Imaging

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Several imaging modalities are available for musculoskeletal disorders. Each modality has a specific role in management. Multimodality imaging is often required in the diagnostic process.

Plain Films

Plain films (X-rays) are the mainstay of imaging in various orthopaedic disorders. They offer a quick and easy way of obtaining the necessary information in the majority of orthopaedic patients. The main drawback is the radiation dose, although this is often minimal when imaging the extremities, or in comparison to Computed Tomography (CT). Plain films are also used in the postoperative period to assess healing and detect implant-related complications.

Computed Tomography

Computed tomography relies on ionising radiation and is a popular orthopaedic imaging modality. It has benefited tremendously from advances in computer software and the development of thinner slice thicknesses. It is now possible to post-process the data in a multitude of ways, the most common of which is multi-planar reformatting. This refers to the reconstruction of data in any desirable plane, most common of which are often the sagittal and coronal planes. Curved reformats are also possible and are used, for example, in patients with scoliosis for imaging of the spine.

CT has a higher spatial resolution than Magnetic Resonance Imaging (MRI). However, it offers relatively poor contrast resolution and is inferior to MRI for evaluating soft tissues. CT is a much quicker scan than MRI and is, therefore, less susceptible to artefacts in patients who are unable to keep still. Furthermore, it allows for a faster turnover of patients. CT scanners have a shorter bore and are therefore better tolerated by claustrophobic patients.

Due to the high-quality imaging, CT scans are increasingly used in the diagnostic work-up, especially in trauma patients (Fig. 16.1). Furthermore, metallic artefacts from implants can be significantly reduced with the newer CT machines and software packages. This allows much greater visualisation and interpretation of the pathology. CT is also used to aid biopsy of deep-seated lesions and in performing joint injections, such as for the sacroiliac and thoracic facet joints. The major drawback of CT is its reliance on ionising radiation.

Common applications of CT in musculoskeletal disorders are-

- Trauma, especially fractures of the spine, pelvis, tibial plateau, ankle, calcaneum and midfoot.

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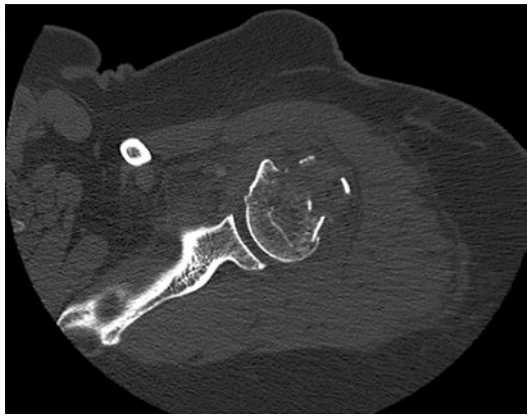

Fig. 16.1 An axial computed tomography scan of the left shoulder demonstrating a comminuted proximal humeral fracture

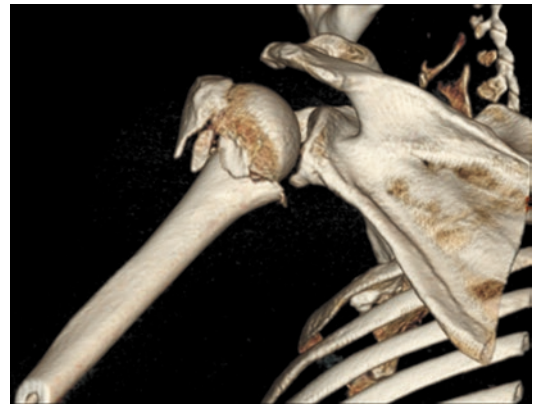

Fig. 16.2 A volume-rendered three-dimensional CT reconstruction of the same proximal humeral fracture

- Postoperative evaluation to assess complications, state of bone fusion, periprosthetic fractures and prosthesis failure.
- Pre-operative planning to aid surgery such as before complex spinal reconstruction or correction
- Assessment of bone lesions, such as, an osteoid osteoma.
- Deep-seated soft tissue lesion biopsy or bone biopsy.
- Guided injections and nerve root blocks.

Dual Energy CT (DECT) is a relatively newer technology that uses X-ray beams of two separate energies to obtain the images. This enables the computer to study the attenuation property of the tissue (or matter) at different X-ray energy levels and therefore, selectively enhance or reduce the effects of specific materials in the body such as iodine or calcium. DECT, therefore, can produce better contrast images and also non-contrast images from a single study (therefore, reducing the dose). It can be used to differentiate tissues of different chemical composition, for example, a gouty tophus from a calcific deposit. It is also helpful in generating better metal artefact reduction images and to potentially detect marrow oedema in the bones.

Some software packages enable three-dimensional (3D) reconstruction of images, including volume rendering and surface reconstructions (Fig. 16.2). Such programs are particularly useful for giving the surgeons a 3D overview of complex fractures and complex spinal abnormalities. It is also possible to 'ghost-out' structures to make fracture lines more clearly visible.

Magnetic Resonance Imaging

The use of MRI has rapidly grown in clinical practice.

MRI scan is acquired by placing the patient in a strong magnetic field, which aligns the nuclei of elements with odd atomic numbers (mostly hydrogen) in the body along the magnetic field. This becomes the steady-state in the magnetic field, and a radiofrequency (RF) pulse is then applied in this steady-state. After the RF pulse is switched off, the steady-state returns to equilibrium with the release of energy in the form of an RF signal, which is detected with the receiver coil.

The above-described 'spin-echo' technique gives T1- and T2-weighted images, depending on the time of application of the RF pulse (TR, repetition time) and the timing of signal acquisition (TE, echo time). Different tissues in the body have different T1 and T2 relaxation times: liquids have long T1 and T2 times, while fat has low T1 and T2 values. Varying the TE and TR times can, therefore, vary the T1 or T2 weighting of images.

Field strength indicates the strength of the magnet. In clinical practice, commonly used MR scanners have field strengths of 1–1.5 Tesla, which allow shorter imaging time and thinner slices compared to older scanners. Also, 3 Tesla scanners are becoming more common in clinical practice. Low-field-strength magnets of 0.3 Tesla have an open configuration and are convenient for imaging claustrophobic patients and extremities such as the elbow and wrist.

MRI is usually performed in at least two and possibly three orthogonal planes.

Commonly used sequences in clinical practice are T1, T2, proton density and STIR (Short Tau Inversion Recovery). The appearance of fluid or fat in different sequences is shown in Table 16.1.

T1 Sequence

Short TE and TR times give a T1-weighted sequence. In this, water returns a low signal and fat returns a high signal. This is a rapidly acquired sequence that provides excellent anatomical detail. Fat, sub-acute haemorrhages and proteinaceous fluids are bright, while fluid is dark. T1-weighted images are generally considered good for looking at bone marrow. However, they are not as good for detecting bone or soft tissue oedema. T1 imaging following gadolinium administration (see later) is often used as a problem-solving tool.

T2 Sequence

Long TE and TR times give a T2-weighted image that is excellent for demonstrating pathological conditions which lead to increased water content—such as oedema, inflammation, infection and tumours. One way to remember this is with the mnemonic 'World War 2'—water is white on T2.

Table 16.1 The tissue appearances in various MRI sequences

	T1	T2	PD	T1/T2/PD with fat-suppression (FS)	STIR
Fluid	Dark	Bright	Bright	Bright	Bright
Fat	Bright	Bright	Bright	Dark	Dark

Proton Density Sequence

Proton-density sequences use a short TE and long TR. This sequence is a mix of T1 and T2, with contrast intermediate between T1- and T2-weighted images. This sequence is used in the assessment of menisci and other structures as part of routine knee protocols. It is often used with fat suppression to increase contrast.

Fast-Spin Echo Sequence

This is an accelerated method of acquiring T2 and proton-density images and is generally referred to as a 'fast' or 'turbo' technique. Fat remains bright on fast or turbo T2 and therefore fat-suppressed sequences are often used to highlight water-containing tissues such as inflammation or tumour. This sequence also reduces artefacts from metal prostheses and can be employed if previous instrumentation is present.

STIR Sequence

A STIR sequence is a specialised spin-echo sequence that suppresses fat from the images, making fluid-containing lesions more conspicuous. This is a very sensitive technique to detect soft tissue and marrow pathology and particularly useful to obtain uniform fat suppression in larger patients.

T2* (Gradient-Echo T2)

This is faster T2 sequence with fluid bright as in the usual spin-echo T2 sequence. It is particularly good for imaging the ligaments, articular cartilage and fibrocartilage. The advantage of this sequence is that very thin sections can be obtained, which are useful for 3D volume recon-

struction. However, this sequence is degraded significantly by metal because of susceptibility artefacts.

Fast-Spin Echo

This is an accelerated method of acquiring T2 and proton-density images and is generally referred to as a 'fast' or 'turbo' technique. Fat remains bright on fast or turbo T2 and therefore fat-saturated sequences are often used. This sequence also reduces artefacts from metal prostheses and should be employed if previous instrumentation is present.

Gadolinium-Enhanced Scans

Gadolinium administration is used to delineate an abscess or to differentiate between cystic and solid masses, and viable and necrotic tissue, among other uses. T1-weighted sequencing with fat suppression is usually used when gadolinium is administered, making the pathology stand out.

MR Arthrography

MR arthrography involves MR scanning after the intra-articular injection of gadolinium, clearly demonstrating intra-articular structures. This technique is especially useful in assessing glenoid and acetabular labrum in the context of shoulder instability and femoroacetabular impingement. MR arthrography is also useful in the characterisation of hyaline cartilage and osteochondral defects.

Whole-Body MRI

With improvement in MRI scanner and coil technology, we are now able to obtain images of the entire body and the bony skeleton without the need for patient or coil repositioning. This technique is very useful in the context of multifocal disease especially to detect metastasis, myeloma lesions or multifocal inflammatory foci. Whole-body MRI is replacing plain film skeletal survey in the diagnosis of myeloma.

Contraindications to MRI

The following objects are contraindicated within the MRI scanning room: intracerebral aneurysm clips, cardiac pacemakers, defibrillators, biostimulators, internal hearing aids and metallic orbital foreign bodies. However, many of the newer generations of cardiac pacemakers and defibrillators are now MRI compatible.

Relative contraindications are first-trimester pregnancy, middle-ear prosthesis and penile prosthesis. There is often confusion among clinicians with regards to the safety of orthopaedic implants in an MRI scanner: orthopaedic implants including prosthetic joints, screws, plates and rods can be scanned, but steel implants cause artefacts. Titanium devices produce significantly less artifacts. Metallic external fixators should not be scanned.

Common Applications

Common applications of MRI in musculoskeletal disorders are:

- Spine pathology, like, back pain and sciatica.
- Knee joint evaluation—meniscus and cruciate ligament tears (Fig. 16.3), hyaline cartilage defects.
- Shoulder joint evaluation—rotator cuff tear, anterior or posterior dislocation.
- Wrist—triangular fibrocartilage complex and intrinsic ligament tears.
- Soft tissues and bone neoplasms—to characterise and define the extent of lesions.
- Avascular necrosis.
- Osteomyelitis (including, discitis).
- Arthritis.
- Bone-marrow pathology.

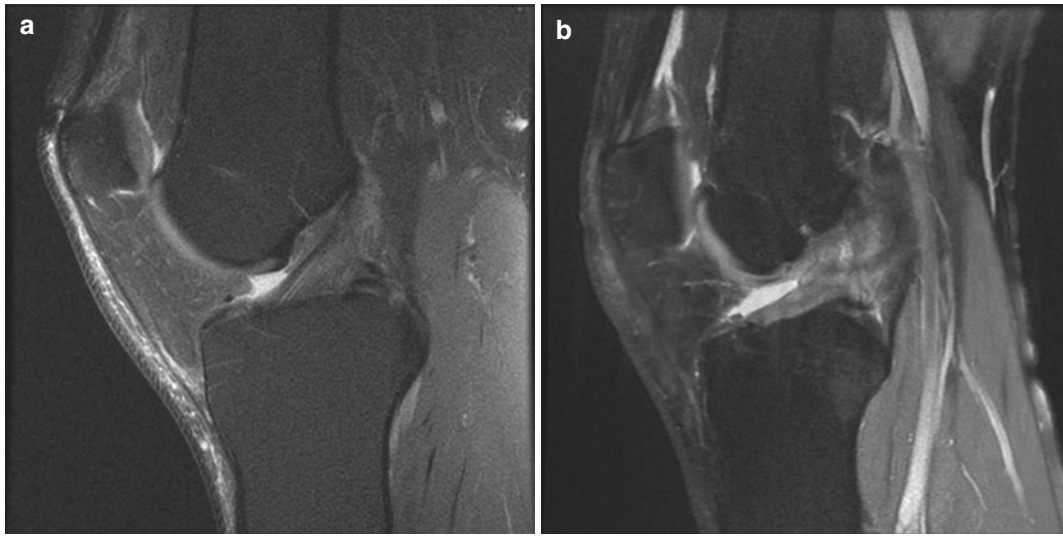

Fig. 16.3 Fat-suppressed sagittal proton-density image of the knee demonstrating (**a**) a normal and (**b**) ruptured anterior cruciate ligament

Ultrasound

Musculoskeletal ultrasound (US) imaging is widely used for a variety of conditions. Compared with MRI, US is less expensive and more patient-friendly, avoiding the claustrophobia sometimes experienced by patients during MR examination. Its real-time and dynamic nature can direct examiners towards the symptomatic area, allowing them to focus on the relevant abnormality. The dynamic capability allows examiners to observe pathologic movements in tendons, bursae or joints with continuous patient feedback. MR and US are often used as complementary imaging modalities to help solve the problem.

However, the US is operator dependent and the US images are often difficult to interpret for others. MR and US are often used as complementary imaging modalities to help interpretation. Another limitation of the US is the dependence of the quality of images on the body habitus. It is not particularly useful in obese patients because of poor beam penetration of high-frequency probes.

Ultrasound offers advantages over CT when used for interventions because it does not use ionising radiation or contrast. US guidance decreases the inaccuracy rate of blind injections into the knee or shoulder joint, which can approach 30% in some instances.

Common Applications

Ultrasound is commonly used to evaluate tendon pathology, especially the rotator cuff tendons. Many studies have been performed on this subject and sensitivity can approach 100% for full-thickness tears, with lower sensitivity for partial-thickness tears. The Achilles tendon is another well-defined structure imaged with diagnostic US. Dynamic US imaging allows small tendon tears become more apparent. This technique can also be used to detect biceps, peroneal or posterior tibialis tendon subluxation.

Diagnostic US can also be used for imaging ligaments such as the ulnar collateral ligament of the elbow; the anterior talofibular and calcaneofibular ligaments of the ankle; and the medial and lateral collateral ligaments of the knee. When combined with dynamic stress imaging, US is a particularly useful modality to identify medial collateral ligament tears or laxity. It is not good for detecting intra-articular knee pathology such as meniscal or cruciate ligaments as ultrasound doesn't travel through bone.

Ultrasound is also an excellent imaging modality for detecting small joint effusions and to guide interventions such as joint aspiration or injection. Doppler US can detect increased blood flow in the synovium and therefore, diagnose active synovitis of inflammatory or infectious aetiology. US is useful for early detection of synovitis or erosion in inflammatory arthropathy such as rheumatoid arthritis, resulting in early treatment and disease modification.

Labral tears of the shoulder and hip are best diagnosed with MRI, but diagnostic US can be used if the defect extends to the peripheral margin of the joint and if it is associated with ganglion formation. The portability, ease of use and high spatial resolution of the US make it an excellent tool for imaging muscular injuries and superficial nerves.

Another vital utility of ultrasound in the musculoskeletal field is its ability to diagnose and differentiate soft tissue lumps and tumours. It is usually the first investigation of choice to ascertain the nature of any soft tissue lump as it can easily diagnose benign lumps such as lipomas and ganglion cysts. It is also useful to diagnose and guide further management in more malignant looking soft tissue lesions such as sarcomas.

Common applications of US in musculoskeletal disorders are:

- Shoulder—rotator cuff pathology.
- Assessment of soft tissue lumps and bumps.
- Tendinosis or tenosynovitis, especially around the ankle and wrist (Fig. 16.4).
- Infection—assessment of joint effusion, soft tissue collection.
- Guided injections.
- Guided biopsy or drainage.

Radioisotope Bone Scan

Radioisotope bone scanning involves the use of radiopharmaceuticals, the most common of which is 99m-Technetium (99m-Tc) attached to a tracer, methylene diphosphonate (MDP). When injected intravenously, this tracer is 'taken up' preferentially by the bone and incorporated into the surface of its calcium hydroxyapatite crystals of the bone to produce insoluble calcium phosphate complexes. The 99mTc emits Gamma rays, which is then detected by the Gamma Camera and computer projects it as a 'hot spot'.

An isotope bone scan thus can provide 'functional' imaging, as the complexes accumulate in areas with increased blood flow or increased bone turnover. Osteoblastic lesions are apparent due to increased bone turnover, while lytic lesions are usually visible due to the surrounding rim of reactive bone. Bone uptake is demonstrated on whole-body views and spot views of the region of interest acquired 2–4 h after injection (delayed phase). In a three-phase bone scan, images are obtained not only in the delayed phase (showing osteoblastic activity), but also in the 'blood flow' (early) and 'blood pool' (intermediate) phases. The three-phase bone scan is commonly used to investigate bone infection, trauma and reflex

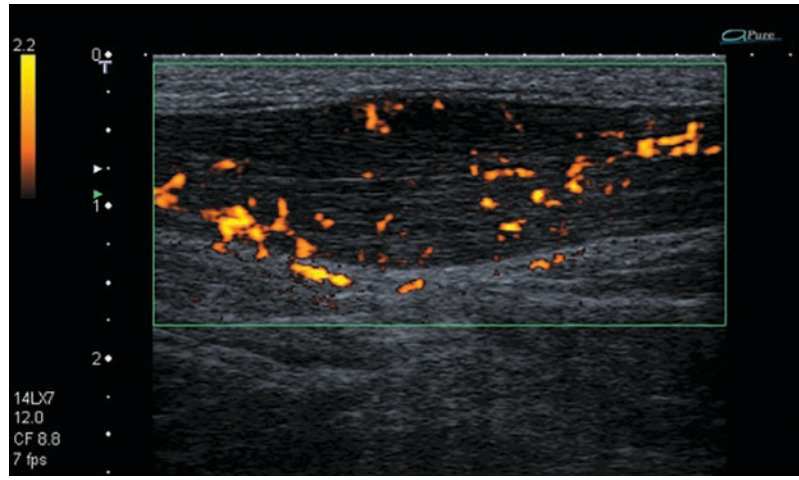

Fig. 16.4 An ultrasound image demonstrates Achilles tendinosis

sympathetic dystrophy. The first (blood flow) phase involves a dynamic flow study, with images obtained every 2–3 s for 30 s following injection. Imaging in this phase indicates the vascularity of the lesion. The second phase (blood pool) is obtained at 5 min, and reflects extracellular fluid uptake within the bone due to changes in capillary permeability.

A positive bone scan in all three phases can suggest an acute lesion of less than 4 weeks with an increased blood flow, whereas a scan positive in only delayed images suggests an abnormality with increased osteoblastic activity. Tc scans help differentiate septic from aseptic loosening in joint replacements. In septic loosening, there is increased uptake in all three phases, while aseptic loosening will lead to increased uptake predominantly in the delayed phase.

SPECT and SPECT/CT

Conventional planar bone scan imaging provides a two-dimensional projection of a 3D source of activity. SPECT, however, which involves taking projection images at many angles in a tomographic fashion, and is, therefore, able to accurately project the source of activity. This method allows removing the activity from overlying or underlying tissues, which would otherwise obscure the image at the required depth of interest.

SPECT scanning improves visualisation and localisation of the uptake (hot spot). It is particularly useful for accurately visualising the area of uptake in more complex anatomical areas such as the posterior elements of vertebrae.

Hybrid imaging combines the functional images obtained with an isotope scan with the anatomical information obtained from CT, thereby overcoming the drawbacks of both modalities. SPECT with CT correlation (SPECT-CT), for example, maybe useful in assessing anterior knee pain, and can demonstrate patellofemoral osteoarthritic change, patellar enthesopathy or osteochondral bone bruising. In assessing painful scoliosis, it can demonstrate the precise location of osteoblastoma.

Common causes of ‘hot spots’ on a bone scan are as follows:

- Trauma and stress fractures.
- Previous arthroplasty—can be positive for up to 3 years.
- Malignant tumours and metastasis.
- Arthritis.
- Loosening in hip and knee prosthesis
- Infections—osteomyelitis.
- Paget’s disease.
- Fibrous dysplasia.
- Benign tumours.
- Bone infarction.
- Soft tissue uptake due to an infection, inflammation or tumour.

Common Applications

In patients with bone tumours/malignancy, bone scanning is used to detect metastasis for staging, assess areas of bone pain with negative radiographs, determine response to treatment, assess the ribs and sternum (which are difficult to assess with plain radiographs) and detect other sites of involvement (Fig. 16.5).

The term ‘super scan’ indicates widespread skeletal disease and is often seen in diffuse metastatic bone disease or metabolic bone disease. This results in diffuse and ‘uniform’ increased isotope uptake in the skeleton, rather than localised hot spots, and can give a false impression of normal skeletal uptake. The kidneys and bladder, which are normally visualised in bone scans due to isotope excretion, are not well visualised in a super scan. This is commonly termed ‘absent kidney sign’.

Positron Emission Tomography

Positron emission tomography (PET) is another form of highly sensitive metabolic imaging in nuclear medicine. It depends on the detection of gamma rays emitted when the positron emitted by the radionuclide tracer collides with the electron indirectly by a positron-emitting radionuclide

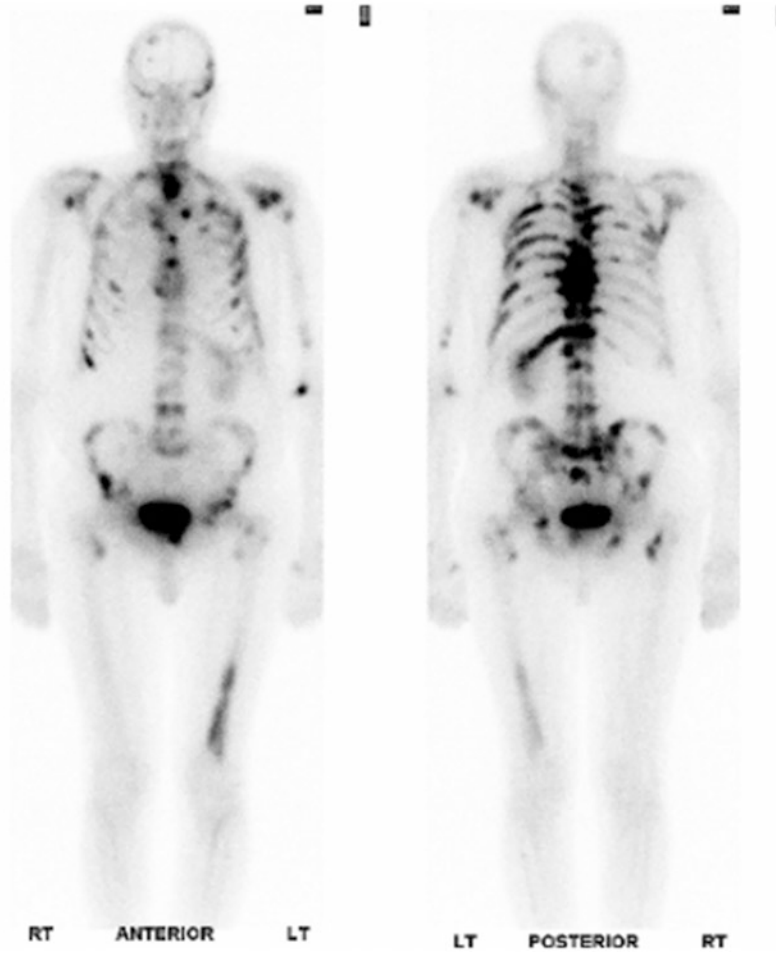

Fig. 16.5 Whole-body planar bone scan (in delayed phase) demonstrates widespread bony metastasis in a patient with prostate cancer

(tracer). The most commonly used tracer is [18F]-2-fluoro-2-deoxy-d-glucose (FDG). FDG, as a glucose analogue, is taken up by high-glucose-using metabolically active cells such as brain, heart and cancer cells. Malignant cells concentrate this radionuclide tracer and retain it until radioactive decay, which is detected by the camera. As a result, FDG-PET can be used for the diagnosis, staging and monitoring of cancers.

Common indications for PET imaging are:

- Head and neck malignancies for detection of the primary lesion.
- Differentiating scar tissue from recurrent disease.
- Monitoring response to treatment.