Dynamic High-Resolution US of Ankle and Midfoot Ligaments: Normal Anatomic Structure and Imaging Technique[1]

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Abbreviations: CFL = calcaneofibular ligament, CNL = calcaneonavicular ligament, LCL = lateral collateral ligament, TFL = tibiofibular ligament

RadioGraphics 2015; 35:164–178

Published online 10.1148/rg.351130139

Content Codes: MK US

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SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Apply US technique to imaging the ankle and the midfoot ligaments.
- Apply dynamic maneuvers to improve visibility of the normal ankle and midfoot ligaments and to increase confidence in sprain detection and grading.
- Describe the normal anatomic structure and main pathologic patterns of ankle and midfoot ligaments at US.

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The ankle is the most frequently injured major joint in the body, and ankle sprains are frequently encountered in individuals playing football, basketball, and other team sports, in addition to occurring in the general population. Imaging plays a crucial role in the evaluation of ankle ligaments. Magnetic resonance imaging has been proven to provide excellent evaluation of ligaments around the ankle, with the ability to show associated intraarticular abnormalities, joint effusion, and bone marrow edema. Ultrasonography (US) performed with high-resolution broadband linear-array probes has become increasingly important in the assessment of ligaments around the ankle because it is low cost, fast, readily available, and free of ionizing radiation. US can provide a detailed depiction of normal anatomic structures and is effective for evaluating ligament integrity. In addition, US allows the performance of dynamic maneuvers, which may contribute to increased visibility of normal ligaments and improved detection of tears. In this article, the authors describe the US techniques for evaluation of the ankle and midfoot ligaments and include a brief review of the literature related to their basic anatomic structures and US of these structures. Short video clips showing dynamic maneuvers and dynamic real-time US of ankle and midfoot structures and their principal pathologic patterns are included as supplemental material. Use of a standardized imaging technique may help reduce the intrinsic operator dependence of US. *Online supplemental material is available for this article.*

Introduction

The ankle ligaments stabilize the bones of the hindfoot during motion, guide and constrain the complex movement of these bones with respect to the leg and midfoot bones, and transmit motion from one hindfoot bone to another (1,2). Bones and ligaments, together with the joint capsule, are functionally linked to form the hindfoot joint complex (3). The biomechanical role of this anatomic complex is to adjust the orientation and shape of the entire foot arch around the major axis of the subtalar joint (also known as the Henke axis) (3,4). In the microscopic context, ankle ligaments consist of type I collagen fibers with parallel orientation. Their normal thickness ranges from 2 to 5 mm, depending on the structure (5–10).

The ankle is the most frequently injured major joint in the body (11), and the lateral compartment is the most commonly affected site (12). Ankle sprains are frequently encountered in individuals playing football, basketball, and other team sports (13,14). These injuries can lead to chronic pain and instability and may delay return to sport activity (15).

TEACHING POINTS

- The ankle is the most frequently injured major joint in the body, and the lateral compartment is the most commonly affected site.
- The ultrasound beam must be directed as perpendicular as possible to the examined structure to avoid anisotropy.
- The anterior talofibular ligament is the weakest and most frequently injured among the three components of the LCL complex of the ankle joint.
- In inversion sprains, the CFL is usually sequentially torn after the anterior talofibular ligament is torn. Thus, if the anterior talofibular ligament is already determined to be normal, an isolated tear of the CFL is unlikely.
- Rupture of the deltoid ligament is rarely encountered without additional injuries to the ankle, owing to the uncommon occurrence of eversion ankle sprains and to the intrinsic thickness of the ligament. Thus, US is not usually used alone in the evaluation of such traumatic events. However, it can be helpful for differentiating a ligamentous injury from a lesion of the adjacent posterior tibial tendon, because both conditions manifest with similar symptoms.

Arthroscopy has been shown to be effective for evaluating ankle ligaments. However, it is expensive and highly invasive, with a complication rate of up to 9% (16). Thus, imaging plays a crucial role in the evaluation of the ankle ligaments. Imaging should start with radiography, which provides information on the osseous anatomic structure (17). Magnetic resonance (MR) imaging and MR arthrography have been shown to enable excellent evaluation of ligaments around the ankle and have the ability to show associated intraarticular abnormalities, joint effusion, and bone marrow edema (18–20). However, MR imaging and MR arthrography are relatively expensive, and images may be burdened by artifacts when metallic implants are present (21,22).

High-resolution ultrasonography (US) has become increasingly important in the assessment of ligaments around the ankle because it is low cost, fast, readily available, and free of ionizing radiation (23). US can provide a detailed depiction of normal anatomic structures and is effective in evaluating ligament integrity. In contrast to MR imaging, US allows performance of dynamic maneuvers, which may contribute to increased visibility of normal ligaments and improved detection of tears. Furthermore, US can be used effectively for patients with metallic implants. It may also be used to detect abnormalities, such as tendonopathy, ganglia, bursitis, joint effusion with loose bodies, and neurovascular abnormalities (23–31). In contrast to US of other joints in the body, US of the ankle is not performed thoroughly but is usually targeted to evaluate specific structures as suggested by clinical findings (32).

In this article, we describe US techniques for evaluating the ankle ligaments and include a brief review of the literature related to the basic anatomic structures and US of these ligaments. Short videos showing dynamic maneuvers and dynamic real-time US of ankle ligaments and their principal pathologic patterns are included as online supplemental material.

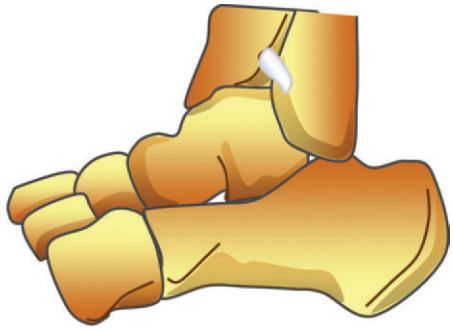
General Principles of US Evaluation

Because ankle ligaments are basically bundles of collagen fibers, at US they appear as echogenic fibrillar structures similar to those elsewhere in the body (32,33). Thus, the ultrasound beam must be directed as perpendicular as possible to the examined structure to avoid anisotropy. Anisotropy is a common occurrence in clinical practice when examining linear structures (eg, tendons and ligaments). It leads to a decrease in the reflected echoes, resulting in reduction of the echotexture and, potentially, simulating a tear (34). However, with experienced US operators, anisotropy has been reported to help differentiate ligaments from the adjacent soft tissue (34).

US of ankle ligaments should be performed with commercially available high-frequency linear transducers with frequencies ranging from 10 to 18 MHz. Images presented in this article were acquired with an iU22 US system (Philips Medical Systems, Bothell, Wash) equipped with a 17–5-MHz linear probe, a MyLab 70 XvG system (Esaote, Genova, Italy) equipped with a 13–6-MHz linear probe, or an Aplio 400 system (Toshiba Medical Systems, Tokyo, Japan) equipped with a 18–7-MHz linear probe. Use of a soft-gel spacer between the US probe and the skin may be helpful to optimize the surface of skin contact but will not improve image quality (35).

Anatomic bone landmarks should be used to align the US probe along the course of the ligaments, which are usually scanned along their longer axis. Short-axis US can be helpful in the context of equivocal findings but is not routinely needed. Damaged ligaments may manifest as different US patterns. Ligament thickening, loss of physiologic fibrillar echotexture, and presence of calcifications suggest chronic or degenerative abnormalities. Interruption or absence of fibers in the expected anatomic location is indicative of a ligament tear.

Specific dynamic maneuvers can be performed to stress the joint and create tension in the ligaments. For assessment of the normal anatomic structure, dynamic maneuvers may help straighten the ligament and, therefore, enable it to be more perpendicular to the US beam. In addition, dynamic maneuvers may be used to increase the



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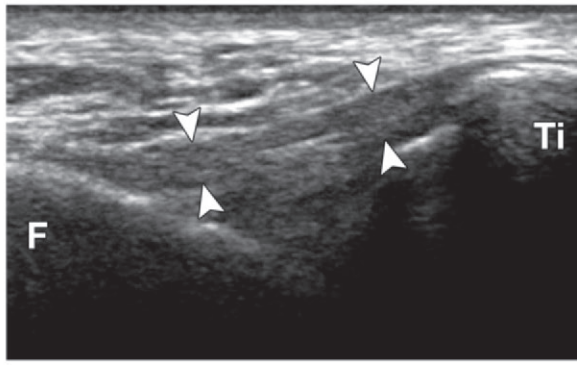


c.

Figure 1. Anterior inferior TFL. This ligament extends obliquely downward and laterally from the anterior margin of the fibular tubercle of the tibia to the anterior border of the distal fibular shaft and lateral malleolus. **(a)** Schematic drawing of the anterior inferior TFL anatomic structure. **(b)** Probe positioning on the lateral ankle. **(c)** US scan of the anterior inferior TFL (arrowheads). *F* = fibula, *Ti* = tibia.

diagnostic accuracy of the detection of tears and to differentiate a partial from a complete tear (36–39). Pertinent dynamic maneuvers are discussed in the relevant sections of this article.

Ankle Ligaments

Tibiofibular Ligaments

Biomechanics.—The tibia and fibula are articulated at their distal end at the inferior tibiofibular joint. This joint is mechanically linked to the ankle and is placed in tension by flexion-extension. It is stabilized by two ligaments, one anterior and one posterior (10).

Anterior Inferior Tibiofibular Ligament.—The anterior inferior tibiofibular ligament (TFL) is a stiff, flattened band lying anterior to and partially blended with the interosseous membrane. Approximately 20% of the anterior inferior TFL is intraarticular (40). It extends obliquely downward and laterally from the anterior margin of the fibular tubercle of the tibia to the anterior border of the distal fibular shaft and the lateral malleolus. The normal thickness of this ligament ranges between 2.6 and 4 mm (10) (Fig 1). A normal anterior inferior TFL may have a fascicular appearance and should not be confused with an injury or tear.

Most studies on the visibility of ligaments around the ankle were performed 15–20 years ago and involved the use of US systems and probes that had lower performance parameters, compared with more recent high-end equipment. Thus, it is possible that the already high detection values reported in the literature have improved. Milz et al (41) reported visibility of the anterior inferior TFL in 89.6% of cases in a series of 48 ankle specimens.

The anterior inferior TFL plays a crucial role in increasing the stability of the distal tibiofibular joint and is involved in up to 11% of ankle sprains (10). In these cases, patients may complain about instability resulting from the widening of the ankle mortise. A 1-mm widening of the ankle mortise implies a 42% loss of contact area of the tibiotalar joint, possibly leading to early osteoarthritis (42). The accuracy of US in the diagnosis of anterior inferior TFL sprains has been reported to be approximately 85% (43). Previous trauma in the anterior inferior TFL is shown in Figure 2. The scanning technique for the anterior inferior TFL is reported below, in addition to other components of the lateral compartment of the ankle.

Posterior Inferior TFL.—The posterior inferior TFL is stronger than the anterior inferior TFL. It extends transversely from the posterior tubercle of the tibial shaft to the posterior aspect of the lateral malleolus. The most inferior fascicles comprise the inferior transverse ligament, which appears as a thick band extending from the posterior tubercle of the talus to the posterior aspect of the tibial articular surface, just lateral to the

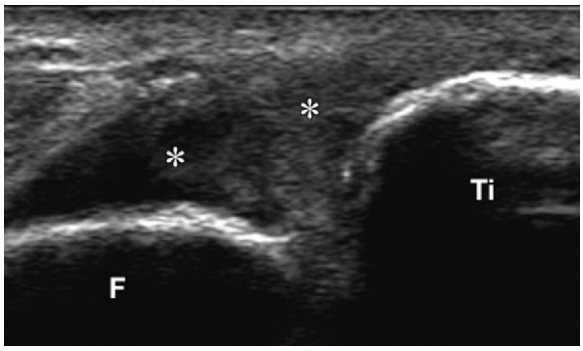


Figure 2. US scan shows a fibrotic appearance of the anterior inferior TFL after previous trauma. The ligament is remarkably thickened and inhomogeneous (*). *F* = fibula, *Ti* = tibia. (Courtesy of Luca De Flaviis, MD, Studio Radiologico De Flaviis, Milan, Italy.)

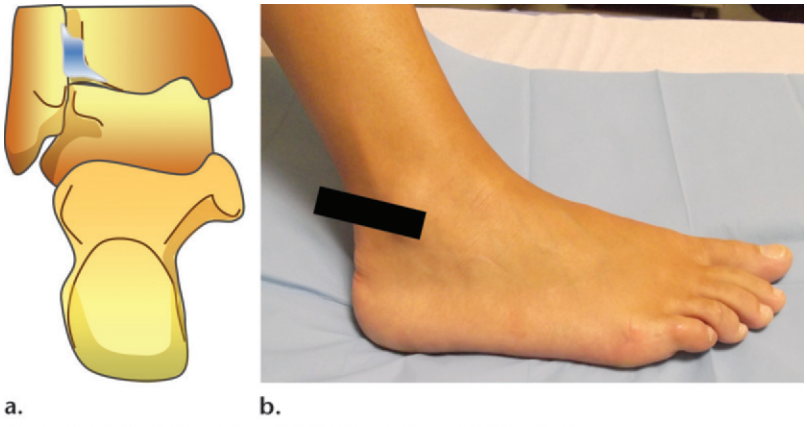


Figure 3. Posterior inferior TFL. This ligament extends transversely from the posterior tubercle of the tibial shaft to the posterior aspect of the lateral malleolus. **(a)** Schematic drawing of the posterior inferior TFL anatomic structure. **(b)** Probe positioning on the lateral ankle. **(c)** US scan of the posterior inferior TFL (arrowheads). *F* = fibula, *Ti* = tibia.

medial malleolus. The posterior inferior TFL is usually less visible than the anterior inferior TFL and is rarely involved in ankle sprains (44). This ligament is not usually assessed as part of routine US of the lateral ankle. However, it can be studied by placing the transducer almost horizontally and medially from the posterior aspect of the tip of the lateral malleolus (Fig 3). Dynamic evaluation of the posterior inferior TFL includes dorsiflexion and eversion of the hindfoot, maneuvers that may reduce anisotropy (45).

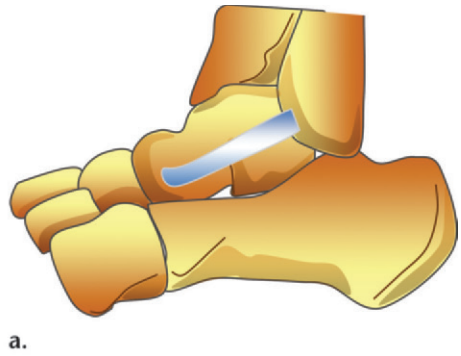
Lateral and Medial Ligaments

Biomechanics.—The joints of the hindfoot are stabilized by two main ligamentous systems (the lateral collateral ligament [LCL] and medial collateral ligament complexes) and two accessory systems (the anterior and posterior ligaments). The collateral functional complexes have the biomechanical purpose of containing the lateral forces that act around the ankle and could be considered as inversion and eversion ligament chains (46,47).

LCL Complex

The inversion ligament chain acts along two axes: the main tension line, originating from the lateral malleolus and extending along the anterior bundles of the LCL complex, and the accessory tension line, originating from the medial malleolus and extending along the posterior bundles of the medial collateral ligament complex. The eversion ligament chain also acts along two lines: the main tension line, originating from the medial malleolus and extending along the anterior bundles of the medial collateral ligament complex, and the accessory tension line, originating from the lateral malleolus and extending along the posterior bundles of the LCL complex (46,48). The LCL complex of the ankle consists of three separate ligaments: the anterior talofibular ligament, the posterior talofibular ligament, and the calcaneofibular ligament (CFL).

Anterior Talofibular Ligament.—The anterior talofibular ligament is the weakest and most frequently injured among the three components of



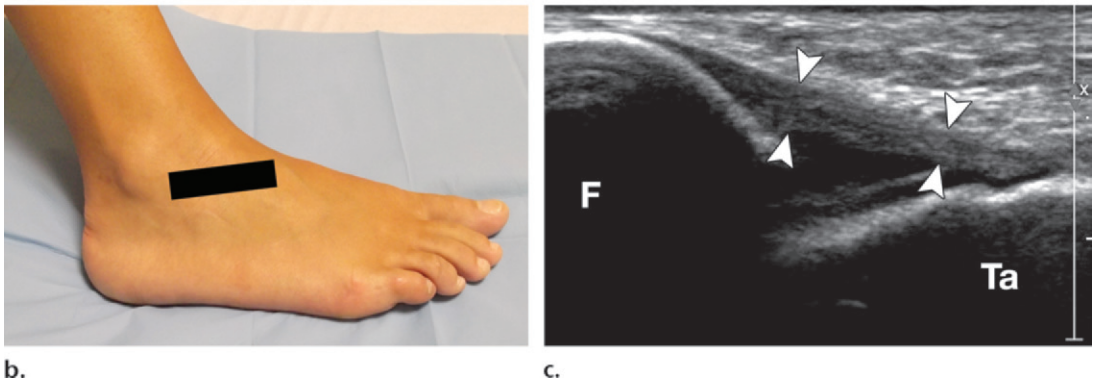


Figure 4. Anterior talofibular ligament. This ligament originates from the anterolateral border of the lateral malleolus and inserts on the lateral surface of the talar neck. **(a)** Schematic drawing of the anterior talofibular ligament anatomic structure. **(b)** Probe positioning on the lateral ankle. **(c)** US scan of the anterior talofibular ligament (arrowheads). *F* = fibula, *Ta* = talus.

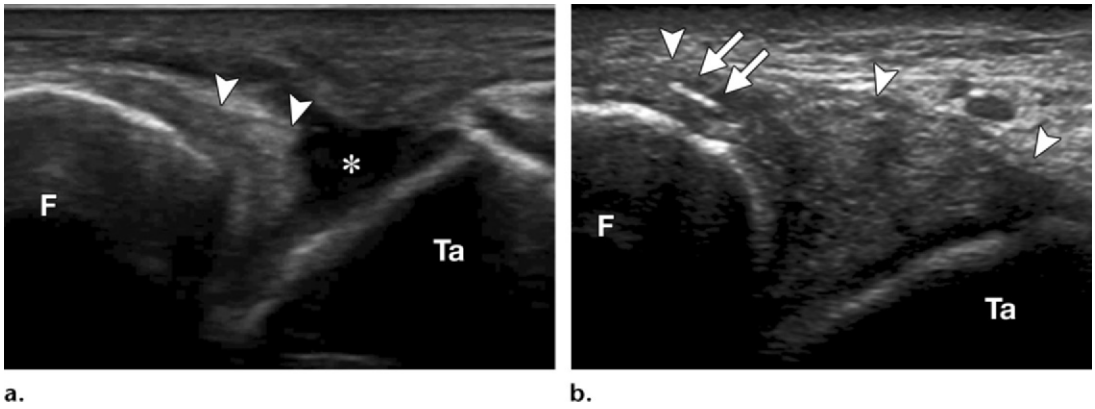
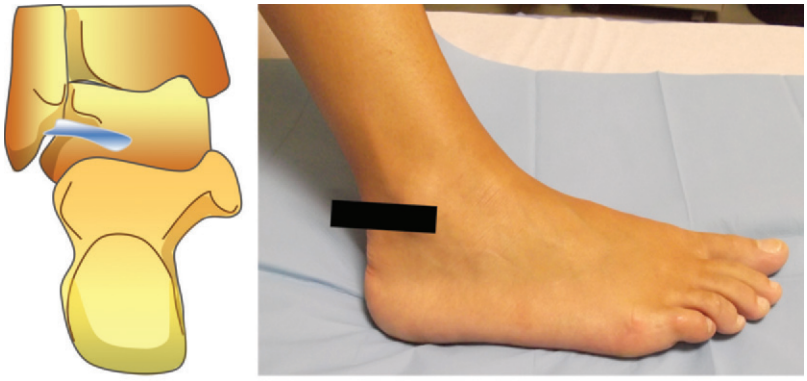


Figure 5. US appearances of injured anterior talofibular ligament. *F* = fibula, *Ta* = talus. **(a)** Acute full-thickness tear of the anterior talofibular ligament in a 27-year-old basketball player. The ligament stump is clearly visible (arrowheads), together with fluid effusion in the anterolateral recess (*). **(b)** Fibrotic appearance of the anterior talofibular ligament after trauma. The ligament is remarkably thickened and inhomogeneous (arrowheads). Note the tiny bone avulsion over the proximal insertion (arrows). (Courtesy of Luca De Flaviis, MD, Studio Radiologico De Flaviis, Milan, Italy.)

the LCL complex of the ankle joint. It connects the anterolateral border of the lateral malleolus and the lateral surface of the talar neck (Fig 4). Along its course, it blends with some fibers of the capsule of the tibiotalar joint. The anterior talofibular ligament serves to stabilize the talus, preventing anterior talar motion. The primary function of the anterior talofibular ligament is to restrain the anterior displacement of the talus with respect to the fibula and tibia. The axis of the anterior talofibular ligament becomes parallel to the axis of the leg when the foot is plantar flexed (ie, pushed down); thus, the anterior talofibular ligament acts as a collateral ligament. Because most sprains occur when the foot is in plantar flexion, injuries to this ligament most frequently occur, either in isolation or in association with the CFL, when the foot is inverted (ie, turned in). In these cases, US findings include diffuse or focal areas of hypoechoic thickening of the ligament, accompanied by intrasubstance linear defects in the context of a partial-thickness tear (19). Small avulsed bone fragments can also result from a traction mechanism (Fig 5).

Friedrich et al (49) reported visibility of the anterior talofibular ligament in 91% of cases in a series of 20 healthy volunteers. Milz et al (41) reported visibility of the anterior talofibular ligament



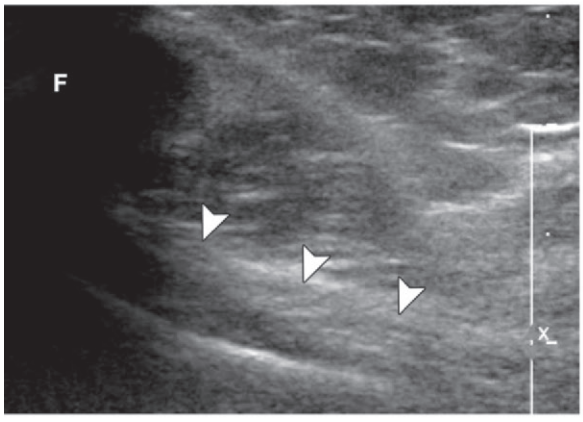


Figure 6. Posterior talofibular ligament. This ligament originates from the lateral tubercle of the posterior process of the talus and inserts on the posterior aspect of the lateral malleolus. **(a)** Schematic drawing of the posterior talofibular ligament anatomic structure. **(b)** Probe positioning on the lateral ankle. **(c)** US scan of the posterior talofibular ligament (arrowheads). *F* = fibula.

in 89.6% of cases in a series of 48 ankle specimens. The accuracy of US in the diagnosis of anterior talofibular ligament and CFL tears has been reported to range from 87% to 100% (32,41).

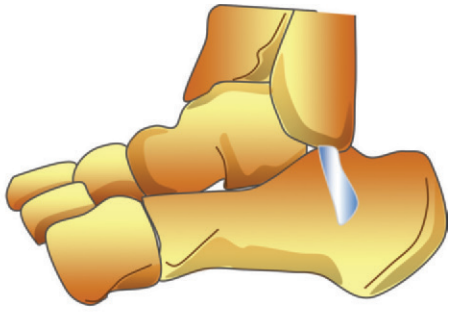
Posterior Talofibular Ligament.—The posterior talofibular ligament is the deepest ligament in the LCL complex. It is intracapsular but extrasynovial and runs horizontally from the lateral tubercle of the posterior process of the talus to the posterior aspect of the lateral malleolus (ie, the fibular malleolar fossa). The primary function of the posterior talofibular ligament is to counteract the posterior displacement of the talus. This ligament is under greatest strain in full dorsiflexion of the ankle (48). The posterior talofibular ligament is rarely torn in ankle sprains, because bone stability protects the ligament when the ankle is in dorsiflexion. Because of its deep location and lack of an adequate US window, this ligament is difficult to assess at US and can be only partially visualized. Therefore, US cannot be considered a valid diagnostic tool for evaluation of the posterior talofibular ligament (32). However, US of this ligament is performed by placing the transducer almost horizontally, with an edge positioned on the posterior tip of the lateral malleolus (Fig 6).

CFL.—The CFL is the longest ligament in the LCL complex. It is a strong cord-like structure with a vertical oblique course deep under the peroneal tendons. It extends from the tip of the lateral malleolus to the trochlear eminence on the lateral surface of the calcaneus, acting as a stabilizer of the subtalar joint (Fig 7) (32). The primary function of the CFL is to restrain inversion of the calcaneus with respect to the fibula. The CFL and the anterior talofibular ligament play different roles according to the ankle position. The CFL is the main lateral stabilizer of the ankle in both the neutral position and dorsiflexion (48). However, the anterior talofibular ligament remains the most commonly injured ligament in the lateral compartment, because the majority of sprains occur during flexion and inversion of the foot.

In inversion sprains, the CFL is usually sequentially torn after the anterior talofibular ligament is torn. Thus, if the anterior talofibular ligament is already determined to be normal, an isolated tear of the CFL is unlikely (32). A partial tear of the CFL is shown in Figure 8.

Scanning Technique for the Lateral Ankle.—The scanning technique for the lateral ankle is shown in Movie 1 (online). The lateral aspect of the ankle is examined with the patient lying supine on the bed, with the knee of the relevant leg flexed 90° and with the foot slightly internally rotated. Another option is to have the foot hang over the edge of the bed to allow the operator to move the ankle correctly, according to the relevant ligaments. In any position, the aim of the dynamic maneuvers is to achieve adequate tension of the relevant ligaments (32,35,50).

The tip of the lateral malleolus is a useful bone landmark on which to start the examination of the lateral ligaments. With the ankle internally rotated, the anterior talofibular ligament is easily imaged by placing one edge of the US probe on the tip of the lateral malleolus with the probe



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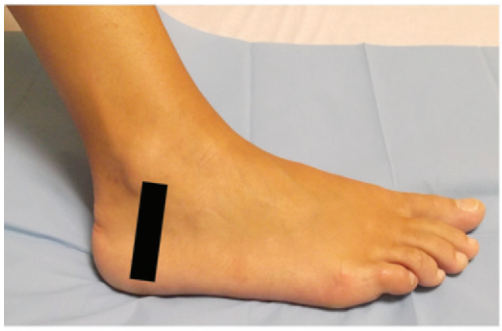

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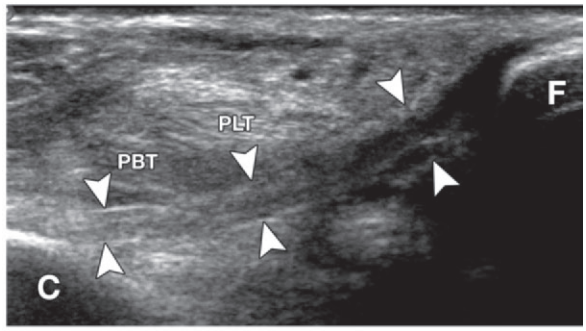


c.

Figure 7. CFL. This ligament originates from the lateral malleolar tip and inserts on the lateral surface of the calcaneus. **(a)** Schematic drawing of the CFL anatomic structure. **(b)** Probe positioning on the lateral ankle. **(c)** US scan of the CFL (arrowheads). *C* = calcaneus. *F* = fibula, *PBT* = peroneus brevis tendon, *PLT* = peroneus longus tendon.

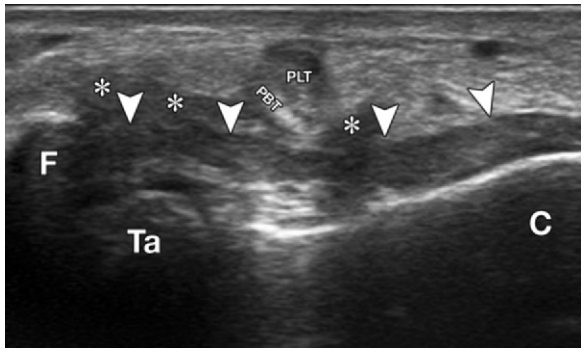


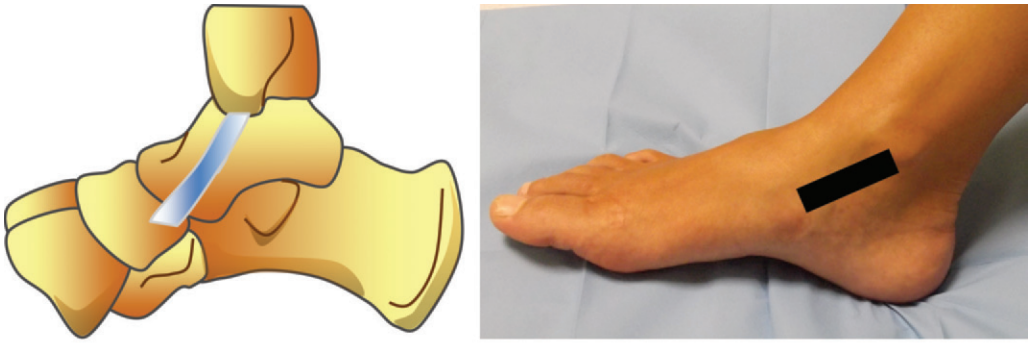
Figure 8. US scan shows a partial tear of the CFL. The ligament appears inhomogeneous and hypoechoic (arrowheads), with periligamentous effusion (*). *C* = calcaneus, *F* = fibula, *PBT* = peroneus brevis tendon, *PLT* = peroneus longus tendon, *Ta* = talus.

almost parallel to the sole of the foot (Fig 4b). The anterior talofibular ligament can be seen as a hyperechoic fibrillar band in tension between the lateral malleolus and the talus (Movie 2 [online]). The functionality of the anterior talofibular ligament can be tested by using the anterior drawer test. This test consists of stressing the plantar flexion and internal rotation of the foot. This may help to differentiate partial- from full-thickness tears by separating the stumps of a torn ligament (Movie 3 [online]).

From the position used to evaluate the anterior talofibular ligament, one edge of the probe should be held over the lateral malleolus and the other edge should be rotated cranially to image the anterior inferior TFL along its major axis (Fig 1b). At this position, the anterior inferior TFL can be seen as a short, thick, hyperechoic fibrillar band extending from the fibular malleolus to the anterior aspect of the tibia. Dynamic evaluation of the anterior inferior TFL may be performed while placing the ligament in tension with dorsiflexion and varus positioning (Movie 4 [online]). The anterior inferior TFL and the anterior talofibular ligament can be easily differentiated on the basis of their anatomic orientations.

To image the CFL, from the position used to image the anterior inferior TFL, one edge of the probe should be held over the tip of the lateral malleolus and the probe should be rotated caudad to reach a coronal plane, with the distal edge of the probe slightly posterior to the lateral malleolus (Fig 7b). The CFL has a concave course, which makes its evaluation particularly challenging. Forced dorsiflexion of the foot tightens the CFL, making it straighter and more perpendicular to the US beam (Movie 5 [online]), thus allowing optimal visibility. On its long axis, the CFL is visualized as a thick hyperechoic fibrillar band extending from the inferior aspect of the lateral malleolus to the lateral surface of the calcaneus. In some cases, short-axis evaluation of the CFL may be helpful (32). In short-axis evaluation, the ligament is seen as an oval-shaped structure located deep under the peroneal tendons, with an echogenicity that may vary according to the orientation of the US beam. When the CFL is continuous, forced dorsiflexion of the foot displaces the peroneal

Figure 9. Tibionavicular ligament. This ligament originates from the anterior border of the anterior colliculus of the medial malleolus and inserts on the dorsomedial aspect of the navicular. **(a)** Schematic drawing of the tibionavicular ligament anatomic structure. **(b)** Probe positioning on the medial ankle. **(c)** US scan of the tibionavicular ligament (arrowheads). *N* = navicular, *Ta* = talus, *Ti* = tibia.



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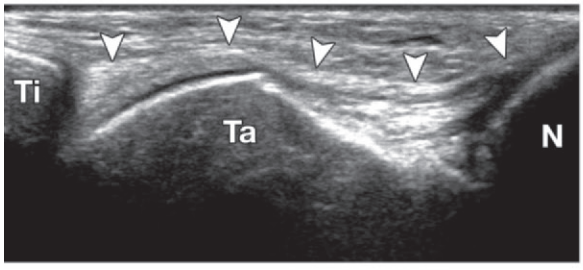


c.

tendons superficially. This is an indirect sign of continuity of the CFL. If displacement is absent and the peroneal tendons do not move during this test, a complete CFL tear can be diagnosed reliably (11). During forced foot dorsiflexion, fluid effusion may cause distention of the lateral talocalcaneal recess (Movie 6 [online]).

Medial Collateral Ligament Complex

The medial collateral ligament in the ankle, also known as the deltoid ligament, is a strong ligamentous complex with various components. Although the anatomic description of this ligament varies widely among different authors (6–8), there is general agreement that the medial collateral ligament consists of two distinct layers. A deep layer extends from the medial malleolus to the talus and consists of the anterior and posterior tibiotalar ligaments. A triangular superficial layer extends from the medial malleolus to the navicular bone, the spring ligament, and the calcaneus and consists of the tibionavicular ligament, the tibiospring ligament, and the tibiocalcaneal ligament (51). The deep layer is stronger and more important for ankle stability than the superficial layer. In addition, the interlacing of the tibiospring ligament, the tibionavicular ligament, and the spring ligament complex supports the talar head and stabilizes the talocalcaneonavicular joint. During ankle motion, all parts of the deltoid ligament act as a unit providing support to the ankle. Insufficiency of the medial collateral ligament may lead to osteoarthritis in the ankle joint (51).

Lesions of the deltoid ligament occur during severe eversion injuries and are usually associated with fractures of the lateral malleolus and with lateral displacement of the talus. Less commonly, deltoid ligament injuries are observed in association with avulsion fractures of the medial malleolus at the site of attachment of its superficial portion. Rupture of the deltoid ligament is rarely encountered without additional injuries to the ankle, owing to the uncommon occurrence of eversion ankle sprains and to the intrinsic thickness of the ligament (14). Thus, US is not usually used alone in the evaluation of such traumatic events. However, it can be helpful for differentiating a ligamentous injury from a lesion of the adjacent posterior tibial tendon, because both conditions manifest with similar symptoms. Focal changes of the deltoid ligament are more frequent than are full-thickness tears. Of note, because of the multilayered appearance of the ligament, detection of focal changes in the ligament may be particularly challenging. In full-thickness tears, findings include ligament interruption, soft tissue edema, and hematoma. Inability to detect the ligament may be a sign of a complete tear, although not all fascicles of the ligament are always present or visible, even in individuals with normal ankles. In these cases, MR imaging should be used to show the injury and to help detect the presence of possible associated findings.

Superficial Layer.—The tibionavicular ligament originates from the anterior border of the anterior colliculus of the medial malleolus and inserts on the dorsomedial aspect of the navicular bone (Fig 9). Some fibers may extend to the superomedial

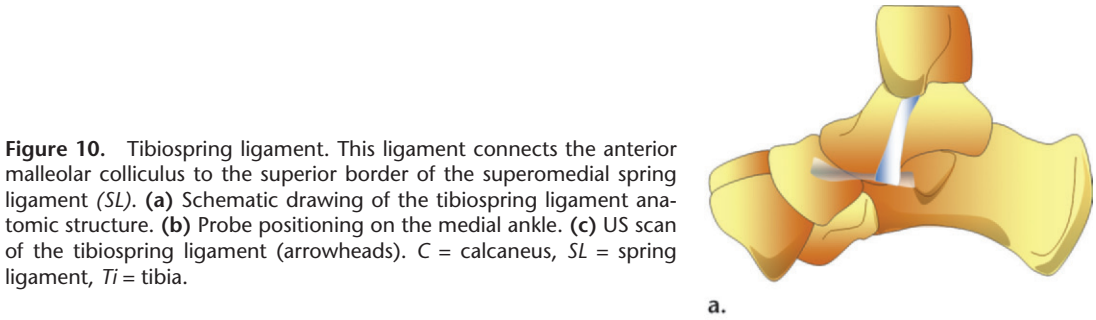


Figure 10. Tibiospring ligament. This ligament connects the anterior malleolar colliculus to the superior border of the superomedial spring ligament *(SL)*. **(a)** Schematic drawing of the tibiospring ligament anatomic structure. **(b)** Probe positioning on the medial ankle. **(c)** US scan of the tibiospring ligament (arrowheads). *C* = calcaneus, *SL* = spring ligament, *Ti* = tibia.

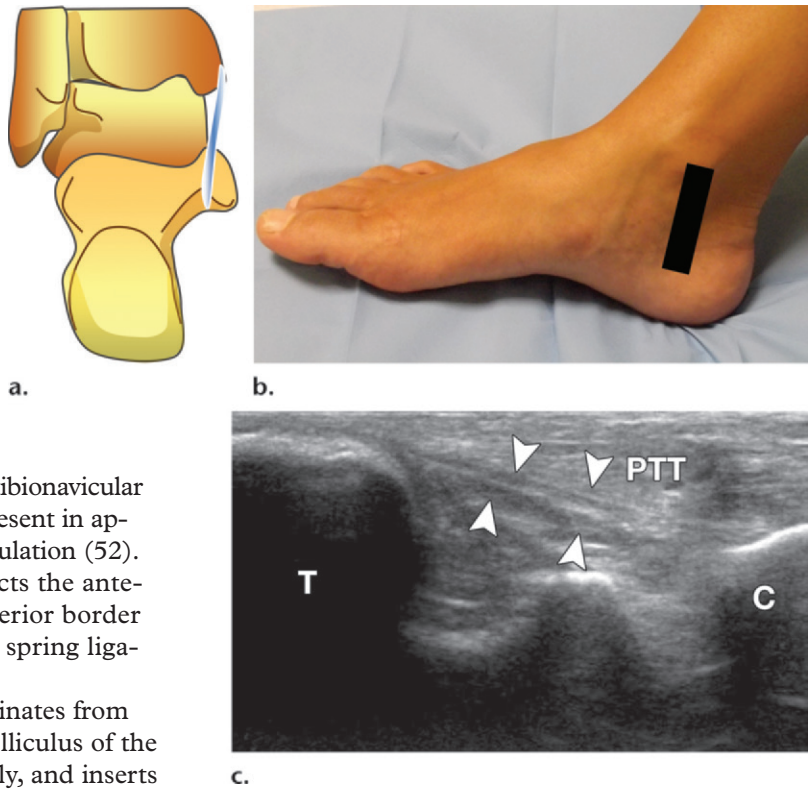


Figure 11. Tibiocalcaneal ligament. This ligament originates from the medial aspect of the anterior colliculus of the medial malleolus, descends vertically, and inserts on the medial border of the sustentaculum tali. **(a)** Schematic drawing of the tibiocalcaneal ligament anatomic structure. **(b)** Probe positioning on the medial ankle. **(c)** US scan of the tibiocalcaneal ligament (arrowheads). *C* = calcaneus, *PTT* = posterior tibial tendon, *T* = tibia.

portion of the spring ligament. The tibionavicular ligament has been reported to be present in approximately 55% of the general population (52).

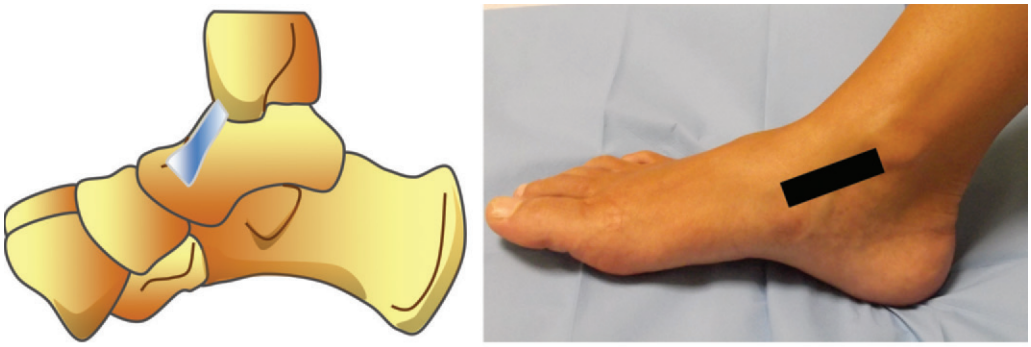
The tibiospring ligament connects the anterior malleolar colliculus to the superior border of the superomedial portion of the spring ligament (Fig 10) (52).

The tibiocalcaneal ligament originates from the medial aspect of the anterior colliculus of the medial malleolus, descends vertically, and inserts on the medial border of the sustentaculum tali (Fig 11). This ligament has been reported to be present in approximately 88% of the general population (52). A partial tear of the tibiocalcaneal ligament is shown in Figure 12.

Deep Layer.—The anterior tibiotalar ligament is a very thin ligament. It originates from the tip of the anterior colliculus and the anterior part of the intercollicular groove of the medial malleolus and inserts on the medial surface of the talus just distal to the anterior part of the medial talar articular surface. Its absence can be attributed to a normal anatomic variance (Fig 13) (52).

The posterior tibiotalar ligament is the thickest of the medial ligaments of the ankle. This ligament originates from the upper segment of the posterior surface of the anterior colliculus, the intercollicular groove, and the surface of the posterior colliculus of the medial malleolus.

Figure 12. US scan shows a partial tear of the tibiocalcaneal ligament. The proximal portion of the ligament has normal fibrillar echotexture (arrowheads). More distally, the ligament is diffusely inhomogeneous (arrow), with some periligamentous fluid effusion (*). The distal insertion of the ligament is also inhomogeneous and hypoechoic (**).



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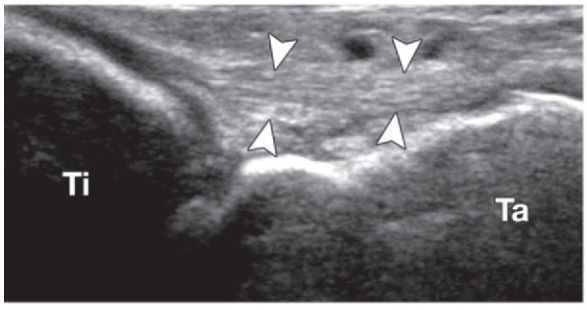

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Figure 13. Anterior tibiotalar ligament. This ligament originates from the tip of the anterior colliculus and the anterior part of the intercollicular groove of the medial malleolus and inserts on the medial surface of the talus just distal to the anterior part of the medial talar articular surface. **(a)** Schematic drawing of the anterior tibiotalar ligament anatomic structure. **(b)** Probe positioning on the medial ankle. **(c)** US scan of the anterior tibiotalar ligament (arrowheads). *Ta* = talus, *Ti* = tibia.

Distally, the fibers insert on the medial surface of the talus under the tail of the articular facet around the posteromedial talar tubercle (Fig 14) (52).

Scanning Technique for the Medial Ankle.— The scanning technique for the medial ankle is shown in Movie 7 (online). The medial aspect of the ankle is examined with the patient lying supine or seated with the plantar surface of the foot rolled externally or in a frog leg position. The probe is placed on the coronal plane somewhat posteriorly at the medial aspect of the palpable tibia (50). A short deep and a longer superficial tibiotalar portion of the deltoid ligament are seen. When the probe is rotated anteriorly, the tibiocalcaneal ligament is seen in an intermediate superficial position and the tibionavicular ligament is seen in an anterior superficial position. At US, both the superficial and the deep bands are oblique to the probe and thus appear as relatively hypoechoic structures in the normal ankle. In particular, the tibiotalar ligament complex, because of its angulation and the fat interspersed between fascicles, is generally hypoechoic at US, and its normal appearance could mimic a tear. In addition, the tibiocalcaneal ligament has a straight vertical course and appears as a thin hypoechoic band located deep under the posterior tibial tendon.

To increase the diagnostic capability when examining such ligaments, dynamic evaluation is recommended. Because of its triangular shape, dynamic evaluation of the deltoid ligament may be performed while creating tension in the ligament components selectively with dorsiflexion (ie, tension of the posterior deep tibiotalar components and laxity of the anterior superficial tibionavicular component) or plantar flexion (ie, tension of the anterior superficial tibionavicular component and laxity of the posterior deep tibiotalar components) (Movie 8 [online]).

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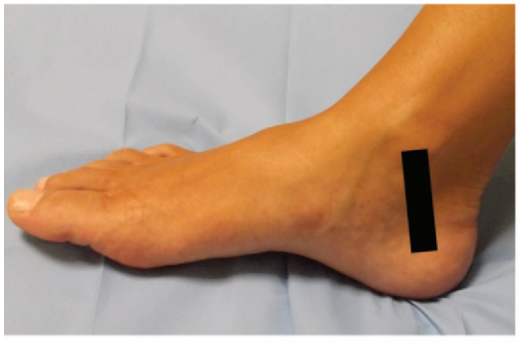

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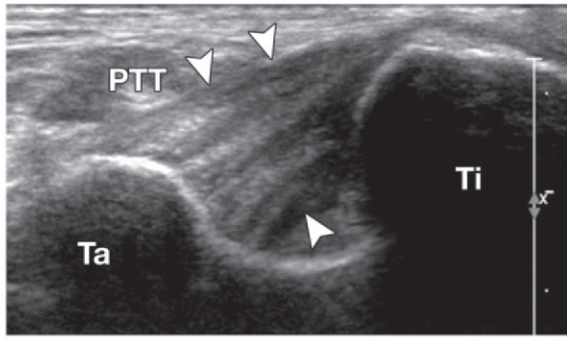

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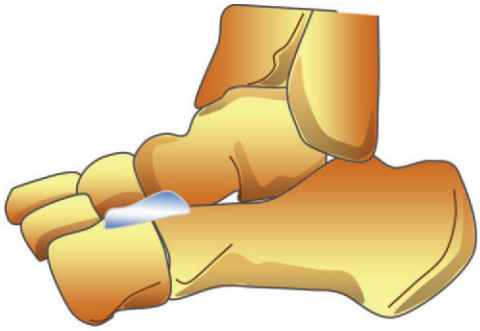
Figure 14. Posterior tibiotalar ligament. This ligament originates from the upper segment of the posterior surface of the anterior colliculus, the intercollicular groove, and the anterior surface of the posterior colliculus of the medial malleolus. The fibers insert on the medial surface of the talus under the tail of the articular facet, up to the posteromedial talar tubercle. **(a)** Schematic drawing of the posterior tibiotalar ligament anatomic structure. **(b)** Probe positioning on the medial ankle. **(c)** US scan of the posterior tibiotalar ligament (arrowheads). *PTT* = posterior tibial tendon, *Ta* = talus, *Ti* = tibia.



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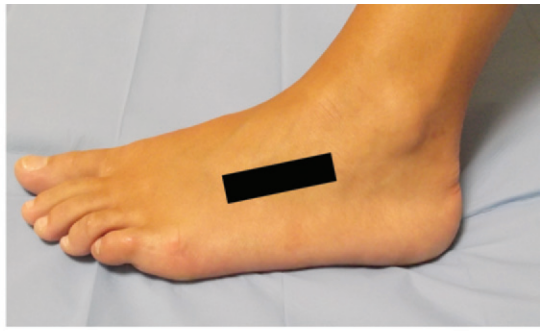

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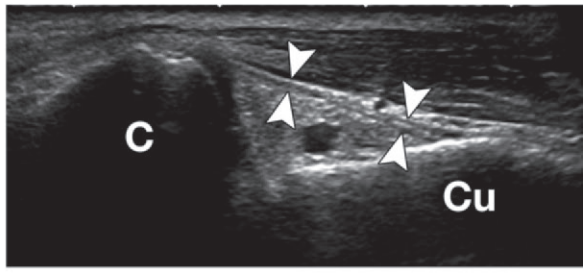


c.

Figure 15. Dorsal calcaneocuboid ligament. This ligament originates from the dorsal aspect of the calcaneus and inserts over the superior aspect of the navicular bone. **(a)** Schematic drawing of the dorsal calcaneocuboid ligament anatomic structure. **(b)** Probe positioning on the superolateral midfoot. **(c)** US scan of the dorsal calcaneocuboid ligament (arrowheads). *C* = calcaneus, *Cu* = cuboid.

Midfoot Ligaments

Lateral Ligaments

The ligaments on the dorsal lateral side of the midfoot are the dorsal calcaneocuboid ligament and the dorsal talonavicular ligament. A third ligament, the bifurcate ligament (also known as the Chopart ligament), is the major stabilizer of the calcaneonavicular joint. The bifurcate ligament extends in two strong bands from the anterior calcaneal tuberosity to the lateral side of the navicular and the dorsal surface of the cuboid. This ligament is scarcely detectable at US. The calcaneocuboid ligament is a thickening of the dorsolateral surface of the fibrous capsule of the calcaneocuboid joint, rather than a real separated ligament (Fig 15). This ligament is injured in up to 5.5% of inversion sprains, one-third of which result in a chronically

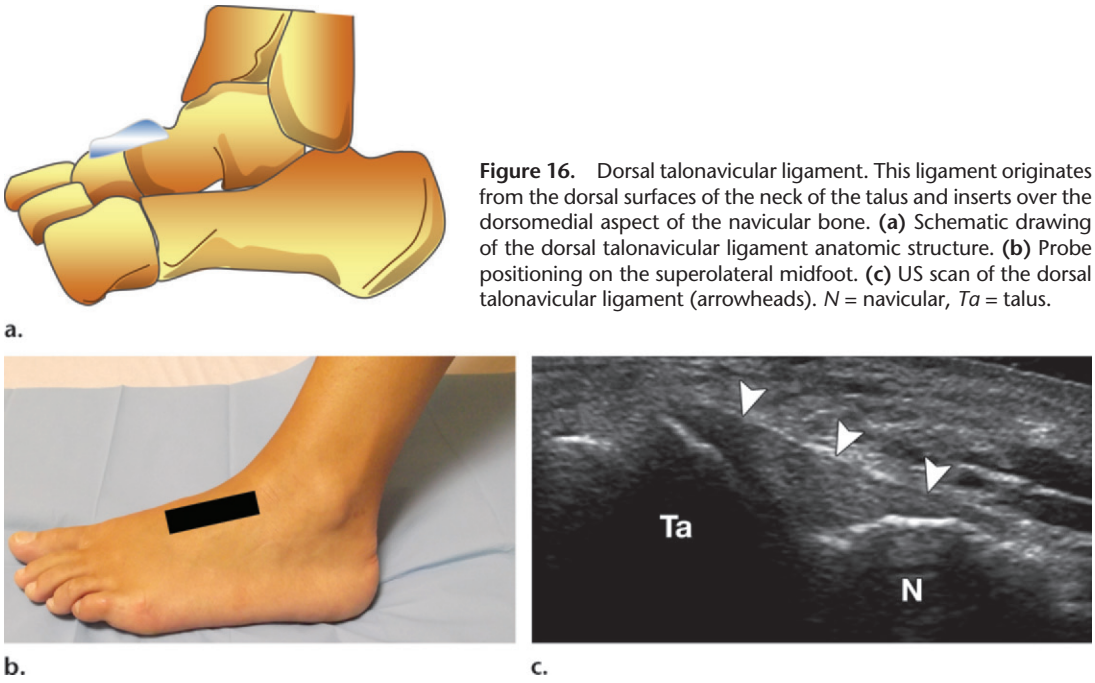


Figure 16. Dorsal talonavicular ligament. This ligament originates from the dorsal surfaces of the neck of the talus and inserts over the dorsomedial aspect of the navicular bone. **(a)** Schematic drawing of the dorsal talonavicular ligament anatomic structure. **(b)** Probe positioning on the superolateral midfoot. **(c)** US scan of the dorsal talonavicular ligament (arrowheads). *N* = navicular, *Ta* = talus.

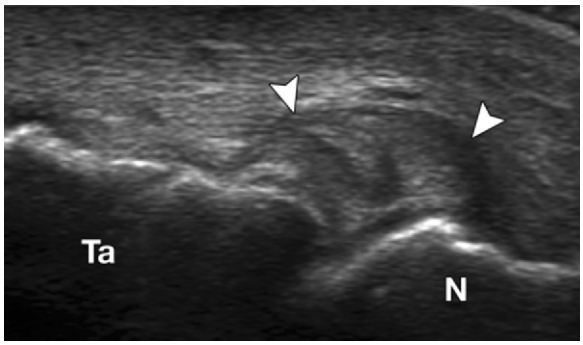


Figure 17. US scan shows a fibrotic appearance of the dorsal talonavicular ligament after trauma. The ligament is remarkably thickened and inhomogeneous (arrowheads). *N* = navicular, *Ta* = talus. (Courtesy of Luca De Flaviis, MD, Studio Radiologico De Flaviis, Milan, Italy.)

unstable calcaneocuboid joint, and is often overlooked at conventional radiography and MR imaging (32). The dorsal talonavicular ligament extends from the dorsal surfaces of the neck of the talus to the navicular (Fig 16). It is joined with the dorsal capsule of the talonavicular joint and is covered by extensor tendons. Dorsal talonavicular ligament tears have been described after inversion injuries associated with forcible plantar strains (53–55).

There are few reports in the literature that discuss midfoot sprains, and these reports reveal a variable incidence of such tears (Fig 17). However, signs of dorsal lateral midfoot ligament damage have been reported in up to 40% of acute ankle sprains, mainly related to the bifurcate ligament. This finding supports the hypothesis that these injuries may occur with higher frequency than is reported in the literature (56).

Scanning Technique for the Lateral Midfoot

To evaluate the dorsal lateral ligaments of the midfoot, the patient is supine or seated in the same position described for the study of the lateral ligaments of the ankle (50). To evaluate the calcaneocuboid ligament, the foot should be placed in slight inversion. The distal edge of the probe should be placed over the base of the fifth metatarsal bone, which represents a useful bone landmark. Then, the probe should be translated approximately 2 cm cranially to encounter the calcaneocuboid joint (Fig 15b). The correct scanning plane is reached when the superficial aspect of the calcaneus becomes almost flat. To assess the dorsal talonavicular ligament, the foot should be plantar flexed to achieve adequate tension. The probe should be oriented for a sagittal scan over the anterior tibiotalar joint recess. Then, the probe should be moved distally until the proximal head is over the neck of the talus and slightly moved laterally (Fig 16b). Because this ligament is not parallel to the skin surface, a gentle distal tilt of the probe may be useful to avoid anisotropy.

Medial Ligaments

The plantar calcaneonavicular ligament (CNL) is also known as the spring ligament complex. It blends with the deltoid ligament and is one of the major stabilizers of the longitudinal arch of the foot. This complex extends from the calcaneus to the navicular bone. The spring

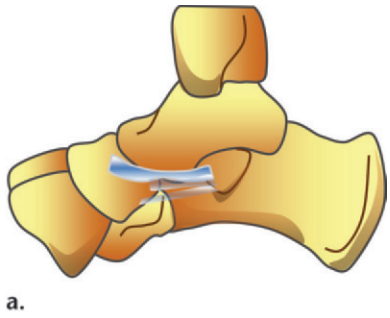
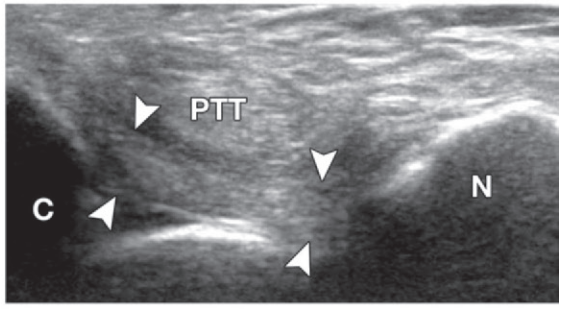


Figure 18. Superomedial CNL. This ligament originates from the substentaculum tali of the calcaneus and inserts on the superomedial navicular. It lies deep under the posterior tibial tendon, from which it is separated by a fibrocartilaginous gliding zone. **(a)** Schematic drawing of the superomedial CNL anatomic structure. **(b)** Probe positioning on the medial midfoot. **(c)** US scan of the superomedial CNL (arrowheads). *C* = calcaneus, *N* = navicular, *PTT* = posterior tibial tendon.



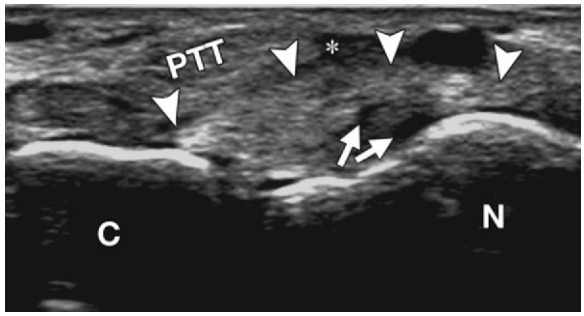


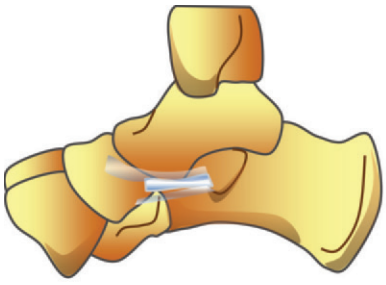
Figure 19. US scan shows a partial tear of the superomedial CNL after trauma. The ligament is thickened and inhomogeneous (arrowheads) and partially discontinuous in its deep portion (arrows). Fluid effusion can be seen around the ligament (*). *C* = calcaneus, *N* = navicular, *PTT* = posterior tibial tendon.

ligament includes three portions that can be easily differentiated: the superomedial CNL, the medioplantar oblique CNL, and the inferoplantar longitudinal CNL. The distal part of the superomedial CNL is directly articulated with the talar head. At this level, the articular surface of the superomedial CNL is covered with fibrocartilage, creating a gliding articular surface with the head of the talus. This area is also known as the spring ligament–fibrocartilage complex (Fig 18). In acute traumatic injury, the spring ligament complex is infrequently injured; to our knowledge, only two cases of isolated spring ligament injury have been reported (Fig 19) (51). Because of the proximity of the spring ligament to the posterior tibial tendon and the integral function of the ligament in stabilizing the plantar arch, spring ligament injuries are often associated with posterior tibial tendon dysfunction. Mansour et al (51) reported posterior tibial tendinosis in 18 of 19 patients affected by superomedial CNL insufficiency.

The medioplantar oblique CNL extends from the calcaneal coronoid fossa to the medial aspect of the navicular bone (Fig 20). The inferoplantar longitudinal CNL lies anteriorly to the medioplantar oblique CNL, extending from the calcaneal coronoid fossa to the inferior navicular bone. This is the thickest of the three components of the spring ligament (Fig 21).

Scanning Technique for the Medial Midfoot

To evaluate the CNL, the patient is supine or seated in the same position described for the study of the deltoid ligament complex (50). The ligament is scanned along the long axis by placing one tip of the US probe inferior to the medial malleolus, over the sustentaculum tali, and tilting the other end slightly superiorly toward the superomedial aspect of the navicular bone (Figs 18b, 20b, 21b) (51). The superomedial CNL has a longitudinal course, appears as a thin hyperechoic band connecting the sustentaculum tali and the navicular bone, and is located deep under the posterior tibial tendon (Fig 18c). In some cases, short-axis evaluation of the CFL may be helpful (32). The medioplantar oblique CNL and the inferoplantar longitudinal CNL components of the spring ligament are only occasionally seen at US because of their deep and complex course. Dynamic evaluation of the



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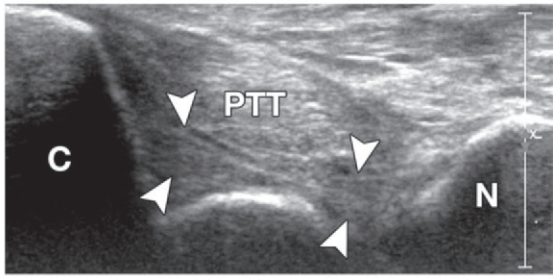
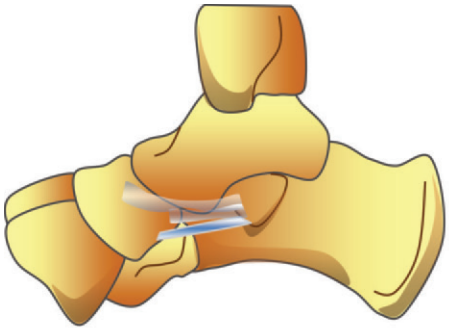


c.

Figure 20. Medioplantar oblique CNL. This ligament extends from the medial portion of the navicular to the calcaneal coronoid fossa. **(a)** Schematic drawing of the medioplantar oblique CNL anatomic structure. **(b)** Probe positioning on the medial midfoot. **(c)** US scan of the medioplantar oblique CNL (arrowheads). *C* = calcaneus, *N* = navicular, *PTT* = posterior tibial tendon.



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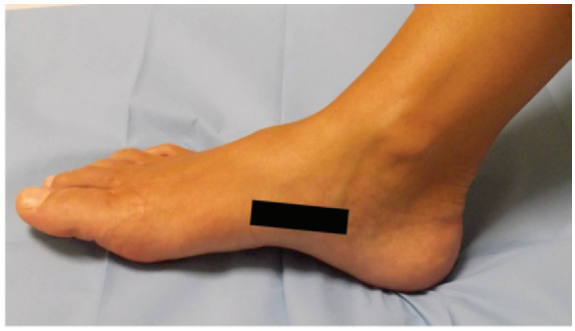

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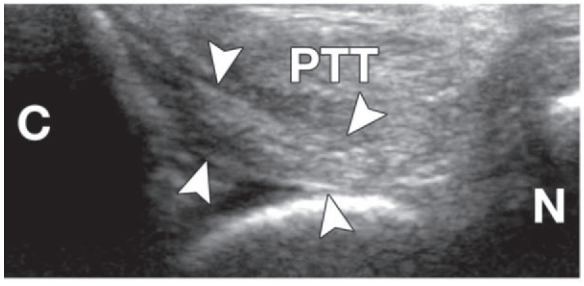

c.

Figure 21. Inferior plantar longitudinal CNL. This ligament lies anterior to the medioplantar oblique CNL, extending from the inferior navicular to the calcaneal coronoid fossa. This is the thickest of the three components of the spring ligament. **(a)** Schematic drawing of the inferior plantar longitudinal CNL anatomic structure. **(b)** Probe positioning on the medial midfoot. **(c)** US scan of the inferior plantar longitudinal CNL (arrowheads). *C* = calcaneus, *N* = navicular, *PTT* = posterior tibial tendon.

spring ligament could be performed by tensioning the structure with valgus alignment of the heel and abduction at the talonavicular joint.

Conclusions

US has shown valuable results in the evaluation of the normal and pathologic anatomic structures of the ankle and provides an imaging modality alternative to MR imaging and MR arthrography. Use of a standardized imaging technique that allows dynamic imaging may play an important role in the assessment of the anatomic structure and main pathologic patterns of the ankle. However, US is limited to imaging of superficial soft tissue and is not able to depict deeper abnormalities such as a bone bruise, hidden fracture, or cartilage lesion. Thus, additional evaluations with other imaging modalities (ie, conventional radiography and MR imaging) may be needed to detect lesions associated with ligament tears.

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