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MAGNETIC RESONANCE IMAGING OF THE ANKLE: TECHNIQUES AND SPECTRUM OF DISEASE

BY ALI MOSHIRFAR, MD, JOHN T. CAMPBELL, MD, A. JAY KHANNA, MD, RONALD P. BYANK, MD, DAVID A. BLUEMKE, MD, PHD, AND JAMES F. WENZ SR., MD

In the sequences with which to evaluate the ankle joint. The purposes of this report are to (1) update orthopaedic surgeons on current magnetic resonance imaging techniques and pulse sequences with which to evaluate the ankle joint. The purposes of this report are to (1) update orthopaedic surgeons on current magnetic resonance imaging techniques and indications for

magnetic resonance imaging of the ankle, and (2) elucidate the typical appearance of the normal ankle joint and its common disease entities on magnetic resonance imaging.

Essentials of Magnetic Resonance Imaging

Process of Image Production^{1,2}

(Figs. 1-A, 1-B, and 1-C)

The process of image production involves seven steps. (1) The patient is placed supine on the scanner bed. (2) The



Figs. 1-A, 1-B, and 1-C Process of image production. (Reprinted from: Khanna AJ, Cosgarea AJ, Mont MA, Andres BM, Domb BG, Evans PJ, Bluemke DA, Frassica FJ. Magnetic resonance imaging of the knee. Current techniques and spectrum of disease. J Bone Joint Surg Am. 2001; 83 [Suppl 2 Pt 2]:128-41.) **Fig. 1-A** Alignment of the protons within a patient, with the external magnetic field (Bo) applied by the superconducting magnet in a typical magnetic resonance imaging scanner. **Fig. 1-B** Application of a radio-frequency pulse sequence to the patient, which often aligns the net magnetization vector of the patient at a 90° angle to the external magnetic field. **Fig. 1-C** The longitudinal relaxation of the protons, which is measured to determine the characteristics of a tissue on a T1-weighted image.



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Image Type	Repetition Time	Echo Time	Fat	Water	Advantages	Disadvantages
T1	Short	Short	Bright	Dark	Best anatomic detail, rapid acquisition	Poor demonstration of abnormality/edema
T2	Long	Long	Intermediate	Bright	Moderately sensitive for abnormality/edema, good myelographic effect	Decreased soft-tissue detail, time-consuming
Fat-suppressed T2 or STIR†	Long	Short	Very dark	Very bright	Most sensitive for abnormality/edema, excellent myelographic effect	Decreased soft-tissue detail, time-consuming
Gradient echo	Short	Short	Intermediate	Intermediate	Evaluation of articular cartilage, degenerative changes, and ligaments; excellent for blood	Very susceptible to metallic artifacts (pros- theses), exaggerates effect/appearance of osteophytes

*Modified from Khanna AJ, Cosgarea AJ, Mont MA, Andres BM, Domb BG, Evans PJ, Bluemke DA, Frassica FJ. Magnetic resonance imaging of the knee. Current techniques and spectrum of disease. J Bone Joint Surg Am. 2001; 83 (Suppl 2 Pt 2):129. †Short tau inversion recovery.

strong magnetic field of the scanner aligns the protons within the patient's tissues along the longitudinal axis of the scanner. (3) An electromagnetic pulse is sent into the scanner, allowing for reorientation of the protons in the tissues (typically 90° to the external field). (4) The electromagnetic pulse is turned off, and the protons are allowed to relax to their original state. (5) As the protons relax, they emit a radiofrequency signal that is picked up by the antenna in the scanner. (6) This relaxation radiofrequency signal is processed by the computer (Fourier transformation). (7) Software programs are used to create the images in multiple orthogonal planes.

Definitions

T1 indicates the amount of time required for 63% of the protons to return to their preexcited state and is a measure of the longitudinal relaxation of the protons. T2 indicates the



Figs. 2-A, 2-B, and 2-C Types of pulse sequences. Fig. 2-A Axial T1-weighted image.Fig. 2-B Axial T2-weighted image. Fig. 2-C Axial fat-suppressed T-2 weighted image.

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AITFL PITFL Lat. Mal.

Fig. 5

Talus PTT FDL ATFL PTFL

Fig. 6

Figs. 3 through 8 Axial T1-weighted images showing the normal anatomy of the ankle from superior (Fig. 3) to inferior (Fig. 8). EHL = extensor hallucis longus, EDL = extensor digitorum longus, TA = tibialis anterior, PTT = posterior tibial tendon, FDL = flexor digitorum longus, FHL = flexor hallucis longus, AITFL = anterior-inferior tibiofibular ligament, PITFL = posterior-inferior tibiofibular ligament, Ant N/V = anterior neurovascular bundle, Post N/V = posterior neurovascular bundle, Lat. Mal. = lateral malleolus, Med. Mal. = medial malleolus, PB = peroneus brevis, PL = peroneus longus, ATFL = anterior talofibular ligament, and PTFL = posterior talofibular ligament.

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amount of time for 63% of the protons to "dephase"—that is, to start precessing at frequencies different from the applied electromagnetic pulse. This decay rate is a characteristic of the tissue.

Types of Pulse Sequences

By manipulating the strength of the radiofrequency pulse, how frequently it is applied, and how long after the pulse the relaxation energy is measured, the images can be weighted to emphasize the T1, T2, or gradient-echo characteristics of a tissue (Table I).

T1-weighted images (Fig. 2-A) offer the best anatomic detail and are used to evaluate anatomy, fractures lines, and other osseous detail. T2-weighted images (Fig. 2-B) have a lower resolution; however, they are more sensitive to pathologic changes in the tissue, particularly to any process in which cells and the extracellular matrix have increased water content.

Fat-suppressed T2-weighted fastspin-echo and STIR (short tau inversion recovery) images (Fig. 2-C) represent T2-weighted images that are acquired with a pulse sequence to suppress fat and accentuate fluid. Therefore, these sequences are most sensitive for highlighting pathologic changes and edema in the bone and soft tissues.

Gradient-echo pulse sequences are intermediate views between T1-weighted and T2-weighted images. Gradient-echo images are excellent for the evaluation of articular cartilage integrity and the assessment of hemorrhage, which produces a signal drop out.

Basic Steps in

Image Interpretation

The basic steps to evaluate a magnetic resonance image of the ankle joint systematically include the following. (1) Determine the pulse sequence of all the images (Tables I and II). (2) Look for normal anatomy on T1-weighted and gradient-echo images and evaluate for the presence of any abnormal structures. Evaluate all structures described under "Normal Anatomy of the Ankle on Magnetic Resonance Imaging" below. (3) Confirm that all tissues are homogeneous

ABLE II Tissue Characteristic	s on Magnetic Resonan	ce Imaging*		
Tissue Type	T1	T2†	STIR †	Gradient Echo
Cortical bone	Very low	Very low	Very low	Very low
Red marrow	Intermediate	Intermediate	Intermediate	Intermediate
Yellow marrow	High	Intermediate	Very low	Low
Fat	High	Intermediate	Low	Intermediate
Fluid	Low	High	Very high	Intermediate
Muscle	Intermediate	Intermediate	Low	Intermediate
Ligaments and tendons	Low	Low	Very low	Very low
Physeal scar	Low	Low	Low	Low
Hyaline cartilage	Intermediate	Intermediate	Intermediate	Intermediate

*Modified from Khanna AJ, Cosgarea AJ, Mont MA, Andres BM, Domb BG, Evans PJ, Bluemke DA, Frassica FJ. Magnetic resonance imaging of the knee. Current techniques and spectrum of disease. J Bone Joint Surg Am. 2001; 83 (Suppl 2 Pt 2):130. †With the fast-spin-echo technique, fat-suppressed T2-weighted images are used at some institutions. †Short tau inversion recovery.

EDL Lat. Mal. PL PB

Fig. 9



Figs. 9 through 12 Sagittal T1-weighted images showing normal anatomy of the ankle from lateral (Fig. 9) to medial (Fig. 12). EHL = extensor hallucis longus, PTT = posterior tibial tendon, FDL = flexor digitorum longus, FHL = flexor hallucis longus, EDL = extensor digitorum longus, Med. Mal. = medial malleolus, Lat. Mal. = lateral malleolus, PB = peroneus brevis, and PL = peroneus longus.

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on T1-weighted images. If they are not, check the T2-weighted and T2-weighted fat-suppressed images to verify any abnormality. (4) Evaluate the T2-weighted images for areas of increased signal due to increased water content (which is sensitive, but not specific, for an abnormality). (5) Correlate the magnetic resonance imaging findings with the clinical history to determine the most likely diagnosis.







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Fig. 16

Figs. 13 through 17 Coronal T1-weighted images showing the normal anatomy of the ankle from posterior (Fig. 13) to anterior (Fig. 17). PTT = posterior tibial tendon, FDL = flexor digitorum longus, FHL = flexor hallucis longus, PTFL = posterior talofibular ligament, PTTL = posterior tibiotalar component of the deltoid ligament, Post. N/V = posterior neurovascular bundle, PB = peroneus brevis, CFL = calcaneofibular ligament, Med. Mal. = medial malleolus, and Lat. Mal. = lateral malleolus.







Fig. 15

Normal Anatomy of the Ankle on **Magnetic Resonance Imaging** Axial Images (Figs. 3 through 8)

 $T^{
m he\ axial\ sequences\ are\ important\ in}_{
m evaluating\ the\ ankle\ because\ they}$ demonstrate many structures better than

do sagittal or coronal images. These images are reviewed systematically from superior to inferior cuts. Because most structures are seen on cross sections, it is important to follow each structure from image to image throughout its entire course.

Fig. 17

Muscles and tendons3: The tibialis anterior and the extensor hallucis longus can be seen as the two most anteromedial structures at the level of the ankle joint superficial to the anterior neurovascular bundle. The extensor



Figs. 18 and 19 Axial views showing a partial sprain of the anterior talofibular ligament on fat-suppressed images. **Fig. 18** On this T2-weighted image, the arrow indicates increased fluid signal around the ligament.

digitorum longus has a broad appearance at the level of the ankle joint and lies more laterally than the extensor hallucis longus. The peroneus tertius is sometimes difficult to visualize because of its small cross section; however, it is the most lateral tendon on the anterior aspect of the ankle.

The posterior tibial tendon lies just posterior to the medial malleolus at the level of the ankle joint. The flexor digitorum longus is posterior to the posterior tibial tendon and medial to the posterior neurovascular bundle. The flexor hallucis longus has a broad muscle belly at the level of the ankle joint and lies lateral to the posterior neurovascular bundle.

The flexor hallucis longus is seen well between the two tubercles of the posterior process of the talus. The peroneal tendons are seen just posterior to the fibula. The peroneus brevis lies against the osseous surface of the fibula, and the peroneus longus is more superficial at the level of the ankle joint. The Achilles tendon comprises the tendinous insertion of the soleus and the gastrocnemius muscles of the calf. It inserts on the calcaneal tuberosity and is the most posterior midline tendon structure at the level of the ankle joint. The Achilles tendon normally has an oblong shape.

*Ligaments*³: The anterior and posterior-inferior tibiofibular ligaments constitute the syndesmotic ligament complex at the level of the ankle joint. The convex articular surface of the distal end of the fibula articulates with a concave facet at the inferior lateral aspect of the tibia. This distal tibiofibular joint is stabilized by the interosseous ligament between the MAGNETIC RESONANCE IMAGING OF THE ANKLE: TECHNIQUES AND SPECTRUM OF DISEASE

tibia and the fibula and by the anterior and posterior-inferior tibiofibular ligaments that extend from the fibular notch of the tibia to the distal end of the fibula.

The anterior talofibular ligament and the posterior talofibular ligament, along with the calcaneofibular ligament, constitute the lateral collateral ligament complex of the ankle (see "Coronal Images" below). The anterior talofibular ligament and the posterior talofibular ligament extend anteriorly and posteriorly from the fibula to the talus. The anterior talofibular ligament is a flat band that extends anteromedially from the anterior margin of the lateral malleolus to the neck of the talus. The posterior talofibular ligament extends medially and slightly posteriorly from the posterior tip of the lateral malleolus to the posterior lateral process of the talus.

*Neurovascular structures*³: The anterior neurovascular bundle, which includes the anterior tibial artery, anterior tibial vein, and deep peroneal nerve, is slightly lateral and deep to the extensor hallucis longus. The posterior neurovascular bundle, composed of the posterior tibial artery, vein, and nerve, lies between the flexor digitorum longus and flexor hallucis longus posteriorly.

Sagittal Images (Figs. 9 through 12)

Sagittal images allow most structures to be viewed longitudinally along their courses. These images should be viewed systematically from lateral to medial.

*Muscles and tendons*³: The posterior tibial tendon can be identified as the first structure just posterior to the medial malleolus. On the sagittal image, the longitudinal course of this tendon can be identified as it heads for its primary inser-



This T1-weighted image shows attenuation and the disorganized appearance of the ligament, as evidenced by the increased signal around the tendon (arrow).



Fig. 20

Coronal T2-weighted image showing a thickened calcaneofibular ligament with increased signal throughout its structure and disruption in its normal vertical course.



Fig. 21

Coronal T2-weighted image showing a tear in the superficial fibers of the deltoid ligament (arrow).

tion on the tuberosity of the navicular. The flexor digitorum longus and flexor hallucis longus can be identified as the two tendons posterior to the posterior tibial tendon; they show a longitudinal and oblique course in this plane. On the sagittal images, the flexor hallucis longus is the deepest posterior comMAGNETIC RESONANCE IMAGING OF THE ANKLE: TECHNIQUES AND SPECTRUM OF DISEASE



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Figs. 22 and 23 Axial images showing a type-I posterior tibial tendon tear on T1-weighted (Fig. 22) and fat-suppressed T2-weighted (Fig. 23) images. Note the enlargement of the posterior tibial tendon and heterogeneous signal within the substance of the tendon. The arrow in each figure indicates the posterior tibial tendon.

partment muscle, lying against the bone. The Achilles tendon can be followed to its insertion on the calcaneal tuberosity. If



Fig. 24



Fig. 25

Figs. 24 and 25 T2-weighted (Fig. 24) and fat-suppressed T2-weighted (Fig. 25) axial images showing peroneal tendinitis with fluid signal seen within the peroneal tendon sheath.

the retrocalcaneal bursa contains fluid (as from inflammation), it can often be identified on T2-weighted images.

Ligaments: Coronal and axial images are better for identifying these structures. MAGNETIC RESONANCE IMAGING OF THE ANKLE: TECHNIQUES AND SPECTRUM OF DISEASE



Fat-suppressed T2-weighted axial image showing a peroneus brevis tear. Note the hemorrhage and inflammation within the sheath and the enlargement of the tendon.

Coronal Images (Figs. 13 through 17)

Coronal images should be viewed systematically from posterior to anterior. These images are useful for evaluating the medial and lateral ligamentous complexes of the ankle.

*Muscles and tendons*³: Although the coronal images are not the ideal images for identifying muscles and tendons, the posterior tibial tendon, flexor digitorum longus, and flexor hallucis longus can be identified with relative ease. The posterior tibial tendon can be identified as a longitudinal dark signal on T1-weighted images just posterior to the medial malleolus. The broad origin of the flexor hallucis longus from the posterior two-thirds of the fibula and the interosseous membrane can be easily identified on the coronal images.

*Ligaments*³: The medial collateral ligament complex of the ankle, or deltoid ligament, has superficial and deep layers. The superficial layer consists of the tibionavicular ligament and the tibiocalcaneal ligament. The tibionavicular ligament originates from the medial malleolus and attaches into the tuberosity of the navicular. The tibiocalcaneal ligament is often seen as a thick, dark band extending from the medial malleolus inferiorly to the sustentaculum tali of the calcaneus. The tibiotalar ligament constitutes the deep layer of the deltoid ligament. It extends from the medial malleolus to cover the entire nonarticular medial side of the talus. The lateral ligament, anterior talofibular ligament, and the posterior talofibular ligament. The calcaneofibular ligament is

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Fig. 27

T1-weighted axial image showing peroneal subluxation. There is a lack of a well-developed fibular groove.





T1-weighted sagittal image showing Achilles tendinosis. The tendon is thickened with focal anteroposterior enlargement. Note the edema in the fat around the intact tendon.



T1-weighted sagittal image demonstrating a chronic Achilles tendon rupture with widening and degeneration of the tendon and longitudinal stripes of high signal. The Achilles tendon has lost its thin crescent shape.



Fat-suppressed T2-weighted sagittal image showing a ganglion cyst with high fluid signal of the cyst.

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Fig. 31

Figs. 31 and 32 T1-weighted coronal (Fig. 31) and fat-suppressed T2weighted coronal (Fig. 32) images showing an osteochondral defect of the lateral talar dome. Note the low signal on T1-weighted images and the high signal on the fat-suppressed T2-weighted images.

best seen on coronal images, extending from the tip of the lateral malleolus into the lateral wall of the calcaneus.

Evaluation of Pathologic Conditions of the Ankle

Ligaments

A nkle sprains are common injuries, varying from mild to severe⁴; lateral ligament injuries are more common than medial ones^{5,6}. Ligament injuries are best evaluated on T2weighted and T2-fat-suppressed weighted magnetic resonance imaging scans. These images usually show increased signal, signifying edema and fluid collection representative of trauma. Discontinuity in the ligament on T1-weighted and T2-weighted images signifies disruption.

The anterior talofibular ligament is the weakest and most vulnerable of all ankle ligaments. Tears in this ligament are best diagnosed on axial images (Figs. 18 and 19). The second most common pattern of ankle injury is a combined injury to the anterior talofibular ligament and calcaneofibular ligament. Isolated tears of the calcaneofibular ligament are extremely uncommon⁶. Unlike the anterior talofibular ligament, tears of the calcaneofibular ligament are best seen on the coronal T2-weighted and T2-fat-suppressed images (Fig. 20).

Isolated injuries of the deltoid ligament are uncommon⁶. The deltoid ligament injuries are best viewed on coroMAGNETIC RESONANCE IMAGING OF THE ANKLE: TECHNIQUES AND SPECTRUM OF DISEASE

nal T2-weighted and T2-fat-suppressed images (Fig. 21). Therefore, magnetic resonance images must be carefully correlated with clinical examination to avoid false-positive results.

Posterior Tibial Tendon Dysfunction

Posterior tibial tendon dysfunction is the most common cause of adult-onset flat-foot deformity⁷. The pathophysiology involves dysfunction and degenerative changes within the tendon. Posterior tibial tendon tears can be classified into three types on the basis of their characteristics on magnetic resonance imaging (Table III)⁸. A type-I tear has longitudinal splits in the tendon resulting in hemorrhage, scar formation, and thickening of the tendon. The posterior tibial tendon can be enlarged to four to five times the size of the adjacent flexor digitorum longus (Figs. 22 and 23). Type-II tears are more severe, with longitudinal splits that cause the tendon to attenuate to one-half to one-third of its original thickness. Type-III tears represent a complete rupture of the tendon with retraction of the stump and a visible gap. Posterior tibial tendon tears are best diagnosed on T2-weighted and T2-fat-suppressed axial images.

Peroneal Tendon Disorders

Magnetic resonance imaging is a valuable tool with which to diagnose a peroneal abnormality. The axial images are ideal



Fig. 32

TABLE III Types of Posterior Tibial Tendon Tears				
Type of Tear	Description	Magnetic Resonance Imaging Characteristic		
I	Most common, enlarge- ment of tendon (4 to 5 times the size of the flexor digitorum longus)	Increased signal within the tendon on short echo time and T2 images		
II	Smaller than normal tendon (same size or smaller than flexor digitorum longus)	Attenuation of tendon and lack of high signal as seen in type I		
111	Complete tendon rupture	Absence of tendon and edema of surrounding tissue on T2 images		

for revealing evidence of tendon sheath effusion and synovitis, as is often seen in peroneal tendinitis⁹ (Figs. 24 and 25). Peroneal tendon ruptures, although uncommon, may occur as a result of trauma or inflammatory arthritis (Fig. 26). Some believe that peroneal tendon tears occur secondary to chronic abrasion of the tendon against the posterior ridge of the fibula¹⁰. Chronic peroneal tendon subluxation or instability has been reported with attenuation of the superior peroneal retinaculum and a shallow retrofibular groove⁶. Both of these are well visualized on T1-weighted axial images (Fig. 27).

Achilles Tendon Problems

The Achilles tendon does not contain a synovial sheath but rather is invested by loose connective tissue⁸. Normally, it should have a flat or concave anterior margin with a low, homogeneous signal on axial images. In Achilles tendinosis (Fig. 28), there is a loss of the sharp tendon interface with the surrounding tissues, and the tendon may appear thickened and heterogeneous. Chronic tendinosis can lead to tendon rupture, frequently at 2 to 6 cm proximal to its insertion into the calcaneal tuberosity¹¹ (Fig. 29).

Cysts

A ganglion cyst occurs in the setting of degeneration in an area of the joint capsule or tendon sheath and eventually results in an outpocketing of mucoid degeneration. The cyst shows high signal intensity on T2-weighted images consistent with fluid (Fig. 30). On T1-weighted images, the cyst shows intermediate intensity. Cysts may also show rim enhancement with gadolinium contrast infusion.

Osteochondral Defect

(Osteochondritis Dissecans)

Separation of articular cartilage from its underlying subchondral bone is known as an osteochondral fragment or osteochondritis dissecans. These lesions are often initially misdiagnosed clinically as ankle sprains¹². Lateral lesions occur more commonly and present in more advanced stages than do medial lesions^{12,13} (Figs. 31 and 32). A stable lesion is defined as MAGNETIC RESONANCE IMAGING OF THE ANKLE: TECHNIQUES AND SPECTRUM OF DISEASE

one having intact cartilage with a solid fibrous attachment. An unstable lesion has either synovial fluid or granulation tissue at the interface with the subchondral bone^{14,15}.



Fig. 33



Figs. 33 and 34 T1-weighted (Fig. 33) and fat-suppressed T2-weighted (Fig. 34) sagittal images showing osteonecrosis of the talus. Much of the talar body appears to be involved.



Fig. 35

T1-weighted sagittal image showing no evidence of osteonecrosis in the talus after open reduction and internal fixation with titanium screws. Note the lack of metal artifact when titanium screws are used. MAGNETIC RESONANCE IMAGING OF THE ANKLE: TECHNIQUES AND SPECTRUM OF DISEASE

Osteonecrosis of the Talus

Magnetic resonance imaging is believed to be more sensitive than scintigraphy in diagnosing osteonecrosis of the talus and has the added advantage of better anatomic resolution¹⁶. T2-weighted images typically show low signal intensity in the talar dome consistent with necrosis and early changes of the classic double-ring sign (Figs. 33 and 34)¹⁶. Because there is a risk of osteonecrosis after talar neck fractures, open reduction and internal fixation with titanium screws is recommended to minimize the metal artifact on postoperative magnetic resonance imaging studies (Fig. 35).

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