The Diabetic Foot

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Diabetes mellitus can adversely affect the musculoskeletal system in a variety of ways. One of the more common complications that arise as a result of long-standing or poorly controlled diabetes is the "diabetic foot". The diabetic foot is an umbrella term for a spectrum of different pathologies affecting the foot in diabetes patients, including neuropathic arthropathy and infection, with each process either existing in isolation or in conjunction with others at any given time.

Pathogenesis of neuropathic arthropathy includes the neurotraumatic and neurovascular theories. Diabetes, particularly in long-standing disease, can have a significant impact upon the vasculature, with blockage and/or obliteration of both small and large peripheral vessels, leading to chronic tissue ischemia of the periphery, especially the feet. The vasa nervorum of the peripheral nerves also becomes ischemic, leading to small-fibre, predominantly sensory, peripheral neuropathy. The patient loses proprioception and the ability to sense and respond to trauma (neurotraumatic). Recurrent episodes of microtrauma to the desensitized joint play a major role in the development of the neuropathic joint (neurotraumatic). Bone, cartilage, ligamentous and tendon injuries occur. Motor fibres are involved with subsequent loss of muscle tone and function and can lead to joint instability and deformity. Altered vascular control may lead to hyperaemia, secondary bone resorption and weakening of subchondral bone (neurovascular). Autonomic involvement often presents as areas of dry skin and areas of fissures that predispose to ulceration.

Diabetic patients also have impaired immunity and are more susceptible to infections and thus can more readily develop secondary infections of the ulcers. Infection in the non-healing ulcers can penetrate into the deep tissues of the foot, and/or sinus tracts can develop. The sinus tracts tunnel between the skin and the underlying bone or joints, which can lead to osteomyelitis, septic arthritis and deep soft tissue infections. Ulcers occur at typical sites of bony prominences. In weight-bearing patients these include plantar aspects of the 4th and 5th metatarsal heads, tuft of great toe and at heel. Patients with rocker-bottom foot deformity develop ulceration under the fallen cuboid bone in the midfoot. Although the neuropathic joint is most commonly seen in chronic diabetic patients, it may also be seen in many conditions including the following pathologies: tabes dorsalis, congenital insensitivity to pain, spinal cord trauma, syringomyelia, meningomyelocele, alcoholism and amyloidosis.

The difficulty that both clinicians and radiologists face in managing these patients is in the identification of infections and distinguishing these from a neuropathic arthropathy. Both of

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these phenomena can exist concurrently, which further complicates the picture and makes distinguishing between them difficult.

Neuropathic Arthropathy (Charcot Joint)

Isolated neuropathic arthropathy appears to occur due to repeated trauma and posttraumatic skeletal inflammation. It can present as an indolent process or as an acutely swollen, red, hot joint, thus mimicking a septic joint. Given the pain insensitivity due to peripheral neuropathy, the patient typically continues to weight-bear on the acutely inflamed joint, which then leads to trabecular microfractures and subsequent bone and joint damage with loss of the normal architecture and deformity. The management of an acute Charcot joint requires an attempt at early diagnosis through education and screening of patients by healthcare professionals and immediate total offloading of the affected joint to prevent further damage and to promote healing. This can be accomplished through the use of modified or specialty footwear.

Imaging can be helpful both in confirming a Charcot joint and in differentiating it from an infectious arthropathy. This section will focus on the findings of a Charcot joint. The following session discusses the imaging of infectious arthropathies in diabetes and will offer strategies on differentiating these from neuropathic arthropathies.

Imaging

Several patterns of neuropathic arthropathy can occur and include atrophic, hypertrophic and mixed. In the atrophic form there is a dominance of bone resorption, whereas in the hypertrophic form, there is a dominance of new bone formation with large osteophytes, sclerosis and joint destruction. The atrophic form is most commonly seen in non-weight-bearing joints and upper motor neuron pathology.

Initially joints may appear normal. Diffuse periarticular soft tissue swelling and joint effusions are present early in the disease. Subtle subluxation may be present. There is progressive joint deformity and destruction. In mid- and late-stage disease, the *6 D's* are present in variable degrees: *d*eformity, *d*estruction (of bone and joint), *d*ebris (intra-articular bone and cartilaginous bodies), *d*ensity (increased subchondral sclerosis), *d*islocation and *d*egeneration (changes of osteoarthritis/attempted repair).

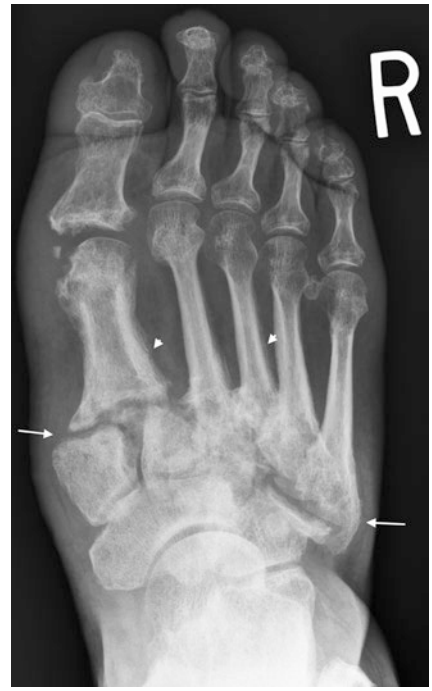


Fig. 14.1 AP foot radiograph in a 67-year-old female diabetic with long-standing foot problems. There is a homolateral Lisfranc fracture dislocation (*arrows*, the first to fifth metatarsals are dislocated laterally at the TMT joints with associated fractures), there is increased sclerosis, and there is periosteal reaction along the lateral proximal and mid-diaphysis of the first and third metatarsals (*arrowheads*). The first MTPJ is widened, bony destruction with periarticular erosions and intra-articular debris

For the purpose of interpreting radiographic findings, the progression of neuropathic arthropathy has been classified into three stages by Eichenholtz and later a preradiographic stage was added: Stage 0 represents the earliest symptoms where reactive osseous oedema can be seen on MRI, while plain radiographs remain normal. In Stage 1 there is acute arthropathy with bone dissolution, Stage 2 represents the early repair phase (coalescence), and Stage 3 represents the chronic healing phase (remodelling). This staging is not commonly used in clinical practice but is useful in understanding the progression of a Charcot joint.

Radiographs (Figs. 14.1 and 14.2)
In Stage 0, radiographs are typically normal; however it may demonstrate joint space widening.

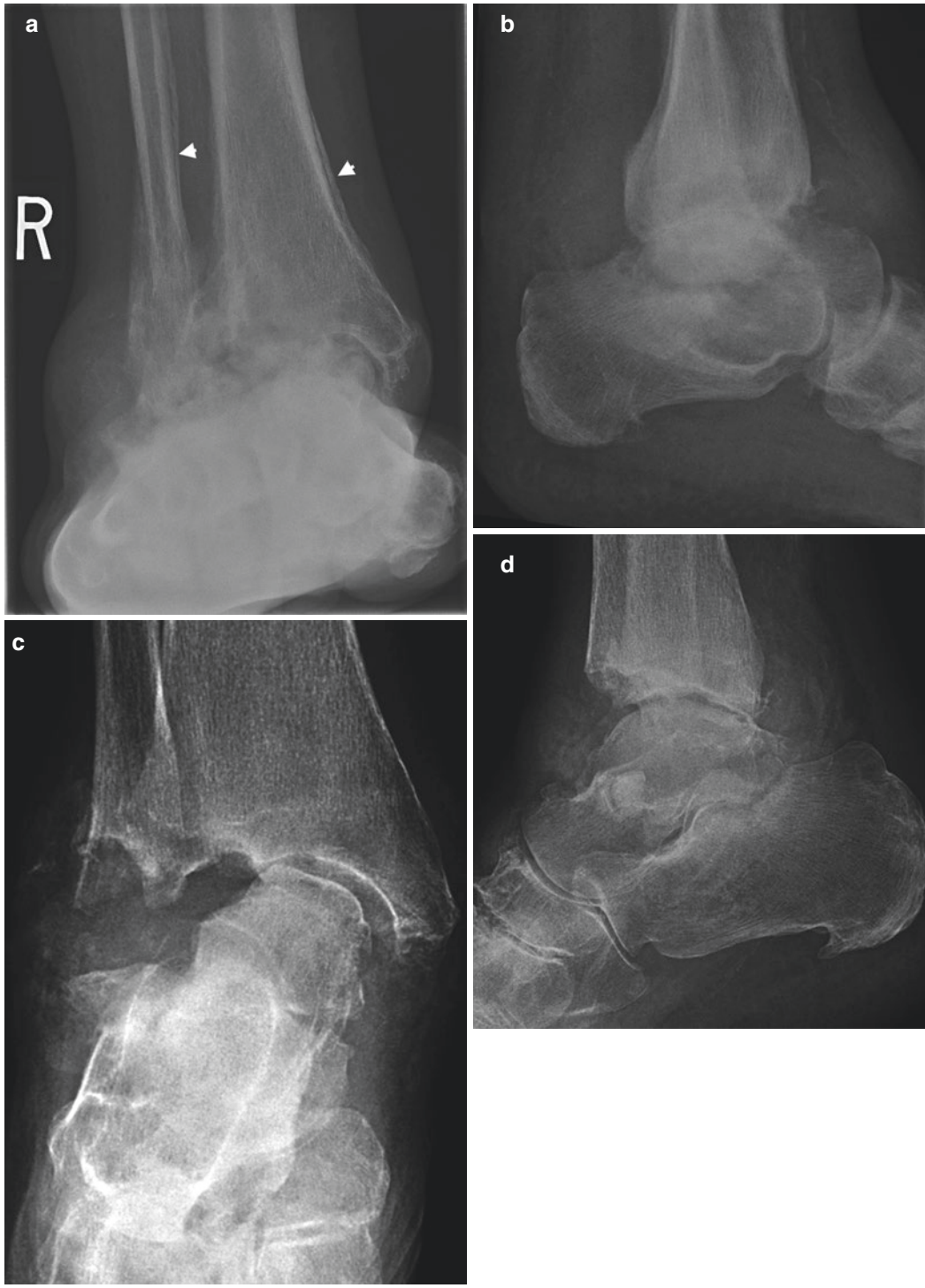


Fig. 14.2 A 55-year-old male diabetic with neuropathic arthropathy of the ankle joint. (**a**) AP and (**b**) lat radiographs demonstrate complete joint space loss, large joint effusion, destruction with partial collapse talar dome, extensive erosions tibia, sclerosis, internal debris, osteophytosis and chronic periosteal reaction (*arrowheads*) of the tibia and fibula. No soft tissue ulceration identifiable (**c**, **d**) in different patients with less advanced secondary degenerative change. (**e**, **f**) Sag reformatted CT on bone windows in a different patient demonstrates exuberant new bone formation post-ankle joint fusion which is seen in hypertrophic neuropathic joints

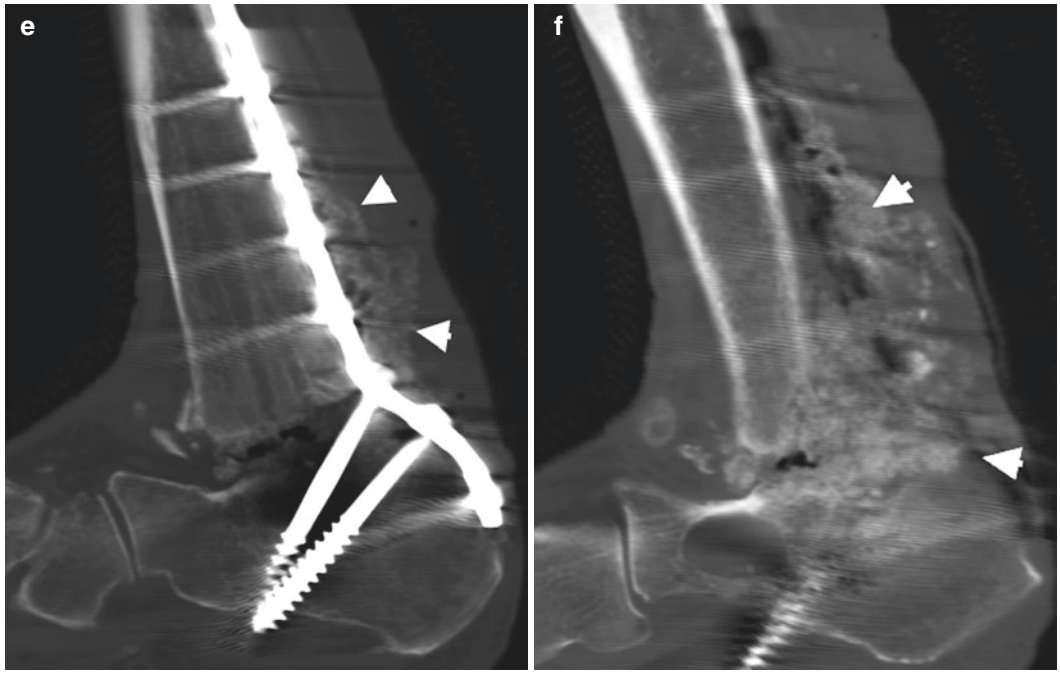


Fig. 14.2 (continued)

Radiographs of Stage 1 can show demineralization of the bone and findings of bone damage including fragmentation, disorganization, subluxations or osteoarthrosis with subchondral cystic changes. In Stage 2 there is evidence of healing with callus formation, reabsorption of bony fragments and debris and bony remineralization. Persistent changes of subluxations and bone deformity are often present. These changes also carry into Stage 3, though further rounding and smoothing of bony deformities are seen in this chronic healing stage, and bones can develop subsequent ankylosis and/or superimposed degenerative changes.

Magnetic Resonance Imaging (MRI) (Fig. 14.3)

The earliest finding in a neuropathic arthropathy on MRI is bone oedema, with hyperintensity on T2W imaging, often with visible trabecular stress fractures without cortical disruption, seen as hypointensities on T1W imaging. Joint effusion and cartilaginous damage or thinning can be seen. Soft tissue oedema is frequently visible as high signal intensity on T2W imaging of the soft tissues. There are periodically early deforming joint changes with subluxations, even prior to abnormalities on radiograph, though this is more prominent in the subsequent stages. Stage 1 changes encapsulate all of those seen in Stage 0 with progression of bony deformities and damage. In Stage 2, there tends to be improvement in the degree of bony and soft tissue oedema, with development of callus. In Stage 3, the acute oedematous changes have resolved, and persistent bony deformities and changes of osteoarthrosis are seen.

CT (Fig. 14.4)

CT will demonstrate similar bony and joint findings as described in MRI although it cannot assess bone marrow oedema and is limited in assessing the soft tissues. Occasionally CT will be acquired for a detailed bone assessment prior to surgery.

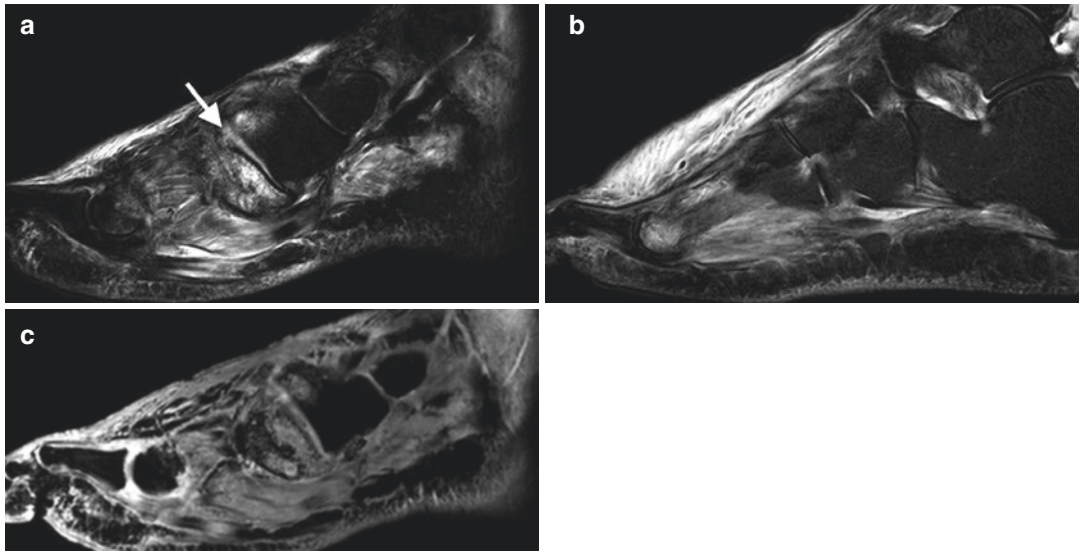


Fig. 14.3 A 44-year-old male diabetic with 6-month history of foot pain diagnosed with Charcot joint with fractures and diffuse soft tissue oedema and tenosynovitis. (**a**, **b**) Sag T2 FS of navicular-medial cuneiform (*arrow*) and 2nd MTPJ, respectively, with extensive bone marrow oedema, tenosynovitis, soft tissue and extensive dorsal subcutaneous oedema without soft tissue ulceration and (**c**) Sag T1FS PG demonstrate diffuse enhancement areas of oedema without evidence of soft tissue collections

Ultrasound (Fig. 14.5)

Ultrasound has a limited role. It is excellent in assessing related soft tissue pathology, excluding soft tissue collection and assessing joint effusions.

Nuclear Medicine

This has a limited role. The involved joint will demonstrate increased osteoblastic activity and increased uptake on bone scan, but this can be inferred from radiographic findings.

If successful treatment is initiated early, prior to the development of bony changes, the progression to later stages and subsequent permanent arthropathy and deformity can be avoided.

Diabetic Foot Infections

Given that the vast majority of diabetic foot infections occur as a result of direct inoculation of the affected site from skin barrier breakdown, the absence of an ulcer makes osteomyelitis or septic arthritis and a presentation of foot swelling and erythema in a patient with peripheral neuropathy and supportive radiographic findings is likely due to a neuropathic joint without superimposed infection. Clinically, infected ulcers appear as purulence of the ulcer with surrounding erythema. Those ulcers that are greater than 2×2 cm have a high likelihood of being complicated by underlying osteomyelitis. When the underlying bone is visible at the base of the ulcer or can be probed with a sterile instrument, osteomyelitis is almost certainly present.

Identification of an organism in a diabetic ulcer is best accomplished by culturing the tissue removed by curettage rather than merely swabbing the ulcer surface. The infections are most commonly due to gram-positive cocci; however they can be polymicrobial, and concurrent infection with gram-negative bacilli or anaerobic organisms is common. Treatment of diabetic foot infections is beyond the scope of this text; however some basic principles are outlined: All ulcers should receive appropriate wound care including mechanical offloading if possible. Antibiotics covering the cultured organisms, tailored to sensitivities, are the mainstay. Combination

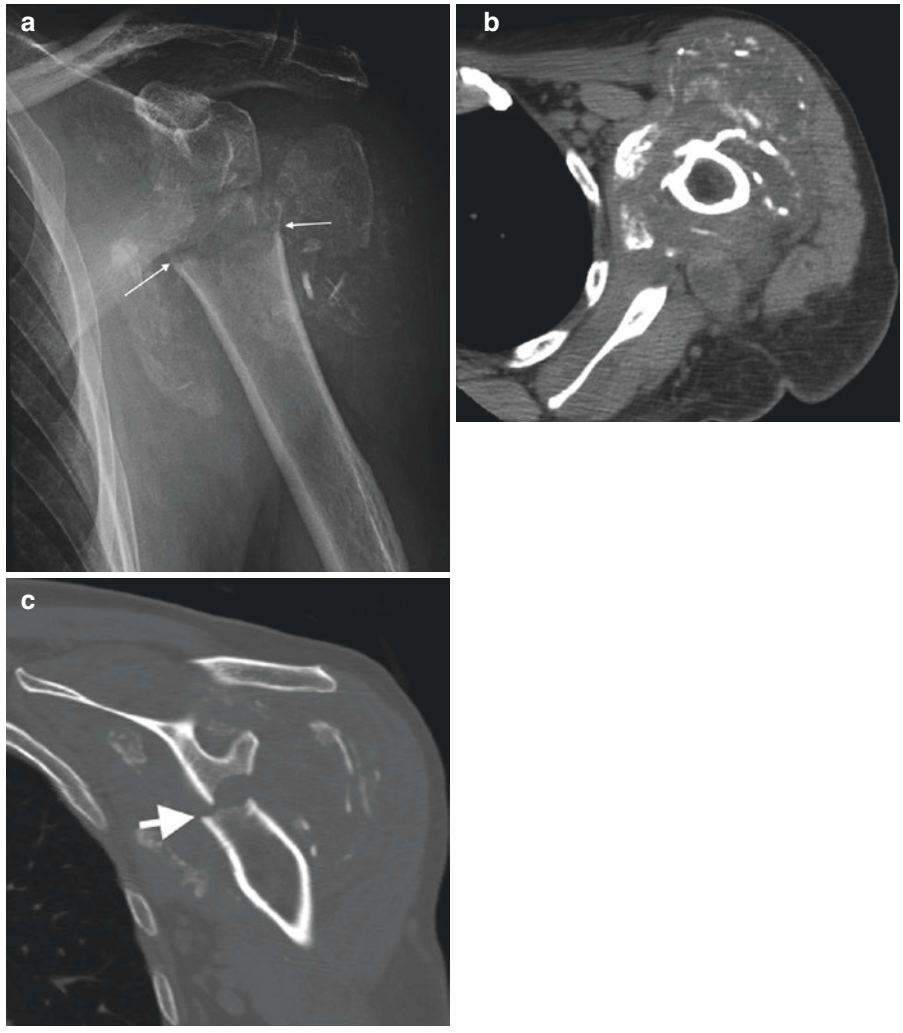


Fig. 14.4 Neuropathic arthropathy of the shoulder on (**a**) AP radiograph demonstrating diffuse soft tissue and joint swelling, multiple fractures with variable degree of osteolysis of bone fragments, bony debris, disorganization and dislocation without increased density in keeping with an atrophic neuropathic type joint. Note the straight transverse margin surgical neck humerus fracture (*arrows*); this is surgical like and should always raise possibility of a neuropathic joint when seen. (**b**) Axial soft tissue and (**c**) Cor reformatted on bone windows CT of the same joint demonstrating similar changes as described above

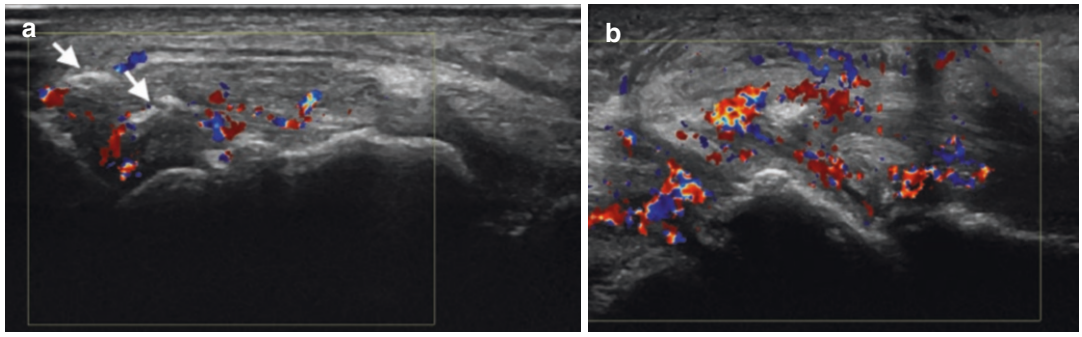


Fig. 14.5 Ultrasound of Charcot ankle joint demonstrating (**a**) increased internal flow on colour Doppler in keeping with active synovitis surrounding echogenic internal loose bodies (*arrows*) confirmed as avulsed bony fragments on radiographs (not shown) and (**b**) extensive periarticular tendinosis and tenosynovitis

antibiotic therapy may be required. Development of soft tissue infections and underlying osteomyelitis typically requires several weeks of intravenous antibiotics, with duration based on severity and patient response. Hyperbaric oxygen therapy has shown some benefit in non-healing ulcers. Surgery may be required in patients with severe infections, particularly those with significant vascular compromise, for removal of infected tissue or limb amputation if necessary.

Imaging can be helpful to assess for diabetic foot complications and in identification of osteomyelitis or septic arthritis and differentiating from an isolated neuropathic joint. MRI is particularly helpful in this regard; however other modalities can play a role as well. Osteomyelitis and septic arthritis are reviewed here. Cellulitis, abscesses and retained foreign bodies are reviewed in the chapter.

Imaging

Radiographs (Figs. 14.6 and 14.7)

Radiographs reveal predominantly major structural abnormalities of the bones of the foot. Both septic arthritis and neuropathic arthropathies can appear similar in this modality: Bony demineralization, disorganization, erosive change, bony fragmentation and joint narrowing and destruction can be present in both. Identification of superficial soft tissue deformity on radiograph

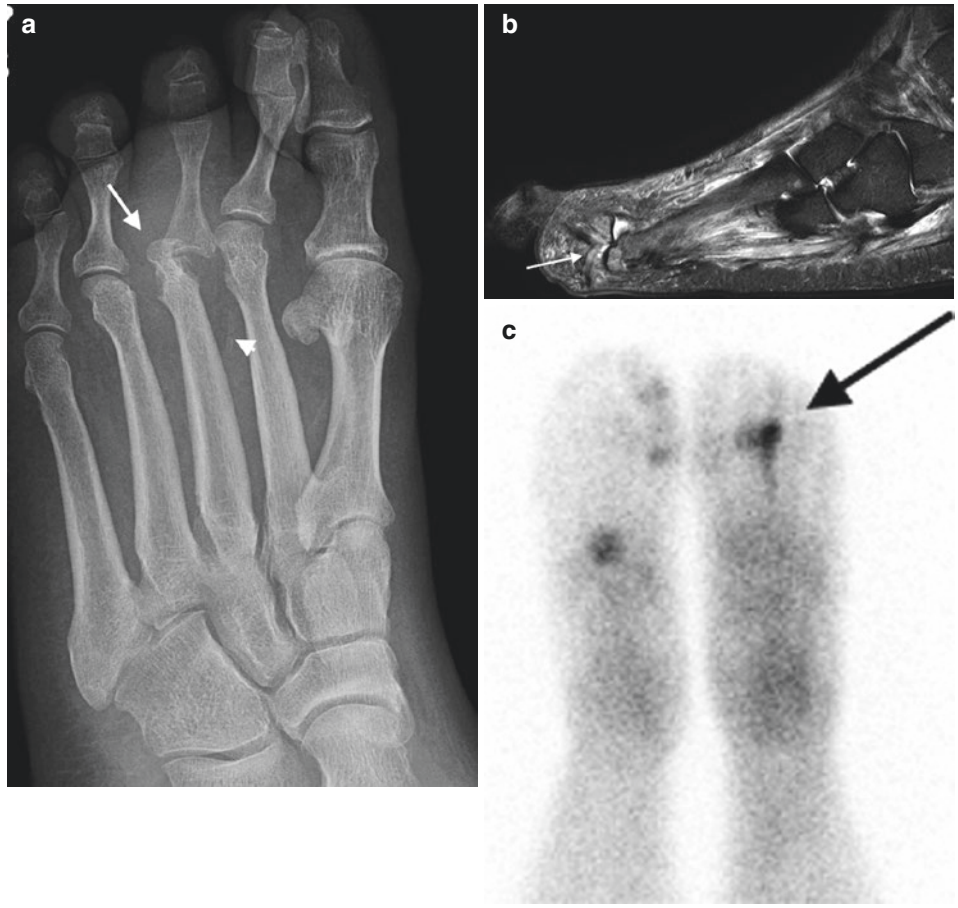


Fig. 14.6 Septic arthritis of the 3rd MTPJ in a 43-year-old male diabetic. (**a**) Oblique radiograph of the left foot demonstrates dislocation at the 3rd MTPJ (*arrow*) with erosions of the metatarsal head and diffuse soft tissue oedema. Note the mild vascular calcification (*arrowhead*). (**b**) Sag T1FS post-gadolinium in the same patient demonstrating enhancement within the joint and pericapsular and periarticular bone marrow oedema enhancement. (**c**) Delayed image from a bone scan, plantar view, demonstrating increased uptake at 3rd MTPJ (*arrow*) (also increased on flow and blood pool phases, not shown)

suggests ulceration. The underlying bone should be carefully assessed. There may be atrophy of the soft tissues at the site of ulceration. Gas produced from anaerobic infections can be appreciated in the tissues on radiographs. Periosteal reaction on the surface of bones may also be a helpful clue to osteomyelitis, particularly if soft tissue changes as described above are

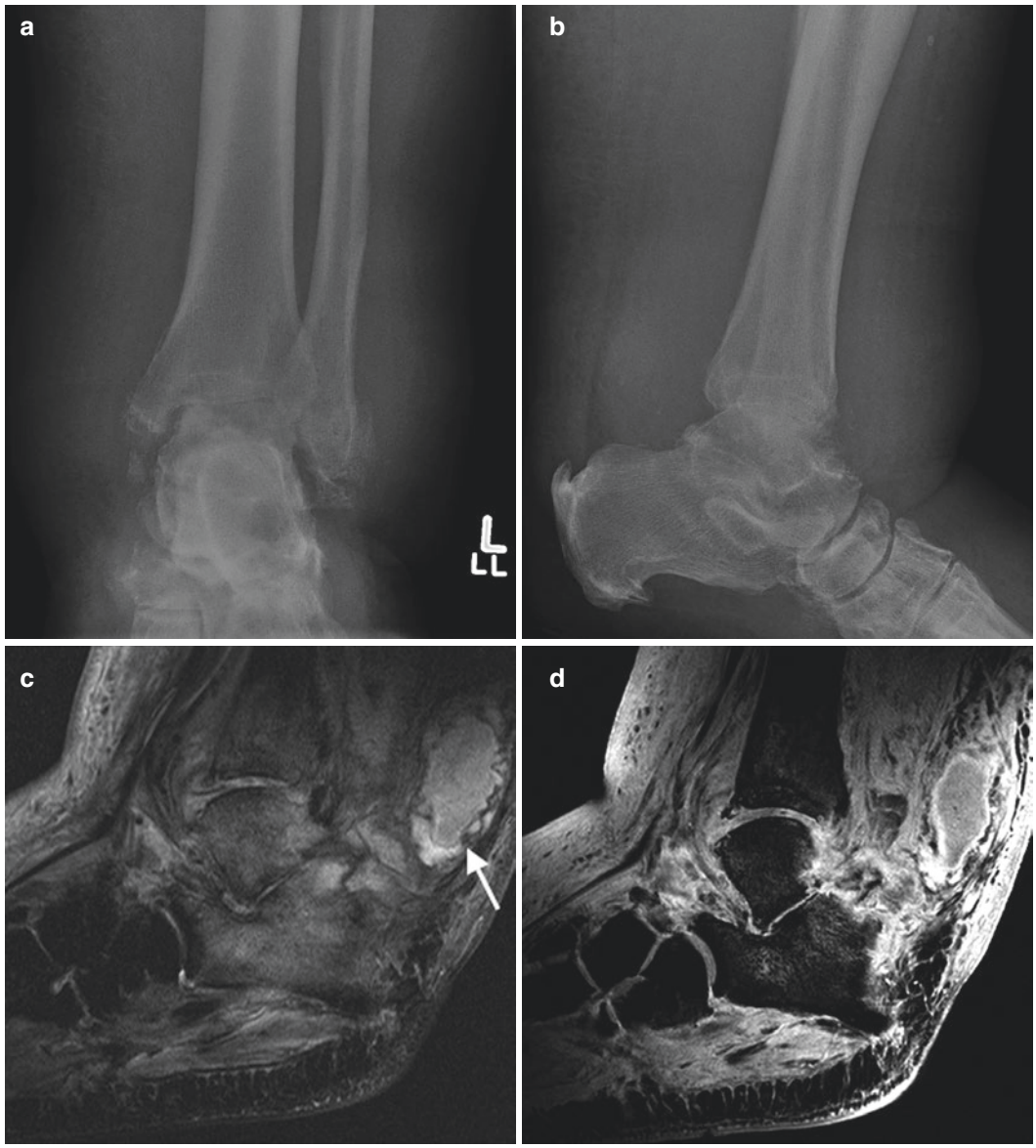
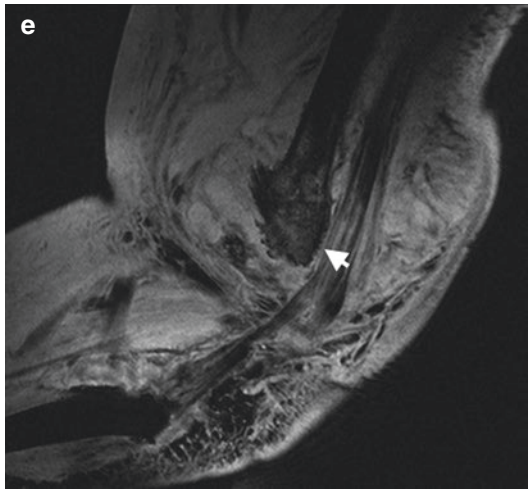


Fig. 14.7 A 61-year-old male diabetic with osteomyelitis of the left ankle. (**a**) AP and (**b**) lateral radiographs demonstrate joint effusion, diffuse soft tissue swelling, joint space loss with central erosions and multiple chronic (well corticated) avulsed bone fragments. (**c**) Mid-Sag T2FS MRI with extensive bone marrow oedema in the tibia, talus and calcaneus and ankle joint effusion communicating with a large collection in Kager's fat pad (*arrow*). (**d**) Sag T1FS post-gadolinium demonstrating diffuse soft tissue and ankle joint enhancement with rim enhancement collection posteriorly. (**e**) Lateral Sag T1FS PG demonstrating similar enhancement as in (**d**) but also demonstrates extensive erosions of the fibula (*arrowhead*) and infective tenosynovitis adjacent to the peroneal tendon sheaths with tendinosis. (**f**) Delayed bone scan image, AP view, with marked uptake at ankle joint



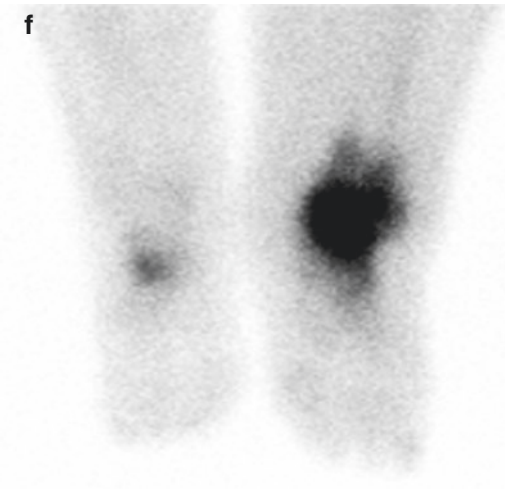


Fig. 14.7 (continued)

present. Overall the sensitivity and specificity for plain radiographs in diabetic foot infections is low (~50 and ~75 %, respectively); however their availability and low cost means that they are generally still the first modality used in the evaluation of the diabetic foot.

MRI (Figs. 14.6, 14.7, and 14.8)
Identification of osteomyelitis in diabetic foot infections and differentiating it from reactive bone marrow oedema seen in a neuropathic joint are best accomplished with MRI. Given that osteomyelitis typically occurs via contiguous spread from a surface ulcer, the common sites of osteomyelitis correspond to the most common sites of cutaneous ulceration: the areas distal to the tarsometatarsal joints, the calcaneus as well as the malleoli of the ankle. Midfoot areas can develop osteomyelitis particularly in the setting of a neuropathic arthropathy where an ulcer develops over a pressure area created by the abnormal configuration of the rocker-bottom foot.

Evidence of a soft tissue infection overlying the area of bone marrow oedema strongly suggests osteomyelitis. Ulcers can be appreciated on MRI as an area of focal skin interruption with raised edges and associated soft tissue defect in the centre. The ulcer base is often hyperintense on T2W imaging due to the presence of granulation tissue with a high water content and

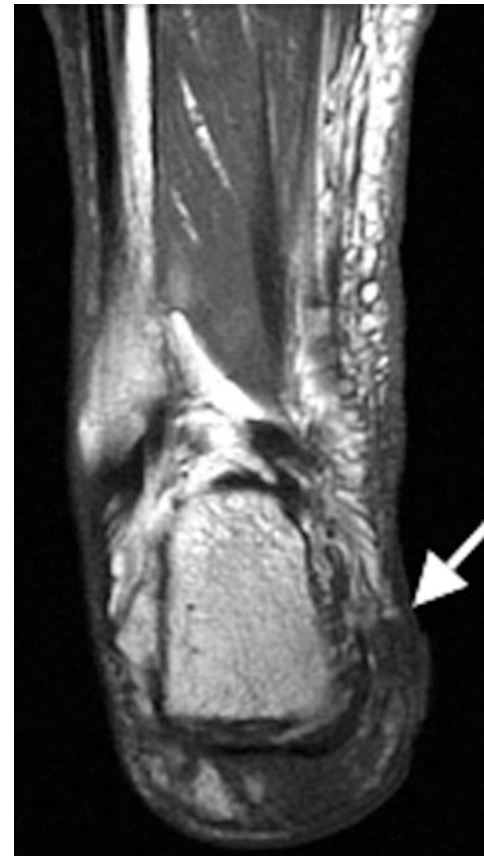


Fig. 14.8 An 86-year-old with DM, chronic renal failure and foot ulcer over medial calcaneus (*arrow*) extending to deep soft tissues. Note the normal underlying marrow SI on T1 indicating no imaging features of osteomyelitis

demonstrates enhancement post-gadolinium administration. An enhancing sinus tract may be identifiable extending from skin to bone or joint. The underlying bone demonstrates oedema which is high SI on T2 and low SI on T1. The latter is a more sensitive finding for osteomyelitis. If bone marrow is high on T2 but not clearly low on T1, this suggests reactive osteitis rather than osteomyelitis. Areas of bone marrow involvement may enhance post-gadolinium. Gadolinium is often not required in the diagnosis of osteomyelitis but is useful in the assessment of associated pathologies such as collections and devitalized areas if required. Restricted diffusion may be present on diffusion-weighted imaging.

Differentiation between septic arthritis and neuropathic joint follows some of the principles outlined above and can be very challenging. The findings of a contiguous soft tissue infection or sinus tract are highly suggestive of septic arthritis. Typically, septic arthritis is associated with complex joint effusions with intense synovial enhancement. Reactive marrow changes, or more significant changes with low intensity on T1W images indicating osteomyelitis, may be seen in the adjacent bone.

Ultrasound

Ultrasound can be helpful for the appreciation of abscesses, soft tissue collections and joint effusions which are also amenable to ultrasound-guided drainage (see section "Abscess" Chap. 13).

CT

CT can be helpful to better assess bony changes, including fragmentation and erosive change, and is the most sensitive modality for determining the presence of gas in the tissues. It is limited in the assessment of soft tissue pathology and cannot assess bone marrow oedema.

Nuclear Medicine (Figs. 14.6 and 14.7)

Osteomyelitis can be seen on bone scan as abnormal uptake in the affected area, particularly in phase 1 and 2 of scanning. Unfortunately, a neuropathic joint will often demonstrate the same abnormalities. There is some benefit to following a positive bone scan with an indium-labelled white blood cell scan, which will reveal areas of active inflammation or infection, as white blood cells will migrate to these areas. Early on in the acute phase of neuropathic arthropathy, a white blood cell scan may be positive and thus may appear identical to osteomyelitis; however once the arthropathy has become more chronic, the vigorous migration of white blood cells into the bone ceases, giving a negative result. A negative finding white blood cell scan would argue against the presence of osteomyelitis.

PET

Positron emission tomography (PET) is a modality whereby ^{18}F-fluorodeoxy-D2-labelled glucose (FDG) molecules accumulate in states of high cellular metabolism and cell turnover and thus accumulate at sites of infection. It has been observed that in patients with diabetic foot, FDG accumulates significantly more in patients with osteomyelitis than in those with neuropathic arthropathy. In addition, PET can be coupled with CT scanning to better delineate the anatomy. This modality continues to be under investigation and is not readily available in many centres; thus it is not typically used as a first-line investigation in diabetic foot.

Further Reading

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