Postoperative Magnetic Resonance Imaging of the Foot and Ankle

Carolyn M. Sofka, MD*

This article is accredited as a journal-based CME activity. If you wish to receive credit for this activity, please refer to the website: www.wileyhealthlearning.com

ACCREDITATION AND DESIGNATION STATEMENT

Blackwell Futura Media Services designates this journal-based CME activity for a maximum of 1 AMA PRA Category 1 Credit™. Physicians should only claim credit commensurate with the extent of their participation in the activity.

Blackwell Futura Media Services is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians.

EDUCATIONAL OBJECTIVES

Upon completion of this educational activity, participants will be better able to discuss suggested MRI protocols for evaluating the postoperative foot and ankle.

ACTIVITY DISCLOSURES

No commercial support has been accepted related to the development or publication of this activity.

Faculty Disclosures:
The following contributors have no conflicts of interest to disclose:

Editor-in-Chief: C. Leon Partain, MD, PhD
CME Editor: Scott B. Reeder, MD, PhD
CME Committee: Scott Nagle, MD, PhD, Pratik Mukherjee, MD, PhD, Shreyas Vasanawala, MD, PhD, Bonnie Joe, MD, PhD, Tim Leiner, MD, PhD, Sabine Weckbach, MD, Frank Korosec, PhD
Authors: Carolyn M. Sofka, MD

This manuscript underwent peer review in line with the standards of editorial integrity and publication ethics maintained by Journal of Magnetic Resonance Imaging.

The peer reviewers have no relevant financial relationships. The peer review process for Journal of Magnetic Resonance Imaging is double-blinded. As such, the identities of the reviewers are not disclosed in line with the standard accepted practices of medical journal peer review.

Conflicts of interest have been identified and resolved in accordance with Blackwell Futura Media Services’s Policy on Activity Disclosure and Conflict of Interest. No relevant financial relationships exist for any individual in control of the content and therefore there were no conflicts to resolve.

INSTRUCTIONS ON RECEIVING CREDIT

For information on applicability and acceptance of CME credit for this activity, please consult your professional licensing board.

This activity is designed to be completed within an hour; physicians should claim only those credits that reflect the time actually spent in the activity. To successfully earn credit, participants must complete the activity during the valid credit period.

Follow these steps to earn credit:

- Log on to www.wileyhealthlearning.com
- Read the target audience, educational objectives, and activity disclosures.
- Read the article in print or online format.
- Reflect on the article.
- Access the CME Exam, and choose the best answer to each question.
- Complete the required evaluation component of the activity.

This activity will be available for CME credit for twelve months following its publication date. At that time, it will be reviewed and potentially updated and extended for an additional period.
Foot and ankle procedures are commonly performed most often in the setting of trauma or for realignment such as hallux valgus or acquired adult flatfoot deformity correction. Complications of these procedures occur not infrequently and therefore diagnostic imaging of the postoperative foot and ankle is often needed. Magnetic resonance imaging (MRI) is ideal for imaging the postoperative foot and ankle, as it can evaluate both osseous and soft-tissue pathology. Using tailored MR pulse sequences to reduce metal artifact helps to increase diagnostic yield and evaluation of the regional anatomic structures. This review discusses suggested MRI protocols for evaluating the postoperative foot and ankle as well as the MRI appearance of commonly performed procedures in the foot and ankle such as internal fixation for fractures, forefoot and flatfoot realignment surgeries, and cartilage restorative procedures, as well as some of the more commonly encountered postoperative complications.

Key Words: Magnetic resonance imaging; foot; ankle; avascular necrosis of the talus; flatfoot reconstruction; osteochondritis dissecans (OCD)


TECHNICAL CONSIDERATIONS

MAGNETIC RESONANCE IMAGING (MRI) in the postoperative evaluation of the foot and ankle can be challenging, as conventional MRI protocols, such as standard spin echo imaging, can result in relatively nondiagnostic images. Routine pulse sequence parameters often employed preoperatively in the evaluation of the musculoskeletal system are in general of limited utility postoperatively, such as conventional spin echo imaging, frequency selective fat suppression, and gradient echo imaging. In addition, the inherent anatomy of the foot and ankle necessitates additional MR protocol considerations given its location at the periphery of the body with its resultant positioning off center of the main magnetic field, as well as the presence of multiple curved structures (tendons and ligaments) resulting in inherent poor fat suppression.

For the evaluation of the musculoskeletal patient, especially one in which the clinical concern is one of an acute soft tissue or osseous injury such as a fracture, a water-sensitive pulse sequence, such as frequency selective fat suppression sequence or fast inversion recovery, is typically employed. In the postoperative setting, considering the anatomic considerations of a relatively peripheral structure such as the foot and ankle, a fast inversion recovery sequence is favored in contrast to frequency selective fat suppression (1,2). In the presence of metallic implants (screws for calcaneal or medial cuneiform osteotomies, for example, in the setting of acquired adult flatfoot reconstruction), there is less ability to perceive fat and water at different resonant frequencies, resulting in image distortion and the characteristic “flare” seen about metallic hardware with conventional fat suppression (1).

Fast spin echo imaging is preferred in the postoperative setting as opposed to routine spin echo sequences. With fast spin echo imaging, short interecho spacing allows for less time for dephasing to occur (3,4). Increasing echo train length, plus the inherent short interecho spacing with fast spin echo imaging, decreases chances of missetting, resulting in less image distortion in contrast to conventional spin echo imaging in the setting of implantable hardware (1,3,4).

The use of intravenous or intraarticular gadolinium contrast material in the postoperative setting is controversial and is highly dependent on radiologists’ preferences. Consideration must be given to the limitations of frequency selective fat suppression sequences, often paired with standard spin echo T1-weighted imaging, in the setting of metal when intravenous contrast material is used. Intravenous contrast material has been shown in several studies, however, to diagnose infectious osteomyelitis with greater specificity than without (5,6).

Most clinical MRI centers have the choice nowadays to image the musculoskeletal system with either a 1.5T or higher field strength (3T) magnet. In the preoperative setting, higher field strength imaging (3T) has resulted in high resolution imaging of trabecular bone and tendon in the foot and ankle (7,8). The improvement in the signal-to-noise ratio provided by higher field strength imaging certainly allows for improved image resolution and possibly decreased scan times, especially if parallel imaging is employed; however, there is increased susceptibility artifact encountered with higher field strengths, limiting its utility in the postoperative setting (9,10). Potential improvements in image quality when using higher field strengths can further be obtained by using high-field strength-compatible dedicated extremity coils; however, in general, an eight channel coil array or dual-channel quadrature extremity foot and ankle coil can provide diagnostic images either at 1.5T or 3T (9,10).

More advanced MRI techniques are available on some software platforms for improved imaging around metal. Multiacquisition with variable resonance image combination (MAVRIC) and slice-encoding metal artifact correction (SEMAC) techniques have demonstrated significant reduction of susceptibility artifact near metallic implants, most clinically employed in the setting of arthroplasty (11–14). While MAVRIC and SEMAC techniques are based on slightly different methods (MAVRIC uses a 3D approach while SEMAC is based on a 2D slice-selective technique), both methods have been shown to reduce metal artifact by approximately a factor of 10 compared to 2D fast spin echo images (13). By successfully imaging in extreme off-resonance conditions, such as in the presence of metal by compartmentalizing broad spectral ranges into discrete frequency bins, a composite image is created with significantly decreased distortion in the readout direction (12).

Positioning of the foot in the magnet can be adjusted to tailor imaging specifically to the forefoot or ankle. Placing the foot in a slight degree of plantarflexion is suggested for imaging the forefoot, while slightly dorsiflexing the foot can improve imaging of the ankle by allowing for inclusion of the distal tibia in the foot and ankle coil without resulting in loss of signal.

A suggested protocol for imaging the postoperative foot and ankle can be found in Table 1.
TRAUMA

Postoperative complications following internal fixation of foot or ankle fractures are infrequent; however, some that may require MRI evaluation include fracture malunion or nonunion, posttraumatic osteoarthritis, or other cartilage damage from intraarticular extension of fractures, avascular necrosis, and tendon entrapment or injury from either the fracture or the hardware.

MRI has been shown to be highly accurate in diagnosing small cartilage abnormalities even in the postoperative setting, often in the presence of metal (15). Intraarticular extension of fractures through the subchondral plate and overlying cartilage can damage the articular cartilage, resulting in focal chondral shear injuries and early development of posttraumatic osteoarthritis (Fig. 1). In general, posttraumatic osteoarthritis is thought to occur in 14%–50% of all ankle fractures (16–19). Certainly, malunion is one of the most important causes of developing osteoarthritis after sustaining an ankle fracture; however, concomitant ligament damage and the subsequent development of arthrofibrosis can also predispose to early osteoarthritis (20–24). Considering that the majority of the surface of the talus is cartilage, it is not unexpected that there would be a high risk of osteoarthritis after a talar fracture (25,26). It has been shown that, more significant than the number of chondral injuries sustained during an ankle fracture, is the location of the lesions that is predictive for developing posttraumatic osteoarthritis. Stufkens et al (27) have shown that lesions over the anterolateral aspect of the talus as well as at the medial malleolus have increased risk for developing posttraumatic osteoarthritis compared to other locations in the ankle.

Avascular necrosis of the talus is also a common indication for MRI, often with internal fixation in place. Talar neck fractures can result in the development of avascular necrosis especially if they are displaced, with the risk of necrosis increasing with higher grades of talar fractures (Hawkins or Martin-Weber classification systems). The primary extra osseous blood supply to the talus with variable intraossous anastamoses contributes to the development of avascular necrosis in the setting of fractures (28). Radiographically, avascular necrosis can usually only be reliably diagnosed at ~6–8 months after the initial injury. Nonvisualization of the “Hawkins sign,” a

Table 1
Suggested MR protocol for the post operative ankle (1.5T)

<table>
<thead>
<tr>
<th>Protocol</th>
<th>TR/TE</th>
<th>Slice Thickness</th>
<th>Matrix</th>
<th>ETL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagittal inversion recovery</td>
<td>4000/15</td>
<td>3.4mm/0 gap</td>
<td>256 x 192</td>
<td>T1 150</td>
</tr>
<tr>
<td>Sagittal FSE PD</td>
<td>4000/30-40*</td>
<td>3mm/0 gap</td>
<td>512 x 384*</td>
<td>ETL 16</td>
</tr>
<tr>
<td>Coronal FSE PD</td>
<td>4000/30-40</td>
<td>4mm/0 gap</td>
<td>512 x 352</td>
<td>ETL 16</td>
</tr>
<tr>
<td>Axial FSE PD</td>
<td>4000/30-40</td>
<td>3.3mm/0 gap</td>
<td>512 x 256</td>
<td>ETL 16</td>
</tr>
</tbody>
</table>

*TE, bandwidth and matrix ↑ on 3T
Optional:
Direct coronals (coronal to talocrural joint): eg for OCD lesions of the talus
+/- gadolinium for infection

Figure 1. a: Anteroposterior radiograph of the right ankle demonstrating internal fixation for bimalleolar fractures. The lateral ankle joint space extending into the lateral gutter is narrowed; however, the medial aspect appears preserved. b: Coronal fast spin echo MR image in the same patient clearly demonstrates osteoarthrosis in the medial margin of the ankle with full thickness cartilage loss, remodeling of the subchondral plate, and cysts (arrow) despite the presence of metal hardware.
subchondral radiolucent line confirming viability of the talus, suggesting the development of avascular necrosis, occurs only at ~6–8 weeks (29). Often, therefore, avascular necrosis of the talus is suspected clinically prior to any radiographic changes. It is in this setting where MRI is most useful.

The characteristic mixed serpiginous signal intensity of avascular necrosis can be identified on all pulse sequences (30,31) (Fig. 2). Frankly necrotic bone is uniformly low signal intensity on all pulse sequences having no mobile water protons. Complications of necrosis can also be evaluated with MRI including the degree (percentage) of involvement, the amount of collapse of the articular surface, the status of the overlying articular cartilage, and the presence of subchondral fractures (32).

Soft-tissue abnormalities in the setting of internal fracture fixation can also be evaluated with MRI, including tendon abnormalities, tears or frank entrapment, either within the fracture or by the hardware. Occasionally, the hardware will impinge on a regional tendon or nerve that can be identified with high-resolution MRI. Alternatively, fracture reduction may fail due to the presence of interposed tendon or peristeum (33–42).

**ACQUIRED ADULT FOOT DEFORMITIES**

The two most commonly performed procedures in the foot and ankle for adult foot reconstruction are hallux valgus correction and flatfoot reconstruction.

There are over 100 procedures for correcting hallux valgus deformity. These include both distal and proximal procedures; with distal procedures usually performed for more mild deformities and proximal procedures for more severe malalignment. Osteotomies, arthrodeses, and excision arthroplasties may be performed, all usually dependent on surgeon preference as well as the severity of the deformity. One of the more commonly performed procedures includes the Chevron osteotomy, which is a V-shaped distal first metatarsal osteotomy with the metatarsal head shifted laterally as well, as the modified Lapidus procedure, which is a first tarsometatarsal joint fusion in the setting of hypermobility of the first ray (43).

Commonly encountered complications after hallux valgus correction surgery can be evaluated with MRI. These can include nonunion or delayed bone healing, avascular necrosis, a shortened first metatarsal, first metatarsophalangeal osteoarthritis, hallux varus, second toe metatarsalgia, insufficiency fractures of the lesser metatarsals, or infection. Changes in biomechanics as well as decreased bone density in the setting of forefoot reconstructions has been shown to lead to insufficiency fractures of the lesser metatarsals, such as after excision arthroplasty of the first metatarsophalangeal joint, or even after more minor procedures such as Morton’s neuroma excision or fifth metatarsal delayed union revision (44–50).

In the setting of adult acquired flatfoot deformity, the type of procedure performed (if any) will depend on the degree of deformity (51–53). In adult acquired flatfoot deformity, there is loss of the arch of the foot leading to hindfoot valgus, medial uncovering of the head of the talus, and tendon and supporting ligament insufficiency. A staging system exists to grade the severity of deformity in adult flatfoot based on criteria including the severity of longitudinal arch and hindfoot malalignment as well as the degree of uncoverage of the head of the talus, which is used to determine appropriate surgical correction. For early stages (I and IIa), the usual choice of procedure is tenosynovectomy, tendon transfer, possibly with medial calcaneal slide osteotomy and a Cotton procedure (medial cuneiform osteotomy); for stages IIb and III, surgical correction usually includes those procedures as for the early stages as well as possible lateral column lengthening and hindfoot fusion; and for stage IV, ankle fusion or ankle arthroplasty (43,51,54). Minimally invasive deltoid ligament reconstruction in combination with a triple arthrodesis has also been suggested to correct the valgus hindfoot deformity in patients with Stage IV-A acquired adult flatfoot deformity (55). Peroneus longus tendon autograft has been used for deltoid ligament reconstruction with good results, as well as Achilles or hamstring tendon allograft, with the added benefit of no potential donor site morbidity (55,56).

For patients who have persistent pain after surgical correction for adult flatfoot, MRI may be indicated. One should look for osteotomy healing (bridging trabecular bone), integrity of soft-tissue reconstructions, insufficiency fractures, and infection. Residual deformity with osteotomy malunion or nonunion is one of the most common indications for revision surgery after flatfoot reconstructions (57).

For soft-tissue reconstructions (long medial flexor tendon transfer) integrity and remodeling of the
graft should be seen over time, with the transposed tendon, usually flexor digitorum longus, becoming more well defined and hypointense over time (Fig. 4). In the setting of failure to heal, the graft will remain persistently hyperintense and will become thickened with no identifiable tendon fibers visualized (Fig. 5).

SOFT-TISSUE RECONSTRUCTIONS

Soft-tissue reconstruction procedures in the foot and ankle can include tendon or ligament augmentation procedures. It is important when evaluating MR images of postoperative soft-tissue reconstructions in the foot and ankle to have some understanding of the

Figure 3. a: Anteroposterior standing radiograph of the foot in a patient with metatarsalgia status post hallux valgus correction and bunionectomy. Expected postoperative changes are noted with no adverse features. b: Coronal fast spin echo image of the same patient demonstrating a subchondral insufficiency fracture (arrow) of the second metatarsal head accounting for this patient’s postoperative pain.

Figure 4. a: Sagittal fast spin echo MR image in a patient 1 year status post long medial flexor tendon transfer in the setting of flatfoot reconstruction demonstrates the expected MR appearance of healed tendon transfer with diffuse uniform low signal appearance of the anastamosed tendon (arrow). b: Axial fast spin echo MR image in the same patient demonstrates the normal expected postoperative appearance status post healed long medial flexor tendon transfer (arrow).
procedure performed. For example, for tendon reconstructions, one can perform primary end-to-end anastomoses or use a harvested regional tendon or allograft for augmentation (58).

Ligament reconstruction procedures usually involve the lateral ankle ligaments. In general, these are usually either a primary repair, such as the Brostrom procedure, or an augmentation procedure (and variants), which uses extensor retinaculum to reinforce the torn anterior talofibular ligament or an augmentation procedure (59–63). Of note, primary repair procedures do not address subtalar joint instability. In contrast, augmentation procedures, such as the Evans, Chrisman-Snook, and Watson-Jones procedures use some form of peroneus brevis tendon rerouting (64). Such procedures can restrict subtalar joint motion and the surgeon has to be cognizant not to induce significant constraint to the hindfoot (64–65).

The integrity of the soft-tissue reconstruction can be evaluated with MRI. Identification of a remodeled contiguous hypointense ligament (primary repair) or tendon augmentation should be identified in successful cases (Fig. 6). Poorly remodeled ligament augmentation procedures are seen as ill-defined hyperintense fibers, demonstrating areas of full thickness discontinuity in the setting of complete disruption or primary failure to heal (Fig. 7).

CARTILAGE

There are a variety of cartilage restorative procedures available to address lesions in the foot and ankle. Most commonly, the primary cartilage abnormality is an osteochondral lesion (osteochondritis dessicans [OCD]) of the talar dome.

The three main types of cartilage restorative procedure are: bone marrow stimulation techniques such as debridement, curettage, drilling, or microfracture; tissue-based cartilage repair such as osteochondral autograft transfer system (OATS) or mosaicplasty; and cell-based cartilage repair (autologous chondrocyte implantation or matrix-induced autologous chondrocyte implantation [ACI]) (66). The surgical approach used will typically depend on both the location and size of the lesion.

Figure 5. Axial fast spin echo MR image in a patient 6 months status post long medial flexor tendon transfer demonstrating failure to heal with markedly thickened hyperintense tendon fibers with no identifiable tendon remodeling (small arrows).

Figure 6. a,b: Sagittal fast spin echo MR images in a patient status post lateral ankle ligament reconstruction using peroneus brevis tendon rerouting demonstrating the expected postoperative appearance with uniformly low signal intensity tendon graft, as well as an intact osseous tunnel through the fibula (arrows).
lesion (67). These factors will also determine the type of surgical exposure needed (arthroscopy, arthrotomy, or medial malleolar osteotomy, for example).

When evaluating postoperative cartilage restorative procedures on MRI, certain morphologic characteristics should be evaluated. These include the degree of filling of the defect, the morphologic characteristics of the reparative tissue, the presence or absence of cartilage delamination, the extent of peripheral integration (fissures), the appearance of subjacent bone marrow edema, and, in the setting of tissue-based cartilage procedures (OATS, mosaicplasty), the restoration of the radius of curvature and potential displacement (Fig. 8). All morphologic characteristics combine to

Figure 7. a: Sagittal fast spin echo MR image demonstrating complete chronic disruption of lateral ankle ligamentous reconstruction with an empty fibular tunnel (arrows). b: Axial fast spin echo MR image in the same patient demonstrating complete dehiscence of the anterior talofibular ligament (thick arrow).

Figure 8. a: Sagittal fast spin echo MR image demonstrating changes from OATS procedure with focal osteochondral plug in the medial talar dome. The subchondral plate is minimally depressed, however, the radius of curvature of the articular surface is largely approximated (arrow). b: Coronal fast spin echo MR image in the same patient demonstrates the osteochondral plug (arrow) with fairly uniform osteochondral signal intensity with a small fissure at the native cartilage interface laterally. Artifact from screws transfixing medial malleolar osteotomy is present.
provide prognostic information; however, the degree of filling of the defect, the morphologic characteristics of the repair tissue, and the presence or absence of persistent subchondral bone signal abnormalities have been shown to have the highest prognostic yield (66).

**NEUROMA RESECTION**

Morton’s neuroma is a common cause of metatarsalgia. While surgical excision of neuromas has largely been replaced by percutaneous injections, often with ultrasound guidance, surgical treatment of neuromas is still performed in clinically intractable cases. Persistent pain after neuroma excision is an indication for MRI. Distinguishing between operative changes and neuroma recurrence can be difficult; however, symptomatic individuals have been shown to have a higher frequency of abnormalities including recurrent proliferative fibrous tissue formation and/or intermetatarsal bursitis compared to asymptomatic individuals (68). Administration of intravenous contrast material has also been shown to aid in diagnostic accuracy of Morton’s neuromas (69).

**INFECTION**

Infection is always a consideration in the postoperative setting. Technical considerations for imaging the postoperative foot and ankle in the setting of suspected infection include using at least one fat suppressed or inversion recovery sequence to evaluate for bone marrow edema pattern. In the forefoot, the plane of imaging should ideally be perpendicular to the metatarsals or phalanges so as to diminish volume average concerns. The use of intravenous gadolinium is controversial, as well as having similar weighting of pre- and postgadolinium images for comparison, and both are certainly radiologist-dependent; however, intravenous contrast material has been shown to increase specificity for osteomyelitis (5,6,70) (Fig. 9).

Often it will be apparent that the patient has an infection clinically. Indications for MRI in this setting are not to make the diagnosis of infection, but to evaluate for potential complications such as deep soft tissue or bone abscess formation and the extent of involvement, either involving implantable hardware or tracking along tendon sheaths.

**SUMMARY AND CONCLUSIONS**

In summary, MRI is a useful and reliable way to image the postoperative foot and ankle. Metal artifact reduction techniques should be employed especially in the setting of metal implants. In the setting of infection, intravenous gadolinium contrast material can also be employed.

Some knowledge of the surgical procedure performed is needed. In the setting of osteotomies, the presence of bone healing (bridging trabeculae) should be evaluated as well as tendon integration/donor site morbidity for soft-tissue reconstructions. Acute events such as fractures and reinjury should always be considered as well as infection.

**REFERENCES**
