CHAPTER 9

Musculoskeletal imaging

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Musculoskeletal imaging concerns itself with imaging of bones, joints, muscles, and peripheral nerves. This chapter will discuss the role of the different imaging modalities in the evaluation of the musculoskeletal system, the normal appearance of musculoskeletal-specific structures, and the critical concepts in the analysis of musculoskeletal examinations. Brief overviews of trauma, arthritis, tumors, and interventional procedures will follow.

Imaging modalities

Radiography
Radiographs of biological tissues result in four densities: air, fat, soft tissue, and bone. The variation in soft tissue density between that of water, blood, muscle, and other organs is so small that these cannot be differentiated on a radiograph. Many structures in the extremities are bordered by fat, allowing one to identify normal contours. Radiography is particularly suited to imaging bones for two reasons: the very large difference in density between the bone and soft tissue and their high spatial resolution. Radiographs are the workhorse of the imaging of the arthritis, the initial assessment of bone tumors, the evaluation of orthopedic instrumentation, and, of course, trauma. Due to the relatively low cost of radiographs and wide availability, radiographs serve as the initial diagnostic study for all musculoskeletal complaints.

Limitations of radiography include limited ability to evaluate complex three-dimensional structures (such as the cervical spine, the sacroiliac joints, and the complex fractures), limited ability to penetrate large volumes of tissue, and quite limited ability to evaluate soft tissue pathology.

Routine diagnostic radiographic examinations have at least two (anteroposterior and lateral) and often more projections that are tailored to the body part in question. The tangential patellar view (or “sunrise view”) of the knee, the mortise view of the ankle, and the outlet view of the shoulder are examples.

By convention, dense structures (such as bone) are bright on radiographs, whereas less dense structures (such as air) are dark.

Fluoroscopy
Fluoroscopy is a real-time radiographic imaging method using X-rays. The primary use of fluoroscopy in musculoskeletal radiology is to guide needles for joint injections/aspirations and bone biopsies. Fluoroscopy is often used intraoperatively to guide and/or evaluate the placement of orthopedic instrumentation. The primary limitation of fluoroscopy is the use of ionizing radiation.

By convention, fluoroscopic images are displayed such that dense structures are dark compared to less dense structures, which are bright—the inverse of the radiographic convention.

Computed tomography
Compared to radiography, in which all soft tissue regardless of whether it is muscle, tendon, blood, or water looks the same, computed tomography (CT) is able to detect much greater variations in soft tissue density, which leads to much greater contrast resolution. Different soft tissue types can often be differentiated, such as tendon versus muscle. The difference in density between blood products and simple fluid can also be detected. With intravenous contrast, abscesses can be detected and intramuscular masses can also be detected. Finally, the acquisition of the images is rapid, taking no more than several seconds for a focused examination, such as the shoulder. An entire body can be scanned in the setting of trauma in around a minute.

Cross-sectional imaging is particularly important for the evaluation of skeletal trauma, both for identification and characterization. Fractures of the pelvis and cervical spine may be difficult to see on radiographs, and the ability to review axial, coronal, and sagittal cross-sectional images is essential to make an accurate diagnosis. Characterization of complex fractures is much easier on CT and guides surgical management. Examples include acetabular fractures, tibial plateau fractures, and some ankle fractures. CT is often obtained to evaluate for intra-articular bone fragments following reduction of a joint dislocation when there is an associated fracture. Except in the setting of extremity infection and rare instances of soft tissue tumors, intravenous contrast is not routinely used in musculoskeletal imaging.
Limitations of CT include insufficient soft contrast for the specific characterization of many abnormalities, metal artifact, and radiation exposure. Metal artifact results in streaks of apparent high or low density due to the interaction between the reconstruction algorithm and the marked disparity in density between metal and adjacent tissue, including the bone.

Magnetic resonance imaging
Magnetic resonance imaging (MRI) is the standard imaging modality for internal derangement of joints, bone marrow imaging, and tumor imaging. The primary reason for MRI’s importance in musculoskeletal imaging is its unparalleled soft tissue contrast. Like CT, MRI has the ability to evaluate complex three-dimensional structures, such as the sacroiliac joints, though CT retains an edge in evaluating bone anatomy and mineralized tissue (such as mineralized tumor matrix).

Differentiating normal from abnormal tissues in musculoskeletal MRI is achieved by exploiting the concept that pathology, due to its association with free water, is bright on T2-weighted images and dark on T1-weighted images. Fat, on the other hand, is bright on both T1- and T2-weighted images. To make pathology stand out from fat, T2-weighted images are fat suppressed (bright pathology on a dark background), whereas T1-weighted images are not (dark pathology on a bright background) (Figure 9.1).

A few specific situations in musculoskeletal MRI involve the use of contrast material. For questions regarding infection or evaluation of tumors, intravenous contrast is used. MRI performed with intra-articular contrast is referred to as MR arthrography.

MRI has a number of limitations. First, due to its dependence on a uniform magnetic field, anything that distorts the magnetic field will affect the image. The most important situation that affects MR image formation is the presence of indwelling metal, such as a hip prosthesis. Although usually minor, motion artifact caused by patient movement may also be problematic on MRI.

All musculoskeletal MRI examinations involve a combination of T1- and T2-weighted sequences, often in more than one plane. Specific details and combinations may differ depending on the body part or clinical question. The vast majority of musculoskeletal examinations are for internal derangements, and routine protocols have been developed for every joint; these protocols do not employ intravenous or intra-articular contrast. For cases involving the administration of intravenous contrast, the routine protocols are often pared down to allow for the additional sequences needed to evaluate for tissue enhancement while still imaging the area in a reasonable amount of time.

Ultrasonography
Ultrasonography (US) is a real-time imaging modality based on the use of high-frequency sound waves and processing their reflections. The high resolution achievable with modern ultrasound equipment allows excellent characterization of tendons, ligaments, and nerves. Achievable resolution is directly proportional to the frequency of the sound wave—high resolutions require the use of high frequencies. Unfortunately, the depth of tissue penetration decreases with increasing frequency. As a result, high-resolution ultrasound excels in the evaluation of superficial structures, such as the rotator cuff of the shoulder. Another clinical advantage of ultrasound in comparison to the other modalities discussed here is the ability to perform dynamic evaluation of joints. Stress imaging, which can also be performed with fluoroscopy, can easily be performed with ultrasound without the radiation exposure. The real-time nature of sonography also lends itself well to guidance for percutaneous procedures. Additional advantages are low relative cost and portability.

The normal soft tissues of the musculoskeletal system have readily identifiable echotextures. Muscle in the short axis has a “starry sky” appearance, tendons and ligaments in the long axis have a fibrillar appearance, and nerves in the long axis have a fascicular appearance. Simple fluid, for example, joint fluid, is anechoic. Figure 9.2 shows the normal sonographic appearance of the patellar tendon and bony attachments and a subdeltoid fluid collection before and after aspiration.

Limitations of US include limited depth of penetration, inability to image through bone, anisotropy, and operator dependence. As discussed previously, high-resolution imaging is best reserved for superficial structures. The deeper a structure is from the skin surface at a particular frequency, the less signal is received back at the transducer to form images. This is a particular problem for deep tendons, such as the iliopsoas tendon, and in obese individuals at all sites. An oft-cited limitation of musculoskeletal sonography is operator dependence.

Sonography lends itself best to targeted examinations, such as the rotator cuff or lateral ankle. Most regions have a set of well-defined structures that need to be evaluated. For example, the rotator cuff examination includes evaluation of the long head of biceps tendon, the rotator cuff muscle bulk, and the acromioclavicular joint. The lateral ankle examination includes evaluation of the peroneal tendons, the lateral ankle ligaments, and the sinus tarsi.

Radionuclide imaging
Radionuclide imaging is a metabolic imaging modality wherein a tissue-specific radiotracer is injected and images are acquired after the radiotracer has had time to accumulate in the target tissue.
Radionuclide imaging for the musculoskeletal system is reserved for two general situations: evaluation for osseous metastatic disease and as a substitute for MRI when contraindications to MRI exist. The two most common radionuclide examinations are the technetium-99m methylene diphosphonate (MDP) “bone scan” and fluorodeoxyglucose (FDG) positron emission tomography (PET). In both cases, a radiotracer is injected intravenously and the patient is imaged at a later time, 3 h for the “bone scan” and on the order of an hour for PET/CT. The bone scan radiotracer is taken up by areas of elevated bone turnover, such as might be seen in metastatic disease, fractures, or degenerative diseases. The PET radiotracer FDG is taken up by areas of elevated glucose metabolism. As such, both of these processes are sensitive, but not particularly specific. Both imaging studies represent metabolic activity and need to be correlated with anatomic imaging. Bone scans need to be interpreted in conjunction with contemporary radiographs or other anatomic cross-sectional imaging modality (CT or MRI).

Today, PET images are routinely acquired with CT images in the same scan to provide anatomic localization.

The primary limitations of radionuclide bone scan and PET/CT are low spatial resolution and whole-body radiation dose. Spatial resolution for the bone scan is on the order of 10 mm, which can make lesion localization difficult. The low-resolution and nonspecific nature of the bone scan eventually led to its replacement by MRI for all indications except whole-body assessment for metastatic disease. PET/CT is reserved for metastatic disease assessment, especially when nonosseous metastases are common, the bone scan is equivocal, or the process is normally “cold” on bone scan.

**Appearance of normal tissues**

In this section, the normal appearances of bone, muscle, tendon, ligament, articular cartilage, fibrocartilage, and peripheral nerve will be discussed. Knowledge of the normal appearance is essential to identifying pathology.
Bone
Bone is a complex tissue composed of both mineralized and nonmineralized components. The nonmineralized component is composed of extracellular matrix, osteoid, and a variety of cells, mainly osteoblasts and osteoclasts. Osteoblasts and osteoclasts are cells responsible for bone deposition and resorption, respectively. The general architecture of bones is a dense outer layer, the cortex, and a less dense inner layer, the medullary cavity. The nonmineralized spaces in the medullary cavity are bordered by thin spicules of bone called trabeculae. These spaces are filled with hematopoietic marrow early in life and are near completely replaced by fat in adulthood. Bone constantly undergoes remodeling in response to its load environment. Blood supply reaches the medullary cavity via nutrient foramina that penetrate the cortex.

The periosteum is a connective tissue layer that invests bones and is rich with blood vessels, nerves, as well as osteoblasts and osteoclasts. This layer plays an essential role in fracture healing but also can be stimulated by inflammatory processes and tumors:

- Imaging methods based on X-rays exploit the relative difference in density between the cortex and medullary cavity. The edges of the bone always appear much denser than the central portion because the medullary cavity is confined to the center of the bone. The inner and outer layers of the cortex are always smooth with abrupt transitions in density between both the external soft tissues and the medullary cavity of bone.
- The fine network of trabecular bone is often able to be visualized on radiographs and to varying degrees on CT.
- On MRI, mineralized tissue appears dark, regardless of its nature. As cortical bone represents highly mineralized tissue, cortical bone is uniformly dark on both T1-weighted and T2-weighted images. In adults, the medullary cavity is filled with fat and is therefore bright on both T1-weighted and T2-weighted images. Hematopoietic marrow appears somewhat darker than normal fat, but never darker than skeletal muscle. The trabecular bone can occasionally be seen, particularly in the periphery of the marrow cavity. Certain sequences make the trabecular structure more apparent but potentially at the expense of soft tissue information.
- As the soft tissue–bone interface represents a large change in acoustic properties, the vast majority of sound is reflected back to the transducer. Bone, therefore, appears as a bright line on sonographic images with minimal, if any, detail beyond the bone surface.
- Normal periosteum is not visible on any imaging modality.

Muscle
Muscle is composed of a relatively uniform population of myocytes, which are organized into fibers and fascicles, which are collections of fibers; a small amount of fat may occasionally interdigitate between the muscle fascicles. Muscles are covered in a thin connective tissue layer known as fascia.

The transmission of the contractile forces to the tendon and ultimately to the bone occurs initially at the myotendinous junction. This junction may be centrally located in the muscle or may even be at the periphery of the muscle, such as might be seen in the gastrocnemius and soleus attachments to the Achilles tendon or the rectus femoris muscle:

- The modalities most suited to imaging muscle are MRI and ultrasound.
- On MRI, muscle is of a uniform brightness “intermediate” between fat and bone. Small penetrating vessels can often be seen. For the evaluation of bone marrow abnormalities and soft tissue masses, the intensity of muscle serves as an internal referent, abnormalities being isointense, hyperintense, or hypointense to muscle. Subtle pathologic findings are often evident on fluid-sensitive sequences when they are not seen on other sequences or modalities.
- In cross section, muscle has a “starry sky” appearance on sonographic images. All the tiny fascial septa investing the muscular subunits create acoustic reflectors that are easily seen on ultrasound. In the long axis, muscle has a characteristic striated appearance.
- Muscle appears to be of generally uniform density on CT occasionally with wisps of interdigitating fat. Muscle has a density between that of proteinaceous fluid and blood with considerable overlap. With the addition of intravenous contrast, penetrating vessels can be identified.
- On radiographs, muscle looks like any other soft tissue structure, including fluid and blood. Muscles are identified by their silhouette against the very low-density subcutaneous adipose tissues.

Tendon
Tendons are a connective tissue that efficiently transmit the contractile forces generated by muscle to bone. They are composed of a highly ordered array of collagen fibrils, noncollagenous matrix, and a few cells. At the muscular end of the tendon, they interface with muscle tissue at the myotendinous junction. At the bone end of the tendon, they interface with bone at the enthesis. The enthesis represents a very short, but very strong, interface between tendon and bone:

- Tendons are best imaged using sonography and MRI (Figure 9.3).
- Sonographically, tendons have a highly ordered fibrillar appearance. Bright lines are thought to represent collagen fibers, and dark lines likely represent noncollagenous matrix. In cross section, tendons appear to have bright speckles on a relatively hypoechoic background. The sound beam must strike tendon at exactly 90° or the reflected sound waves are directed away from the transducer resulting in artifically low signal, a property known as anisotropy.
- On MRI, tendons are, in general, uniformly dark on both T1-weighted and T2-weighted images.
- Tendons are only visible in a few places in the body on radiography. The patellar tendon and Achilles tendon are profiled both anteriorly and posteriorly by fat, allowing the soft tissue density of the tendon to stand out.
- Tendons on CT are denser than muscle and are often readily visualized. For both radiography and CT, the density of associated pathology is usually similar enough to the density of the tendon that a specific determination of the abnormality is not possible.
- The normal peritendinous tissues are, in general, not visible on any imaging modality.

Ligament
Ligaments connect bone to bone at joints and provide stability at the joints. Ligaments are very similar structurally to tendons, though they are much thinner than tendons. The ligament–bone interface is called the enthesis, similar to the tendon–bone interface. Due to their association with joints, ligaments may represent focal areas of thickening within a joint capsule, such as the inferior glenohumeral ligament of the shoulder or the medial patellofemoral ligament of the knee. The joint capsule can be considered a specialized form of ligament but is lined internally by synovial tissue:

- Ligaments are best evaluated by MRI and sonography (Figure 9.4).
- On MRI, ligaments appear either as dense, linear bands of hypointensity on both T1-weighted and T2-weighted images or, if the ligament is thin enough, as a striated band of tissue. All major ligaments at the joints are readily appreciated on MRI.
**Figure 9.3** Normal patellar tendon. Longitudinal MRI (a) and US (b) and short-axis MRI (c) and US (d) images of the patellar tendon. White arrows point to the posterior border of the tendon. The MR images demonstrate a well-defined uniformly hypointense/dark linear band coursing from the patella to the tibia.

**Figure 9.4** Normal medial collateral ligament. Coronal T2-weighted fat-suppressed MRI (a), long-axis medial collateral ligament US (b), and coronal CT (c) images show a normal medial collateral ligament. The arrows show the deep border of the ligament on these images. On MRI, the ligament is a thin uniformly dark band of tissue. On US, the ligament is thin with a barely discernible fibrillar structure. On CT, the ligament is slightly more dense than surrounding tissue. The ligament in (d) is no longer distinct due to surrounding fluid and soft tissue edema secondary to trauma (note the fractured tibial plateau); the status of the ligament cannot be determined in this case.
Sonographically, ligaments have a similar striated/fibrillar appearance as tendons and also exhibit anisotropy. All superficial ligaments are readily evaluated sonographically, but deep ligaments, such as the anterior cruciate ligament (ACL), cannot be seen. Normal joint capsules are easily seen on both MRI and ultrasound.

- Large dense ligaments, such as the posterior cruciate ligament, can be seen on CT and have a similar density to tendons. Ligaments are otherwise not routinely visible on either CT or radiography.

**Articular (hyaline) cartilage**

Hyaline cartilage provides some degree of shock absorption and a low-friction environment so that articulating bones may move without damage. At the bone–cartilage interface, there is a region of calcified cartilage before its transition to the mineralized subchondral bone. The transition between the mineralized cartilage and nonmineralized cartilage is known as the tide mark:

- Articular cartilage is best imaged by MRI.
- Normal cartilage has a smooth surface and a layered appearance on T2-weighted, including proton density (PD), images.
- Articular cartilage is superficial enough to be evaluated sonographically in a few locations such as the femoral trochlea and the anterior talar dome. Normal cartilage appears uniformly anechoic. Articular cartilage has soft tissue density on radiographs and on CT. On routine radiographs, cartilage can be inferred on weight-bearing radiographs by the fact that the bones do not touch, but otherwise appear lucent.

- On CT, there is insufficient contrast difference between synovial fluid and cartilage to adequately assess the cartilage. Visualization of cartilage on radiography and CT requires intra-articular contrast, either air or iodinated contrast, to make out the cartilage interface. Figure 9.5 shows examples of the normal appearance of hyaline cartilage on MRI, US, and CT arthrography. ("Hyaline" refers to the glass-like appearance of thinly sectioned cartilage at histopathology, not its radiographic appearance.)

**Fibrocartilage**

A number of fibrocartilage structures exist in the body, including the knee menisci, the glenoid and acetabular labrums, the triangular fibrocartilage of the wrist, and the discs within the pubic symphysis and temporomandibular joints. The knee menisci and the glenoid and acetabular labrums represent dense connective tissue structures formed into either a complete ring in the case of the glenoid labrum or incomplete rings in the case of the menisci and acetabular labrum. These rings serve to deepen the socket in which the ball, femoral condyle in the case of the knee, sits thus decreasing unwanted motion (subluxations) at these joints. In addition to helping to stabilize the joint, the knee menisci help to distribute load across the entire joint as the actual contact point between the femoral condyle and tibial plateau is quite small. The triangular fibrocartilage of the wrist serves predominantly as a load distributor:

- MRI is the preferred method for evaluation of the knee menisci as well as both the glenoid and acetabular labrums (Figure 9.6).
These structures normally have very distinct margins and are quite dark on both T1-weighted and T2-weighted images.

- The morphology is best depicted in the knee where the menisci appear as hypointense triangles at the periphery of the medial and lateral tibial plateau; the base of the triangle is oriented toward the periphery, and the apex of the triangle is oriented toward the inside of the joint. The glenoid and acetabular labrums have a similar appearance but may be more rounded in appearance.

**Peripheral nerve**
The peripheral nerves represent bundles of axons, each surrounded by insulating Schwann cells, bundled together by connective tissue. Nerves are usually surrounded by fat, and they usually follow blood vessels destined for the same body region as part of a neurovascular bundle:

- The peripheral nerves are best imaged with US and MRI (Figure 9.7).
- The sonographic appearance of nerves is often described as “fascicular”: hypoechoic tubes in a hyperechoic background. The hypoechoic tubes are generally uniform in size.
- The appearance on MRI is quite similar to the sonographic appearance: grouped hypointense lines surrounded by bright fat. The presence of surrounding fat is extremely useful for the identification of nerves, so non-fat-suppressed sequences are used when nerve anatomy is important to evaluate.

Figure 9.6 Normal fibrocartilage. Sagittal PD-weighted (a), coronal T2-weighted fat-suppressed (b), axial T1-weighted fat-suppressed (c), and sagittal T1-weighted fat-suppressed arthrogram (d) MR images of fibrocartilage. The knee menisci (a and b) and the glenoid (c) and acetabular (d) labrums normally have a well-defined triangular appearance (arrows). The sagittal image in (a) demonstrates the normal appearance of the anterior and posterior horn of the lateral meniscus. The coronal image in (b) demonstrates the normal appearance of the medial and lateral meniscal body. The axial image in (c) shows the normal appearance of the anterior and posterior glenoid labrum at the equator of the glenoid. The sagittal image of the hip in (d) shows the normal anterior acetabular labrum.
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Critical concepts in musculoskeletal imaging

Several fundamental concepts are essential to keep in mind. First, some types of infection are emergency conditions that require immediate action. Second, normal radiographs do not exclude the diagnosis of fracture. Third, the distinction between bone-centered and joint-centered diseases will help to tailor the differential diagnosis for a finding. Fourth is the determination of whether a process is localized or systemic.

Infectious emergencies

Septic arthritis, gas gangrene, and necrotizing fasciitis are extremely destructive processes requiring emergent intervention. Recognizing these conditions is essential to preserve the function of joints (septic arthritis) and soft tissue (gas gangrene/necrotizing fasciitis).

Septic arthritis

As untreated infection of a joint can lead to rapid destruction of that joint, rapid establishment of a diagnosis is essential to preserve the articular cartilage. When an infected joint is suspected (severe joint pain, fever, elevated serum inflammatory markers), an aspiration will need to be performed to establish a definitive diagnosis:

- Often, the aspiration is performed by a musculoskeletal radiologist using fluoroscopic or ultrasound guidance.
- In cases of indeterminate clinical suspicion, an MRI or ultrasound may be obtained prior to aspiration to establish the presence of a joint effusion.

Aspirated fluid is sent for cell count and differential in addition to Gram stain and culture. Unfortunately, the Gram stain often shows no organisms and the culture may take too long to produce a result. The cell count with differential has excellent accuracy for diagnosing joint infection and has successfully guided management of suspected joint infections. In cases where minimal fluid is obtained, preference is often given to the cell count over the culture and Gram stain.

Figure 9.8 depicts septic arthritis and an example of the effect of delayed treatment on a joint.

Soft tissue infections requiring emergent intervention

Two types of soft tissue infections require emergent intervention to limit morbidity and prevent death: necrotizing fasciitis and gas gangrene. Both are associated with soft tissue gas, which are readily detectable on radiography and CT and play a central role in the diagnosis of these conditions. Necrotizing fasciitis is an infection of the...
subcutaneous tissues and the superficial and deep fascia. Gas gangrene, also known as septic myonecrosis, is an infection of muscle. While both entities occur after a traumatic event causing a disruption of the skin, the injury may not be apparent in the case of necrotizing fasciitis. The vast majority of cases of necrotizing fasciitis occur in people who are overtly immunosuppressed or who have relative immunosuppression as might be seen in diabetes, chronic alcohol abuse, and malignancies. Necrotizing fasciitis has also occurred following surgical procedures, such as cesarean section, though this is rare. Gas gangrene is associated with direct inoculation of muscle through an open wound with soil.

Necrotizing fasciitis is usually polymicrobial, while gas gangrene is mostly associated with *Clostridium perfringens*, though it can be caused by any soil-based anaerobe. *Clostridium perfringens*, and other clostridial species, causes direct muscle injury through the production of exotoxins that destroy the muscle. Exotoxins play a role in tissue necrosis with infection by other organisms:

- The most specific imaging finding in these conditions is the presence of soft tissue gas. Large collections of gas are readily identifiable on radiographs, but tiny bubbles of gas may only be detectable on CT.
- Gas usually results in complete signal dropout on MRI; large collections are easily identifiable, but small bubbles may blend in with the surroundings, as fascia is often dark on all sequences as well.
- The gas in necrotizing fasciitis is usually located along the fascial planes, often adjacent to the superficial fascia. The gas in gas gangrene is intramuscular.

Figure 9.8 Septic arthritis. Septic arthritis associated with implants is a feared complication as the implant has to be removed (a). In this case, there are a large joint effusion, overlying soft tissue swelling, and, most importantly, erosion of the undersurface of the anterior femoral component (arrow). The presence of gas in a joint (b), such as in this knee, is due either to a recent surgical procedure, penetrating trauma, or gas-forming organism. On MRI, a large effusion with synovial hypertrophy and underlying bone marrow edema is concerning for infection as seen on this axial postcontrast T1-weighted fat-suppressed image (c). In (d), the patient had delayed diagnosis and treatment of third digit metacarpophalangeal joint septic arthritis that resulted in joint space loss (compared to the adjacent digits) and irregularity of the articular surface.
While gas is best appreciated on radiographs and CT, the soft tissue findings of both necrotizing fasciitis and gas gangrene are best appreciated on MRI.

- CT is very insensitive to muscle pathology due to the considerable overlap in densities between normal and abnormal tissues. The main difference between the two entities is the epicenter of infection: the subcutaneous tissues and fascia for necrotizing fasciitis and a muscle for gas gangrene.
- Fascial edema is manifested by fluid-intensity brightness in the fascia on MRI and effacement of normal fat planes on CT.
- In necrotizing fasciitis, there is often adjacent muscle edema. In septic myositis/myonecrosis, infected tissue demonstrates high signal on T2-weighted images. Contrast-enhanced MRI will show marked enhancement of inflamed tissue (muscle and/or fascia). Complete lack of enhancement is consistent with necrotic tissue.
- Contrast-enhanced CT is often not helpful except to identify abscesses.
- Findings of cellulitis often accompany necrotizing fasciitis and gas gangrene and are characterized by increased soft tissue density (CT) or increased signal on T2-weighted images (MRI) within the subcutaneous tissues.
- On US, fascial planes may become hypoechoic and adjacent muscle may become hyperechoic, a nonspecific sign of muscle injury. Soft tissue gas is, however, readily identifiable sonographically as numerous hyperechoic foci with posterior often hyperechoic streaking oriented along a fascial plane.

Figure 9.9 demonstrates the appearance of soft tissue gas in the setting of necrotizing fasciitis and gas gangrene on US, CT, and MRI.

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Figure 9.9 Soft tissue gas on US, CT, and MRI. On US, soft tissue gas appears like bright foci with the so-called “dirty” posterior acoustic shadowing as seen in this case of necrotizing fasciitis (a) where the gas bubbles are arrayed along the superficial fascia. On CT, gas is readily identifiable as completely black areas. In (b), there are large collections of gas in the subcutaneous tissues as well as a gas-containing abscess. On MRI, gas is represented by tiny round foci of little to no signal on all sequences. In the case shown here, the sagittal STIR image (c) depicts a collection (arrows) of bright material interspersed with innumerable tiny dark dots representing an abscess containing gas. From the same case as (c), the axial T1-weighted fat-suppressed image following the administration of contrast (d) shows a somewhat ill-defined low-signal region dissecting from the dorsum of the foot to the plantar aspect between the first and second metatarsals. The tiny foci of lower signal correspond to bubbles of gas.
Normal radiographs in the setting of trauma
A normal radiograph after trauma is due to one of two possibilities: the body part in question is normal, or the body part in question is fractured, but simply not detectable on the radiograph. There are two reasons for negative radiographs in the setting of a fractured bone: the fracture is nondisplaced or the fracture plane is not profiled in any of the obtained projections:
- When the fracture is still thought to be likely, appropriate management and repeat radiographs at least 14 days from the date of the injury can be obtained.
- Alternatively and depending on the clinical circumstances, an MRI can be obtained.

Fracture healing occurs in two phases: an osteoclastic phase and an osteoblastic phase. The osteoclastic phase is characterized by resorption of bone about the fracture site. In adults, the peak of osteoclastic activity occurs 2 weeks following injury:
- Imaging at this time or later would hopefully make the fracture visible as a new radiolucent line at the site of the fracture.
- The osteoblastic phase begins 1–2 weeks after the osteoclastic phase resulting in the formation of callus, which is visible radiographically (Figure 9.10). In children, this process is dramatically accelerated.
- CT may be helpful in the case where the fracture plane is not adequately profiled as can be observed on occasion in the acetabulum. The resolution of CT is less than that of radiography, so truly nondisplaced fractures will still not be seen on CT.
- MRI excels at the identification of fractures not because it is better at detecting the fracture line, but because it is able to visualize the marked surrounding reactive bone marrow edema. There is often a corresponding hypointense line on T1-weighted images that more closely corresponds to the fracture line; seeing this line surrounded by bone marrow edema is consistent with a fracture. If one does not see this line, contusion could also be entertained.

One scenario is worth specific mention. When a person over the age of 70 falls on their hip and radiographs are negative for a fracture, MRI should be obtained (Figure 9.11). The primary reason for this is that the morbidity and mortality following an undiagnosed and subsequently displaced hip fracture are extremely high. Rapid diagnosis and treatment are thought to mitigate against these dismal outcomes. In addition to the previously stated reasons why fractures may be occult on radiographs, people over the age of 70 often have osteopenic bones, making it even more difficult to identify trabecular disruption:
- These fractures are also often occult on CT.
- Unfortunately, the elderly are more likely to have contraindications to MRI (e.g., cardiac pacemakers, spinal cord stimulators, and the like), so CT is often the next step in these individuals.
- Alternatively, a radionuclide bone scan can be performed several days later (to allow the healing process to ramp up to a level that would be visible in the setting of osteopenic bones).

A radiographic sign of a nondisplaced, radio-occult fracture worth mentioning in this context is the presence of an effusion. Effusions are not well seen except in a few locations in the body, most notably the knee and the elbow. In the knee, a lipohemarthrosis indicates the presence of a fracture (Figure 9.12); fat can only enter a joint when there is an open path from the bone marrow into the joint. In the elbow, the elevation of the anterior and/or the posterior fat pad of the distal humerus is consistent with an effusion and, in the setting of trauma, most often indicates a radio-occult/nondisplaced radial head fracture.

Bone-centered versus joint-centered disease
Bone pathology adjacent to the joints may either be due to pathology originating within the joint itself or in the bone adjacent to the joint. Establishing whether the underlying process originates within the bone adjacent to the joint or from within the joint itself will help to focus the differential diagnosis.

The classic example of a bone-centered process that might be mistaken for a joint-centered process is osteonecrosis. Osteonecrosis often results in findings similar to osteoarthrosis (OA) as the disease progresses. Given that OA is far more common than osteonecrosis and given the overlap in imaging findings between these two entities in the later stages of disease, particularly radiographically, it would be easy to incorrectly assign the findings to OA. OA is characterized by a progression from cartilage destruction leading to loss of joint space, subchondral sclerosis, and subchondral cyst formation occurring generally equally on

Figure 9.10 Time course of healing of a nondisplaced radio-occult intra-articular base of thumb metacarpal fracture. The initial radiograph (day 0) shows no evidence for fracture and was read as normal. Again, on the subsequently obtained radiograph (day 16), the fracture remains occult. Not until the next radiograph (day 31) is the presence of a fracture revealed by the presence of a small amount of callus along the ulnar aspect of the base of the metacarpal. The amount of fracture callus is noticeably increased on the final image in this series (day 43).
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both sides of the joint. Osteonecrosis is characterized by bone marrow infarction, followed by increased bone density/sclerosis. As the disease progresses, there is progressive involvement of the articular surface that eventually leads to subchondral fracture and articular surface collapse. Articular surface collapse results in an incongruent articular surface leading to cartilage destruction and, ultimately, the classic findings of OA. Even in this case, there is often greater involvement on the side of the joint in which the osteonecrosis manifested. Figure 9.13 illustrates the radiographic progression of femoral head osteonecrosis.

Localized versus systemic disease

The clinical implications of bone findings when found in multiple bones are often quite different than when found in a single bone. Syndromic and other systemic conditions are often, but not always, known at the time of the first identification of a multifocal/polyostotic bone lesion. It is therefore important to recognize that a polyostotic process is present. Similarly, implications for an arthrosis affecting a single joint (monoarticular) are quite different from one affecting many joints (polyarticular). Two examples will be illustrated here: fibrous dysplasia and periosteal reaction.

Figure 9.11 MRI of a nondisplaced intertrochanteric hip fracture. Coronal T1-weighted (a) and fat-suppressed T2-weighted (b) images demonstrate a nondisplaced left intertrochanteric femur fracture; the radiographs were negative for fracture. Note the well-defined hypointense curvilinear region through the intertrochanteric region of the left proximal femur that corresponds to the fracture itself (arrow). In (b), the reverse situation is true: the fracture and surrounding bone marrow edema are quite bright in comparison to the normal fat-suppressed bone marrow (arrow).

Figure 9.12 Lipohemarthrosis—radiograph versus CT. Lateral radiograph (a) and axial CT (b) depictions of a blood- and fat-filled knee effusion (lipohemarthrosis) following tibial plateau fracture. The distinction between the synovial fluid and blood cannot be made on a radiograph, but can be made on CT due to its higher contrast resolution.
A variety of bone tumors may have associations with syndromes or have other clinical implications, such as increased risk for malignancy, when found in more than one bone. A classic example is fibrous dysplasia. Polyostotic fibrous dysplasia is associated with the endocrine disorder McCune–Albright syndrome, whereas a solitary area of fibrous dysplasia will have only localized effects (Figure 9.14).

Periosteal reaction is a nonspecific finding that is typically a reaction to an inflammatory process. Cellulitis and stress fractures are commonly seen localized causes for periosteal reaction. Certain bone tumors are also associated with localized periosteal reaction. One systemic cause for a polyostotic periosteal reaction is an entity known as hypertrophic osteoarthropathy, which is often associated with pulmonary disease. The association with pulmonary malignancy is high; polyostotic periosteal reaction should always raise the possibility of lung cancer (Figure 9.15).

**Musculoskeletal trauma**

Musculoskeletal trauma is very common ranging from visually obvious fractures and dislocations resulting from high-energy impacts to more subtle soft tissue injuries. The vast majority of fractures and dislocations can be diagnosed radiographically, whereas soft tissue injuries often require MRI to make a definitive diagnosis.

**Fractures and dislocations**

Any bone in the body may be fractured and any joint may be dislocated:

- Radiographs are the initial and often only imaging modality needed for diagnosis.
- Occasionally, CT is needed to evaluate more complex structures.
This section will discuss the identification of fractures and dislocations, stress fractures, and pathologic fractures.

**Diagnosis of a fracture**

The most obvious sign of a fracture is a lucent line separating the bone into two pieces. The greater the degree of displacement, the easier it is to recognize the fracture. For rapid trauma series, one view may be all that is obtained. Common signs of fracture are cortical step-offs and deformities, whereas an uncommon feature is a sclerotic line, resulting from overriding of the fracture margins. Figure 9.16 provides examples of these fracture signs.

Comminuted fractures are fractures in which more than one fracture line is present at the same location resulting in many pieces. A segmental fracture refers to long bone fractures with two separate fractures, such as one in the proximal shaft and one in the distal shaft. Intra-articular fractures have a fracture line extending to a joint; articular surface discontinuity may result in early posttraumatic OA. Depressed articular surface fragments are important to note as bone grafting may be needed to restore the articular surface; compressed bone does not spring back to its normal height. Open fractures, sometimes called compound fractures, are fractures where there is direct communication between the fracture site and the outside air; these fractures are at much greater risk for infectious complications. Figure 9.17 shows examples of these complicating fracture modifiers.

**Fracture mimics**

There are two main fracture mimics, nutrient foramina and accessory ossicles (Figure 9.18). Nutrient foramina are intracortical obliquely oriented channels that allow the bone’s neurovascular bundle to access the internal structure of the bone. These foramina appear radiographically as linear luencies in one cortex, unlike an actual fracture that should involve both cortices. Accessory ossicles represent either intratendinous ossifications or unfused secondary ossification centers and are mostly found about the foot and ankle. Classic examples of intratendinous ossifications are os peroneus (within the peroneus longus tendon) and os navicularis (within the tibialis posterior tendon near its navicular attachment). The classic example of an unfused secondary ossification center is an os trigonum, an unfused posterior process of the talus. Os navicularis deserves special mention because there are 3 types, the type 2 variant of which may simulate a fracture and may result in chronic medial foot pain: type 1 is a round bone completely enveloped by the tibialis posterior tendon; type 2 is rounded proximally but squared off against the navicular proper, with intervening fibrous tissue; and type 3 results in a large projection off the navicular bone that has been called a cornuate navicular. The squared-off nature of the type 2 variant can result in a linear lucency through the medial navicular that may simulate a fracture.

**Example: Ankle fractures**

Ankle fractures are very common, the most common involving either the medial or lateral malleolus (Figure 9.19). There are, however, several other fractures about the foot and ankle that may simulate a typical medial or lateral malleolus fracture that should be considered. These include a base of fifth metatarsal fracture, anterior process of calcaneus fracture, lateral process of talus fracture, and a posterior malleolus fracture (Figure 9.20). Isolated medial and posterior malleolus fractures should prompt evaluation for a proximal fibular fracture due to the transmission of forces up the interosseous membrane.

**Stress and insufficiency fractures**

Stress and insufficiency fractures do not occur as a result of a single traumatic event. Instead, they are the result of repetitive stresses that overtime exceed the bone’s ability to heal. Stress fractures occur as a result of abnormally high stresses in otherwise normal bone. Athletes are the most likely population to develop stress fractures, though military recruits have a high incidence as well—hence the name “march fracture” to describe a metatarsal stress fracture. Insufficiency
fractures occur as a result of normal stresses in abnormal bone. The most common stress fractures occur in the tibia, metatarsals (Figure 9.21), calcaneus, and femoral neck. Insufficiency fractures often occur in the lumbar spine, the sacrum, and the proximal femur and are usually the result of osteoporosis or osteomalacia.

Pathologic fractures
A focal bone lesion, benign or malignant, greatly weakens the bone, and a usually low-energy traumatic event results in fracture through this lesion (Figure 9.22). Recognizing the pathologic nature of a fracture is important as this may be the first clue that the patient has an underlying metabolic or malignant process. Sometimes, the only hint is a vague area of lucency about the fracture site that cannot be explained by the fracture itself.

Diagnosis of a dislocation
Diagnosis of a dislocation is based on the derangement of the normal relationships between joints:
- Findings can be subtle from widening of the normal joint space to mild incongruity at the joint (subluxation) to complete dissociation of the normal relationship (dislocation).

Common dislocations include the anteroinferior shoulder dislocation, the posterior hip dislocation, and dislocations of the joints of the fingers. All joint dislocations imply some degree of soft tissue damage ranging from disruption of the joint capsule to major ligament rupture and to vascular compromise. Some of these injuries may be inferred from the imaging, but often the dislocation has been at least partially reduced by the time they receive an imaging study. In dislocations where vascular compromise is a risk,
Figure 9.17 Modifiers of fracture severity. All fractures shown here are comminuted. (a) PA radiograph of the wrist demonstrates a minimally displaced distal radius fracture with extension into the radiocarpal joint. Intra-articular extension increases the likelihood of early posttraumatic osteoarthrosis. Also note the ulnar styloid tip fracture. (b) Coronal CT image of a lateral tibial plateau fracture with a large markedly depressed and rotated articular surface fragment. In order to restore the articular surface, bone graft or cement material will be needed. (c) Lateral radiograph of the femur demonstrates a comminuted fracture with extensive soft tissue gas both anterior and posterior to the fracture. This fracture is likely an open fracture. (d) Lateral radiograph of the distal finger demonstrates a comminuted fracture of distal tuft. The overlying finger nail appears elevated. Because of the involvement of the nail bed, even if not overtly elevated, fractures of the distal tuft are considered open fractures.

Figure 9.18 Fracture mimics. Coned PA radiograph of two proximal phalanges (a) shows the appearance of normal nutrient foramina (arrows). Lateral radiograph of the mid femur (b) shows the typical appearance of a nutrient foramen in this bone (arrow). Oblique radiograph of the foot (c) demonstrates an unfused base of fifth metatarsal apophysis. The dorsal–plantar view of the foot (d) demonstrates a type of os navicularis (arrow) that has a linear interface with the navicular bone. The linear squared-off nature and close apposition to the underlying navicular can be confused with a fracture. Note, however, that the cortex is rounded on both sides of the interface and that there is identifiable cortex at the interface; a fracture would not have cortex along the fracture line.
such as in posterior knee dislocations, a vascular study is often indicated to exclude this complication. MRI is usually obtained after major dislocations to assess the soft tissue injuries so that an appropriate surgical plan can be devised.

Not all subluxations and dislocations are the result of direct trauma. OA is a common cause of mild subluxations. More severe subluxations and even dislocations are seen in the later stages of the erosive inflammatory arthropathies, such as rheumatoid arthritis (RA).

**Internal derangement of joints**

Intra-articular and periarticular soft tissue damage may be the result of both acute trauma and degenerative processes:

- MRI or ultrasound can be used to assess for these types of injuries, with the role of ultrasound limited to the more superficial structures, such as ligaments and tendons.
- MR arthrography is a specialized form of MRI where a gadolinium-based contrast agent is injected directly into the joint of interest. This serves three purposes: first, it distends the joint separating structures that might otherwise be closely apposed to each other; second, small communications between the injected joint and other spaces can be identified, which might otherwise not be evident; and third, overt clefts in menisci and even bone can be identified.
- In patients who cannot have an MRI, an analogous CT arthrogram can be performed.

**Figure 9.19** Bimalleolar ankle fracture. AP radiograph of the left ankle demonstrates an oblique medial malleolus fracture and a transverse lateral malleolus/distal fibular fracture, which was most likely the result of an inversion injury. Usually, the side with an oblique fracture is impacted (in this case by the talus), and the side with the transverse fracture is avulsed.

**Figure 9.20** Nonmalleolar ankle-related fractures. The fractures illustrated in this figure (arrows) are fractures that occur with similar mechanisms as standard medial or lateral malleolar fractures or refer pain to the ankle and should be considered when the medial and lateral malleoli are intact. (a) Base of fifth metatarsal fracture. (b) Anterior process of calcaneus fracture. (c) Posterior malleolus fracture. The arrow points in the direction of the fracture line. Note the articular surface incongruity of the posterior tibiotalar (ankle) joint. (d) Lateral process of talus fracture.
Metatarsal stress fractures.

Dorsal–plantar radiograph of the foot (a) reveals periosteal new bone along the distal third metatarsal shaft, which is consistent with a stress fracture. In cases where the radiographs are normal and a stress fracture is still being considered, MRI can be obtained. Axial (long axis to the foot) T2-weighted fat-suppressed image of the lateral forefoot (b) reveals increased signal within the marrow of the distal fifth metatarsal shaft (compared to the fourth metatarsal) and periosteal edema (arrow). These findings are consistent with an early stress fracture.

Pathologic fractures.

PA (a) and oblique (b) radiographs of the little finger reveal a lucent, slightly expansile lesion in the proximal phalangeal base. Through this lesion, consistent with an enchondroma, is a fracture that is identifiable by the cortical step-offs (arrows). Lateral (c) and AP (d) radiographs of the distal femur reveal a displaced fracture through a subtle lucent lesion (arrows), which turned out to be a myeloma deposit.
The focus of the section is to describe the general types of joint-related soft tissue pathologies that are encountered, with a discussion specific to tendons, ligaments, fibrocartilage, and articular (hyaline) cartilage.

**Tendons**

Tendon tears are characterized by overt gaps in the course of the tendon from muscle to bone or changes in the morphology of the tendon. For superficial tendons, MRI and sonography are equivalent in accuracy. MRI can provide a more global view of surrounding pathology. For cases where there is doubt about whether a tear is full thickness or partial thickness, dynamic examinations can easily be performed as part of a sonographic examination. Perhaps the most common tendon tear is a rotator cuff tear (Figure 9.23):

- Several meta-analyses and systematic reviews of the accuracy of MRI and ultrasound for diagnosing rotator cuff tears have shown that both perform equally well for full-thickness tears and only moderately well for partial-thickness tears.

- MR arthrography has a slight edge on the nonarthrographic MRI and sonographic examinations for partial-thickness tears but involves a joint injection.

- Tendinosis is a common disorder of tendons caused by overuse and age-related tendon degeneration. The first sign of tendinosis is enlargement of the tendon with an otherwise preserved structure. This is followed by progressive collagen fiber damage that ultimately leads to changes in macroscopic morphology including surface irregularity and internal clefts. Fiber disruption is readily seen sonographically:
  - The morphologic changes are apparent on both MRI and sonography. Tendinosis is often a precursor to tendon tear, especially in the rotator cuff.

- Tenosynovitis is an inflammation of the tendon sheath, which is often caused by chronic friction. People with an inflammatory arthritis are also prone to developing this condition. Tenosynovitis is characterized by an effusion with one or more of the following signs of synovial inflammation: hyperemia, fibrin deposition, and/or thickening of the synovial lining of the sheath (Figure 9.24).

![Figure 9.23 MRI and US of a full-thickness partial-width superior rotator cuff tear.](image-url)
An effusion in the absence of the other findings is most likely reactive:
- Both MRI and sonography can adequately characterize tenosynovial inflammation by demonstrating the effusion, identifying hyperemia (enhancement of the synovium on MRI and color Doppler flow on sonography), and identifying material within the sheath. Thickening of the sheath is not always apparent due to reactive inflammatory changes external to the sheath.

Ligaments

Ligament tears are quite common in the lower extremity. The anterior talofibular ligament is likely the most frequently torn ligament in the body but is rarely a source of long-term ankle instability. Tears of the ACL of the knee can cause sufficient instability that ultimately leads to early knee OA. Tears of the other ligaments of the knee are also associated with knee instability, though not to the degree arising from an ACL tear. Ligament tears of any joint are for the most part due to direct trauma, though coexistent inflammatory arthritis can greatly weaken ligaments, increasing their susceptibility to tears.
- Ligaments are linear well-defined structures on imaging; any departure from this appearance is consistent with a tear (Figure 9.25).
- Sonography is suited to evaluation of the lateral ankle ligaments and the collateral ligaments of the elbow, knee, and fingers—any superficial ligament. The scapholunate ligament can be evaluated as well by experienced sonographers. MRI remains the gold standard for evaluation of the cruciate ligaments of the knee.

Fibrocartilage

Evaluation for knee meniscal tears is one of the most frequent, if not the most frequent, reasons a knee MRI is ordered. The knee menisci are quite large in comparison to the glenoid and acetabular labrums and are relatively easy to evaluate on MRI; all of these structures are triangular in shape. Any alteration of this morphology is consistent with a tear. For the menisci, tears are usually characterized by fluid-filled intrameniscal clefts, possibly with a displaced fragment. For both the glenoid and acetabular labrums, tears may also be manifested by intrameniscal clefts but are more frequently characterized by clefts at the attachment site of the labrum to bone and/or cartilage or abnormal morphology.

Three main types of knee meniscal tears are horizontal, vertical, and radial tears. Both horizontal and vertical tears are types of longitudinal tears. While all of these tears compromise the function of the meniscus to some degree, a full-thickness radial tear
essentially inactivates the meniscus by interruption of the longitudinal collagen fiber network that provides the tensile ('hoop') strength of the meniscus:

- Knee meniscal tears are readily seen on conventional MRI (Figure 9.26).
- The diagnosis of labral tears is complicated by the presence of adjacent structures that may obscure a tear or mimic a tear.
- The anterior inferior glenohumeral ligament of the shoulder often abuts the anteroinferior labrum, and the hip joint capsule often lies directly on top of the acetabular labrum. To mitigate this effect, MR arthrography is performed to distend the joint and lift these adjacent structures off the labrum.
- If the patient cannot have an MRI, CT arthrography can be performed.

Figure 9.27 shows examples of glenoid and acetabular labral tears as well as a triangular fibrocartilage tear.

**Articular cartilage**

The majority of cartilage disease is degenerative in nature, whether due to abnormal stresses or due to instability as might be seen with knee meniscal and ACL tears (Figure 9.28). Acute trauma also produces cartilage disease due to direct cartilage impact or focal shear (Figure 9.29). Degenerative cartilage disease is characterized by more diffuse thinning of the cartilage, whereas traumatic cartilage...
defects are often focal full-thickness defects with well-defined margins. Alternatively, acute traumatic events may result in cartilage delamination where a cleft parallel to the articular surface develops, often at the cartilage–bone interface. The treatment for degenerative cartilage disease is mainly supportive, but when symptoms become intolerable, joint replacement is often performed. Focal traumatic cartilage defects may be treated via a number of surgical methods including microfracture and cartilage transplantation; sheared cartilage generally cannot be reattached.

Loose chondral bodies, resulting from trauma or degenerative breakdown of the cartilage, may be present. The posttraumatic chondral body is often easy to recognize as its shape matches the defect at the donor site. Degenerative loose bodies often begin as small fragments of cartilage that grow slowly over time due to diffusion of nutrients through the synovial fluid; ultimately, they ossify, hence the term osteochondral body. Loose bodies often migrate into a recess, such as the suprapatellar recess or the posterior tibiofemoral joint at the intercondylar notch. Occasionally, however, they may become interposed between two articular surfaces resulting in a block to flexion or extension of the knee:

• The standard for imaging articular cartilage is MRI.
Musculoskeletal imaging

• Focal intrasubstance signal changes herald the onset of early chondrosis, which are followed by actual loss of cartilage beginning at the articular surface and progressing toward the subchondral bone.
• Occasionally, blistering of the cartilage surface will be observed. Fissuring is also a common finding in the diseased state. Elevated bone marrow signal deep to the cartilage abnormality may reflect more acute and symptomatic disease.
• CT arthrography is a reasonable alternative to cartilage assessment in the patient who has contraindications to MRI, with the limitation that the subchondral bone marrow cannot be assessed.

Arthritis

The most common disease of the joints is degenerative joint disease or osteoarthrosis (OA). The inflammatory/erosive diseases of the joints are sufficiently common as a group to warrant discussion as well. While OA is characterized by cartilage loss and reactive bone changes with variable but usually minor associated synovial inflammation, the inflammatory arthritides are characterized by inflammation of the synovium and adjacent soft tissue structures with relatively minor cartilage and bone changes, especially early in the disease. The erosive diseases will ultimately erode the bone supporting the cartilage leading to cartilage loss as a secondary effect.

Figure 9.27 Shoulder, wrist, and hip fibrocartilage tears. Axial T2-weighted fat-suppressed MR image through the inferior glenoid (a) demonstrates an abnormal-appearing anteroinferior labrum (long arrow), especially when compared to the posterior labrum (short arrow) with a cleft between the labrum and the glenoid consistent with a tear. Axial T1-weighted fat-suppressed MR image through the mid glenoid (b) demonstrates a tear of the posterior labrum (arrow), with associated periosteal stripping. Note the normal anterior labrum. Coronal T2-weighted fat-suppressed MR image of the wrist (c) reveals a full-thickness cleft in the membranous portion of the triangular fibrocartilage (arrow). Sagittal T2-weighted fat-suppressed MR image of the hip (d) reveals a cleft at the chondrolabral junction of the anterior labrum consistent with a tear (arrow).
Degenerative articular cartilage derangements. Sagittal PD-weighted MR image through the medial tibiofemoral compartment of the knee (a) demonstrates region of full-thickness cartilage loss in the central weight-bearing region of the femoral condyle (long arrow) and diffuse full-thickness thinning of the central tibial plateau. Note the thickness of the non-weight-bearing region cartilage (short arrow); this can be used as an internal reference for the normal thickness of the cartilage for this person. Sagittal PD-weighted MR image through the lateral tibiofemoral compartment of the knee (b) demonstrates a more focal region of full-thickness cartilage loss in the posterior weight-bearing region of the femoral condyle where it overlies the posterior horn of the lateral meniscus (arrow). Coronal T2-weighted fat-suppressed MR image through the bodies of both menisci (c) reveals full-thickness cartilage loss in the medial tibiofemoral compartment with underlying bone marrow signal changes; the bone marrow signal changes (arrows) are often associated with symptoms. Sagittal CT arthrogram image through the medial tibiofemoral compartment of the knee (d) reveals full-thickness irregular cartilage loss of the posterior weight-bearing region consistent with cartilage degeneration.
The term “arthritis” literally means joint inflammation. This accurately describes the situation in diseases such as RA, psoriatic arthritis, and systemic lupus erythematosus. Degenerative joint disease is commonly termed “osteoarthritis,” though it in fact often has minimal associated inflammation. As a result, a more accurate term for “osteoarthritis” is “osteoarthrosis”.

- Imaging evaluation of arthritis is predominantly based on radiographs. The standard hand radiographic series for arthritis is a PA radiograph of both hands and a slightly oblique view that is known as the Norgaard (or “ball catcher”) view; the patient is asked to position their hands as if they were going to catch a ball. Some institutions also acquire a true lateral radiograph.
- Advanced imaging modalities such as MRI and ultrasound are reserved for indeterminate cases usually to document synovitis but also subradiographic erosions. Tendon disease is a common feature of the inflammatory arthritides; MRI or sonography is needed to assess these structures.
- Imaging features that help to characterize the arthritides include periarticular bone density, distribution (symmetric vs. asymmetric, proximal, or distal hand involvement), and the presence of bone production. Soft tissue calcifications can also be helpful in certain situations.
- The following is a brief discussion of OA, RA, the seronegative spondyloarthropathies, and gout, focusing on radiographic imaging findings.

**OA**

OA is characterized by loss of cartilage, reactive subchondral bone remodeling, osteophyte formation, and normal bone density. The most common sites are the distal interphalangeal joints of the hands, the hips, the knees, and the great toe metatarsophalangeal joint. The presence of osteophyte formation separates this entity from the other arthritides:

- On radiographs, the presence of cartilage can only be inferred by the separation of the two articulating bones by a radiolucent space (Figure 9.30). Osteophytes are projections of bone at the peripheral edges of the affected joint that appear to broaden the articular surface as a whole.

Figure 9.29 Acute/subacute articular cartilage derangements. Axial T2-weighted fat-suppressed MR arthrogram image of the shoulder through the glenoid (a) reveals a large delaminating cartilage lesion of the anterior glenoid (arrow) following direct trauma to the shoulder; high signal in the humeral head is likely related to a contusion. Axial T2-weighted fat-suppressed image of the knee through the patella (b) reveals an intrasubstance cartilage delaminating lesion (arrow). Sagittal T2-weighted fat-suppressed image through the medial tibiofemoral compartment of the knee (c) reveals a large osteochondral lesion with an in situ fragment (short arrow) and a fluid-filled void (long arrow) where another osteochondral fragment used to be located following a knee injury. The displaced fragment may cause mechanical symptoms of locking if interposed in a joint.
Subchondral sclerosis represents increased density within the subchondral bone. “Cystic” spaces (“cyst” is a misnomer, since there is no epithelial lining), also termed “geodes,” often form in the subchondral bone as well due to inspissation of fluid through damaged bone over time.

Radiographs are not sensitive for cartilage damage as there can be marked cartilage damage with a normal-appearing joint space; all that is needed is a pillar of normal thickness of cartilage to give the illusion of a normal joint.

MRI may be considered to evaluate the extent of cartilage damage and to evaluate the status of the supporting soft tissue structures, such as the menisci and ligaments of the knee. Meniscal and ligament tears contribute to cartilage degeneration by creating microinstability in the tibiofemoral joints of the knee. A variant of OA is known as “erosive OA,” which essentially only affects the hands of postmenopausal women (Figure 9.31):

- In this variant, erosions form in the central articular aspect of the articular surface, usually at the distal interphalangeal joints.
followed by the proximal interphalangeal joints. In combination with osteophyte formation at these joints, a “gull-wing” deformation is created. The thumb carpometacarpal joint and the scaphotrapezial joint are also usually affected, though without obvious focal erosions.

As OA is very common, it may coexist with the other arthritides later in life.

**RA**
RA is an autoimmune symmetric inflammatory/erosive arthritis characterized by periarticular osteopenia and marginal erosions. The hands and feet are most commonly affected, but any joint in the body may be involved (Figure 9.32). Periarticular osteopenia is due to hyperemia related to adjacent inflammation that leads to increased bone resorption. Synovial inflammation leads to the formation of a pannus that erodes into the bones at joints at the margins of the articular cartilage, hence the term “marginal” erosions. In advanced disease, the entire articular cartilage is completely eroded and bones can become fused together (ankylosis), which is common in the carpus. In the hands, it affects predominantly the carpus and metacarpophalangeal joints. One of the most sensitive sites for early erosive involvement in the hand is the ulnar styloid. Distention of the metacarpophalangeal joint capsules due to synovial hypertrophy is a feature of active disease. In the feet, erosions commonly occur at the metatarsal heads and posterior calcaneus, but the most specific site for RA in the foot is the fifth metatarsal head. The presence of erosions is important to document as this usually necessitates giving the patient high-potency disease-modifying antirheumatic drugs:

- On imaging, active erosions are characterized by concavities in the normal contour of the bone without an identifiable cortex at its base. Often, however, erosions are not well profiled on radiographs and appear as round lucencies. Lucencies, unfortunately, are a nonspecific finding that may represent subchondral cysts related to OA or vascular channels (as may be seen in the carpus). Overt erosions are clearly helpful, but numerous lucencies in the typical pattern of involvement still remain highly suggestive of RA.
On cross-sectional imaging, erosions must be documented in two planes. Active erosions appear bright on contrast-enhanced MRI and exhibit hyperemia on sonographic evaluation.

Inactive erosions have a thin sclerotic rim at the base of the erosion. On MRI, there will be no associated enhancement and no demonstrable hyperemia will be seen sonographically.

Tenosynovitis and bursitis are common features of RA (and the other inflammatory arthritides). These entities are often not appreciable radiographically unless very severe resulting in soft tissue contour abnormalities.

MRI and sonography are the mainstay for evaluation of these entities. The use of contrast with MRI is helpful to document synovial inflammation as reactive effusions may appear identical to the inflamed counterpart.

Seronegative spondyloarthropathy

The seronegative spondyloarthropathies are a diverse group of autoimmune inflammatory/erosive arthritides that have in common a negative rheumatoid factor. These entities include psoriatic arthritis, reactive arthritis, ankylosing spondylitis (AS), and inflammatory bowel disease (IBD)-related spondyloarthropathy.

All four of these entities are associated with sacroilitis and enthesitis. While AS and IBD-related spondyloarthropathy are associated with erosive joint disease (usually the hip), they are predominantly associated with enthesitis of the spine. On the other hand, psoriatic and reactive arthritides are particularly associated with periarticular erosive disease.

This section will focus on sacroilitis and psoriatic arthritis.

Sacroilitis

The sacroiliac joints are a complex irregular joint that distribute load from the axial skeleton to the pelvis. The joint is oblique such that the anterior portion is more lateral than the posterior portion. Only the anterior aspect of the joint is synovial. Synovitis, therefore, will only affect this part of the joint. The other portions of the joint are held together by strong ligaments, which can be involved with enthesitis. Sacroilitis in AS and IBD-related spondyloarthropathy is generally symmetric, while sacroilitis associated with psoriatic and reactive arthritides is generally asymmetric. The end point for AS and IBD-related spondyloarthropathy is sacroiliac joint ankylosis:

- Radiographs are the initial imaging study in suspected sacroilitis. The typical radiographic series for evaluation of the sacroiliac joints is an AP view of the sacroiliac joints with tube tilted cranially to accommodate the oblique orientation of the sacrum supplemented by bilateral oblique views to profile the joints. Erosions, areas of narrowing, and subchondral sclerosis are all features of sacroilitis.
- In cases when radiographs are normal, but clinical suspicion remains high, MRI may be obtained to document sacroiliac joint synovitis in the absence of radiographic findings.

Sacroilitis and the other inflammatory arthritides are often not appreciable radiographically unless very severe resulting in soft tissue contour abnormalities.

Psoriatic arthritis

Psoriatic arthritis, which is associated with the skin condition psoriasis, is an asymmetric erosive arthropathy associated with marginal erosions and bone production. The distribution is quite different from that of RA in that it typically involves the metacarpophalangeal joints and interphalangeal joints of one or more fingers. The erosions of psoriatic arthritis are associated with “fluffy periostitis,” fine wisps of bone production about the erosions. Enthesitis plays a much bigger role in psoriatic arthritis than in RA. Any ligament or tendon attachment may become ossified as a result of chronic inflammation; periarticular enthesophytes are common in psoriatic arthritis. Enthesis ossification is not a feature of RA.
The radiographic findings include marginal erosions, fluffy periostitis, and enthesophytes in the classic distribution. Soft tissue inflammation is best characterized on MRI or ultrasound:
- The classic soft tissue feature of psoriatic arthritis is the “sausage digit,” one uniformly swollen digit secondary to severe flexor tenosynovitis.

Reactive arthritis is a seronegative spondyloarthropathy that follows an enteric or urogenital infection. While reactive arthritis has lower limb predominant manifestations, the imaging appearance is identical to that of psoriatic arthritis.

Figure 9.34 shows examples of some of the radiographic features of psoriatic and reactive arthritides.

**Gout**

Gout is an inflammatory erosive disease due to deposition of monosodium urate crystals. In advanced stages of disease, coalescent deposits of monosodium urate crystals form called tophi. These tophi may result in periarticular erosions, sometimes quite dramatic in size. The classic site of involvement is the great toe metatarsophalangeal joint. The dorsal tarsometatarsal joints of the foot are commonly affected.

Hand and foot involvement is often indistinguishable from RA:
- Radiographic manifestations of gout are marginal erosions (Figure 9.35). They may be characterized by an overhanging edge, a characteristic specific to gout.
- Soft tissue masses associated with the erosions are occasionally identifiable, which also assists in the diagnosis.
- In the absence of an identifiable overhanging edge or soft tissue mass, a serum uric acid level will be needed to establish (or exclude) the diagnosis.

**Tumors**

Tumors and tumorlike lesions of the musculoskeletal system are relatively uncommon.
Figure 9.34  Psoriatic and reactive arthritides. Coned PA radiograph of the left second and third metacarpophalangeal (MCP) joints (a) reveals complete uniform joint space loss of the second MCP joint, a radial marginal erosion of the metacarpal head, and small enthesophyte of the distal radial joint capsule in the setting of normal bone density. The normal bone density and enthesophyte formation increase the likelihood that this patient has psoriatic arthritis based on the radiographs alone. PA (b) and lateral (c) radiographs of a right-hand finger distal interphalangeal joint reveal complete ankylosis of this joint. Ankylosis of an interphalangeal joint is characteristic of a seronegative spondyloarthropathy. Coned dorsal–plantar view of the right metatarsophalangeal (MTP) joints (d) has several findings characteristic of a seronegative spondyloarthropathy: marginal erosions are present involving the great and little toe MTP heads. Bulky capsular enthesophytes are present on the distal aspect of the great toe MTP joint. Uniform joint space loss is present clearly involving the third and fourth digit MTP joints. The little toe MTP joint demonstrates the classic “pencil-in-cup” deformity.

Figure 9.35  Gout. The dorsal–plantar radiograph of the right foot (a) and the oblique radiograph of the right hand (b) demonstrate numerous marginal erosions at the foot metatarsophalangeal and hand metacarpophalangeal joints. The classic radiographic finding of gout is an “overhanging edge” of an erosion (arrows).
The general approach to tumors and tumorlike lesions is based on whether they are bone centered or soft tissue centered. A general approach is presented for each of these broad categories, rather than an exhaustive list.

**Bone tumors**

Many benign and malignant bone lesion histologies have been described. In a few cases, one can predict the histology based on imaging alone. In nonspecific cases, which comprise the majority of cases, one can make general assessments regarding the relative indolence versus aggressivity of the lesion. Then using data on the age of the patient, where in a bone the lesion is located (medullary, cortical; metaphyseal, diaphyseal, and epiphyseal), the type of mineralized matrix, and morphologic details, a narrow differential can be generated. While there is a general trend for benign lesions appearing indolent and malignant lesions appearing aggressive, the association is not sufficient to base diagnosis on these features alone: indolent lesions may be benign or malignant, and aggressive lesions may be either benign or malignant. An example of indolent lesions that cannot be separated on the basis of imaging is an enchondroma and low-grade chondrosarcoma. An aggressive process such as an Ewing sarcoma or certain metastatic lesions can appear identical to an infection, a benign process. Regardless of the histologic origin, any lytic bone lesion may be at risk for pathologic fracture:

- The imaging workup of all bone lesions begins with radiographs.
- Indeterminate cases may require CT to document the type of tumor matrix, extent and configuration of ossification/mineralization, and possible coexistent pathologic fracture (Figure 9.36). CT, however, may occasionally lead to a definitive diagnosis, such as an osteoid osteoma.
- Unless the lesion is clearly benign on radiographs, such as a fibroxanthoma, MRI is obtained to assess both intramedullary and extraosseous extent. Unfortunately, MRI characteristics are for the most part nonspecific. Biopsy is always performed to establish a definitive diagnosis as the histology often dictates whether chemotherapy or radiation therapy is used prior to resection.

Once a definitive diagnosis of a primary bone sarcoma has been made, an evaluation for metastatic disease is performed:

- First, if not already available, an MRI of the entire involved bone is obtained to assess for local “skip” lesions.
- Second, a nuclear medicine bone scan is obtained to assess for skeletal metastasis.

![Figure 9.36 CT of bone lesions.](a) Axial CT image through the left femur reveals dense intramedullary calcifications that have an “arc and whorl” appearance that is characteristic of low-grade chondroid lesions, enchondroma, and low-grade chondrosarcoma. (b) Osteoid osteoma: axial CT image through the left femur reveals focal cortical thickening of the posterolateral cortex with a focal round lucency not connected to a nutrient foramen. This is the classic appearance for a (c) parosteal osteosarcoma: axial CT image through the left femur reveals a well-defined mineralized mass abutting but otherwise completely external to the femur. (d) Myositis ossificans: axial CT image through the left hip reveals a corticated osseous body (arrow) interposed between the proximal femur and the ischium within the quadratus femoris muscle consistent with Myositis ossificans.)
Finally, a CT of the chest is obtained to evaluate for the presence of pulmonary metastases; all sarcoma metastases have a predilection for the lungs.

A short discussion of lesion descriptors follows: lesion margin, type of associated periosteal reaction, lesion density, and age.

**Lesion margin**
The margin of a lesion may be well defined with an abrupt transition from lesion to normal bone or may be ill defined with a gradual transition from clearly identifiable lesion to clearly identifiable normal bone (Figure 9.37). The spectrum from well defined to ill defined parallels the spectrum of indolence from indolent to aggressive. At the indolent end of the spectrum is a unicameral bone cyst, which has an abrupt transition and a sclerotic margin. At the aggressive end of the spectrum are osteosarcomas, lymphomas, and infection, which have quite ill-defined and gradual transitions to normal bone, an appearance sometimes termed “permeative.”

A benign indolent lesion warranting special mention is the fibroxanthoma, which when small is called a fibrous cortical defect and when large a nonossifying fibroma (Figure 9.38). These are quite

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**Figure 9.37** Bone lesion zone of transition. The spectrum from abrupt zone of transition with sclerotic margin to ill-defined permeative parallels the spectrum of lesion activity from indolent to aggressive. (a) Unicameral bone cyst—AP radiograph of the left humerus reveals a large medullary, slightly expansile mostly lucent lesion. The zone of transition is abrupt with sclerotic margin (arrow). (b) Giant cell tumor of bone—AP radiograph of the right knee demonstrates a lucent lesion in the proximal tibia that abuts the articular surface and without identifiable matrix. The zone of transition is abrupt but without a sclerotic margin. (c) Lymphoma—AP radiograph of the left knee demonstrates an ill-defined/permeative lesion in the proximal tibia with cortical breakthrough (midlength arrow) and likely associated soft tissue mass (small arrows). The zone of transition is gradual; the exact borders of the lesion are difficult to determine (long arrow is probable distal extent of the lesion). (d) Osteosarcoma—AP radiograph of the distal right femur reveals an ill-defined lesion in the femoral metadiaphyseal region with “cloud-like” regions of increased density and large extraosseous component. The zone of transition is quite gradual; the transition to normal bone is not likely represented on this image.

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**Figure 9.38** Nonossifying fibroma. (a) Mortise radiograph of the left ankle reveals a cortically based lucent lesion with sclerotic borders consistent with a nonossifying fibroma, a common benign bone lesion. (b) Lateral radiograph of the left distal femur reveals a well-defined cortically based somewhat ovoid sclerotic region consistent with an involuted nonossifying fibroma.
common and often occur in the metaphyseal regions of long bones. They are lytic, sometimes expansile lesions centered in the cortex with an abrupt zone of transition including a thin sclerotic margin. Over time, they involute leaving behind a well-defined region of relative sclerosis compared to the adjacent normal bone.

**Periosteal reaction**

Periosteal reaction is a feature of many processes in the body, benign and malignant. It is often reactive to adjacent inflammatory changes whether due to infection, trauma, a systemic process, or adjacent tumor. Some bone-centered tumors, however, are rapidly growing. When their soft tissue component extends beyond the cortex of the bone, the periosteum becomes involved. The periosteum responds to the injury by trying to lay down new bone. As the tumor continues to grow, it disrupts the periosteal new bone resulting in what is known as interrupted periosteal reaction (Figure 9.39). At the edges of the tumor, the periosteum appears elevated in a triangular fashion, the Codman triangle, with the apex of the triangle toward the edge of the mass and the base toward the center of the mass. Another potential appearance of a rapidly growing tumor is the “hair-on-end” or “sunburst” appearance, often observed with osteosarcoma, where mineralized new bone is deposited in streaks perpendicular to the long axis of the involved bone.

Dense and uninterrupted periosteal reaction is more likely a reactive process, whereas subtle and ill-defined periosteal reaction is more associated with an aggressive process. Bone lesions that may be associated with reactive periosteal reaction include eosinophilic granuloma and chondroblastoma. Pathologic fractures involving an indolent lesion may also result in periosteal reaction/callus formation as part of the healing process rather than direct periosteal irritation. Ewing sarcoma and osteosarcoma are the two primary bone tumors associated with particularly aggressive periosteal reaction. Infection can also be associated with ill-defined, interrupted periosteal reaction. An example of thick, uninterrupted periosteal reaction due to a systemic condition is illustrated in Figure 9.26.

A final type of periosteal reaction is multilayered, or “onion skin,” periosteal reaction. Periosteal new bone is deposited in layers corresponding to alternating periods of increased and decreased activity. This type of periosteal reaction has been associated with Ewing sarcoma, infection/osteomyelitis, and osteosarcoma.

**Lesion density**

Lesions of bone are lytic (more lucent than adjacent normal bone), sclerotic (denser than adjacent normal bone), or of mixed density. The purely lytic lesions include bone cysts, certain fibro-osseous lesions, and multiple myeloma (Figure 9.40). The sclerotic lesions include osteomas and osteosarcomas as well as enostoses (“bone islands”). Mixed lesions generally are lytic with internal calcifications. Tumor matrix refers to the pattern of internal calcifications. There are three types: chondroid, osteoid, and ground glass. Chondroid matrix is described as “arcs and whorls” and represents calcium deposition between grapelike clusters of chondrocytes. Osteoid matrix is ill-defined increased density, due to mineralized osteoid, often superimposed on a background of normal bone density, which has been termed “cloud-like.” Ground glass is a feature of fibrous dysplasia: diffuse variable intermediate density on a background of relative bone lucency, which is due to a relative increase in woven bone. While these types of matrix can help guide a differential diagnosis, it is not uncommon for the matrix to be relatively nonspecific and other features will be needed to narrow down the differential.

Metastatic disease is often lytic, but a few histologies are particularly associated with sclerotic lesions (Figure 9.41): prostate cancer in particular followed by bladder and gastric cancer. Breast cancer has a variable presentation having both lytic and sclerotic lesions.

**Age**

Certain bone lesions are more common in people less than the age of 30, which is likely due to rapid bone and cartilage turnover in the growing skeleton. Epiphyseal lesions such as chondroblastoma and eosinophilic granuloma occur much more frequently in the skeletally immature; chondroblastoma can occur up to the age of 25. Osteosarcoma is most common in the teen years (and most commonly in the distal femur) because of the rapid growth occurring during this time. The unicameral bone cyst and Ewing sarcoma both occur nearly exclusively in the pediatric age group. Metastatic

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**Figure 9.39** Aggressive periosteal reaction. (a) Coned AP radiograph of the right knee in a patient with Ewing sarcoma reveals a mostly lytic eccentrically located lesion in the medial distal femoral metaphysis. At the edges of the lesion are areas of mineralized periosteal elevation known as Codman triangles (arrows). (b) Coned lateral radiograph of the distal right femur in a different patient with osteosarcoma demonstrates an ill-defined intramedullary lesion, with predominate areas of sclerosis. In addition to a Codman triangle (arrow), there is hair-on-end periosteal bone, also known as “sunburst” periosteal reaction, which is a particular sign of an aggressive underlying bone-forming process.
disease is highly unlikely unless there is a known malignancy such as a neuroblastoma. Multiple myeloma is incredibly rare before the age of 30. The giant cell tumor of bone starts in the metaphysis but crosses a closed physis into the epiphysis where it ultimately makes contact with the articular surface.

Chondrosarcoma, metastatic disease, and multiple myeloma are all more common later in life. Osteosarcoma has a minor second peak in incidence in older patients, likely due to sarcomatous degeneration of Paget disease of bone or secondary to prior radiation therapy.

**Soft tissue tumors**

Many soft tissue masses and mass-like lesions occur. The two most common are lipomas and ganglion cysts, both benign entities. Both have clearly defined imaging characteristics and allow for a
diagnosis to be made on the basis of imaging alone. Different mass histologies are common at different sites. For example, in the hands and feet, ganglion cysts and giant cell tumors of tendon sheath are common. If the mass is intra-articular, the differential changes to include pigmented villonodular synovitis and primary synovial osteochondromatosis. Elsewhere in the extremities, the most common lesions are sarcomas, nerve sheath tumors, and vascular lesions (Figure 9.42). Unless the mass has a preponderance of macroscopic fat suggesting a lipoid spectrum tumor, there are essentially no definitive imaging characteristics that can determine the histology of these masses. Biopsy of these lesions is essential for guiding subsequent treatment:

- Imaging evaluation of these lesions begins with radiographs to evaluate for underlying bone involvement.
- MRI evaluates the extent of the mass to document the normal soft tissue structures involved by the mass and whether the neurovascular bundle is involved.
- If the patient cannot get an MRI, either ultrasound or contrast-enhanced CT might be obtained instead. For some lesions, a complete assessment of the mass can be performed with US. Percutaneous biopsy for soft tissue masses is also usually ultrasound-guided.
- For sarcomas, CT of the chest is obtained to evaluate for metastatic disease.

Figure 9.43 demonstrates neurovascular involvement by a large sarcoma and metastatic disease to the chest.

Musculoskeletal interventions

Musculoskeletal radiology employs the use of image-guided procedures for both diagnostic and therapeutic purposes. Diagnostic procedures include arthrography, aspirations, and percutaneous biopsy. Image-guided joint injection and CT-guided radiofrequency ablation have therapeutic benefits. Image-guided fluid aspiration can have both diagnostic and therapeutic benefits.

Arthrography

Conventional arthrography has largely been replaced with diagnostic MRI. The MR arthrogram involves injecting a contrast agent into a joint to make internal joint structures easier to see. For certain pathologies, such as shoulder and hip labral tears, augmenting a routine diagnostic MRI with the use of intra-articular contrast improves the diagnostic quality of MRI by distending the joint so that closely apposed structures are separated from each other (Figure 9.44). The injection of contrast also allows abnormal communications between normally separate compartments to be documented. In general, the guidance modality is fluoroscopy, but sonographic guidance can also be performed, especially in the setting of an iodinated contrast allergy.

Unlike the evaluation of glenoid and acetabular labral tears where the primary benefit of arthrography is joint distention, MRI arthrography of the wrist depends on documenting abnormal communications between normally water-tight compartments. If contrast fills a wrist compartment other than the compartment injected, a ligament tear is suspected. For example, if the radiocarpal joint is injected and contrast opacifies the midcarpal joint, there must be a scapholunate or lunotriquetral ligament tear allowing contrast to pass. This diagnosis is often made on fluoroscopy alone, but subsequent MR imaging is used to better characterize the anatomy of the injury.

Biopsy

Bone biopsies are most readily performed using CT guidance. Bone biopsy can be performed on both lytic and blastic skeletal lesions to diagnose malignancy or to confirm osseous metastatic disease. Additionally, CT-guided biopsy is useful in the setting of osteomyelitis and discitis, where samples can be sent both to microbiology and pathology:

- CT allows for precise needle localization during biopsy of small lesions in precarious locations such as in the spine. CT-guided biopsy most often employs a coaxial technique using an outer penetration cannula, a drill (sometimes), and an inner cutting biopsy cannula.
- US may be used to perform biopsy of soft tissue masses and drainage of cystic lesions in the extremities. Ultrasound allows real-time visualization of the biopsy device within the mass as it takes the sample.

Joint injections

Fluoroscopy or ultrasound can be used to guide joint injections. Intraarticular corticosteroids are often administered as a treatment for synovitis associated with OA, RA, and juvenile idiopathic arthritis. Response to corticosteroid injection is variable, but it can improve clinical symptoms to delay joint replacement or arthrodesis in OA, as well as improve functional limitations of children and adults with inflammatory arthropathies.

Fluid aspiration

Aspiration of joint fluid with imaging guidance employs similar techniques to joint injection. This can be performed using fluoroscopy or ultrasound. A pitfall of using fluoroscopy for aspiration of a prosthetic hip is that the needle can sometimes be completely shadowed by the prosthesis itself, resulting in the lack of needle tip control throughout the procedure. In this setting, ultrasound has the advantage of visualizing the joint space directly so that the needle can be directed into it in a real-time, regardless of prosthesis or native joint. Ultrasound is also a useful tool for aspiration of fluid from cystic masses and tendon sheaths.

Radiofrequency ablation

Osteoid osteomas are solitary bone tumors most commonly found in older children and young adults, which produce a local inflammatory response that can be quite painful. These tumors are centered on a “central nidus” thought to be a vascular lesion. Treatment options for osteoid osteoma include watchful waiting with medical pain management, surgical resection, and radiofrequency ablation. Radiofrequency ablation is often more desirable than resection since no bone is removed and normal physical activity can be resumed shortly after the procedure, even if the tumor is located in a weight-bearing bone. A radiofrequency probe is advanced through the cannula and medullary tunnel of the needle introducer under CT guidance, and its tip is positioned precisely at the tumor nidus. The probe is heated using a radiofrequency generator to a temperature of 90–95°C for 6 min. Full relief of baseline pain is not immediate and may take many months. Follow-up imaging shows the central nidus replaced by sclerotic bone.

The technique of radiofrequency ablation can also be used to treat painful osseous metastatic lesions.
Figure 9.42 Examples of soft tissue masses. **Atypical lipomatous tumor.** Coronal T1-weighted (a) and coronal STIR (b) MR images of the right thigh reveal a large, well-circumscribed, homogeneously bright mass on the T1-weighted image and homogeneously dark on the STIR image within the anterior thigh consistent with a fat-only containing lesion. **Malignant peripheral nerve sheath tumor.** Coronal STIR MR images of both thighs (c) and axial postcontrast T1-weighted fat-suppressed MR image of the left thigh (d) reveal a very large heterogeneous-appearing mass in the medial thigh. The postcontrast image reveals peripheral nodularity, but the mass is predominantly fluid filled consistent with necrosis.
Figure 9.43  Soft tissue tumor. Coronal T1-weighted MR image of both thighs (a) and axial T1-weighted MR image through the distal right thigh (b) reveal a large soft tissue mass (sarcoma) near completely replacing the entire distal thigh; no identifiable bone is seen. The sciatic nerve (arrow) has been displaced posteriorly, and the vascular bundles are likely surrounded by tumor (circles). Axial CT image of the chest (c) reveals multiple large pulmonary nodules in the right lung consistent with, in this patient, metastatic leiomyosarcoma.

Figure 9.44  MR arthrography of the hip. (a) Fluoroscopic image from a left hip arthrogram injection from a lateral oblique approach. The collar of increased density (arrows) about the femoral head-neck junction represents injected contrast proving intra-articular position of the needle tip. (b) Coronal T1-weighted fat-suppressed MR image following left hip arthrogram injection in a different patient.
Suggested reading

Introductory texts in musculoskeletal imaging include:

Excellent focused texts on arthritis and musculoskeletal ultrasound are:

Good comprehensive reference texts include:

Selected reference