J Ultrasound (2014) 17:79–87
DOI 10.1007/s40477-013-0025-x

PICTORIAL ESSAY

Sonographic anatomy of the ankle

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Received: 23 February 2013 / Accepted: 21 April 2013 / Published online: 3 August 2013

Abstract Ankle sonography is one of the most commonly ordered examinations in the field of osteoarticular imaging, and it requires intimate knowledge of the anatomic structures that make up the joint. For practical purposes, the examination can be divided into four compartments, which are analyzed in this pictorial essay: the anterior compartment, which includes the tibialis anterior, extensor hallucis longus, and extensor digitorum longus tendons; the accessory peroneus tertius tendon; and the extensor retinaculum; the medial compartment (tibialis posterior, flexor digitorum longus, and flexor hallucis longus tendons; the flexor retinaculum; the medial collateral—or deltoid—ligament, and the neurovascular bundle); the lateral compartment (peroneus longus, peroneus brevis, and peroneus quartus tendons; superior and inferior peroneal retinacula, lateral collateral ligament); and the posterior compartment (Achilles tendon, plantaris tendon, Kagar's triangle, superficial, and deep retrocalcaneal bursae). Scanning techniques are briefly described to ensure optimal visualization of the various anatomic structures.

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Keywords Ultrasonography · Ankle · Achilles tendon · Flexor tendons of the foot · Extensor tendons of the foot · Ligaments of the ankle

Riassunto L'esame ecografico della caviglia è tra gli esami più richiesti nell'ambito dell'ecografia osteoarticolare; ne deriva la necessità di una conoscenza approfondita delle strutture anatomiche che la compongono. L'approccio ecografico per lo studio della caviglia è, per scopi pratici, organizzato per comparti; si analizzano nel presente pictorial essay le strutture del comparto anteriore (tendine tibiale anteriore, tendine estensore lungo dell'alluce, tendine estensore lungo delle dita, tendine peroneo tertius, retinacolo degli estensori), del comparto mediale (tendine tibiale posteriore, tendine flessore lungo delle dita, tendine flessore lungo dell'alluce, retinacolo dei flessori, legamento collaterale mediale o deltoideo, fascio vascolo-nervoso), del comparto esterno (tendini peronei breve e lungo, tendine peroneo quarto, retinacolo superiore ed inferiore dei peronei, legamento collaterale esterno), del comparto posteriore (tendine d'Achille, tendine del muscolo plantare, triangolo di Kager, borse sinoviali calcaneali superficiale e profonda). Si riporta inoltre qualche breve cenno di tecnica ecografica necessaria per l'ottimale visualizzazione delle strutture descritte.

Introduction

The ankle is the joint most commonly affected by tendon disorders and (along with the knee) trauma-related sprains [1]. In the field of osteoarticular ultrasonography, ankle examinations are among the most frequently ordered studies, especially in the work-up of traumatic, inflammatory, and degenerative tendon disorders and capsule-ligament lesions [1, 2]. Proper execution of the examination

and accurate interpretation of the results requires flawless knowledge of the anatomy of the joint, especially the tendons, capsule-ligament structures, nerves, vascular structures, and bones.

The ankle is a diarthrodial joint that connects the dome of the talus with the distal tibiofibular syndesmosis. It is stabilized by the anteroinferior and anteroposterior tibiofibular ligaments and the transverse ligament. The joint is enclosed in a loose capsule with insertions on the tibiofibular aspect and the sides of the talar trochlea [3]. There are two main recesses, one anterior and one posterior [4].

For educational and practical purposes, the ankle can be divided into four compartments—medial, anterior, posterior, and lateral—each containing various anatomical structures (ligaments, tendons, retinacula, blood vessels, and nerves). This pictorial essay looks at the components of the joint that can be explored sonographically and provides a brief description of the examination technique for each. The ultrasound images and anatomical diagrams are supplemented by magnetic resonance (MR) images, whose typical panoramic views will in our opinion enhance readers' understanding of the in vivo anatomy.

Anterior compartment

The study of the anterior ankle includes exploration of the tibialis anterior (TA), extensor hallucis longus (EHL), and extensor digitorum longus (EDL) tendons; the anterior retinaculum; the deep fibular nerve; the anterior tibial artery (Fig. 1), and, when present, the peroneus tertius (PT) tendon, which is inconstant. The anterior compartment is examined with the patient lying supine on the examination table, with the knee flexed and the sole of the foot resting on the surface of the table [5].

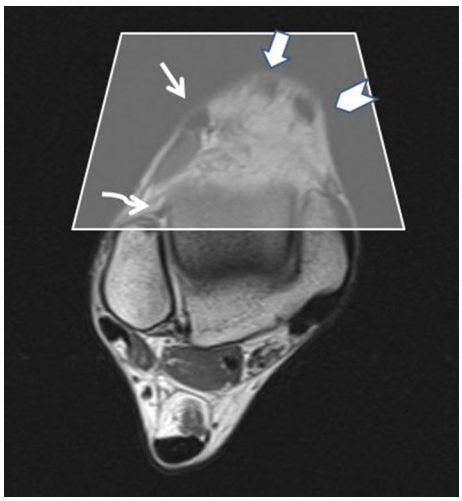

Fig. 1 T1-weighted axial MR image showing the anterior compartment, which contains (lateral to medial): the tibialis anterior (*arrowhead*), the extensor hallucis longus (*thick arrow*), and the extensor digitorum comunis (*thin arrow*). The anteroinferior tibiofibular ligament can be seen near the tibiofibular syndesmosis (*crooked arrow*)

Tendons and retinacula

The tendons here are gliding tendons, which are surrounded by a synovial sheath composed of two layers (visceral and parietal). Between these layers is the mesotendon, which contains blood vessels and nerves [1]. The tendons are derived from muscles located in the anterolateral portion of the leg. The TA tendon (Figs. 1 ,2, 3), the medialmost of the three constant tendons, follows an oblique, inferomedial course to its insertion on the medial aspect of the first cuneiform. Lateral to the TA lies the thinner EHL tendon (Figs. 1, 2). It runs along the dorsum of the foot and inserts into the base of the distal phalanx of the great toe. The lateralmost of the three constant tendons

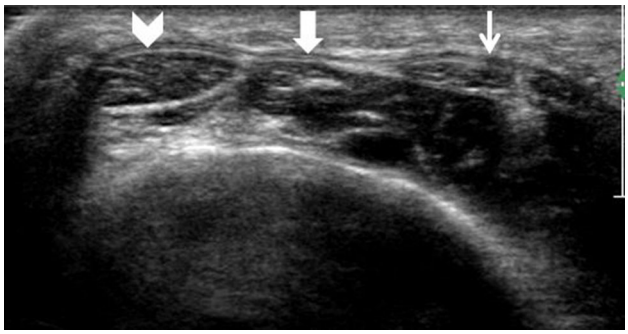

Fig. 2 Anterior axial sonographic image (*panoramic view*) shows the three tendons of the anterior compartment (medial > lateral): the tibialis anterior (*arrowhead*), the extensor hallucis longus (*thick arrow*), and the extensor digitorum longus (*thin arrow*). The curved hyperechoic line deep to these structures represents the cortical bone of the anterior aspect of the distal tibial epiphysis

Fig. 3 Anterior longitudinal sonographic image along the course of the tibialis anterior tendon (*arrow*) (*panoramic view*). The tendon itself, which has a typical fibrillar appearance, is seen running superficial to the anterior recess of the tibiotalar joint. The latter, which can be visualized only when it is distended secondary to effusion fluid, lies between the distal tibial epiphysis (*curved arrow*) and the talar dome (*arrowhead*)

Fig. 4 Anatomic diagram showing the superior and inferior extensor retinacula: the former stretches between the medial tibia and the distal fibula; the latter, which is Y-shaped, extends from the calcaneus to the medial malleolus and talus

is the EDL tendon (Figs. 1, 2). Its proximal segment is broad and thin. Just distal to the neck of the talus, the EDL divides to form four slips, which insert on the dorsal aspects of the distal phalanges of the second, third, fourth, and fifth toes. The PT tendon is an accessory tendon. When present, it runs lateral to the EDL (often within the same synovial sheath) [6] and inserts on the lateral surface of the cuboid [1] or at the base of the fifth metatarsal [6].

All of the extensor tendons run beneath the superior and inferior extensor retinacula (Fig. 4), two fibrous bands that stretch horizontally across the anterior aspect of the ankle. The superior retinaculum extends from the medial aspect of the tibia to the distal fibula. The inferior retinaculum is a Y-shaped band attached to the calcaneus, the medial malleolus, and the talus [6]. Both retinacula are approximately 1 mm thick, and they appear as echogenic bands on ultrasound [1].

Ligaments

On the anterior aspect of the distal tibiofibular joint lies the strong, short anteroinferior tibiofibular ligament (Fig. 5), which can be damaged during particularly severe ankle sprains.

Blood vessels and nerves

The anterior tibial artery is located deeper than the EDL tendon. At the level of the tibiotalar joint plane, the deep

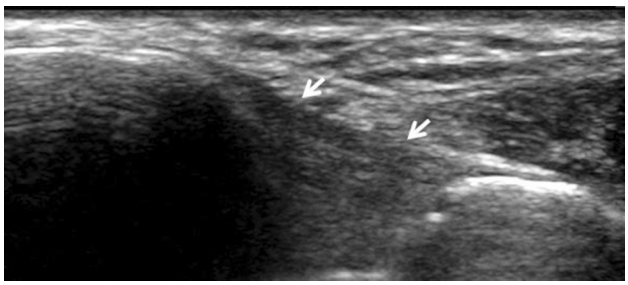

Fig. 5 Anterior axial sonographic image obtained at the level of the tibiofibular syndesmosis (*panoramic image*): the anteroinferior tibiofibular ligament is seen as a moderately thick echoic band on the anterior aspect of the joint (*arrows*)

fibular nerve runs medially to this artery. It then passes over the artery and proceeds laterally.

Medial compartment

The medial compartment contains the tibialis posterior (TP), the flexor digitorum longus (FDL), and the flexor hallucis longus (FHL) tendons; the medial retinaculum; the neurovascular bundle; the subcutaneous medial malleolar bursa; and the medial collateral tibiotalar—or deltoid—ligament) (Fig. 6). The tendons and the neurovascular bundle run through the tarsal canal, an osseofibrous tunnel delimited deeply by the medial aspects of the distal tibia, the talus, and the calcaneus and superficially by the flexor retinaculum. For examination of the medial compartment, the patient is placed in the supine position with the hip flexed and abducted, the knee flexed, and the outer aspect of the foot resting on the table [1].

Tendons and retinacula

The three tendons, each of which is enclosed in a synovial sheath (each in its own sheath), are derived from muscles located deep in the posterior portion of the leg. They run beneath the broad flexor retinaculum (Figs. 6, 7, 8), which extends from the medial malleolus to the medial aspect of the calcaneus.

The TP (Figs. 6, 8) is the largest and most anterior of the three tendons in this compartment. It runs through a special sulcus on the posterior aspect of the medial malleolus and then passes beneath the malleolus, encircling it inferiorly, superficial to the deltoid ligament. It then divides into several slips, which insert onto the tuberosity of the navicular bone and the main insertion then divides into a fan-shaped array of slips that extend to all bones of the tarsus except the talus and the second, third, and fourth metatarsals [7].

A sesamoid bone is sometimes found just proximal to the tendon's insertion into the navicular tuberosity.

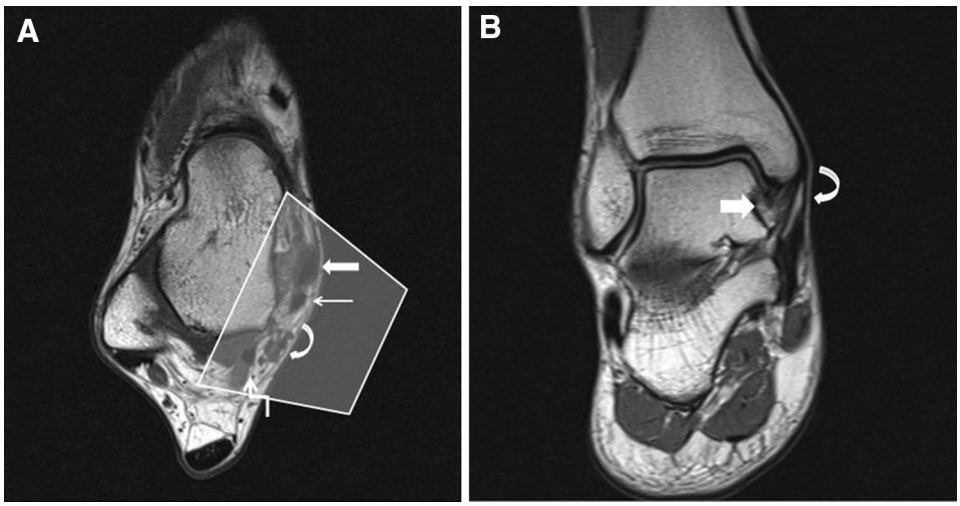

Fig. 6 T1-weighted axial MR image. **a** The medial compartment of the ankle contains the tibialis posterior (*thick arrow*), the flexor digitorum longus (*thin arrow*), the flexor hallucis longus (*right-angled arrow*) tendons; the tibial neurovascular bundle (*curved arrow*), which includes the tibial nerve, the tibial artery, and the posterior tibial veins. Coronal MR image (**b**) clearly depicts the superficial and deep fasciculi of the medial collateral (deltoid) ligament (*straight arrow*) and, superficially, the flexor retinaculum (*curved arrow*)

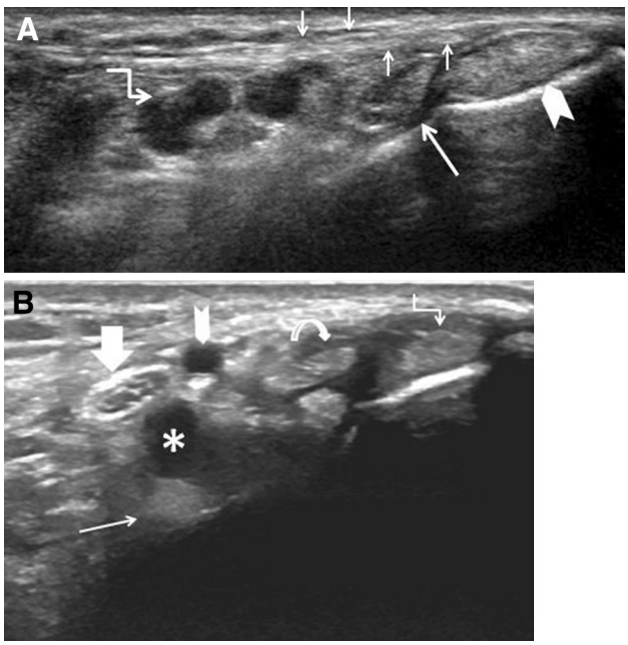

Fig. 7 Sonographic image of the medial retromalleolar area obtained in the axial-oblique plane (*panoramic image*): **a** superficial to the bone plane, moving from the anterior to the posterior, one sees the tibialis posterior tendon (*arrowhead*), the flexor digiotorum longus tendon (*long arrow*), the neurovascular bundle (*right-angled arrow*), and superficial to these structures, the flexor retinaculum, which appears as a thin echogenic band (*short arrows*). Sonographic image of the medial retromalleolar area obtained in the axial-oblique plane, slightly posterior with respect to the images shown in Fig. 7a (*panoramic image*), **b** the posterior tibial artery (*arrowhead*); the tibial nerve (*thick arrow*); and the flexor hallucis longus tendon (*thin arrow*) in the tarsal canal, resting on the surface of the talus. The tendon is especially easy to identify thanks to the presence of effusion fluid in the joint (*asterisk*). Anteriorly, in the retromalleolar zone, the tendons of the tibialis posterior (*right-angled arrow*) and flexor digitorum longus (*curved arrow*) muscles

Posterior to the TP tendon lies the FDL tendon (Figs. 6, 8), which is more slender. It runs beneath the medial malleolus along the inner aspect of the sustentaculum tali (or talar shelf) and then becomes plantar and reaches the plantar fascia. Its distal course ends with insertions into the plantar aspects of the distal phalanges of the second, third, fourth, and fifth toes.

The deepest and most posterior of the three tendons is that of the FHL (Fig. 8). The tendon is reflected on the posterior aspect of the talus, between the medial and lateral tuberosities. Its course then becomes plantar, passing beneath the sustentaculum tali, intersecting the FDL tendon, and inserting into the distal phalanx of the great toe. Because of its position, the FHL tendon is relatively difficult to identify on ultrasound [2], but the task is facilitated by the tendon's proximity to the neurovascular bundle at the level of the tibiotalar joint. In ~20 % of all patients, communication can be demonstrated between the FHL tendon sheath and the tibiotalar joint cavity, a feature that is well known to arthrographers [8, 9].

The medial compartment, too, may contain accessory muscles and tendons: examples include accessory FHL tendons, which run laterally to the FHL, and accessory FDL tendons, which run through the tarsal tunnel and insert into the quadratus plantae muscle or into the FDL tendon itself [10].

Blood vessels and nerves

The neurovascular bundle lies posterior to the FHL tendon. It includes the posterior tibial artery and its satellite vein(s), as well as the tibial nerve, which divides within the tarsal canal to form three terminal branches (Figs. 6, 8).

Bursae

The subcutaneous medial malleolar bursa lies between the medial malleolus and the overlying skin layer. Under physiological conditions, this bursa cannot be visualized sonographically [6].

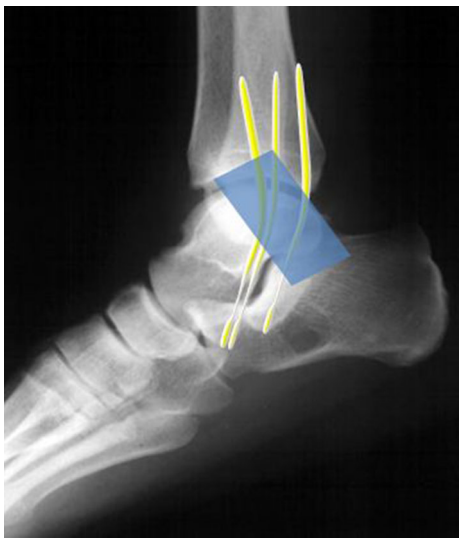

Fig. 8 Diagram showing the flexor retinaculum, which extends from the tibial malleolus to the medial aspect of the calcaneus

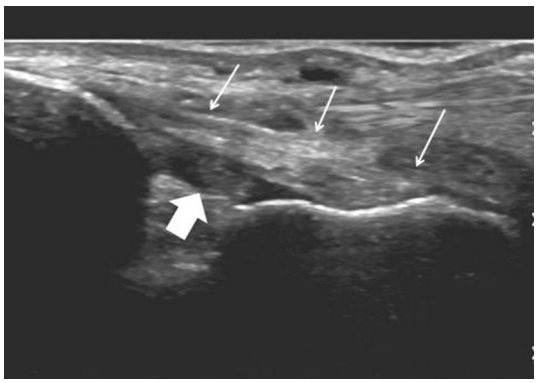

Fig. 9 Sonographic image of the medial submalleolar region (coronal-oblique plane, *panoramic view*): the fasciculi that make up the medial collateral ligament are clearly visualized: the superficial layer (*thin arrows*) and the deep layer (*thick arrow*) at the tibiotalar level, which appears hypoechoic owing to anisotropy

The medial collateral (deltoid) ligament

The medial collateral (deltoid) ligament is actually a ligament complex with multiple components (Figs. 6, 9). It is generally agreed to include a deep band, short and stumpy, which extends from the summit of the medial malleolus to the medial aspect of the talus, and a superficial delta-shaped layer with several bands (moving anteroposteriorly): the tibionavicular ligament, which inserts distally into the navicular tuberosity; the tibiotalar ligament; and the tibiocalcaneal ligament, which extends to the sustentaculum tali. The robust medial collateral ligament is decidedly less vulnerable to sprains than the lateral collateral complex; it is generally injured as a result of eversion stress [11, 12].

Lateral compartment

The lateral compartment contains the peroneus brevis (PB) and peroneus longus (PL) tendons, the accessory peroneus quartus tendon (PQ), the superior and inferior peroneal retinacula, the lateral collateral ligament, and the subcutaneous lateral malleolar bursa (Fig. 10). This portion of the ankle is examined with the patient's thigh flexed and adducted, the knee flexed, and the inner aspect of the foot resting on the table. Studies of the calcaneofibular ligament are facilitated if the foot is also dorsiflexed, while inversion is more useful during examination of the anterior talofibular ligament.

Tendons and retinacula

The PL and PB tendons are derived from muscles located in the lateral portion of the leg. The spatial relationship between these two tendons varies. In the lateral supramalleolar plane, the PL lies lateral to the PB. The myotendinous junction of the PB is more distal and, therefore, still visible at this level. Behind the malleolus, the PL tendon runs posterior to that of the PB (Figs. 10a, 11). Moving distally, at the inframalleolar level, the tendons are in contact with the lateral surface of the calcaneal body and separated from one another (the PB superior to the PL) by a crest of bone known as the peroneal tubercle (Fig. 10b). From here, the PB extends to its insertion on the base of the fifth metatarsal. The PL continues distally, encircling the inferolateral portion of the cuboid (in the peroneal sulcus) and continuing through the plantar portion of the foot to its insertions on the bases of the first and second metatarsals. At the level of the PL tendon's passage through the peroneal sulcus of the cuboid, there is often an accessory sesamoid bone (os peroneum) [1].

The peroneal tendons' contact with the underlying bone structures is maintained by the presence of two retinacula. The superior one, located in the external retromalleolar region, extends from the lateral malleolus to the outer surface of the calcaneus. The lower one, which is inframalleolar, stretches from the outer edge of the inferior extensor retinaculum to the outer surface of the calcaneus (Figs. 11, 12).

An accessory tendon, the PQ, may also be observed. Its insertion varies (Fig. 13), but the most frequently described sites are the PB or the PL tendon, the fifth metatarsal (base or head), and the outer surface of the calcaneus [13].

Bursae

The subcutaenous lateral malleolar bursa has been described in the literature. It lies between the lateral malleolus

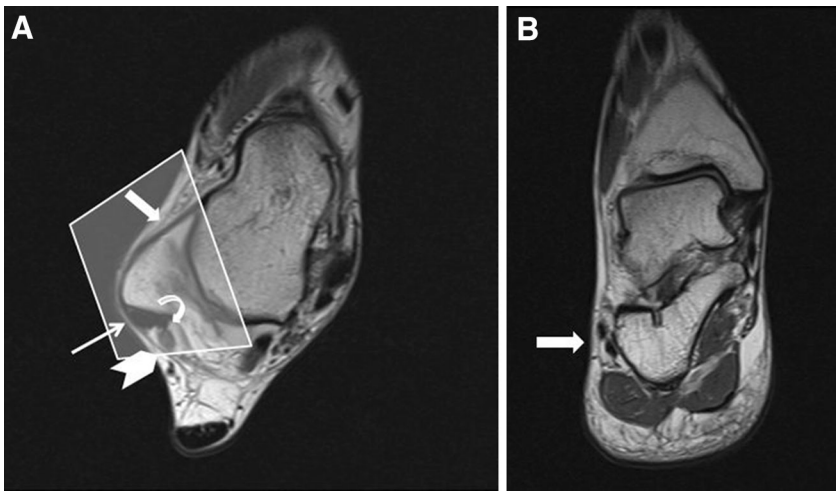

Fig. 10 Axial proton density (PD)-fat suppression (FS) MR image: The lateral compartment of the ankle contains the peroneus longus (*curved arrow*) and peroneus brevis (*thin arrow*) tendons (at the retromalleolar level, the former runs posterior to the latter); the anterior fibulotalar ligament, which stretches from the lateral malleoulus to the outer surface of the talar body (*thick arrow*). Superficial to these tendons lies the superior peroneal retinaculum (*arrowhead*) (**a**). Distally (**b**) the peroneal tendons run along the outer side of the calcaneal body (*arrow*) (the PB superior to the PL), separated by the peroneal tubercle

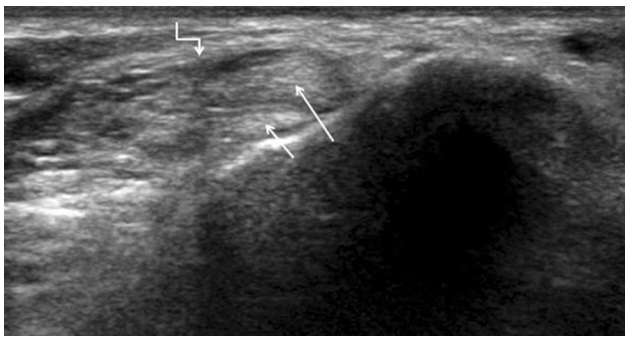

Fig. 11 Axial sonographic image of the retromalleolar region (oblique-external plane): At this level the peroneus brevis tendon (*long arrow*) usually lies anterior and superficial to that of the peroneus longus (*short arrow*), close to the cortical bone of the posterior profile of the malleolus. The thin echogenic band representing the superior retinaculum is easy to identify superficially (*right-angled arrow*)

Fig. 12 Anatomic diagram showing the superior and inferior peroneal retinacula. In the lateral retromalleolar region, the superior retinaculum extends from the lateral malleolus to the outer aspect of the calcaneus. The inferior retinaculum, at the inframalleolar level, runs from the outer end of the inferior extensor retinaculum and the outer aspect of the calcaneus

and the overlying skin. Under normal conditions, it will not be visualized on the ultrasound examination [6].

Lateral collateral ligament

The lateral collateral ligament complex includes three fasciculi: the anterior talofibular ligament (FTA) (Figs. 10, 14), which extends from the anterior aspect of the lateral malleolus to the neck of the talus; the calcaneofibular ligament (FC) (Fig. 15), which lies deep to the peroneal tendons and connects the summit of the lateral malleolus and the outer surface of the calcaneal body; and the posterior talofibular ligament (FTP) (Fig. 16), which runs from the posterior edge of the lateral malleolus to the posterior process of the talus, beneath the posteroinferior tibiofibular ligament.

The FTA ligament is the weakest of the three and the one most frequently involved in ankle sprains; FTA ligament tears are associated with positive findings in the anterior drawer test. The ligaments of the lateral complex can be injured during severe sprains (starting from the most anterior to the most posterior): therefore, in general (although exceptions to the rule are common), damage

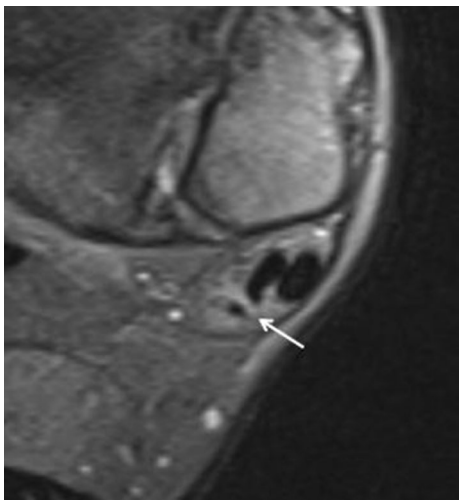

Fig. 13 Axial PD FS MR image: the examination reveals an accessory peroneus quartus tendon (*arrow*), the insertion of which varies

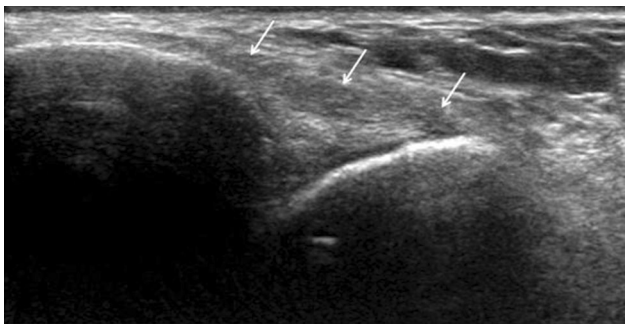

Fig. 14 Anterior perimalleolar sonogram (oblique-external). The anterior fibulotalar ligament (*arrows*) appears as a thin echogenic band that extends from the anterior aspect of the lateral malleoulus to the collum tali

to the FC ligament is usually associated with FTA ligament lesions. Lesions involving the FTP ligament are very rare [12].

Posterior compartment

The anatomic structures found in the posterior compartment are the Achilles' tendon, the tendon of the plantaris muscle, Kager's triangle (Figs. 17, 18, 19), and the retrocalcaneal bursae and are examined with the patient lying prone and the toes resting on the surface of the examination table. This ensures maximal extension of the foot and maximal tension on the Achilles tendon. Later, dynamic studies can be done and Doppler imaging can be carried out to identify signs of hypervascularization. Since excessive tension on the tendon fibers can compress small intratendinous vessels, this phase of the examination is done with

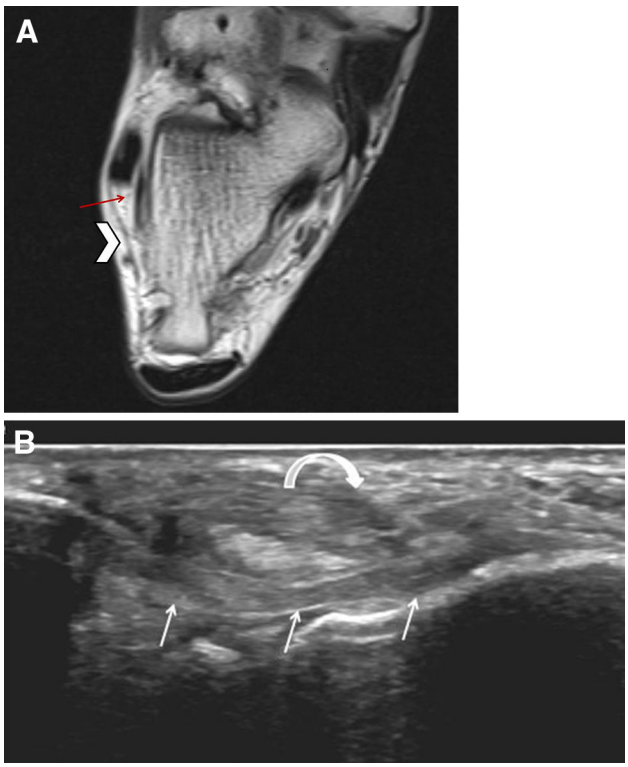

Fig. 15 T1-weighted axial MR image (**a**) depicting the calcaneofibular ligament (*arrow*) that lies deep to the peroneal tendons and runs from the summit of the lateral malleolus to the outer aspect of the calcaneal body. The inferior retinaculum is superficial to the peroneal tendons (*arrowhead*). Coronal sonographic image of the submalleolar region (oblique-external) (**b**) shows the calcaneofibular ligament (*arrows*) running beneath the peroneal tendons (shown in cross section, *curved arrow*), from the summit of the lateral malleolus to the body of the calcaneus. The patient's foot should be dorsiflexed to place maximal tension on the ligament

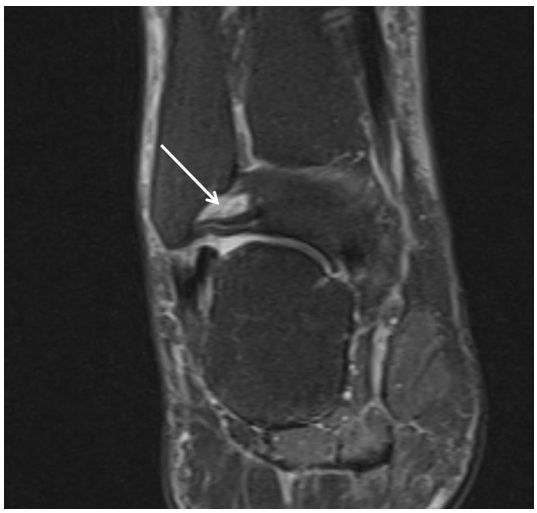

Fig. 16 Coronal PD FS MR image: the posterior tibiotalar ligament (*arrow*) appears as a hypointense band overlying a thin layer of effusion. This ligament is poorly visualized on ultrasound, but it is rarely involved in ankle sprains

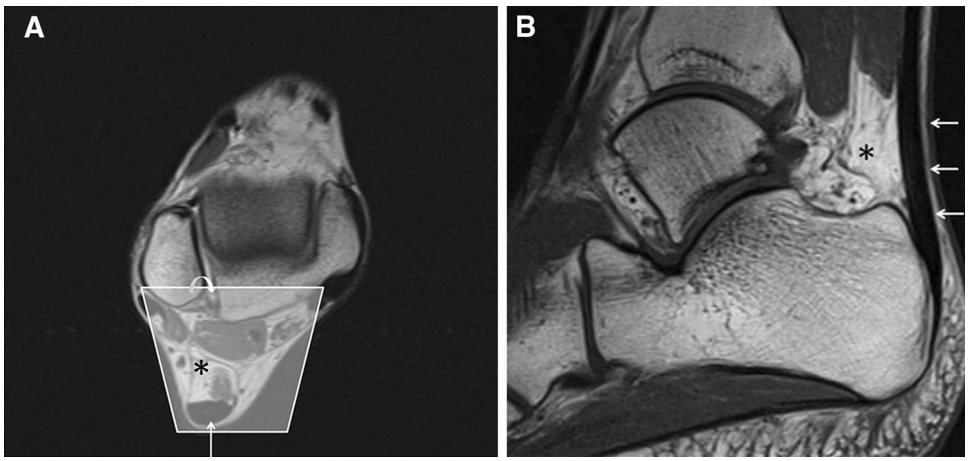

Fig. 17 T1-weighted axial (**a**) and T1-weighted sagittal (**b**) MR images. In the posterior compartment of the ankle, one sees the Achilles tendon (*arrow*), Kager's fat pad (*asterisk*), and the superficial and deep retrocalcaneal bursae (which are not visualized unless they are distended), and the posterior tibiofibular ligament (*curved arrow*), which extends from the posterior margins of the distal epiphyses of the tibia and fibula

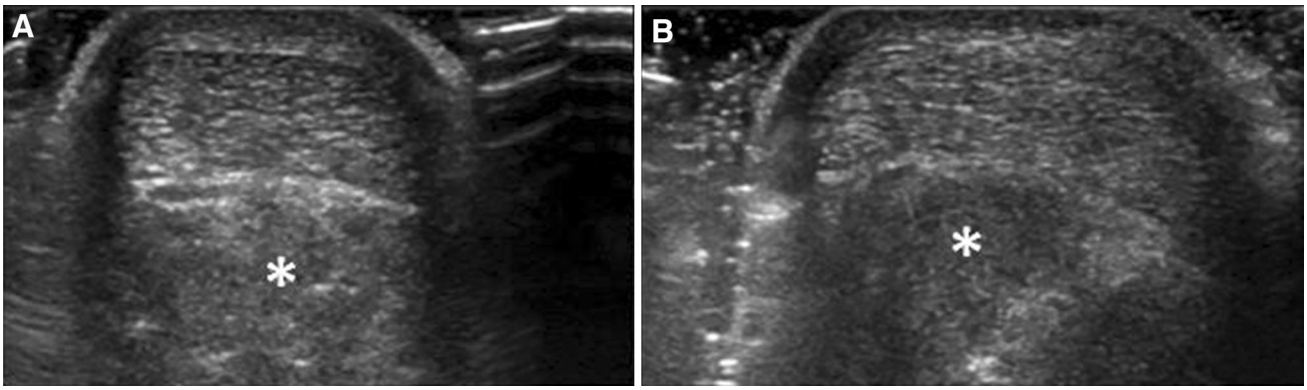

Fig. 18 Axial sonographic images of a normal Achilles tendon, **a** proximal, **b** distal. The anterior margin of the tendon is typically concave. Kager's fat pad (*asterisk*) is located anterior to the tendon

the foot over the edge of the table and the Achilles tendon somewhat more relaxed [11].

Achilles tendon

The Achilles tendon is the strongest tendon in the human body: it is formed by the confluence of the soleus muscles (deep) and the gastrocnemius (superficially) (Fig. 19). It inserts into the posterior aspect of the calcaneus, distal to the posterosuperior tuberosity. The Achilles tendon does not have a synovial sheath as such, but it is surrounded by a band known as the paratenon, which is composed of a single layer of cells and is richly vascularized. The paratenon plays an essential role in furnishing blood to the tendon, which is also supplied by vessels originating at the myotendinous and osseotendinous junctions [14].

Twelve to fifteen centimeters proximal to its insertion, the fibers of the tendon begin to rotate, so that fibers originally on the medial aspect insert posteriorly, and those that were originally posterior fibers insert on the lateral aspect of the calcaneus. The rotation is most accentuated in the preinsertional segment, 5–6 cm before the insertion. A hypovascularized zone has been demonstrated 2–7 cm proximal to the insertion [1].

The Achilles tendon is examined with transverse scans, where it resembles a crescent whose anterior margin is concave (Fig. 18), and with longitudinal scans (relaxed and under tension).

The plantaris muscle originates from the supracondylar ridge of the femur, and its long tendon inserts into the calcaneus [6] or it runs medial to the Achilles tendon (Fig. 20), inserting into the tendon itself or into Kager's triangle.

Bursae

There are two retrocalcaneal bursae: the subcutaneous-calcaneal bursa, which lies between the skin and the distal insertional segment of the Achilles tendon, and the retrocalcaneal bursa, which lies between the preinsertional segment of the tendon and the posterior apophysis of the

Fig. 19 Sagittal sonographic image of the Achilles tendon (*arrows*) from its origin at the confluence of the soleus (deep) and gastrocnemius (superficial) muscles to its insertion on the posterior surface of the calcaneus, distal to the posterosuperior tuberosity (*panoramic image*). Kager's triangle (*asterisk*) is seen between the preinsertional segment of the Achilles tendon and the upper edge of the posterior calcaneal apophysis

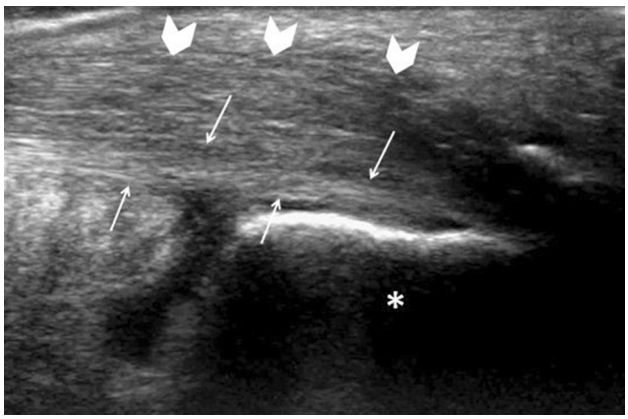

Fig. 20 Sagittal sonographic image obtained at the level of the posterior calcaneal tuberosity. The tendon of the plantaris muscle (*arrows*) is thin. It runs along the medial side of the Achilles tendon (*arrowheads*), and when it does not merge with the latter, it inserts on the calcaneus (*asterisk*). In some cases, it inserts wholly or in part on the Kager triangle

calcaneus. Both are visualized only when they are distended by fluid.

Kager's triangle

This fat-filled space is located anterior to the preinsertional segment of the Achilles tendon above the posterior apophysis of the calcaneus.

Conclusions

Ultrasonography is now the imaging method of choice for the study of traumatic distortion of capsule-ligament structures of the ankle, as well as for degenerative, inflammatory, and traumatic lesions of the ankle tendons [1, 2]. Apart from these indications, ultrasound can also be useful for identifying joint effusions and unrecognized nondisplaced fractures. It has also an established role in the treatment of such lesions, which is increasingly performed under sonographic guidance. It allows dynamic imaging of many structures, which can reveal the mechanisms underlying many lesions of the ankle (e.g., instability, impingement). Its potential is enormous, but it cannot be fully exploited without thorough knowledge of the anatomy of the region [15].

Conflict of interest Matteo Precerutti, Mara Bonardi, Guja Ferrozzi, Ferdinando Draghi declare that they have no conflict of interest.

Ethical standards All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 (5). Informed consent was obtained from all patients for being included in the study.

Human and Animal Studies This article does not contain any studies with human or animal subjects performed by the any of the authors.

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