with mantle cell lymphoma

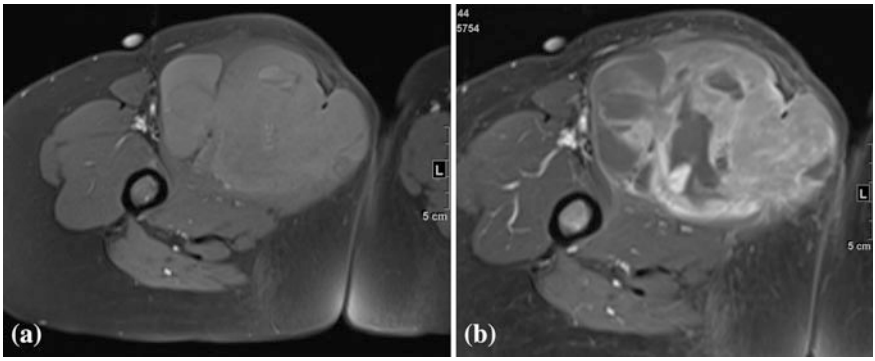

Fig. 14 **a** and **b** Synovial sarcoma. Pre- and post-contrast axial T1 images (**a** and **b** respectively) illustrating the value of postcontrast imaging for a soft tissue mass in this 23 year old woman. There are lobulated areas of enhancing residual tumor interspersed with areas of necrosis following treatment. Although the lesion increased in overall size compared with the prior exam, there was also an increase in the necrotic component, suggestive of treatment response

Although other nuclear medicine techniques provide specific information regarding secondary osseous metastatic disease, they are not discussed here as they are beyond the scope of this chapter (Figs. 16 and 17).

6 Ultrasound

Although there is little indication for its use in characterizing bone lesions, ultrasound can also be helpful in the characterization of extraosseous musculoskeletal soft tissue tumors. Although ultrasound is not specific enough to allow histologic diagnosis, it can provide information regarding the cystic versus solid nature of a lesion, and in some settings may allow differentiation of a tumor from a

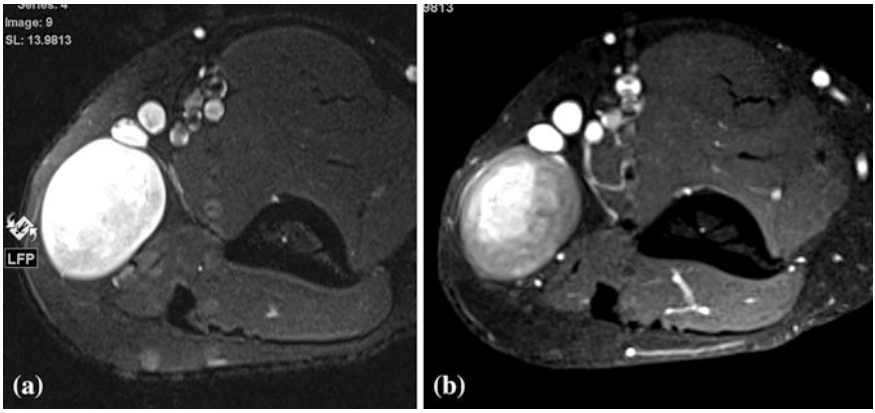

Fig. 15 **a** and **b** Schwannoma. T2 axial fat saturated image (**a**) of the left distal humerus demonstrates a fluid-bright lesion in the medial soft tissues in this 39 year old woman. Post contrast T1 image (**b**) demonstrates that this lesion is a solid enhancing mass, and not a cyst

simple fluid collection [33]. Color Doppler flow imaging can also aid in distinguishing solid from cystic lesions (Figs. 18 and 19).

Patients may present with a palpable subcutaneous lesion, in which case an ultrasound is often the first line of imaging. Ultrasound allows for further characterization without ionizing radiation, and is not as expensive as MRI. Benign fluid collections, such as typical ganglion cysts or Baker's cysts, may be differentiated from solid lesions, which have malignant potential. Although specific histologic diagnosis is not possible on ultrasound, aggressive sonographic features such as invasion of adjacent structures or a lack of well defined margins can prompt further workup with MRI. Ultrasound also offers excellent resolution of very small superficial structures when a high frequency linear transducer is employed, and may also be useful in distinguishing foreign body reaction from a true tumor.

Grayscale imaging may allow suggestion of specific lesions if there is a classic morphology, such as in the setting of plantar fibromatosis, abscess, or ganglion cyst. However, any lesions that appear suddenly, are painful, or that exceed 5 cm in diameter need further evaluation, often with biopsy. Also, if a lesion is deep seated and as such not well evaluated with a superficial transducer, or if all margins of the tumor cannot be well delineated, further evaluation with MRI, and if necessary, biopsy, is warranted [34]. Although a lipoma may be suggested if a solitary lesion has typical sonographic features, sonography has been shown not to be specific for diagnosis [35], as lipomas may have variable echogenicity, ranging from hypoechoic to hyperechoic depending on the adjacent soft tissues. Other lesions with classic features include hemangiomas, which may include phleboliths, and peripheral nerve sheath tumors, which follow the course of a specific nerve. Peripheral nerve sheath tumors may produce symptoms in the distribution of the

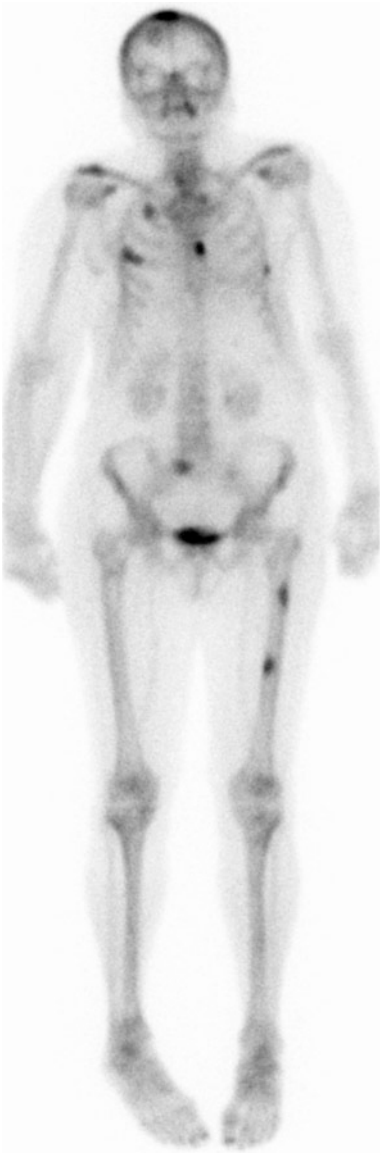

Fig. 16 Metastatic breast cancer. Whole body MDP bone scan in a patient with breast cancer demonstrates several scattered sites of increased uptake, compatible with metastatic disease in this 79 year old woman

nerve, and as such, dynamic sonography is of value as the sonographer is able to elicit typical signs and symptoms in real time during the examination [36].

Following grayscale evaluation, color Doppler flow evaluation of all lesions is necessary, as some solid tumors, most commonly fibrous lesions, may appear hypoechoic to anechoic at grayscale imaging. These may even have smooth margins, further mimicking a cyst [37].

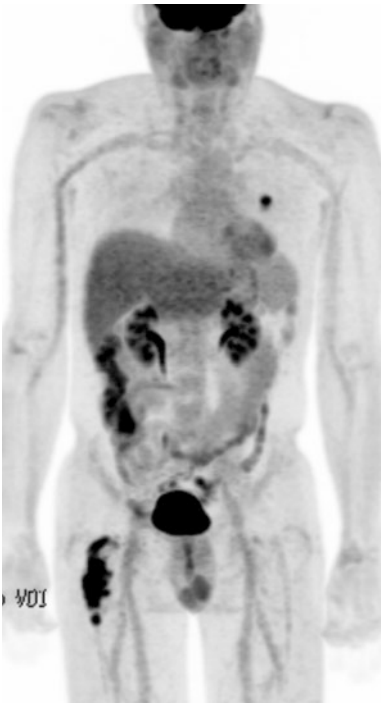

Fig. 17 Metastatic chondrosarcoma. Whole body PET demonstrates a primary chondrosarcoma of the right femur with a metastasis to the left lung in this 58 year old man

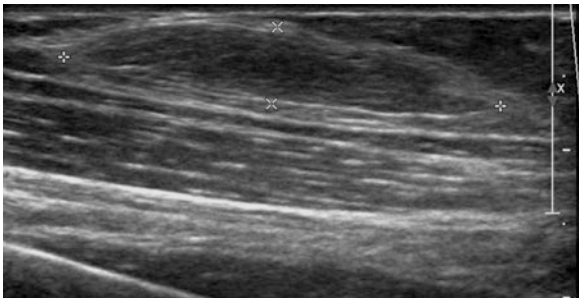

Fig. 18 Soft tissue lipoma. Ultrasound image demonstrates an encapsulated mass that is isoechoic to the adjacent fat, compatible with a lipoma in this 67 year-old woman

Color Doppler flow imaging also aids in distinguishing cystic from solid masses. Cystic lesions will not demonstrate internal pulsatile color Doppler flow; therefore, if a lesion contains flow, it is at least in part solid and not a simple cyst. The absence of flow does not exclude malignancy, as a tumor may have slow flow that is not detectable by Doppler, but the presence of flow excludes a simple cyst. Arrangement of color Doppler flow in morphology suggestive of neoangiogenesis includes disorganized blood vessels, occlusions, stenoses, or trifurcations [38]. Power Doppler flow is a similar technique to color Doppler. Instead of directional information being displayed as alternating colors, power Doppler displays only an absolute value, but may be more sensitive to small amounts of flow.

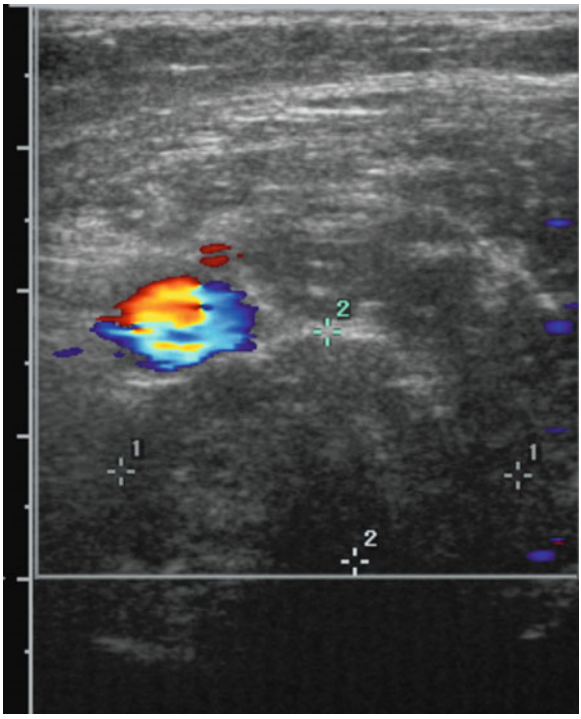

Fig. 19 Soft tissue malignancy. Transverse ultrasound image demonstrates a lobulated hypoechoic mass deep to the gastrocnemius muscle in the popliteal fossa in this 44 year old man

7 Suggestions for Imaging Approach

Initial evaluation of a primary bone tumor should be performed using radiography. If initial radiography is negative but the patient has persistent symptoms, the next study of choice is MRI. However, if the patient is not a candidate for MRI, Tc99 m MDP bone scan or CT may be performed instead.

If the initial radiographic evaluation is positive, and shows suspicious characteristics for malignancy, MRI is the next evaluation of choice. CT and PET/CT may also be helpful to evaluate the cortex and for additional lesions as detailed above. In the setting of a positive radiographic evaluation with benign characteristics, such as in the setting of osteoid osteoma, further characterization with CT can be performed to aid in treatment planning.

Soft tissue lesions, which are often radiographically negative, are ideally further evaluated with MRI. However, patients with abnormal renal function are at increased risk for nephrogenic systemic fibrosis, and as a result may be ineligible to receive gadolinium contrast. Ultrasound may be of value in this setting.

For further details, please refer the ACR appropriateness criteria for primary bone tumors [39].

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