MRI of Sports-Related Injuries of the Foot and Ankle: Part 1

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The ankle is one of the most frequently injured joints in the course of sports activities. MR imaging has become the modality of choice in the evaluation of most of these lesions, especially in competitive athletes.
The purpose of this article is: 1) To illustrate the MR imaging features of a great number of sports-related injuries of the ankle, correlating it with lesional mechanisms and clinical findings, and 2) To review the role of MR imaging in clinical management and surgical planning of these injuries, especially in competitive athletes.
In order to a better understanding of these lesions, a classification based on the anatomic origin are outlined. The spectrum of injuries has been classified in: 1) osseous lesions, 2) ligamentous injuries, 3) tendinous lesions, 4) impingement impingement, and 5) plantar fascial lesions.

Professional and recreational sports activities have increased substantially in the recent decades resulting in an increase in the number and kind of sports-related injuries. The increased prevalence of these injuries has led to a growing interest of several medical specialties about their pathogenic mechanism, clinical manifestations, diagnosis, and treatment. The role of radiologists in this setting is emerging because of the impact of cross-sectional imaging modalities, and especially of magnetic resonance imaging (MRI) which has become the modality of choice in the evaluation of most of these lesions, especially in competitive athletes.[1,2]

The use of MRI for foot and ankle injuries in athletes lags behind the knee, shoulder, or even hip, at most institutions, despite that ankle and foot are commonly injured in sports practice.[3] The fact that the majority of these injuries receive a conservative treatment and lack of familiarity of radiologists with local pathology and complex anatomy of this region may explain the less popularity of MRI of foot and ankle, which however, has a substantial effect in making a clinical decision that has been well demonstrated.[4]

The purpose of this article is to review the MRI features of a great number of sports-related injuries of the ankle and foot, correlating it with lesional mechanisms and clinical findings. Knowledge of the clinical history and the mechanism of injury are important factors in establishing an accurate diagnosis, and in many instances it may provide key information that will allow a specific diagnosis when imaging findings are nonspecific.

The second aim of this article is to review the role of MRI in clinical management and surgical planning of these injuries, especially in competitive athletes.

To a better understanding of these lesions, a classification based on the anatomic origin are outlined. The spectrum of injuries has been classified in: 1) osseous lesions, 2) ligamentous injuries, 3) tendinous lesions, 4) impingement impingement, and 5) plantar fascial lesions.

Osseous Lesions

Stress Fractures

Stress fractures can occur if normal bone is exposed to repeated abnormal stress[5] or if normal stress is placed on bones with compromised elastic resistance (*insufficiency fractures*). For the purpose of this discussion, the term stress fracture is used to refer to fatigue-type fractures.

Stress fractures of the foot and ankle are common in the course of sport activities.[5-7] This type of injury is seen in runners of all levels and, less frequently, in

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athletes engaged in sports that involve jumping and running (such as basketball, soccer, football, and tennis). Accepted risk factors for this type of fractures include training errors, poor footwear, and anatomical variations (pronated feet, cavus feet, and increased external tibial torsion).[5,6]

Metatarsals, tarsal bones, sesamoids, medial malleolus, talus, and fibula can all be involved. In one report, which revised 320 cases of stress fractures in athletes, the tibia was the bone most commonly injured, followed by the tarsals, metatarsals, fibula, and sesamoids.[6]

Based on its location, stress fractures of the foot and ankle may be classified in high, medium, and low risk fractures.[8] Early diagnosis is especially important in high risk stress fractures, in which potentially serious sequelae including joint involvement, displacement, delayed union, nonunion, and recurrence of fracture may occur.

Stress fractures of tarsal navicular and sesamoids are high risk injuries.[8] In the medial mallelus and proximal diaphysis of the fifth metatarsal, stress fractures are considered as medium risk fractures, whereas distal fibula, calcaneus and distal diaphysis of the second to fifth metatarsals are low risk stress fractures locations.[8]

Metatarsals stress fractures are typically described in military recruits, but are also associated with running and dancing (ie, ballet, aerobic dancing). Morton foot (a foot with a short first metatarsal, a longer second metatarsal, and a hypermobile first ray) may predispose to this injury.[5] This fracture typically occurs in the middle or distal diaphysis, being the second and third metatarsals the most commonly affected (Fig 1).[6] The second and third metatarsals are relatively fixed in position within the foot, while the first, fourth, and fifth are relatively mobile. For this reason, when ambulating more stress is placed on the second and third metatarsals; so these have an increased risk for stress fractures. Stress fractures of the base of the second metatarsal are common in ballet dancers, presumably because the first two metatarsals bear most of the bodyweight during some of the positions required in this sport (ie, en pointe, demipointe).[9] Stress fractures of the proximal fifth metatarsal are relatively common in athletes. The proximal fifth metatarsal bears great stress in those who oversupinate when they walk or run. Some authors term these injuries as Jones fractures, including also the acute fracture under this name.[5,8,10] Others prefer to use this term when an acute traumatic event is found. Its location, at more than 1’5 cm of the styloid, permits to differentiate stress fractures of the proximal fifth metatarsal from proximal avulsion fractures.[2,8] The avulsion fracture of the base of the fifth metatarsal is usually associated with a lateral ankle sprain and occurs at the insertion of the peroneus brevis tendon.

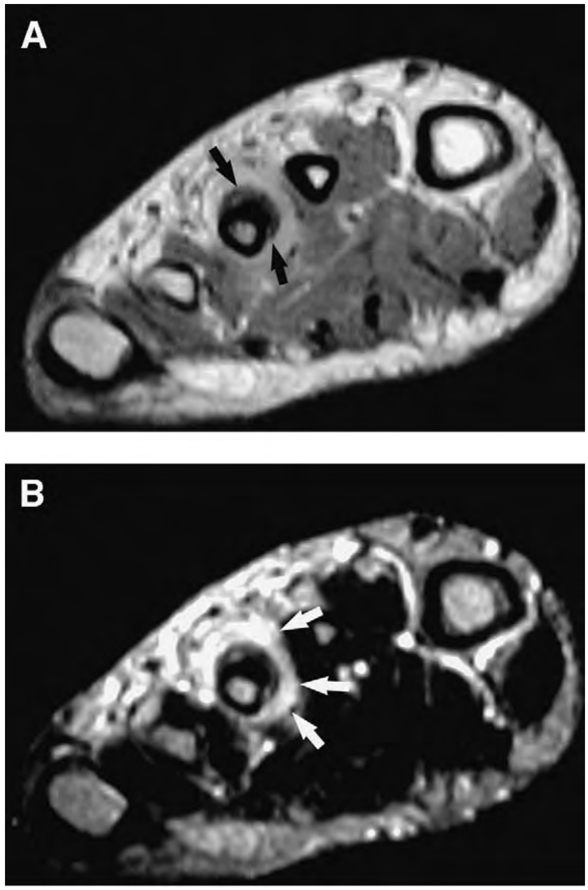


FIG 1. Stress fracture of the third metatarsal. **A**, Coronal proton-density weighted MRI shows low-signal intensity periosteal callus formation surrounding the cortex. **B**, Coronal T2-weigthed MRI demonstrates better adjacent muscle (arrows) and bone marrow edema changes.

Recently, stress fractures of the metatarsal heads have been described.[11,12] These fractures occur in elderly postmenopausal women, but occasionally may be seen in young or middle-aged runners.[11,12]

Among tarsal bones, calcaneus and navicular are the most commonly involved. By contrast, talar and cuboid stress fractures are uncommonly reported in athletes.[13] Calcaneus stress fractures are most commonly observed in military recruits,[14,15] being rarely reported in athletes. The reason for this unknown. The fracture generally involves the posterosuperior or pos-

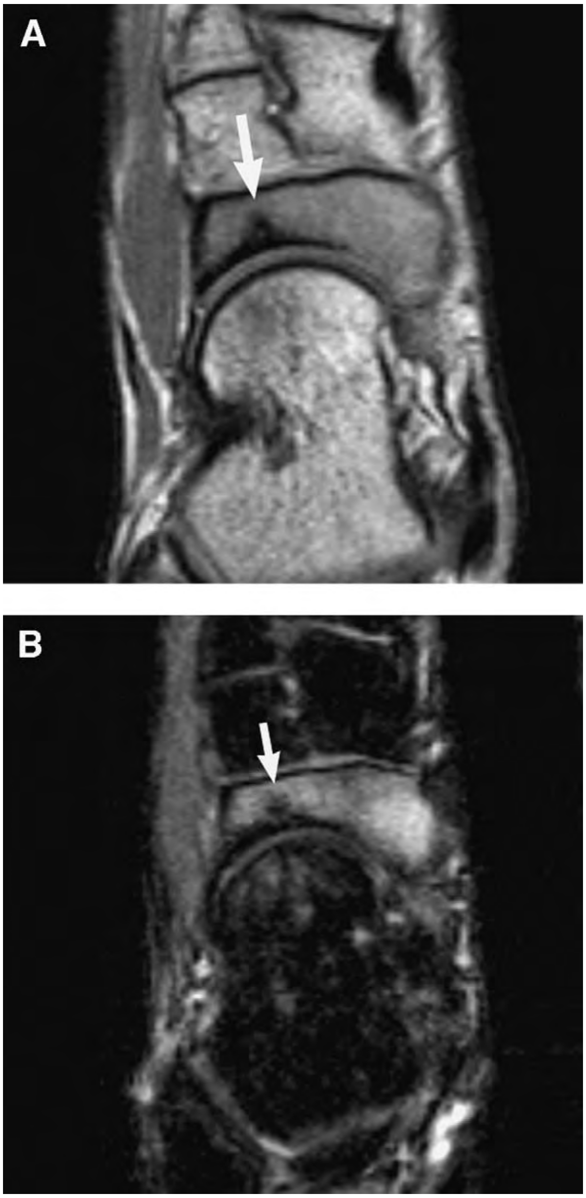


FIG 2. Stress fracture of the tarsal navicular in a soccer player. **A**, **B**, Axial T1-weighted (**A**) and STIR (**B**) MR images show a sagittal ill-defined low-signal intensity fracture line (arrows), with extensive surrounding bone marrow edema.

terior region of the calcanus, with a vertical orientation perpendicular to the trabecular pattern of bone.[14-16] Tarsal navicular stress fractures occur most commonly in runners.[8,17] These lesions occur in a sagittal plane, in the central third of the bone (Figs 2 and 3). The diagnosis is often delayed due to insidious clinical manifestations and difficulty to identify the fracture on radiographs.[17,18] As previously stated, tarsal navicular stress fracture is considered a critical injury because of the high risk of complications, which can be career-

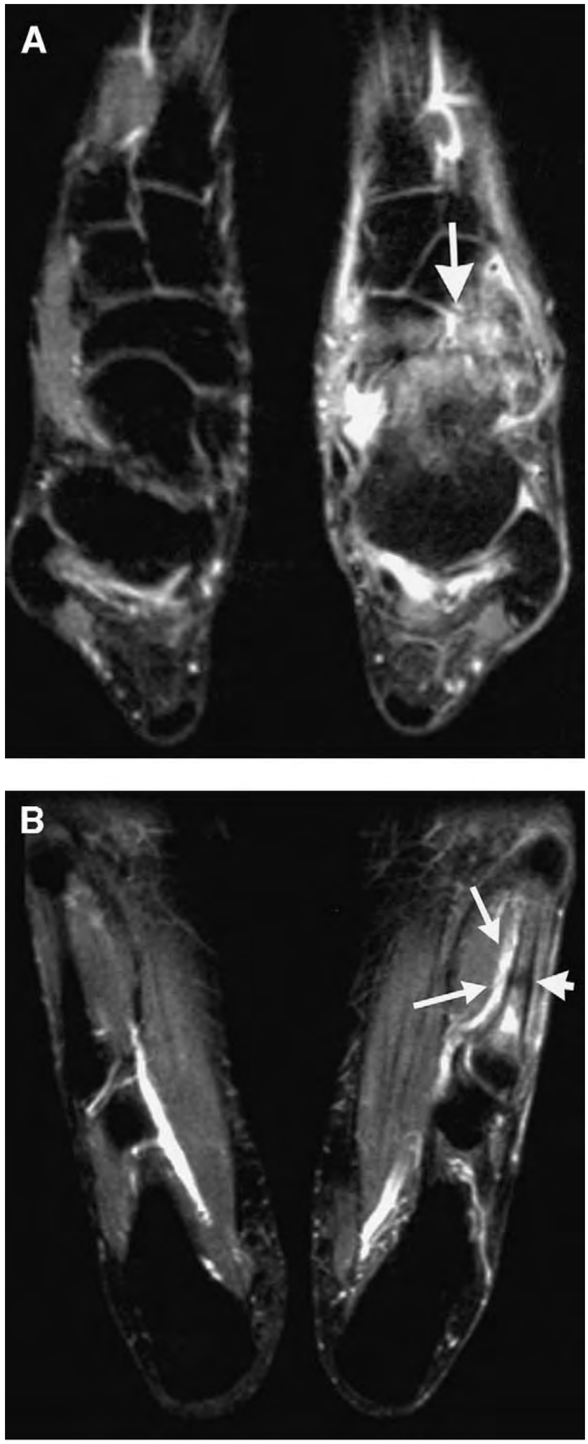


FIG 3. Complicated stress fracture of the tarsal navicular in a young female athlete. **A**, Axial STIR MRI demostrates a complete, displaced stress fracture in the central third of the bone (arrows). There are bone marrow edema changes in both fracture fragments, and talonavicular degenerative changes, with talar subchondral bone marrow edema, small osteophytes and joint fluid. **B**, Axial STIR MRI shows an associated fifth metatarsal stress fracture because of increased weight-bearing on the lateral aspect of the forefoot. Note low signal-intensity fracture line (shorth arrow), and periosteal edematous changes (long arrows).

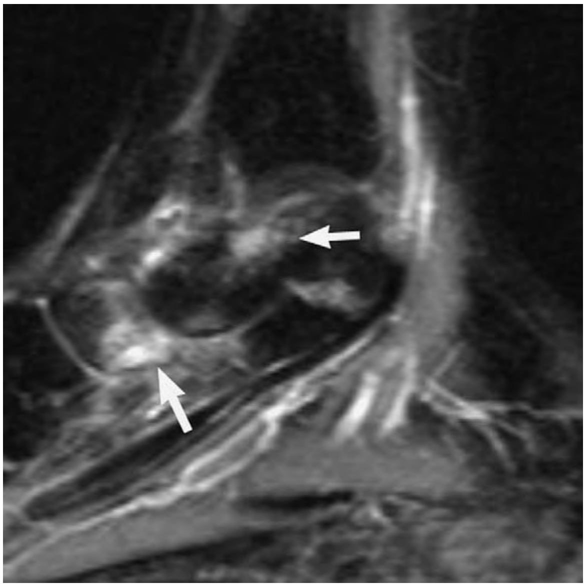


FIG 4. Bone contusion. Sagittal STIR MRI demonstrates ill-defined increased signal intensity in the tarsal navicular and talus (arrows).

ending problems for elite athletes (Fig 3).[6,8,17,18] Fibular stress fractures typically occur in its distal third, a few centimeters proximal to the syndesmosis (Fig 4). These fractures, which are typically seen in runners and ballet dancers, are often associated to a cavus-type foot.[8,9]

Stress fractures of the medial malleolus are very uncommon.[19-21] This type of injury is seen in runners and athletes engaged in sports that require repetitive jumping.[20] The fracture line can either be vertically oriented, originating from the medial malleolus-tibial plafond junction, or arched obliquely through the medial malleolus.[21]

The sesamoids are osicles embedded within the flexor hallucis brevis tendon at the level of the first metatarsophalangeal joint. Stress fractures of the medial or, less frequently, of the lateral sesamoid bone of the first metatarsal occur after repetitive exercises that include forced propulsion on the toe dorsiflexed, such as ballet dancing, sprinting, and running.[5,8,9,22]

Classical clinical feature of stress fractures is pain associated with a particular activity.[5] Pain is relieved by rest and becomes worse when the activity is continued. In metatarsal stress fractures pain usually starts as diffuse, and then localizes at the site of the fracture. Physical examination reveals a tenderness point over an area of induration or palpable mass. In calcaneus stress fractures symptoms include pain and swelling on both sides of the heel; soft tissues lateral and medial to the heel usually are midly swollen. Patients with navicular stress fractures experience insidious onset of dorsal midfoot pain.[17] In cases of sesamoids stress fractures swelling is not a prominent feature; there is, however, marked tenderness to pressure over the involved sesamoid.

Clinical history is paramount in the diagnosis of a stress fracture. Patients usually report incresed intensity or duration of exercise regimen, or a change in the type of activity or the surface on which the activity occurs.[5,6] Often there has been aching in the injured area for weeks or months, but the discomfort has been mild enough for it to be ignored and sports participation continue, until a twisting injury occurs that completes the fracture. Clinical diagnosis of stress fractures of metatarsals, and distal fibula is not difficult.[6] Clinical diagnosis of tarsal stress fractures is somewhat more difficult. In this way, Mathelson et al reported a longer time to diagnosis in tarsal stress fractures in comparison with other locations.[6]

Radiographs should be used as a primary method for the diagnosis of stress fractures. Typical radiographic changes include a focal periosteal reaction, a cortical break (a "black line") and a band of sclerosis. The former two changes predominate in a shaft of a long bone (ie, metatarsals), where the cortex is thick. A band of sclerosis occurs at the end of a long bone (ie, medial malleolus) or small bones (ie, navicular), where the cancellous bone is dominant. Nevertheless, initial radiographs are usually negative.[6,14,23-25] The time period from the onset of pain to positive radiographic evidence of a stress fracture can vary from 2 weeks to 3 months depending on the specific bone injured.[5,6] Moreover, the follow-up radiographs are only positive in about 50% of cases.[14] Tarsal stress fractures are notorious for producing negative radiographic findings.[6] In some locations, limitations of radiographs are enhanced by anatomic variants. In this sense, sesamoid stress fractures are difficult to differentiate radiographically from a normal variant, bipartite or bifid sesamoid, which occurs in approximately 10% of the population and is 10 times more frequent in the medial than the lateral sesamoid.

Because of the low sensitivity of radiographs, bone scintigraphy has usually been used to confirm the diagnosis of stress fractures.[5,6,25] Recently, MRI is being considered the modality of choice to confirm the diagnosis in cases in which radiographs are normal or equivocal, because it is as sensitive but more specific than bone scintigraphy, and permit to detect associated soft-tissue injuries.[8,26] In a recent prospective study in fifty military recruits with stress fractures, MRI was more sensitive than two-phase bone scintigraphy.[27] Moreover, one study found that MRI was more accurate than radionuclide bone scintigraphy in correlating the degree of bone involvement with clinical symptoms.[28]

MRI findings of stress fractures depend on the stage of the disease.[24] In the very early stages, a condition known as "stress response" occurs.[7,8] During this period, edema, hyperemia, and osteoclastic activity develop within the stressed area of the bone. At this stage, MRI often demonstrates signal intensity alteration in the marrow space, with ill-defined low signal intensity on T1-weighted and high signal intensity on T2-weighted and STIR images. This abnormal signal intensity is similar to that seen in a bone contusion. Early findings also include edematous changes on the periosteal surface of bone. Muscle edema adjacent to stressed bone seems to appear more lately (Fig 1). As the stress persists and a fracture develops, MRI will disclose a well-defined low signal fracture line (Figs 2 and 3). Periosteal callus formation appears as a low signal rim running parallel to the cortex (Fig 1). Kiuru et al have described a classification-grading system for stress fractures based on MR findings.[27] This classification establishes several degrees (I to V) that reflect the progression from response to stress, up to the complete fracture. Grade I and II represent endosteal marrow edema and periosteal edema respectively. In grade III, there are associated muscle edema changes. The onset of grade IV is marked by the detection of a fracture line. In grade V, periosteal callus formation is present.

Treatment of stress fractures is conservative, and includes cessation of the offending activity, local physical therapy, and eventually nonsteroid antiinflammatory agents. Immobilization may be required in some locations, especially in the tarsal navicular. Surgical treatment is only indicated in complicated fractures.

Bone Contusion

Bone contusion or bone bruises are thought to represent trabecular microfractures associated with medullary edema and hemorrhage. Radiographic findings are typically normal in these lesions. On MRI, bone contusion appears as ill-defined reticulated areas confined to the medullary space of cancellous bone, with low signal intensity on T1-weighted images and high signal intensity on T2-weighted images, especially fat suppressed T2-weighted and STIR images (Fig 4). These changes are more patent in the acute stage and in most cases resolve in 2 to 3 months. However, there have been described cases of ankle bone contusions persisting for a longer period of time.[29]

For several reasons, MRI diagnosis of bone contusion plays an important role in the management of sports-related injuries. It has been suggested that a delay in the resumption of normal sports activities should be considered in the presence of bone contusions to avoid the progression of any weakening of the mechanical properties of bone related to the trabecular microfracture.[7,30]

On the other hand, bone contusions are often associated with ligament injuries.[30-32] Pinar et al found bone contusions in 7% and 25% of the ankles following fist-time and recurrent sprains, respectively.[30] Injuries of the lateral collateral ligamentous complex are because of an ankle inversion mechanism, which produces medially axial loading. Therefore, bone contusions associated to these ligamentous injuries are mainly located in the medial aspect of the talus or the medial malleolus.[30,31] However, bone contusions of the ankle associated to lateral collateral ligament injuries may also be seen.[30]

Finally, a bone contusion seen on MRI may occur in the absence of major ligament disruptions[30] and sometimes may be the only imaging finding after foot or ankle trauma. Identifying the contusion indicates the cause of pain and avoids further costly or invasive investigations.

"Occult" Fracture

The complexity of ankle and foot anatomy makes it difficult, and sometimes almost impossible, for radiographic identification of small fractures in these locations. These lesions detected by computed tomograpy (CT) and moreover by MR, are know as occult fractures. Calcaneus and talus are the most common location of occult fractures of the ankle and foot.[2]

Fractures of the anterior process of the calcaneus (Fig 5),[33] the base of the cuboid and talus, should be carefuly investigated in those cases of chronic foot and ankle pain after an inversion injury has been sustained, because they are often overlooked.

As in other joints, MRI can help detect these radiographically "occult" fractures of the ankle. In such cases, a traumatic injury has recently occurred

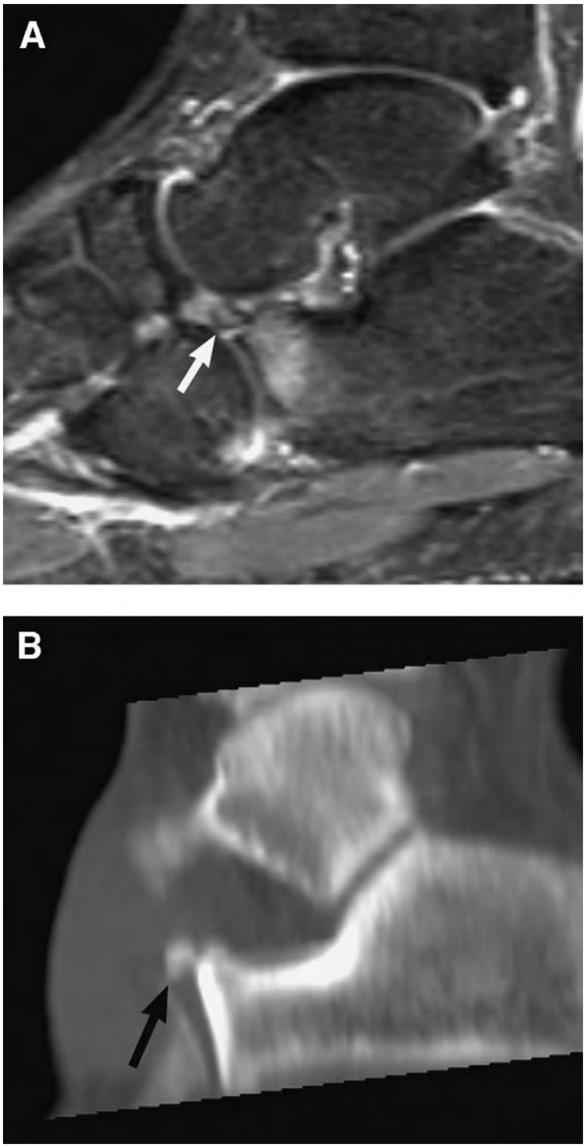


FIG 5. Occult fracture of the anterosuperior calcaneal process in a soccer-player. **A**, Sagittal STIR MRI shows a small fracture (arrow). The bony fragment and the adjacent calcaneus shows ill-defined high signal changes representing bone marrow edema. **B**, Corresponding sagittal reformatted CT scan shows clearly the fracture (arrow).

and MRI discloses a fracture line with very low signal intensity associated with cortical interruption as well as signal intensity changes representing edema and medullary hemorrhage (Fig 5).[2,7,6]

Osteochondral Lesions of the Talus

Articular surface injuries of the talar dome have been variously termed as *osteochondral defects*, *fractures*, or *injuries* as well as *osteochondritis dissecans* and *transchondral fractures*.[34-37] The term *osteochondritis dissecans* was initially used to design a lesion, which was thought to be ischemic, resulting in the separation of a fragment of subchondral bone and cartilage from the articular surface. Since the publication of the classical paper of Berdt and Harry in 1959, the traumatic etiology of these lesions was clearly demonstrated.[34] Currently, osteochondral lesion of the talus (OLT) is the accepted term for a variety of disorders including osteochondritis dissecans, osteochondral fracture, transchondral fracture, and talar dome fracture.[36-40] The primary lesional mechanism is a talar dome impactacion because of inversion injuries. These lesions typically involve medial or lateral aspects of the talar dome.

Medial lesions, which affect the posterior third of the talar border, are caused by inversion injuries with plantar flexion of the foot and external rotation of the tibia (ie, impact between the posteromedial tibia and medial talar margin).[36,41]

Lateral lesions, which affect the anterior third of the talar border, are a result of forced inversion and dorsiflexion of the foot (ie, impingement between the fibular styloid and the lateral margin of the talar dome).[34]

Medial and lateral aspects of the talar dome are involved in approximately 55% and 45% of the cases respectively. Most lateral OLT appear thin and shallow, with the surface fragment greater in width than in depth. In contrast, medial OLT often have a deeper, crater-like appearance. History of trauma is found in nearly all cases of lateral OTL,[42] whereas in medial OTL traumatic antecedent is found in about 75% of cases.[41,42]

Osteochondral lesions of the talus are more common in men than in women. In athletes, the injury is commonly associated with a torsional inversion component, as in basketball or football. There is frequently a long delay in diagnosing these lesion.[36,41,42] Clinical symptoms include exercise-related pain, and less frequently sensations of “clicking and catching,” and persistent swelling.[36,41]

The classification introduced by Berndt and Harty is the most widely accepted staging system of osteochondral talar lesions.[34] This classification describes four stages depending on the integrity of the articular cartilage and the condition of the subchondral bone (Fig 6). Stage I represents subchondral compression fracture, but the overlying articular cartilage remains intact (Fig 7). Stage II consists of a partially detached osteochondral fragment (Fig 8). In Stage III, the

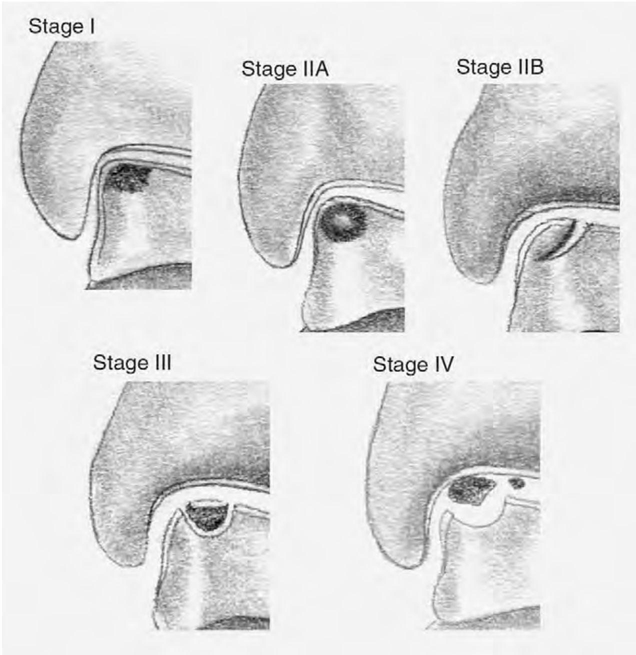


FIG 6. Staging classification of osteochondral talar lesions.

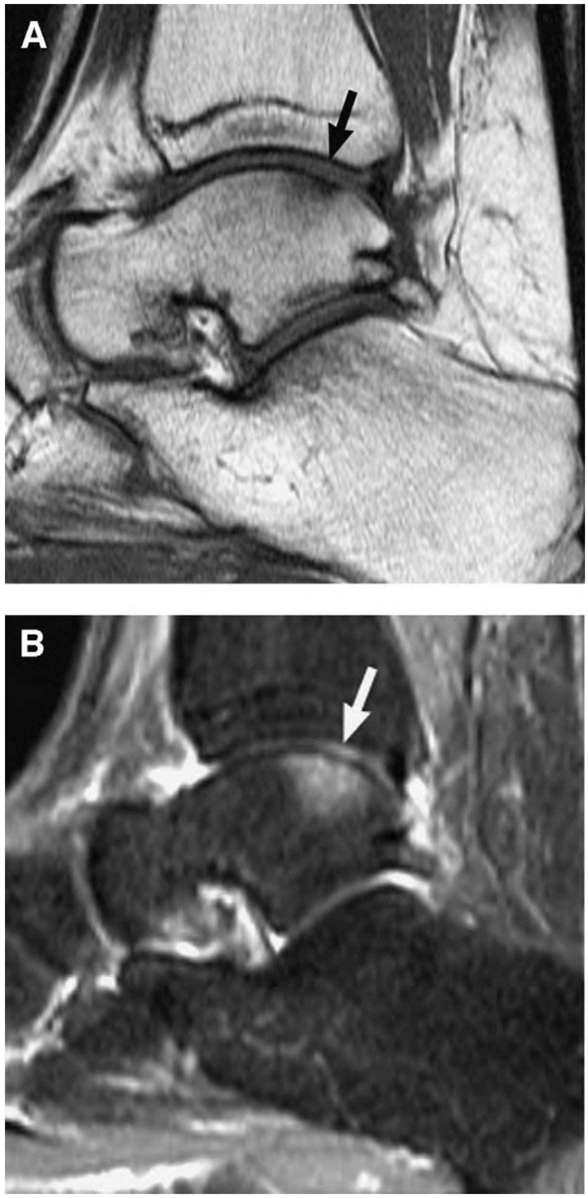


FIG 7. Stage I osteochondral lesion (subchondral bone contusion) of the medial talar dome. **A**, **B**, Sagittal T1-weighted (**A**) and STIR (**B**) images show a focal area of subcondral bone contusion (arrow), associated to a slight depression of the osteochondral surface.

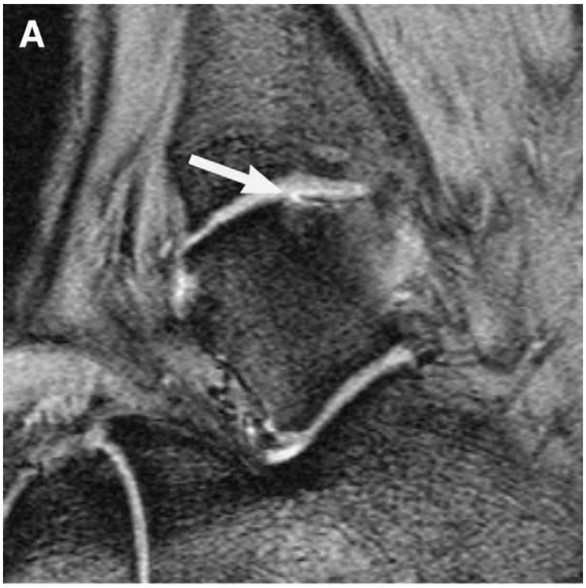
osteochondral fragment is completely detached from the talus but is not displaced (Fig 9). In Stage IV, the osteochondral fragment is detached and displaced, located away from the fracture site.

Radiographs, including anteroposterior, lateral, and mortise views, should be the initial imaging method used when an OLT is suspected.[41] However, radiographs are less sensitive in the detection of the first two stages of the Bernd and Harris classification,[35,41,43] and are also relatively insensitive in evaluating the stability of these lesions.[37]

Both CT and MRI are superior to radiographs in the diagnosis of OLT.[41] In direct comparison of CT with MRI, Anderson et al found that, compared with MRI, CT did not detect stage I lesions in 4 of 24 patients.[35] Moreover, MRI can precisely identify, and localize talar osteochondral lesions with the advantage of assessing the integrity of the overlying cartilage.

MRI has proven to be effective in characterizing all stages of OLT, but is most useful in the identification of radiographically occult OLT and the stratification of in situ lesions into stable and unstable subsets.[1,39-41] MR arthrography (MRA) may provide a better depiction of the talar chondral surface and may be useful in differentianting a stage II versus a stage III lesion (Fig 9).

On MRI, stage I lesions appear as ill-defined subchondral areas of bone contusion with intact articular cartilage.[29,43] Bone contusion may be associated to a focal thickening of the black line that separates the intact cartilage from the subchondral bone marrow, which probably represents compression of the subchondral bone trabeculae. These lesions have been termed as subchondral bone impaction to differentiate them from simple subchondral bone contusion.[44] Osteochondral lesions of the talar dome associated to similar lesions on the tibial plafond[29] are reported in 5% to 11% of the ankles after a sprain. In these kissing



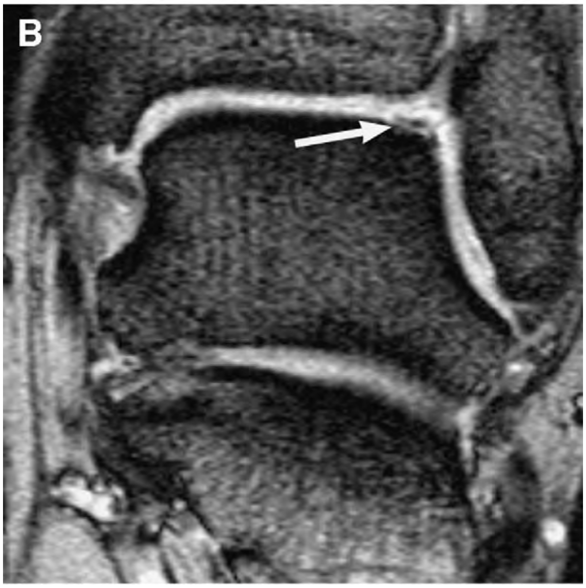


FIG 8. Stage II osteochondral lesion of the lateral talar dome. **A**, **B**, Sagittal (**A**) and coronal (**B**) gradient-echo T2-weighted images reveal a partially detached flat osteochondral lesion (arrow).

FIG 9. Stage III osteochondral lesion of the lateral talar dome. Coronal T1-weighted MRA reveals a completely detached osteochondral fragment (arrowhead) of the medial talar dome.

lesions, tibial plafond injuries most commonly consist of subchondral bone contusions.[29]

For a treatment decision, it is important to distinguish between stable and unstable lesions. MRI diagnosis of OLT instability has relied on the interface between the osteochondral fragment and the parent bone on T2-weighted images.[2,7,39,45,46] A stable or healed osteochondral fragment is characterized by the lack of high signal intensity at the interface between the lesion and the parent bone. The presence of a high-signal line on T2-weighted at the talar interface with the osteochondral fragment is the most reliable sign of instability.[39] This high signal intensity may represent granulation tissue or fluid. An interface that is hyperintense, but not as hyperintense as fluid, indicates the presence of fibrovascular granulation tissue or developing fibrocartilage. At this stage, the lesion is unstable but has the capacity to heal after a period of nonweight bearing or internal fixation.[7] If the interface is isointense with fluid or associated with cystic-appearing areas at the base of a nondisplaced lesion, surgery is indicated (Fig 10).[7]

De Smet et al have described four MRI criteria that indicate instability of the osteochondral lesions: 1) a high signal intensity line on T2-weighted images measuring at least 5 mm in length at the junction of the osteochondral fragment and the underlying bone, 2) a discrete area of homogeneously high signal intensity on T2-weighted images (cyst-like lesion) deep to the osteochondral lesion, measuring at least 5 mm (Fig 11), 3) a focal defect in the articular cartilage measuring at least 5 mm, and 4) a high signal intensity line traversing the cartilage and subchondral bone plate on T2-weighted images, which represents an articular complete fracture.[39,45]

FIG 10. Stage IIb osteochondral lesion. Unstable osteochondral lesion of the medial talar dome. Coronal gradient-echo T2-weighted image shows high signal outlining osteochondral fragment (arrowhead), with associated subcondral cystic lesion (white arrow). Note associated lesion of the deep fibers of the deltoid ligament (black arrow).

FIG 11. Drawing showing a typical ankle sprain. This involves an inversion plantar flexion and internal rotation mechanism leading to tears of the lateral ligaments, including the anterior talofibular and calcaneofibular ligaments.

Although arthroscopy remains the golden standard, MRI is an excellent predictor of fragment stability. In surgical series, correlation between preoperative MRI and MRA assessment of fragment stability ranges between 72 and 100%.[40,47]

MRI can also assess viability of the osteochondral fragment. Necrotic fragments present low signal intensity on both T1- and T2-weighted images and do not enhance after gadolinium injection. Fat-suppressed T1 sequences are helpful in the assessment of osteocondral fragment gadoliniumn enhancement.

In stable OLT, including stage I and most stage II lesions, conservative treatment is recommend. Surgical treatment is advocated for unstable lesions, including stage IV and the majority of stage III OLT. A subset of stage II lesions, especially those laterally located, may be treated surgically. Conversely, a subset of stage III lesions, in particular those located in the medial talar border, may be managed conservatively. Surgical treatment consists of drilling of the lesion to improve perfusion, or excision of the osteochondral fragment and debriment of the defect. Other surgical options include internal fixation of the fragment, and bone grafting.[37] In more advanced, stage IV lesions, fragment excision and debridement of the defect is performed, whereas in earlier lesions (stage II and III) surgical treatment depends on the acute or chronic nature, and size of the lesion.

In the follow-up of surgically treated patients, the indications for MRI examination have not been fully delineated. Some authors believe that MRI is useful in these patients, demonstrating findings that reveal healing.[38,40] Disappearance of high-signal line on T2-weighted at the talar interface will indicate healing of the osteochondral fragment.[38] On the other hand, other authors find poor correlation between clinical symptoms and MRI findings at follow-up after surgical treatment.[48]

Ligamentous Injuries

The ankle joint is supported by three ligamentous groups: the distal tibiofibular ligamentous complex, the lateral collateral ligament, and the deltoid ligament.[2,49,50] Ankle sprain is the most common sports-related injury, accounting for 16% to 21% of all sports-related injuries.[51-53] Athletic activities requiring frequent pivoting and jumping are particularly perilous to the ankle. The highest incidences of ankle sprains occur in sports such as football, soccer, and basketball.[51-53]

Sprains of the ankle ligaments have been classified into three grades, according to severity. Grade I includes stretching of the ligament with an intraligamentous tear associated with minimal swelling and tenderness, slight or no functional loss, and no laxity. Grade II injury is a partial tear of the ligament with moderate pain, swelling, and tenderness. There is mild to moderate laxity. Grade III injuries are complete ruptures of the ligament(s), severe swelling, hemorrhage, and tenderness, associated with gross ankle instability.[2,51,54] Approximately 85% of all ankle sprains are due to inversion forces and therefore, involve the lateral collateral ligamentous complex. Syndesmosis sprains are the second most prevalent (10%) and isolated medial sprains are third.[2,52,54] Most ligamentous injuries are diagnosed clinically without the need for diagnostic imaging and respond to conservative therapy including rest, ice, compression, and elevation (RICE).[51-53,55] Although most ankle sprains do not lead to significant disability, chronic pain or instability sufficient to limit activity may affect 20% to 40% of patients after an ankle sprain.[51-53,55] Currently, the initial evaluation of acute ankle sprains includes a careful clinical history and physical examination.[51,53,55,56] Clinical evaluation may not be sensitive enough to determine true ankle status and function.[54,57]

The role of imaging methods in diagnosis of ankle sprains is controversial. The decision to obtain postinjury radiographic series (anteroposterior, oblique, and lateral) is based on the Ottawa ankle rules.[58] These guidelines state that ankle radiographs should be performed if bone tenderness is present over the lateral or medial malleolus, or if the patient is unable to bear weight for four steps both immediately postinjury and in the emergency department. These criteria have been found to be 100% sensitive for detecting fracture while decreasing the incidence of unneeded radiographs.[58]

Plain radiography is useful in detecting associated avulsion fractures, talar dome injuries, epiphyseal injuries in children, and other bone pathology.[51,56] Stress radiographs help to document lateral ligamentous ankle injury, specially in the evaluation of residual instability, but are not required to make the diagnosis of an acute ankle sprain, offering indirect assessment of the injured ligaments.[56,59-61]

Many studies evaluating the accuracy of various imaging modalities for the detection and characterization of ankle ligament pathology have indicated that MRI is superior to stress radiographs and sonography.[54,56,59-62] Because acute ankle ligamentous injuries are rarely treated surgically, indications for the use of MRI may be limited to the evaluation of ligamentous injury in: acute ankle injuries that demonstrate instability, stable acute injuries involving athletes or litigation, and patients with repeated injuries or instability in whom surgery is contemplated.[2,49,54]

MRI may also have the advantage of depicting lesions often associated with ligamentous injuries, such as anterolateral impingement syndrome, sinus tarsi syndrome, osteochondral lesions of the talar dome and tendon tears.[62-64] Ankle ligaments are readily identified on axial and coronal MRI as low signal intensity structures joining adjacent bones usually delimited by contiguous high signal intensity fat.[2,65,66] Heterogeneity and striation may be noted in some ligaments owing to the presence of fat interposed between their fascicles.[2,65,66]

The MRI criteria for the diagnosis of acute ligament tears of the ankle ligaments include morphologic and signal intensity alterations within the ligament (primary signs) and around it.[67] Primary signs of ligament tear include: discontinuity, detachment, or thickening of the ligament associated with increased intraligamentous signal intensity on T2-weighted images indicative of edema or hemorrhage. Secondary signs of acute ligament injury include extravasation of joint fluid into the adjacent soft tissues, joint effusion, and bone bruises.[2,49,50,65] In chronic tears secondary signs disappear and the ligament can show thickening, thinning, elongation, or wavy contour.[2,49,50,65] MRA is more sensitive and accurate that MRI in the evaluation of ligaments tears. The joint distension obtained with MRA is useful in highlighting acute and chronic lateral collateral ligament tears.[59,62]

Lateral Ligament Complex Injuries

The lateral ligament complex of the ankle consists of three ligaments: the anterior talofibular (ATF), the calcaneofibular (CF), and the posterior talofibular. The ATF ligament is located within the anterolateral joint capsule extending from the anterior aspect of the fibula to the lateral talar neck. The CF ligament arises from the tip of the fibula and passes obliquely downward and posterior to insert into the calcaneus. It is extraarticular and closely associated with the inner sheath of the peroneal tendons. The posterior talofibular ligament is an intraarticular ligament that arises from the medial aspect of the distal fibula and passes almost horizontally to insert along the posterolateral tubercle of the talus.[49,63,65,66]

Lateral ankle sprains occur as a result of landing on a plantar flexed and inverted foot (Fig 11). These injuries occur while running on uneven terrain, stepping in a hole, stepping on another athlete's foot during play, or landing from a jump in an unbalanced position. Contraction of the musculotendinous unit dynamically resists inversion. Static resistance to inversion of the ankle hindfoot complex is provided by the elements of the lateral collateral complex. Therefore, is susceptible to injury with inversion stress with a predictable sequence of injury involving first the ATF, then the CF, and finally, the posterior talofibular ligament. Lesions of the posterior talofibular ligament are infrequent.[49,50,63,65]

Most patients who suffered a lateral ankle sprain return to normal sport and daily living activity. However, as many as 20% to 40% of patients have residual pain sufficient to limit or alter their activity. Patients with chronic ankle dysfunction typically complain of pain during activity, recurrent swelling, a feeling of "giving way," and/or repetitive reinjury.[52,53,59,64] These cases constitute a diagnostic and therapeutic problem.

Chronic pain presenting after lateral ankle sprains may be secondary to a variety of reasons, such as ankle instability, ankle soft-tissue impingement syndromes, sinus tarsi syndrome, peroneal tendons lesions or osteochondral lesions of the talar dome.[55,63,64] Ankle instability can be characterized as mechanical or functional. Frequent giving way without evidence of anatomical ligamentous incompetency is commonly referred to as "functional instability" whereas the objective finding of ligament incompetency (mobility beyond the physiologic range of motion) is termed "mechanical instability."[51,53,55] The incidence of functional instability after ankle sprains has been reported to range from 15% to 60% and seems to be independent of the degree of severity of the initial injury. Mechanical instability is much less prevalent.[51,53,55] Chronic ankle instability is often characterized by repeated episodes of giving way with asymptomatic periods between episodes. In contrast, patients with other causes for chronic ankle pain usually experience a constant aching discomfort in the ankle, although symptoms may wax and wane. This difference in history can often be an important key to the correct diagnosis.[55,64]

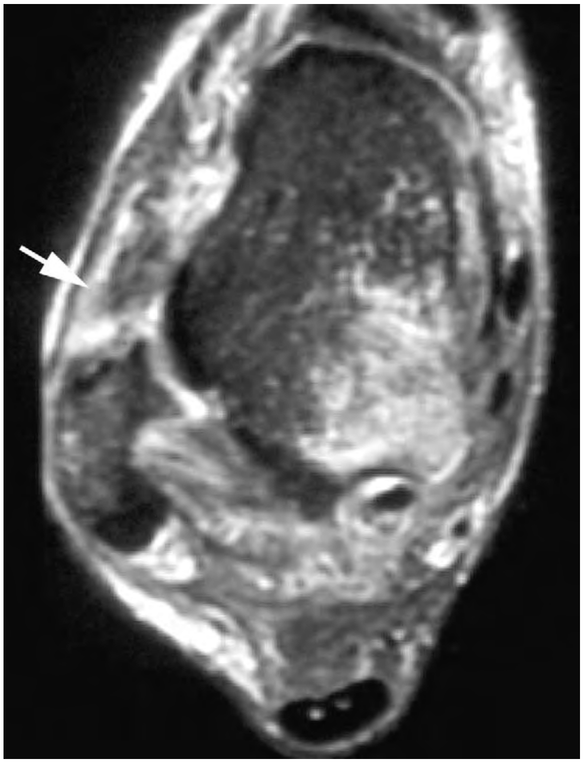


FIG 12. Acute tear of the anterior talofibular ligament. Fat-suppressed proton density-weighted spin-echo axial image reveals indistinctness of the anterior talofibular ligament (arrow), extravasation of joint fluid, and extensive bone bruise in the medial aspect of the talus (asterisk)

The lateral ankle ligaments are easily readily identified with gradient-echo sequences with three-dimensional (3D) fourier transform reformatted images or with axial and coronal imaging with the foot in dorsiflexion and plantar flexion.[49,65] However, the ligaments can be evaluated on routine ankle MRI. Injuries of the ATF ligament are easily seen on routine axial ankle MRI (Fig 12). Injuries of the CF ligament may be detected on routine axial ankle MRI but are more consistently visualized on coronal images (Fig 13).[49,65]

The acute injured ligament is frequently thickened and heterogeneous, and the surrounding fat planes are often obliterated (edema or hemorrhage). Bone bruises in the lateral aspect of the body of the talus and in the tibial malleolus are a frequent secondary sign observed in the acute setting (Fig 12).[2,49,50] Fluid within the peroneal tendon sheath can be a secondary sign of acute CF ligament injury.[49,50]

FIG 13. Chronic tear of the calcaneofibular ligament. Fat-suppressed T2-weighted fast spin-echo coronal oblique image shows disruption of the distal third of the calcaneofibular ligament (arrow).

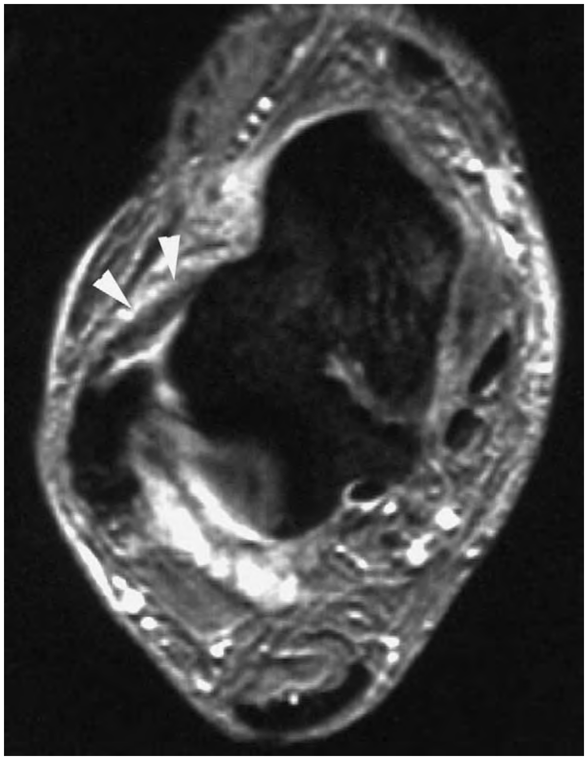


FIG 14. Chronic tear of the anterior talofibular ligament. Axial T2*-weighted image shows thickening and irregularity of the anterior talofibular ligament (arrowheads).

Chronic tear often manifests as thickening, thinning, elongation, and wavy or irregular contour of the ligament (Figs 14 and 15). There is usually no significant residual marrow or soft-tissue edema or hemorrhage. Decreased signal intensity in the fat abutting the ligaments with all pulse sequences is indicative of scarring or synovial proliferation.[2,49,50]

MRA permits a more accurate evaluation of the acute or chronic lateral ankle ligaments injuries (Fig 15).[59,62] Disruption of the CF ligament often results in communication of the ankle joint with the peroneal tendon sheath, which is attached to the superficial surface of the ligament. Therefore, accumulation of contrast in the peroneal sheath at MRA is an indirect but specific sign of CF ligament injury (Fig 15).[59]

MRA has been shown to have an accuracy of 100% and 82% in detecting chronic ATF and CF ligament tears, respectively, whereas conventional MRI has demonstrated an accuracy of 59% in diagnosing chronic lateral collateral ligament tears.[59]

Treatment of lateral ankle ligaments injuries is conservative and include the “RICE” regimen, and early controlled motion with functional brace. Surgical management of acute ankle sprains is rarely indicated. Numerous surgical techniques have been described to correct ankle instability with an 80% to 90% success rate. Direct repair of the ATF y CF ligaments has a success rate similar to that for augmented reconstructions (tenodesis).[51,53,55,56,59]

Medial Ligament Complex Injuries

The deltoid ligament or medial collateral ligament is composed of three superficial (tibionavicular, tibiospring, and tibiocalcaneal) and two deep (anterior and posterior tibiotalar) bands.[49,66] This ligament is much less commonly injured than the lateral collateral complex, accounting for only 5% to 6% of all ankle ligaments injuries.[2,49,68] Deltoid ligament injuries most commonly occur in association with lateral ligamentous pathology, a fibular fracture, or syndesmotic injuries.[2,49,68] Isolated ruptures of the deltoid ligament are rare but can occur as a consequence of an eversion-lateral rotation injury. Contusions of the

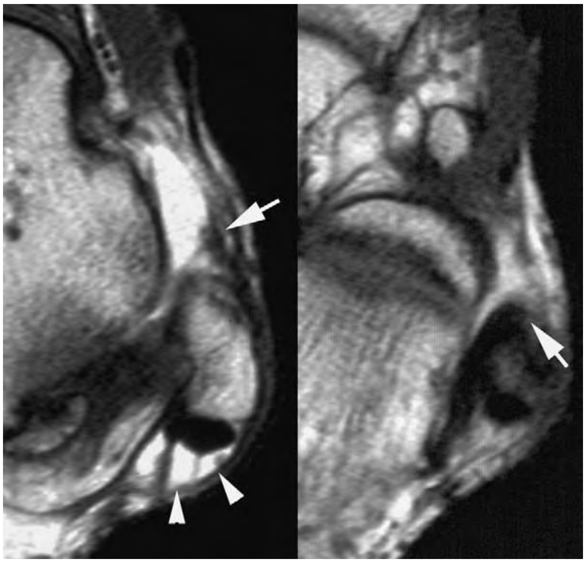


FIG 15. Chronic tear of the anterior talofibular and calcaneofibular ligaments. MRA T1-weighted axial images show disruption of the anterior talofibular and calcaneofibular ligaments (arrows). Note extravasation of fluid into the peroneal tendon sheath (indirect sign of the calcaneofibular ligament tear) (arrowheads).

FIG 16. Partial tear of the medial deltoid ligament. Coronal T2*-weighted image demonstrates increased signal intensity and thickening of the deep fibers of the deltoid ligament (arrow).

deltoid ligament, particularly of its posterior tibiotalar component, are frequently associated with inversion sprains, in which the deep posterior fibers of the medial deltoid ligament become crushed between the medial wall of the talus and the medial malleolus.[49,69] The sequence of injury usually follows the strengths of the fascicles of the deltoid ligament. The relatively weak tibionavicular and tibiocalcaneal ligament are injured before and most frequently than the stronger tibiospring and posterior tibiotalar ligament.[68] Complete ruptures (84%) are most frequent than partial tears (16%).[68] Bands of the medial ankle ligament appear on MRI as low signal intensity structures. Posterior tibiotalar ligament appears as a thick band with striations because of the presence of fat interposed between their fascicles 19,20.[68]

MRI readily identifies all the bands of the deltoid ligament, with exception of the anterior tibiotalar ligament, visualized consistently only in 84% of the studies. MRI may show ligamentous interruption, the thickened soft tissues and evidence of subchondral bruising of both the medial talus and medial malleolus (Fig 16). Injuries of the posterior tibiotalar appear most commonly with loss of the regular striations than discontinuity of the ligament. Avulsion injuries are easily diagnosed in the acute and chronic settings showing the bone fragment adjacent to an irregular medial malleolus.[49,68]

Treatment of the deltoid ligament is controversial and depends of the associated lesions. Grade I and II lesions are managed conservatively. Isolated acute deltoid tear (grade III injuries), avulsion of the medial malleolus and chronic deltoid sprains with lengthening ligament are surgically treated.

Syndesmosis Sprains

The anterior and posterior tibiofibular ligaments, the inferior transverse ligament, and the interosseous membrane form the distal tibiofibular ligamentous complex.[49] The increased awareness of injuries of the syndesmosis produced the greater reported incidence of syndesmosis sprains (10-17%).[49,52,55] Most of the syndesmosis sprains occur in high impact or collision sports where greater amounts of stress may be placed onto the ankle. The incidence of syndesmosis sprains in high impact sports was >30%, but it was <5% in low impact sports.[52,55] The mechanism of injury may be pronation and eversion of the foot combined with internal rotation of the tibia on a fixed foot. The presence of a syndesmosis sprain is a strong predictor for the likelihood of chronic ankle dysfunction.[52,55]

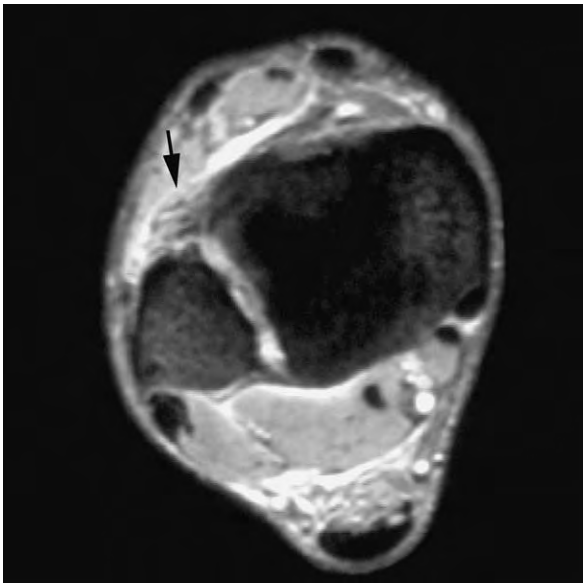


FIG 17. Acute syndesmosis sprain. Axial T2*-weighted image shows indistinctness and swelling of the anterior tibiofibular ligament (arrow).

FIG 18. Chronic syndesmosis sprain. Axial T1-weighted spin-echo MR shows irregular soft-tissue surrounding the anterior tibiofibular ligament (arrow).

Syndesmosis injuries is frequently associated with eversion-type ankle fractures, particularly high fibular fractures (Maissoneuve) and rupture of the deltoid ligament.[52,55] About 10% of all ankle ligament injuries involve a partial tear of the anterior talofibular (AITF) ligament.[55] Partial tears of the anterior AITF ligament are more common in soccer and football players because of the violent external rotation and plantar flexion trauma of the ankle that is often experienced. Isolated complete syndesmosis injuries without fracture represent only the 3% of the ankle ligament injuries. These ruptures occur in various sports, such as skiing, motocross, skating, and soccer and other ball sports.[52,55] Pain and tenderness are located principally on the anterior aspect of the syndesmosis. The patient is usually unable to bear weight on the injured leg. Physical examinations are useful in diagnosing these cases. Active external rotation of the foot is painful. The squeeze test is considered positive when compression of the tibia against the fibula at the midportion of the calf, proximal to the syndesmosis, produces pain in the area of the interosseous membrane or its supporting structures.[52,55] Radiographic diagnosis is carried out by anteroposterior and mortise radiography. Injuries of syndesmotic ligaments are sometimes difficult to diagnose by radiographic examination when the tears are incomplete or if there is no opening of the distal tibiofibular joint. Stress radiographs in external rotation and in both dorsiflexion and plantar flexion, can display the diastasis between the tibia and fibula.[52,55]

MRI may show tears of the syndesmotic ligaments, manifested as thickening, lack of visualization, or irregularity of these ligaments, and detect associated lesions (Figs 17 and 18).[49]

Partial isolated syndesmosis tears should be treated conservatively. A complete tear is managed by suture of the ligament and temporary fixation of the tibia and fibula with a syndesmosis screw, cerclage or Kirschner wires.[55]

Sinus Tarsi Syndrome

The sinus tarsi is an anatomic space that is bounded by the talus and calcaneus, the talonavicular and posterior subtalar joint, and continues with the tarsal canal medially.[70,71] The contents of the sinus tarsi include fatty tissue, vessels, joint recesses, nerve endings, and five ligaments. These include the medial, intermediate, and lateral roots of the inferior extensor retinaculum, the cervical ligament, and the ligament of the tarsal canal (Fig 19). The sinus tarsi ligaments

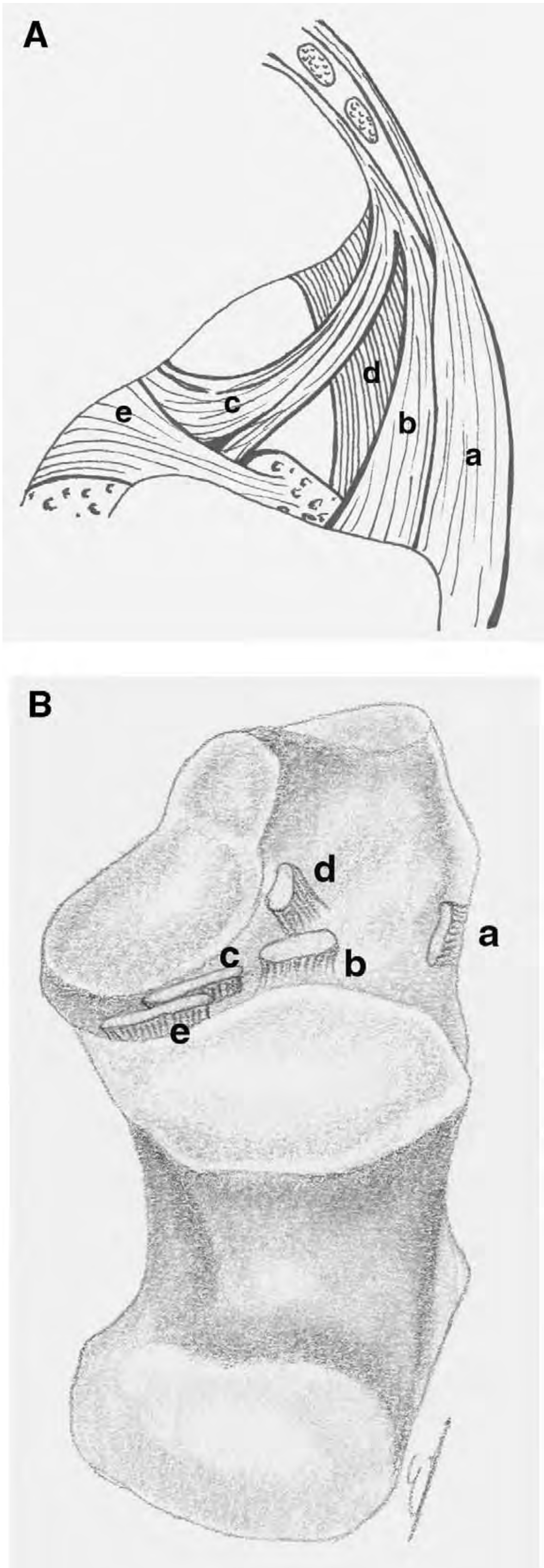


FIG 19. Sinus tarsi ligaments. **A**, Axial view of the sinus tarsi and tarsal canal. **B**, Coronal section of the subtalar joint. **a**: lateral retinacular root. **b**: intermediate retinacular root. **c**: medial retinacular root. **d**: cervical ligament. **e**: ligament of tarsal canal.

constitute a unit with the lateral ankle ligaments to stabilize the lateral aspect of the ankle and the hind foot.[70,71]

Sinus tarsi syndrome is a clinical condition characterized by pain along the lateral aspect of the foot, hind foot instability, focal pain to palpation over the tarsal sinus, and pain relief following injection of local anesthetics into the tarsal sinus.[70,71]

Sinus tarsi syndrome commonly develops after an inversion injury (70%) and is often associated with tears of the lateral collateral ligaments. Subtalar instability is estimated to be present in about 10% of patients with lateral instability of the ankle. Other etiologies of the sinus tarsi syndrome are posterior tibial tendon tears and inflammatory conditions such ankylosis spondylitis, rheumatoid arthritis or gout, ganglion cysts, and foot deformities.[70,71] Sinus tarsi syndrome is most frequently encountered in sports prone to develop ankle inversion injuries like soccer, basketball, and football.[70,71]

MRI is the imaging method of choice in the evaluation of tarsal sinus and in the diagnosis of sinus tarsi syndrome and associated conditions. Obliteration of the fat in the sinus tarsi space with fluid replacement, inflammatory tissues, synovial proliferation, fibrous scarring, and disruption of the sinus tarsi ligaments are potential MR findings in this condition.[70-72] Associated MR manifestations include lateral collateral ligament tears and occasionally posterior tibial tendon tear. Osteoarthritis of the subtalar joint and subchondral cysts may be present in advanced cases.[70]

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