INTRODUCTION

In the recent years, advances in imaging have revolutionized the medical practice. Since the late 1980's MR imaging has become the modality of choice for the assessment of musculoskeletal disorders. However, with the advancement of CT technology through development of multidetector scanners, CT scan is again gaining grounds in the evaluation of musculoskeletal diseases.

Besides, ultrasound has been slowly but surely gaining strength as a very useful tool in musculoskeletal imaging in particular for tendon and ligament disorders and to guide interventions. Note however, that radiographs should be always performed as the primary investigation and remain a cornerstone in imaging.

In the following article we will be addressing some specific topics that are frequently encountered in the daily clinical practice outlining the use of different imaging modalities.

RADIOLOGICAL APPROACH FOR IMAGING OF PRIMARY BONE TUMORS

In the appropriate clinical setting, patients with primary bone tumors can present with a constellation of symptoms and signs related to the tumor or they can be totally asymptomatic and the tumor discovered incidentally on imaging studies. Those with symptoms typically complain of pain, altered function, and a palpable mass or a pathologic fracture [1]. In clinical practice, a significant number of malignant bone tumors initially go undiagnosed because of low index of suspicion. The problem of under detection and delayed diagnosis was discussed by Grimer and Sneath [2] and they reported that 22% of malignant bone tumors are initially missed. Of these cases, 58% were inoperable or required amputation, whereas only 15% of patients in whom diagnosis was made at the initial presentation required amputation. Early diagnosis and prompt referral would undoubtedly improve prognosis [2].

Reaching a reasonable differential diagnosis or a specific diagnosis is often a complex process which requires close cooperation between the orthopaedic oncologist, radiologist and pathologist. When a clinician is confronted with a solitary bone lesion, there is a wide variety of lesions that should be considered, but most importantly, nonneoplastic processes should be ruled out first. Lesions to be considered should include malignant and benign tumors, exuberant callus, stress fracture, infection and solitary metastasis. Based on the initial differential diagnosis or specific diagnosis, patient management can take one of three pathways, depending on how aggressive the lesion appears to be [3]:

1. Lesions that are thought to be benign, stable or regressing in size can be ignored. Examples of such lesions include vertebral hemangioma, bone island (Figures 1a, 1b) and non-ossifying fibroma.

2. Lesions that are benign, but can be locally destructive or have a malignant potential should be followed-up with periodic imaging. Such lesions include enchondroma
Figures 2a, 2b, 2c), fibrous dysplasia and aneurysmal bone cyst.

3. Lesions suspected of being malignant that require staging for local spread and distant metastasis. Primary bone sarcomas fall under this group (Figure 3) [3].

Imaging Approach

A systematic approach is required for formulating a short differential diagnosis or suggesting a specific diagnosis. The approach starts with ruling out normal variants and benign processes which mimic neoplasm. This is followed by carefully going over a checklist to evaluate solitary bone lesions when a neoplasm is considered. This checklist includes the patient’s age, the location of the lesion, rate of growth or how aggressive the lesion is, tumor matrix, and finally, the type and characteristics of the periosteal reaction formed around the lesion [3-4].

The significance of knowing the patient’s age has been well emphasized in the literature. The majority of
Primary bone tumors occur between the second and fourth decades of life. A lytic bone lesion occurring in a patient above the age of 50 years should raise the possibility of metastasis (Figure 4a) or multiple myeloma (Figure 4b) whereas a lytic lesion in a child raises the possibility of Langerhans cell histiocytosis [1, 3] (Figure 5).

The anatomic location of the bone lesion provides significant clues to what the diagnosis might be. It is important to determine whether the lesion is epiphyseal, metaphyseal or diaphyseal. Does it originate from the medullary space, cortex or from the surface of the bone? The most frequent sites for metastasis and multiple myeloma are the spine, pelvis and ribs i.e. the axial skeleton. Primary bone tumors such as Ewing’s sarcoma or chondrosarcoma often occur in the pelvis. Chondroblastomas are classically located in the unfused epiphysis or apophysis but may present later (Figure 6). Osteoblastoma has a predilection for occurring in the posterior
elements of the vertebra (Figure 7). A lytic lesion in the subchondral bone of the knee epiphysis is most likely a giant cell tumor (Figure 8). Lesions of the sternum are almost always malignant, typically representing metastasis whereas the vast majority of patellar lesions are benign [3].

Rate of growth of the lesion also known as biologic activity determines whether the lesion is benign or malignant. This can be determined accurately by assessing the margin of the lesion. The margin of the lesion is a reflection of the relative aggressiveness of the neoplastic process. A well-defined lesion with or without a sclerotic margin (Figure 9) has a narrow zone of transition (between the lesion and the healthy native bone) and is unlikely to be aggressive [5-6].

A lesion with ill-defined margins has a wide zone of transition and most likely is an aggressive tumor. Less aggressive lesions are described radiographically as having a geographic pattern of bone destruction whereas highly aggressive lesions often have moth-eaten or
permeative patterns of bone destruction [5-6] (Figure 3, Figures 10a, 10b).

One of the most important features that help in categorizing a bone lesion is the tumor matrix [7]. The matrix is the acellular substance produced by the mesenchymal cells in the tumor. Absence of a radiographically discernible tumor matrix significantly limits our ability to come up with a specific diagnosis. Different matrices are produced by different tumors but only the chondroid and osteoid matrices become calcified and, therefore, are radiographically identifiable. On radiographs, the chondroid matrix reveals white dots, rings, c-shaped and popcorn like calcifications (Figure 11, see also Figure 2b). Such matrix is seen in cartilage forming tumors such as enchondroma, chondroblastoma and chondrosarcoma. Osteoid matrix has a confluent, cloud like appearance. It is seen in lesions such as osteoblastoma, osteosarcoma (Figure 12), myositis ossificans and fracture callus [7].

Another defining feature of solitary bone lesions is the type of periosteal reaction associated with the lesion. The current thinking pertaining to the periosteal reactions is shaped by the classic work of Edeiken and his co-workers [8]. Periosteal reactions can be divided into two types: solid or uninterrupted (Figure 13) and interrupted (Figures 3 and 14). There are subtypes under these two types. A solid periosteal reaction is almost always associated with
a benign lesion. An interrupted periosteal reaction signifies an aggressive lesion, and with few exceptions, such as a fulminant infection or a fast-growing aneurysmal bone cyst, it is almost always associated with a malignant tumor. Interrupted periosteal reactions are fairly complex and three subtypes have been described. These are the lamellated (or onion skin), sunburst (or spiculated) and amorphous. The lamellated periosteal reaction often produces a Codman’s triangle (Figure 14). The Codman’s triangle typically occurs where the tumor mass breaks out through the newly formed periosteal layers. The Codman’s triangle is not specific for malignant tumors although most commonly seen in such conditions. It can also occur with osteomyelitis and fast growing aneurysmal bone cysts. The sunburst and amorphous periosteal reactions are always associated with malignant lesions such as Ewing’s sarcomas (Figure 3) [8].

Some radiographic signs are diagnostic of certain tumors and can be very useful in arriving at an accurate diagnosis [3].

Ivory vertebra: This description is applied when the entire vertebra, especially the vertebral body appears densely sclerotic on radiography or CT scan. This appearance is highly suggestive of blastic metastasis such as in prostate carcinoma (Figure 15).

Corduroy pattern: Denotes the presence of a thick striated trabecular pattern in the lesion. It is highly suggestive of a hemangioma (Figures 16a, 16b).
The **Rind sign**: This indicates the presence of a thick cortical margin around the lesion (Figure 17). It denotes a benign, inactive or stable lesion and is often seen in association with small arrested foci of fibrous dysplasia typically located in the femoral neck.

**Ground-glass appearance**: Is a radiographic metaphor that describes expansile lesions that are neither lucent nor sclerotic, but rather ground glass in density. This appearance should raise the possibility of fibrous dysplasia (Figure 17).

The **fallen fragment sign**: This sign indicates the presence of a pathologic fracture in a simple cyst, typically in the humerus (Figure 18). To demonstrate this sign, the radiographic examination should be taken in the upright position to allow the fractured fragment to fall down and settle at the dependent portion of the cyst.

**Fluid-fluid levels**: These can be detected on MRI and sometimes on a CT examination. The sign is diagnostic of aneurysmal bone cyst or telangiectatic osteosarcoma (Figures 19a, 19b) [9].

Once the presumptive diagnosis of a malignant bone tumor is made, local staging should be performed before...
proceeding to a biopsy. All patients with malignant bone tumors should also be studied for distant metastasis, using a chest CT scan to rule out the presence of pulmonary metastasis.

RADIOLOGICAL APPROACH FOR IMAGING SOFT TISSUE TUMORS

There are four types of soft-tissue masses that patients can present with and they include: malignant soft-tissue tumors, benign soft-tissue tumors, inflammatory lesions, and posttraumatic masses such as myositis ossificans and false aneurysms. Patients with soft-tissue tumors usually present with painless palpable mass. The presence of a painful mass usually suggests an inflammatory process. Physicians invariably request a radiographic examination which rarely yields diagnostic information. The next step is usually an MRI which often helps in arriving at a differential diagnosis and occasionally a specific diagnosis [10-11].

The most common malignant soft tissue tumors are sarcomas and they include malignant fibrous histiocytoma (MFH), liposarcoma, fibrosarcoma and synovial sarcoma. Among these the MFH is the most common, accounting for about 24% of all soft-tissue sarcomas. Soft-tissue sarcomas are relatively rare, representing about 1% of all malignant tumors, but they are still about two to three times more common than malignant bone tumors [10-11].

Benign soft-tissue tumors are far more common than soft-tissue sarcomas. Lipoma, desmoid tumor (aggressive fibromatosis), hemangioma and nerve-sheath tumor are the most common benign tumors [12-13].

Soft-tissue tumors are typically solitary, however, some can present as multiple lesions. Lipoma, aggressive fibromatosis, neurofibroma and hemangioma can be multiple.

Certain lesions show a predilection for a specific anatomic location. This is true of epithelioid sarcoma where more than 40% of epithelioid sarcomas occur in the hand and wrist [11]. The majority of clear cell sarcomas occur in close relationship to tendons and ligaments.

Imaging of Soft-Tissue Tumors

Radiographs can sometimes reveal a homogeneous low density tumor consistent with fat-containing lesion such as lipoma. Calcifications and ossifications can also be detected radiographically. Calcifications are seen in about one-third of synovial sarcomas (Figure 20). Rounded calcifications or calcified phleboliths are often visible in hemangiomas (Figure 21).

Because of its improved soft-tissue contrast and multiplanar imaging capabilities MRI is currently considered
the imaging modality of choice for studying soft tissue masses. One drawback of MRI is its limited ability in providing tissue characterization for the majority of soft-tissue tumors and also its inability to differentiate benign from malignant lesions [14]. Soft-tissue tumors should be imaged in at least two orthogonal planes using T1 and T2-weighted sequences. T1-weighted fat-suppressed sequences without and with IV gadolinium administration are also helpful in differentiating solid from cystic masses or tumor necrosis. Arriving at a specific diagnosis based on MRI signal characteristics alone can be difficult. It is also often impossible to tell if a lesion is benign or malignant. Malignant lesions, however, are typically large (> 5 cm), deep and have inhomogeneous signal intensity on MRI [10, 12-13].

There are a small number of soft tissue tumors, mainly benign tumors, which have characteristic or diagnostic MRI findings and they will be discussed below [10, 12-13].

**Lipoma:** This is by far the most common benign mesenchymal neoplasm; it is the most commonly encountered soft-tissue tumor on MRI. Lipomas can attain a large size. On MRI, they have signal characteristics identical with subcutaneous fat where they exhibit high signal intensity on both T1- and T2-weighted images (Figures 22a, 22b). When a lipoma is within a muscle or between fascial planes, the diagnosis is almost always correctly made. With multidetector CT (MDCT) and its multiplanar and 3D capabilities, this modality can easily detect lipomas and delineate their extent. A well differentiated liposarcoma can present with MRI and CT findings resembling a lipoma, however, it has heterogeneous signals on MRI and thick septations between its fatty lobules.

**Liposarcoma:** This is the second most common soft-tissue sarcoma accounting for 16-18% of all malignant soft-tissue tumors [11]. The lesion occurs most commonly in the extremities, particularly the thigh. The CT and MRI appearance of liposarcoma correlates with the amount of fat in the lesion. Well differentiated liposarcomas contain more fat than less differentiated liposarcomas [11] (Figures 23a, 23b).

**Aggressive fibromatosis:** This lesion is characterized by the proliferation of fibrous tissue which can have locally aggressive behavior [12]. Aggressive fibromatosis has a tendency to recur after resection. In the limbs, the lesion can be single or multiple. The signal characteristics on MRI depend on its content of collagenous

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**Figure 22:** Subcutaneous lipoma involving the shoulder region posteriorly. Axial T1-weighted (a) and coronal T2-weighted (b) images showing a lesion that has high signal intensity similar to the subcutaneous fat. Few thin septations are noted within it.

**Figure 23:** Low grade liposarcoma involving the posterior thigh. Sagittal T1-weighted image (a) shows a predominantly high signal intensity lesion with areas of low signal (arrow) and few septations. On STIR image (b), the lesion shows low signal intensity regions denoting suppressed fat. However there are several non-fatty areas of high signal (arrows) due to cellular elements and fluid.
material. Lesions consisting primarily of acellular collagen have low signal intensity on T₁- and T₂-weighted images i.e. fibrous material (Figures 24a, 24b). Lesions rich in cellular elements show low signal intensity on T₁-weighted images and bright signals on T₂-weighted images.

Soft tissue hemangiomas: These are common soft tissue tumors representing 7% of all benign tumors. They can be subcutaneous, intramuscular or intrasynovial. Large-vessel (cavernous) hemangiomas have characteristic imaging appearance on MRI. On T₁-weighted images, the lesion contains areas of increased signal intensity which represent fat (Figure 25a). Hemangiomas typically show marked enhancement after gadolinium administration (Figure 25b). On T₂-weighted images, the lesion shows high signal intensity (Figure 25c) with sometimes serpentine or lobular vessels containing central low signal intensity dots which represent high velocity flow voids [11-12].

Nerve sheath tumors: Two histologic types are identified in the extremities and these are: benign schwannoma and neurofibroma. It is often difficult to differentiate these two tumors by MRI, but some clinical and imaging signs can be helpful. A schwannoma often involves the flexor surfaces of the extremities and it grows eccentrically from the nerve. Neurofibroma can be solitary or multiple, especially in patients with type 1 neurofibromatosis. It typically grows from the center of the nerve causing fusiform expansion of the nerve. Neurofibromas grow slowly, but when rapid growth is observed, malignant degeneration should be considered. On MRI, peripheral nerve sheath tumors show signals

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**Figure 24.** 22-year-old woman with recurrent soft tissue fibromatosis in the left thigh. Coronal T₁-weighted image (a) shows the lesion to be isointense to muscles with sheath-like areas of low signal (arrow). Coronal T₂-weighted image (b) shows the lesion to be of intermediate to high signal with similar sheath-like areas of low signal intensity corresponding to the most fibrous elements.

**Figure 25.** Soft tissue hemangioma of the right thigh in a 14-year-old male. Sagittal T₁-weighted image (a) shows an isointense soft tissue lesion with area of high signal content compatible with fat. Following IV gadolinium administration, sagittal T₁W image (b) shows intense heterogenous enhancement of the lesion. Axial T₂W image (c) : the lesion is of high signal with septations.
that are isointense to skeletal muscle on T\(_1\)-weighted images and hyperintense on fluid-sensitive sequences (T\(_2\)W, STIR images) (Figures 26a, 26b, 26c, 26d, 26e). After gadolinium injection, these tumors show variable degrees of enhancement [10-12].

**Elastofibroma dorsi:** This is a slow-growing pseudo-tumor of the soft tissues which typically occurs on the posterolateral aspect of the chest wall in the subscapular region. On T\(_1\)- and T\(_2\)-weighted images, this lesion is nearly isointense with muscle (Figures 27a, 27b). Because of the typical location and MRI signal characteristics, a specific diagnosis is almost always made and a biopsy should be avoided.

**WHOLE BODY MR IMAGING (WBMRI)**

MR imaging has been proven since its early use in the late 1980’s to be very sensitive in detecting bone marrow infiltration and bone involvement by various disease processes to much better extent than radiographs. The use of WBMRI as a screening tool for bone marrow infiltration has been advocated back in 1997, in particular with the use of turbo sequences. WBMRI has indeed proven its efficacy in the assessment of bone metastasis (Figure 28) [15] and multiple myeloma (Figure 29a, 29b) [16-17]. The sequences used vary to some degree and include mainly coronal fast short-tau inversion-recovery (STIR), and/or T\(_1\)-weighted images of the head and neck, chest, upper limbs, abdomen, pelvis.
Additional sagittal STIR and/or T₁-weighted of the spine [17] and axial T₁-weighted images of the skull are sometimes performed. Depending on the protocol used, total scan time ranges from 40 minutes to 1 hr 30 minutes when more than coronal views are used. WBMRI is also useful in the assessment of response to chemotherapy where IV gadolinium is sometimes used. The degree of enhancement was shown to reflect the response to therapy whereby decreased enhancement is compatible with good response [18].

WHOLE BODY CT SCAN (WBCT)

The advent of multidetector CT scan (MDCT) has resulted in the increased use of CT scan in the assessment of musculoskeletal diseases because of the capabilities of acquiring very thin cuts, and secondary 2D and 3D reconstructed images. CT interpretation using soft tissue or intermediate windows (in addition to the bone window setting) is very useful in detecting...
intramedullary lesions not causing cortical erosions (Figure 30a).

In the era of total body scanning, WBCT has been recommended in the workup of newly diagnosed patients with multiple myeloma [19-21], being more sensitive than radiographs. Other authors advocated however the use of Positron Emission Tomography (PET) in combination with CT scan (PET/CT) as the initial workup as well as for follow-up of patients with multiple myeloma (MM) [17].

A recent research by Horger et al. [22] showed encouraging results for the evaluation of the course of medullary lesions of MM at follow-up CT, including the assessment of lesion density and size. CT scan is also better than MRI for the assessment of fracture risk.

Besides, unpublished data shows a possible promising role of WBCT in detecting bone metastasis. The advantage of CT scan is that it assesses at the same time the chest, abdomen and pelvis for metastatic workup (Figures 30b, 30c).

Published data shows however the important use of the integrated PET/CT which has a very high positive predictive value for bone metastasis and lymphoma reaching 98% [23]. PET/CT and MRI have also equal sensitivity in detecting metastasis. In addition, WBCT is very effective in assessment of polytraumatic patients for detection of fractures, injuries to the organs within the chest, abdomen and pelvis in addition to evaluating the patency of the vascular tree.

SHOULDER PAIN AND ROTATOR CUFF DISEASE

Shoulder pain is a very common clinical presentation and is commonly due to rotator cuff disease (RC). Radiographic images are frequently normal in acute settings [24]. However, in cases with chronic symptoms abnormal findings can be encountered and these include soft tissue calcifications (Figure 31).
calcification over greater tuberosity (Figure 31), acromioclavicular joint osteoarthritis causing impingement rotator cuff tear and superior displacement of the humeral head.

Since its advent, MRI has been proven to be highly accurate in detecting RC injuries. It provides information about tear dimensions, thickness (partial versus full thickness; complete versus incomplete) and tendon retraction. In addition it helps in assessment of muscle atrophy information about coracohumeral arch and cause of impingement such as thick coracoacromial ligament and acromioclavicular joint osteoarthritis [25]. This helps in determining the treatment selection and prognosis [25].

Several sequences may be used. A tear (Figure 32) is seen as very high signal intensity focus within the tendon substance which is normally of low signal intensity on all sequences [25]. Muscle atrophy is seen as loss of muscle volume and fatty replacement being of high signal on $T_1$-weighted images.

More recently ultrasound (US) has been more frequently used in assessment of rotator cuff tendons and has proven to be a powerful and accurate method for detection of rotator cuff tear [24, 26]. Ultrasound needs state-of-the-art machine and operator expertise. On US, tendons appear as homogeneous hyperechoic bands. A tear is seen as hypoechoic area within the substance of the tendon (Figure 33a), discontinuity or tendon thinning. Ultrasound also assesses the presence of calcification (Figure 33b), fluid in the subdeltoid subacromial bursa or shoulder joint, muscle atrophy. Tendon degeneration is seen as inhomogeneity of tendon substance (Figure 33a). Use of dynamic imaging of the shoulder can reveal impingement on the supraspinatus tendon and abnormal humeral head translation.

Moreover, US-guided treatment of RC calcifications has been advocated percutaneously using fine needle. The technique consists of doing lavage and aspiration of the calcification after injecting Lidocaine near the calcification; then fragmentation and aspiration of the calcifications is done. The yield of this technique is quite effective in some series [27] (Figures 34a, 34b).
HIP Fracture

Hip fracture is a common traumatic disorder in particular related to motor vehicle accident. However, it has particular detection challenges in elderly patients where the radiographic changes may be subtle because of osteopenia (Figure 35a), or because the fractures may be non-displaced or incomplete fractures (Figure 36a). In addition, a traumatic event is not frequently elicited. Delay in detection of the fracture has a secondary high morbidity. Accurate and early detection of the fracture has been made easy by MRI (Figure 35b) which has a higher sensitivity than the plain radiographs [28-30]. MRI shows bone marrow edema appearing as low signal on T₁W images and high signal on T₂W and short-tau inversion recovery (STIR) images. A fracture line is of low signal on all sequences. Besides, MRI shows other unsuspected bone and soft tissue injury including pelvic bone fracture or contusions, surrounding muscle contusions and muscle and tendon tears [30].

With the advent of multidetector CT (MDCT) with 2D and 3D reconstructed images, CT scan is showing increased detection accuracy when compared to radiography and to analyzing axial scans alone (Figures 36b, 36c, 36d) [31]. But so far no comparative studies between MRI and CT scan were performed. CT can also assess details about fractures pertinent to surgical approach as well as associated acetabular fractures.

**Figure 35**

85-year-old lady with sudden severe right hip pain while walking.

**a.** Radiographs did not reveal definite fracture except for minimal sclerosis at the level of the right femoral neck (arrow).

**b.** MRI was then performed. Coronal STIR images revealed a low signal intensity line (arrowhead) corresponding to the sclerotic area on the radiograph and compatible with old insufficiency fracture. There was however a high intensity fracture line (arrow) lateral to it with surrounding bone marrow edema denoting acute fracture not seen on the radiograph. Soft tissue edema seen as high signal was also noted around the right hip.

**Figure 36.** 68-year-old man with right hip trauma.

**a.** Radiographs show suspicious linear fracture near the lesser trochanter (arrow). CT scan was then performed.

**b-c.** Coronal 2D reconstructed images show an anterior intertrochanteric fracture (arrow in b) extending posteriorly to reach the greater trochanter (arrow in c).

**d.** Coronal 3D reconstructed image nicely demonstrates the fracture (arrows).
OSTEOPOROSIS, SPINAL FRACTURES AND INTERVENTIONAL PROCEDURES

Primary osteoporosis is defined as skeletal disorder characterized by compromise of bone strength with diagnostic criteria of bone fragility based on measurement of bone mineral density (BMD) and/or presence of fracture. Four categories are present depending on the severity of abnormal BMD [32]. Osteoporosis is a major public concern and is the main cause of vertebral fracture (85%). For example, in the United States 30 million women and 14 million men are affected. The importance of this disease results from significant increased risk of fracture, the decrease in the quality of life, chronic back pain and limitation of daily activities [33]. In addition, the presence of vertebral fracture is a sign of increased risk of other fractures in the skeleton (spine, hip). Vertebral fractures are frequently undetected by clinicians and under diagnosed by radiologists, rendering the importance of recognizing these fractures on imaging. An important note is that unsuspected osteoporotic fracture may be detected by other imaging studies performed for other reasons (for example lateral chest X-rays) and hence should be mentioned.

Diagnosis of Osteoporosis

There are several methods to measure bone densitometry. The most commonly used techniques are dual energy X-ray absorptiometry (DEXA) and quantitative computerized tomography (QCT) [32]. DEXA utilizes an X-ray source that emits 2 photon beams of different energy and measures the differential absorption of energy from these beams by tissues. QCT has an advantage to selectively measure the trabecular and cortical parts of the vertebral body. But it is less used because of high radiation, limited availability and higher precision error.

Radiographic Diagnosis of Fractures

When dealing with osteoporotic fracture radiologists should not make diagnosis only on the basis of qualitative impressions. They are however encouraged to use a semi-quantitative approach described by Lenchik et al. [33] as seen on the lateral view. In this approach a mild fracture (grade 1) has a 20-25% loss of height; moderate fracture (grade 2) 26–40% loss of height (Figure 37), and severe fracture (grade 3) more than 40% loss of height.

Other Imaging Techniques

Although well centered plain radiographs are sufficient for the diagnosis of fracture, multidetector CT (MDCT) with sagittal reconstruction and MRI are very sensitive for the diagnosis.

MRI on the other hand is an important tool to differentiate benign from pathologic vertebral fracture, especially in elderly patients with osteoporosis. Signs of benign fracture include mainly normal bone marrow signal (Figure 38a), hypointense fracture line parallel to end-plate with or without bone marrow edema (Figures 38a, 38b, 38c), fluid or air within the fractured vertebra, and absence of paravertebral soft tissue mass (Figure 38d) [34-35].

Figures 37 and 38:

Figure 37. Osteoporotic fracture. Semi-quantitative method of measurement. Lateral radiograph. There is fracture of a mid thoracic vertebral body (arrow). Measuring the height between the black dots of the involved vertebra and the one lower to it, gives an estimate of the loss of height which is here around 38% (i.e. moderate). There is also decreased bone density in keeping with some degree of osteoporosis.

Figure 38. Benign vertebral fractures

a. Elderly patient with subacute back pain. Sagittal T₁-weighted MR image of the thoracic spine. There are fractures of several vertebral bodies with preserved bone marrow signal compatible with benign fractures. Hypointense line (arrow) is noted parallel to the upper endplate of a mid thoracic body compatible with fracture typically seen in benign conditions.

b-c. 82-year-old man known to have chronic anemia presenting with acute back pain. Sagittal T₁-weighted (b) and T₂-weighted (c) MR images of the spine showing diffused low intensity on T₁-weighted images due to red marrow reconversion. In addition, one vertebral body (arrow) shows a low signal intensity line seen on both sequences similar to that described in Fig. a. It is surrounded by bone marrow edema due to acute benign fracture.

d. Sagittal T₁-weighted MR image in an elderly patient with vertebral fracture. Fluid (arrowheads) is seen within the vertebral body typical for benign fracture.
Causes of Back Pain other than Osteoporosis

Back pain is the second most common clinical complaint encountered by primary care physicians [36]. There is a very wide spectrum of diseases causing back pain including degenerative, traumatic, infection/inflammation, neoplasm both benign and malignant, and conditions related to growth disturbances in pediatric population. However, it is beyond the scope of this article to discuss all these entities. In the radiological evaluation of back pain, initial imaging should always include plain radiographs which give an overall assessment in particular for degenerative change and alignment. MR imaging however has an established crucial role in the assessment of diseases causing back pain including degenerative disc disease, tumors, spondylodiscitis, early spondyloarthropathy, tumor extent in particular within the spinal canal and bone marrow infiltrative processes such as metastasis (Figure 39) and multiple myeloma (Figure 40). In fact, MRI is the best imaging modality to assess myeloma. In some instances it was also proven to be more sensitive than bone scan for the detection of bone metastasis [37-38].

Intravenous gadolinium is not routinely used for the assessment of back pain. However indications for its use include infectious diseases, postoperative spine, in the assessment of response to therapy in multiple myeloma, focal spine tumors and in limited cases of diffuse bone marrow changes in order to differentiate normal red marrow from tumor infiltration.

CT scan is helpful in some conditions such as determination of fracture risk in myeloma, extent of spinal fracture, spondylolysis and in the diagnosis and assessment of some tumors such as osteoid osteoma (see also section on WBCT).

Vertebroplasty and Kyphoplasty

During the last decade, two new therapeutic procedures were introduced for the treatment of vertebral osteoporotic fracture: percutaneous vertebroplasty and kyphoplasty [39]. These techniques have good short-term results regarding pain relief, functional status, correcting kyphosis and to prevent further rapid collapse. So far however, no data is available with regards to long-term results. Besides osteoporotic fracture, these interventions are also used to treat osteolytic metastasis and multiple myeloma causing vertebral collapse.

Technically, vertebroplasty (Figures 41a, 41b) con-
sists of placing a needle under fluoroscopic control within the vertebral body through a transpedicular or posterolateral approach. Then cement consisting of polymethylmethacrylate polymer (PMMA) is injected until resistance is felt by the operator or the cement reaches the posterior vertebral wall. This results in filling and expansion of the vertebral body. The overall complications are limited and include mainly cement leak. Neurological complications are rare. The kyphoplasty technique is an evolution of the vertebroplasty. It employs balloon catheters inflated with contrast agent to restore the morphology of the collapsed vertebral body reducing the kyphosis. Then stabilization with bone cement injection is done after removal of the balloon (Figures 42a, 42b, 42c).

With both techniques, more than one vertebral level can be injected with cement at the same session.

IMAGING OF THE DIABETIC FOOT

Diabetic foot is a broad term used to describe a variety of clinical problems affecting patients with diabetes mellitus. These problems are the result of vascular insufficiency, peripheral neuropathy and foot infections. Vascular disorders of the feet typically involve large and medium vessels causing atherosclerosis and microangiopathy of the skin and muscles.

Diabetic neuropathy of the foot, also known as Charcot’s foot or neuropathic joints, can involve the forefoot producing metatarsophalangeal and interphalangeal joint deformities, but is seen more commonly in the midfoot (Lisfranc’s joint) (Figure 43a) and hindfoot (subtalar and ankle joints). Fracture-dislocations of the Lisfranc’s joint along with flattening of the longitudinal arch of the foot are the most common features of neuropathic arthropathy in the diabetic foot (Figure 43b). Severe deformity of the ankle following a neuropathic fracture is another common radiographic finding in patients with a diabetic foot.

Probably the most difficult problem in terms of diagnosis and treatment is that of infections involving the soft tissues and the bones in the diabetic foot. Generalized and localized factors contribute to foot infections in patients with diabetes mellitus, including poor blood supply, abnormal sensation, and minor trauma. Soft tissue infections most often start in the toes. Cellulitis and abscess formation are commonly the result of skin infections. In the feet of diabetic patients, osteomyelitis is typically a chronic infection contiguous with a skin ulcer. Ulcers most commonly occur on skin areas with high pressure. In the bone, infection starts at the cortex and most patients with this form of osteomyelitis lack generalized symptoms. Abscess formation and sinus tracks are common in the soft tissues of the foot. Diagnosing osteomyelitis in the diabetic foot with imaging techniques has always been a challenge [40]. Radiography and MRI have become the
Figure 44
Diabetic foot infections

a-b. Osteomyelitis and septic arthritis involving the first metatarso-phalangeal joint (arrow). Radiograph (a) reveals significant destruction of the joint. Sagittal T1-WMR image (b) showing significant abnormal bone marrow signal at the level of the metatarsal head and base of the proximal phalanx with bone destruction. There is significant overlying soft tissue edema.

c. Different patient with 1st metatarso-phalangeal infection. There is an adjacent soft tissue abscess (arrow) seen on this axial T2-fat saturation MR image following IV gadolinium administration. Presence of fluid collection with thick rim enhancement is diagnostic of abscess.

d. Another patient with similar infection. Sagittal STIR image shows edema involving the 1st metatarsal head (M) and base of the proximal phalanx (P). Asmall sinus tract (arrow) extends from the level of the joint to the skin of the plantar aspect of the foot. Joint effusion is also present (arrowhead).

Modalities of choice in this regard. Radiography is still used as the initial examination where findings of osteopenia and bony erosions are highly suggestive of osteomyelitis (Figure 44a), but the sensitivity of radiography in the early stages of osteomyelitis is low and its ability in detecting soft tissue and marrow abnormalities is limited [40-42].

The usefulness of MRI for diagnosing osteomyelitis in patients with diabetic foot has been shown by several reports, however, the MR findings of osteomyelitis can be simulated by other pathologic processes affecting the diabetic foot. These include neuropathic osteoarthropathy and abnormal biomechanical stresses resulting from foot deformity. This makes the interpretation of signal abnormalities in the marrow difficult and often equivocal. Another confounding factor relates to the fact that many diabetic patients referred for imaging of their feet for osteomyelitis have underlying neuropathic bone changes which can resemble osteomyelitis on MRI [41].

To improve specificity of MRI some authors have classified the MR findings in osteomyelitis of the diabetic foot into two groups: 1) primary MR criteria, and 2) secondary criteria. The primary MR criteria include decreased marrow signal intensity on T1-weighted images (Figure 44b), increased marrow signals on T2-weighted images, and marrow enhancement after intravenous injection of gadolinium. Craig et al. [43] have stressed that such abnormal signals in the marrow should be intense and confluent in order to make the diagnosis of osteomyelitis with confidence. Other authors have shown that faintly dark signals or reticular non-confluent dark signals on T2-weighted images often do not represent osteomyelitis [42].

The importance of the secondary criteria lies in improving the specificity of the primary findings. These have been recently highlighted by some investigators [40-41]. They include: an adjacent soft tissue fluid collection, i.e., an abscess (Figure 44c), a sinus tract (Figure 44d), subcutaneous fat edema, cutaneous ulcer and cortical interruption.

The MR findings in Charcot’s arthropathy of the foot should be distinguished from those of infection and they include: preservation of normal subcutaneous fat, absence of soft tissue fluid collections, presence of subchondral cysts and intraarticular loose bodies (Figure 43a).

MUSCULOSKELETAL ULTRASOUND

With the technical advances, ultrasound has been playing an important role in the assessment of various musculoskeletal (MSK) diseases. When compared to MRI, the advantages of ultrasound (US) include: lower cost, better availability, better acceptance by patients, and no contraindication to its use. In addition, it has real time capability, so it can be used as a dynamic study [44].

It is evident from the literature that US is a cost-effective tool for focal problem solving issues and in guiding interventions. Although US cannot replace MRI in many indications (e.g., bone marrow disease, bone tumors) it should be the first line imaging modality for other indications such as rotator cuff diseases. The main indications for US include tendon disease mainly at the level of the shoulder and ankle (Figures 33a, 33b; Figure 45) [45-46], ligament injuries (e.g., ankle) [47], joint effusions (e.g., knee, hips, ankle), superficial foreign bodies [48], assessment of small joints for inflammatory arthropathy [49]. Ultrasound may be used also as an adjunct to MRI in the assessment of muscle injury and superficial MSK masses (e.g., Morton neuroma) (Figure 46).

It is important to know that to obtain best results with ultrasound, there is a need for state-of-the-art equipment.
and optimal examinations should be performed by experienced operators. Besides, ultrasound can be used as guidance for interventions such as injections in tendon sheath, subdeltoid subacromial bursa, joint or cyst aspiration, biopsy of superficial lesions and treatment of rotator cuff calcifications (Figure 34a).

REFERENCES


