Pedal complications of diabetes develop in approximately 15% of diabetics over their lifetime, with approximately one fifth of diabetic patients being hospitalized at some point for pedal infections [1–4]. With approximately 15 million people affected by diabetes in the United States alone, this translates to almost 2.3 million patients who experience diabetic foot complications [5].

This problem is of key interest to the radiologist, because they are often consulted in the diagnosis and management of pedal diabetic complications. The societal costs are impressive with the cost of treating a single foot ulcer estimated at $28,000 over a 2-year period [6,7]. Further costs related to lower-extremity amputation in the diabetic population is estimated at over $1 billion with approximately 50,000 lower extremity amputations performed each year in the United States [8].

Amputation further predisposes to contralateral limb complications because of subsequent shifting of weight-bearing forces. Within 2 years of amputation, the contralateral lower extremity has a 50% incidence of serious complications with a risk of 50% to 66% of contralateral amputation within 5 years [9,10].

Pedal complications of diabetes have long presented a challenge for the clinician and radiologist. The foot is distinctly susceptible to the manifestations of diabetes because of numerous factors. The peripheral neuropathy, both motor and sensory, that results from diabetes subsequently leads to repetitive unrecognized microtrauma, and the peripheral autonomic neuropathy results in dry, cracked skin [11]. This may manifest initially as callus formation, and subsequently proceed to soft tissue injury and ulceration, osteomyelitis and abscess formation, and neuropathic joint [12,13]. The peripheral vascular disease results in poor healing and response to infection and chronic ischemia. In addition, several other metabolic derangements and hyperglycemia result in impaired immunologic function and wound healing. Debridement and amputation are often necessary [14,15].

The clinical manifestations of acute diabetic foot infection are often difficult to distinguish from changes related to neuroarthropathy [16]. Probing the ulcer bed to underlying bone is highly specific and easy to perform; however, it has very low sensitivity [17–19].

Imaging plays a key role in the identification of soft tissue, bony, and articular complications. The distinction is critical because the management differs significantly between these two entities. CT scan and plain films offer useful bony anatomic information. Their soft tissue detail is lacking, however, and their sensitivity and specificity for determining infection is low, especially in the early stages of infection [20–22]. Bone scan provides poor anatomic detail and often vague localization [23–26]. MR imaging is relied on primarily as the imaging tool for pedal complications related to diabetes [27–32].

MR imaging protocol for diabetic foot

Imaging of diabetic foot complications necessitates a good clinical history and often a quick examination by the performing radiologist to optimize the quality of the study. The location of the ulcer...
should be clearly identified and the examination then
tailored to that location. The entire foot should not be
imaged when there is a specific location in question.
Nor should both feet be imaged simultaneously, ex-
cept in rare circumstances.

The forefoot is unique in its orientation, much like
the hand, and the imaging planes required to fully
evaluate this region are also unique. The foot and an-
kle require completely different imaging parameters.

If the forefoot and toes are the focus of the
examination, then a small surface coil is ideal (either
3 or 5 in), or if the foot is not swollen, the wrist
coil can be used. The plane perpendicular to the toes
(short-axis view) is the key plane in which to evaluate
ulcers and their relationship to underlying osseous
structures (Table 1). A T1-weighted image is used to
evaluate marrow changes and subcutaneous fat, and a
fat-suppressed T2-weighted image, usually a STIR, is
ideal in the short axis to evaluate for edema within the
bone, soft tissues, and surrounding tendinous struc-
tures [33,34]. Sagittal views and a plane parallel to
the toes (long-axis view) are ideal for imaging the
metatarsophalangeal and interphalangeal joints in the
evaluation of septic arthritis. If there are toe defor-
mities, the short-axis images may be misleading. It
is usually possible, however, to “read through” this
problem.

The midfoot and hindfoot should be imaged with
an extremity coil, such as the chimney-type knee
coil. The sagittal plane is ideal for evaluation of
midfoot neuropathic involvement, the plantar surface,
and the posterior calcaneus. A T1-weighted and a
fat-suppressed fluid/T2-weighted image are both re-
quired in this plane. Axial and coronal planes are
useful in the evaluation of the malleoli and the sur-
rounding tendons (Table 2).

Contrast administration is extremely useful in the
evaluation of diabetic pedal complications. Bland
subcutaneous edema does not enhance following
contrast administration; however, cellulitis often dem-
strates patchy enhancement. Contrast also aids in
the detection of sinus tracts and abscesses. Detection
of osteomyelitis is also facilitated by contrast admin-
istration. It is imperative, however, that fat-saturated
T1-type images be obtained both before and after
contrast administration, in identical planes, to fully
evaluate regions of abnormal enhancement. Most of
the time these are not obtained with conventional

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Short-axis plane is consistent, however, the corresponding longitudinal plane should be tangent to the area of interest (ie, if the ulcer is lateral or medial, a long axis view would be more valuable than a sagittal). If the MR imaging unit has high gradients, then a third postgadolinium administration plane can be added without adding too much time. FMPSGPR/T1 Fat Sat/VIBE 3DGRE sequences are all adequate postgadolinium sequences, however, T1 fat sat is far more time costly.

**Abbreviations:** ETL, echo train length; fat sat, saturated fat; FOV, field of view; TE, echo time; TR, repetition time; TSE, turbo spin echo; 3DGRE, three-dimensional gradient recalled.

Table 2

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Coronal imaging plane can be used if ulcers reside on the medial or lateral soft tissues, however, axial images will also cover this region adequately. If the MR imaging unit has high gradients, then a third postgadolinium administration plane can be added without adding too much time.

**Abbreviations:** ETL, echo train length; fat sat, saturated fat; FOV, field of view; STIR, short-T1 inversion recovery; TE, echo time; TR, repetition time; TSE, turbo spin echo; 3DGRE, three-dimensional gradient recalled.
spin echo technique, but more often with various types of two-dimensional and volume-acquired turbo gradient echo sequences (fast multislice spoiled gradient [FMPSPGR], volumetric interpolated breath-hold examination [VIBE], and so forth). It should be noted that the distinction is not whether an abnormality enhances, but how it enhances, which leads to the differentiation of neuropathic changes from infection, as discussed later.

Many of the diabetic feet that are imaged have previously undergone surgery for debridement, arthrodesis, or partial foot-sparing surgery. Surgical changes and areas of magnetic susceptibility can obscure regions of interest and contrast is very useful in this setting. Several metal suppression techniques may also be useful to decrease metallic artifact and increase conspicuity of underlying abnormalities. In these situations avoid using gradient echo technique and substitute STIR images for frequency-selective fat-suppressed images.

**Diabetic foot infection**

**Callous or ulceration**

One of the more common pedal complications of diabetes is that of callous formation and ulceration. Skin callous formation is often the result of abnormal biomechanics in the diabetic population secondary to the peripheral neuropathy complicating this disease. In addition, abnormal areas of friction and poor-fitting footwear contribute further to callous formation.

The autonomic dysfunction that results from chronic diabetes also plays a role, because it contributes to dry callous from lack of perspiration. The lack of moisture precipitates skin cracking, which is further complicated by direct inoculation of infection [35].

The location of diabetic foot callous parallels the sites of skin pressure. In the nonneuropathic foot this occurs under the metatarsal heads, usually the second. If a hallux valgus is present, which is frequent in all neuropaths regardless of stage, callous occurs medial to the first metatarsal. In neuropathic feet with mid-foot dominance and a rocker-bottom foot, callous has been shown to be most prominent under the cuboid. In most other neuropathic feet the callous is most prominent at the heads of the first and second metatarsal bones, at the fifth metatarsophalangeal joint, and on the planar surface of the posterior calcaneus.

Callus is often appreciated on MR imaging and demonstrates low signal intensity on T1-weighted images. On T2-weighted images the callus generally appears low to intermediate signal. The appearance on MR imaging may sometimes be confusing, especially after contrast administration where there can be significant enhancement, in which callous may mimic focal soft tissue infection. The location of the callous and the lack of adjacent soft tissue changes, however, should aid in the diagnosis (Fig. 1).

![Fig. 1. Callous signal characteristics on MR imaging. (A) Short-axis T1-weighted image demonstrates focal area of low signal soft tissue within the plantar subcutaneous fat at the fifth metatarsal head (arrow). (B) Short-axis T1 fat-saturated image post-gadolinium administration demonstrates intense enhancement of the callous (arrow). Location of the callous and the lack of adjacent soft tissue changes should lead one away from misdiagnosing this as soft tissue infection.](image-url)
The altered biomechanics and neuropathy result in callus hypertrophy. This is not, however, mechanically protective callus. The persistent weight-bearing and microtrauma in these regions results in callous breakdown. The result is focal ulceration. This focal ulceration, often combined with inoculation and decreased diabetic immune function, facilitates subsequent infection, often polymicrobial. These areas of ulceration have been shown to correspond with the regions related to persistent microtrauma and increased pressure during ambulation [36]. Callus breakdown with ulceration has been shown to be most prevalent at the first and fifth metatarsal heads, on the plantar surface of the second and third metatarsal heads, and on the dorsal surface of the toes. In the hindfoot, ulceration is most commonly seen at the posterior aspect of the calcaneus and at the medial and lateral malleoli.

On MR imaging ulceration is commonly identified as a defect of the overlying soft tissues, often adjacent to the bony prominence with granulation tissue seen at the ulcer base. The region of granulation tissue is low signal on T1-weighted images and high signal (or intermediate) on T2-weighted images. Following contrast administration there is intense enhancement at the ulcer base and often “tramtrack” peripheral enhancement at the developing sinus tract (Fig. 2) [33,37].

Cellulitis and abscess

Although many ulcers are treated with antimicrobial therapy and if ischemic, debridement, many infected ulcers progress to more severe soft tissue infection, such as sinus tracks, severe cellulitis, and abscess formation. Cellulitis can often clinically be suggested on the basis of an erythematous, swollen, and warm lower extremity. This, unfortunately, is also the clinical presentation of acute neuropathic disease. The lower extremity and foot in noninfected, nonneuropathic is often edematous on MR imaging, secondary to soft tissue ischemia and venous insufficiency in diabetics. In both this “disease caused” benign edema and infectious cellulitis, the overlying skin may be mildly thickened and the subcutaneous fat reticulated on T1-weighted images. Both entities may also show increased signal on T2-weighted images. The administration of intravenous contrast proves very useful because regions of cellulitis demonstrate ill-defined enhancement. Diabetic ischemia does peculiar things to soft tissues, however, often shown by patchy irregular enhancement.

Focal abscess formation is not infrequent in the diabetic population, with reports estimating that between 10% and 50% of all cases that have pedal osteomyelitis have concomitant soft tissue abscesses [38,39]. As a general rule, abscesses are much more common in childhood musculoskeletal infections than adult ones. Among adults, however, diabetics have a not insignificant incidence.

Many of these intramuscular and intermuscular abscesses are quite small. There is invariable adjacent soft tissue infection with edema and rim enhancement [40]. Soft tissue abscesses demonstrate low to intermediate signal on T1-weighted images and high signal on T2-weighted images. There is substantial rim enhancement following intravenous contrast administration. Abscesses are significantly more common following inoculatory trauma (Fig. 3).

Abscesses, when present in the subcutaneous tissues, are quite easy to miss and are often fairly large. In this situation they may only show moderate reticulation of the subcutaneous fat.

Foreign body granuloma

The sensory neuropathy that accompanies diabetestes may also manifest as inability to identify foreign bodies that have entered the superficial or deep soft tissues. These may become chronically imbedded and incite an inflammatory reaction without a frank abscess. There may be no accompanying soft tissue ulceration at the site of entry, and usually because of the sensory neuropathy, no history of trauma. The inflammatory changes are seen as high signal on T2-weighted images and low signal on T1-weighted images. Not infrequently, there may be little or no T2 signal changes, although marked enhancement is usually seen after contrast administration (Fig. 4).

The foreign body itself may be difficult to identify because they are usually quite small; however, an area of magnetic susceptibility or signal void should be sought within the granulomatous response and plain film or even CT correlation may also be useful to identify the inciting agent. It is not that surprising to suspect a body on MR imaging, yet not definitively visualize the body.

Septic arthritis

The interphalangeal and metatarsophalangeal joints are most commonly involved in septic arthritis, because of their superficial location and proximity to areas of ulceration [41,42]. Direct inoculation from the ulcer is the most common mode of infection in the diabetic population.

A joint effusion, often complex, is present on MR images of a septic joint [41]. Joint fluid is
not synonymous with an effusion. Each joint has physiologic fluid. This becomes a diagnostic dilemma most often in the first metatarsophalangeal joint. Distention dorsally in this location is the best sign of an effusion. There may also be synovial or capsular distention at the affected joint. After contrast administration there is usually intense enhancement (Fig. 5).

The adjacent bony surfaces may demonstrate edematous changes, seen as increased T2 signal, which can be seen in either septic arthritis or osteomyelitis. In septic arthritis, the corresponding T1-weighted images should not demonstrate overt decreased signal, otherwise, osteomyelitis should be suspected. The most specific findings of septic arthritis are bony erosions, bone marrow edema, and carti-
lage destruction [41]. An adjacent soft tissue defect or ulcer also elevates the suspicion considerably.

Differentiating osteomyelitis from reactive bone marrow edema

The use of MR imaging to evaluate for osteomyelitis has increased steadily over the past decade. Sensitivity and specificity with respect to osteomyelitis have rates of over 90% [37]. Both osteomyelitis and bone marrow edema demonstrate high signal on T2-weighted images and inversion recovery images; however, osteomyelitis also demonstrates low bone marrow signal on T1-weighted images, whereas reactive bone marrow edema shows fairly normal T1 signal. Following contrast administration there is marrow enhancement in the presence of osteomyelitis, but sometimes also with reactive edema (Fig. 6).

The single best way to diagnose osteomyelitis is to find the ulcer or sinus track and follow it down to bone. If the marrow is abnormal signal on a T1-weighted image at that location, there is osteomyelitis present [37,41,42]. Note should then be made of extent of disease. Osseous extent is best determined on T1-weighted images. In fact, extent can be overdiagnosed on T2 or enhanced images. Articular involvement and soft tissue extent is best evaluated on contrast-enhanced images.

Spread of infection

There are three fascial compartments of the foot. The medial one goes to the base of the first meta-
tarsal. The lateral one extends to the base of the fifth metatarsal. The central one extends proximally into the mid and hindfoot and is actually contiguous with the calf muscles.

These compartments represent partial barriers to the spread of infection. That is, infection spreads proximally within them, rather than between them. The barriers are, however, imperfect and spread can occur, albeit less commonly, between compartments [43].

Joint spaces are, however, poor obstructions to the spread of infections, and periarticular osteomyelitis frequently spreads to the adjacent joint. Interestingly, tendons and their sheaths are not a common pathway for the spread of infections.

Several other points about tendons are important. First, although they are an infrequent route for proximal spread, their sheaths are not uncommonly infected [34]. Outside the hand, the most commonly infected tendons are the peroneals. That is because many ulcers occur at the lateral malleolus. Outside of the toes, where flexor digitorum and extensor digitorum infections, focally, are common, the next most common tendon infection is the Achilles. This is directly related to posterior ulceration.

Fig. 4. Foreign body. Sagittal T2 fat-saturated image of the ankle (A) and a coronal T2 fat-saturated image at the level of the posterior calcaneus (B) demonstrate focal fatty infiltration and edema of the plantar soft tissues (arrowheads) associated with a small well-defined region of lower signal intensity centrally representing a foreign body (arrow). No magnetic susceptibility related to the foreign body is appreciated. Sagittal (C) and axial (D) T1 fat-saturated images post-gadolinium administration show nicely the focal soft tissue enhancement of the plantar surface (arrowheads) related to the foreign body. The site of the foreign body itself does not demonstrate significant enhancement.
Fig. 5. Septic arthritis of interphalangeal joint. (A, B) Sagittal and short-axis STIR images of the forefoot with increased signal at the third proximal interphalangeal joint, flexor tendon sheath (arrow), and surrounding soft tissues. (C) Long-axis T1 fat-saturated post–gadolinium administration image demonstrating intense enhancement of the third proximal interphalangeal joint representing septic arthritis (arrow). A common location for ulceration is the dorsal interphalangeal joints, especially in patients who have more proximal neuropathic disease.

Fig. 6. Reactive bone marrow edema. (A) Axial T1-weighted image through the hindfoot demonstrates soft tissue infiltration within the posterior tissues (arrows), but normal bone marrow signal within the posterior calcaneus itself. (B) Axial T2 fat-saturated image at the same level shows moderate increased signal within the posterior calcaneus (arrow). (C) Axial T1 fat-saturated image post–gadolinium administration demonstrates moderate enhancement of the posterior soft tissues consistent with soft tissue inflammation and cellulitis; however, there is no enhancement of the underlying calcaneus. The T1 and postcontrast imaging features indicate that this is reactive bone marrow edema, rather than underlying osteomyelitis.
Most of these tendon infections are focal. Most soft tissue infections are local, close to the sinus track, or region of osteomyelitis. Distant spread, especially from medial or lateral compartment infections, is rare.

Care should be taken to assess for the degree of enhancement of the infected soft tissues. Devitalization is a common complication of diabetes. This is difficult to see using current imaging techniques but likely will be a significant indication for imaging in the next 2 years. Currently, a modestly abrupt cutoff of enhancement can be seen with devitalized soft tissues. In these patients, unfortunately, the usual MR imaging signs of osteomyelitis may be less reliable.

The presence of secondary signs is also useful in any differentiation of osteomyelitis from reactive bone marrow edema. An overlying cutaneous ulcer or sinus tract may be evident. Soft tissue ulceration over bony protuberances is often seen in diabetics and direct extension of infection is the primary mechanism of spread.

In addition, cortical interruption has been shown to have a high positive predictive value for osteomyelitis [37]. On T2-weighted sequences, periosteal reaction may be seen as circumferential high signal surrounding the cortex. This is seen to enhance avidly following contrast administration (Fig. 7). This can

Fig. 7. Calcaneal osteomyelitis. (A, B) Axial T1-weighted image and T2 fat-saturated image of the hindfoot show extensive deep soft tissue ulceration (arrowheads) with associated focal decreased T1 bone marrow signal (arrows) in the posterior calcaneus corresponding to increased T2 signal, indicating osteomyelitis. (C) Sagittal T1 fat-saturated image post–gadolinium administration of the ankle showing enhancement within the posterior aspect of the calcaneus (arrowheads) with adjacent deep ulceration and soft tissue thinning. The posterior soft tissues are nearly absent. This is a common appearance in debilitated diabetics. Small fluid collections and abscesses are seen adjacent to the superior and inferior aspect of the calcaneus (arrows).
also be seen in neuropathic disease, especially about
the proximal metatarsal shafts.

**Neuroarthropathy**

*Differentiating diabetic neuroarthropathy versus osteomyelitis*

Clinically and radiologically, neuroarthropathy
can mimic osteomyelitis. The patient may present
with an erythematous and swollen foot in both
situations. On MR imaging both entities may
demonstrate subchondral bone marrow signal abnormalities
and joint effusions, periosteal reaction, and soft tissue
inflammatory changes.

Aid in the distinction between the two entities can
be made on MR imaging mainly based on distribution
of disease. Osteomyelitis is predisposed to occur at
pressure points and areas of ulceration along bony
protuberances [36,37]. Consequently, the most common
locations for osteomyelitis are at the metatarsal

![Image](a.png)

![Image](b.png)

![Image](c.png)

![Image](d.png)

Fig. 8. Rapidly progressive neuroarthropathy in a diabetic patient. (A) Sagittal T2 fat-saturated image demonstrates diffuse soft
tissue edema (*arrows*) involving the midfoot and significant bone marrow edema within the tarsal and metatarsal bones. (B, C)
Short-axis T1 and T2 fat-saturated images show extensive soft tissue infiltration and edematous changes. Regions of bone
marrow edema within the first and second metatarsals (*arrowheads*) correspond to regions of mildly decreased T1 marrow
signal, which are suspicious for underlying osteomyelitis. (D) Sagittal T1 fat-saturated images after gadolinium administration
demonstrate significant enhancement within the tarsometatarsal joints and somewhat less enhancement within the bones
themselves. Although the signal characteristics are consistent with osteomyelitis, the lack of adjacent soft tissue defects or ulcers,
sinus tracts, or abscess mitigates against osteomyelitis and supports the diagnosis of neuroarthropathy. Acute neuroarthropathy
can clinically mimic osteomyelitis.
heads and at the interphalangeal joints in the forefoot and at the plantar aspect of the posterior calcaneus or distal fibula in the ankle and hindfoot.

Neuropathic changes tend to predominate in the midfoot. The only common location for infection or osteomyelitis in the midfoot is in the cuboid in severe, midfoot, neuropathic patients. MR imaging findings of neuroarthropathy in acute or rapidly progressive disease (Fig. 8) differ from those seen in more chronic or longstanding involvement (Fig. 9). In the acute setting, more prevalent bone marrow edema and joint effusions are seen, leading these patients to have a more difficult MR imaging differentiation from acute infection or osteomyelitis.

Occasionally, the situation arises where infection is a concern in the patient who has neuropathic arthropathy. Recently the “ghost sign” was described as a potential useful observation to distinguish between the presence or absence of infection [31]. Areas of osteomyelitis on the background of a neuropathic joint may appear to be dissolved on T1-weighted images and subsequently may appear

Fig. 9. Chronic neuroarthropathy. (A) Sagittal T2 fat-saturated image of the midfoot and hindfoot in a patient who has chronic neuroarthropathy demonstrating predominately midfoot destructive changes and bone marrow edema (arrows). Edema is also present within the plantar muscles, a finding often seen in chronic neuroarthropathy (arrowheads). (B) Sagittal T1-weighted image again shows the midfoot destructive changes (short arrows) and a rocker deformity at the calcaneocuboid articulation (long arrow). Coronal T2 fat-saturated image (C) and coronal T1-weighted image (D) through the hindfoot demonstrate hindfoot valgus secondary to destructive neuroarthropathy involving the subtalar joints (arrows) with associated bone marrow and soft tissue edema. A superficial plantar soft tissue ulcer is also present (arrowheads).
more regular on postcontrast T1-weighted images and on T2-weighted images. In addition, white cell scanning, either with indium or with in vivo labeling (Neutraspec), may be useful in this clinical circumstance.

**Diabetic muscle infarction**

Muscle ischemia and infarction is a well-documented although uncommon manifestation of diabetes. This complication has typically been described in the calf and thigh muscles of diabetics. Multiple sites of involvement are not uncommon and this can be seen bilaterally in up to one third of affected patients. It should be noted that bone infarcts are also seen bilaterally in up to one third of affected patients. The signal on T1-weighted images can be normal [46,47]. If the abnormal signal is localized to one muscle compartment and there are associated edematous changes, compartment syndrome must be considered as a secondary complication.

Clinically, the patient presents with pain and swelling over the involved area without a history of trauma [44,45]. Pain can be gradual or sudden in onset. MR imaging of the affected region demonstrates enlarged, edematous muscles on T2-weighted and inversion-recovery images. The signal on T1-weighted images can be normal [46,47]. If the abnormal signal is localized to one muscle compartment and there are associated edematous changes, compartment syndrome must be considered as a secondary complication.

**References**


