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Anterior talofibular ligament's superior fascicle as a cause of ankle microinstability can be routinely identified by ultrasound

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Abstract

Purpose: Chronic pain can affect up to 40% of patients after ankle inversion sprains. The current hypothesis to explain this high percentage of chronic pain is a partial/total rupture of anterior talofibular ligament (ATFL) superior fascicle, a structure that has recently been described as intra-articular and as having a different function than ATFL's inferior fascicle. This has created the need for diagnosing ATFL superior and inferior fascicles independently. Therefore, the objective of this study is to investigate if the ATFL's superior fascicle can be visualized on ultrasound, and to describe its ultrasonographic appearance.

Methods: Twenty fresh-frozen ankle specimens were used in this 4-phases study. First, the specimens were scanned on US to identify what was believed to be ATFL's superior fascicle. Second, ATFL's superior fascicle was sutured under direct arthroscopic vision. Next, the specimens were scanned on US to obtain an image of the sutured structure. Finally, the specimens were dissected to confirm that the suture was indeed placed on ATFL's superior fascicle.

Results: On the 20 specimens studied, full correlation was obtained between US, arthroscopic suture and specimen dissection. ATFL's superior fascicle US appearance is provided.

Conclusion: ATFL's superior fascicle can be visualized on US, which will allow to undergo diagnosis of isolated injuries to that fascicle, a common finding in ankle microinstability. The results of this study will facilitate the diagnosis of partial or complete rupture of ATFL's superior fascicle, likely increasing the amount of ankle microinstability diagnosis, impacting clinical management of ankle sprain consequences.

KEYWORDS

anatomy, ankle injuries, joint instability, ultrasonography

Abbreviations: ATFL, anterior talofibular ligament; CFL, calcaneofibular ligament; IRB, Institutional Review Board; LFTCLC, lateral fibulotalocalcaneal ligament complex; MHz, megahertz.

INTRODUCTION

Ankle inversion sprains are one of the most common injuries both among sports and in the working population [1–3]. The anterior talofibular ligament (ATFL), and particularly its superior fascicle, is the first structure to go into tension during forced inversion and it is the weakest component of the lateral collateral ligament complex of the ankle.

Despite ankle sprains being considered minor injuries, up to 40% of patients can end up with chronic pain [4]. Recent anatomical findings have established that ATFL has two fascicles, one superior and one inferior. The inferior fascicle is connected to the calcaneofibular ligament (CFL), forming an isometric ankle stabilizing structure named the lateral fibulotalocalcaneal ligament complex (LFTCLC) (Figure 1) [5]. On the other hand, ATFL's superior fascicle is an intra-articular structure [6], which is expected to negatively affect its healing capacity. Furthermore, ATFL's superior or inferior fascicles injury will have different clinical relevance [7].

These findings gave rise to the concept of ankle microinstability [8–11]: a partial or total rupture of ATFL's superior fascicle that could explain the high percentage of patients with chronic pain after an ankle sprain. Ankle sprains and instability have traditionally been diagnosed using the clinical history and orthopaedic manoeuvres such as the anterior drawer test and the talar tilt test [12–14]. Both tests should be performed during the physical examination [15–17]. However, ATFL's superior fascicle injury seems more challenging to diagnose, as manual tests appear to be insufficiently sensitive to detect it [12].

Furthermore, independent assessment of ATFL's fascicles is also difficult on imaging, with only one recent study reporting on the individual diagnosis and visualization of ATFL fascicles using MRI [18]. Ultrasonography is a cost-effective and accessible alternative in the diagnosis of ankle ligament injuries both in the acute or chronic settings [19–23], however in most instances the US appearance of ATFL is described generically [19, 24–26]. Only one study to date has performed an in-depth ultrasound examination of ATFL, specifying which of the two fascicles is being visualized and described [27]. Nevertheless, this study did not perform a dedicated, confirmatory marking of the fascicle to ascertain whether the visualized structure was indeed ATFL's superior fascicle.

Consequently, a cadaveric study was designed in which ATFL was scanned on ultrasound and images recorded; subsequent to this an arthroscopic suture was placed on the ATFL superior fascicle under direct visualization using previously validated methodology [6]; then, the ATFL was scanned again on ultrasonography to visualize the suture placed on ATFL's superior fascicle and therefore confirm its ultrasonographic appearance. As a last step and to confirm the findings, all specimens were dissected to confirm that the suture was indeed placed on ATFL's superior fascicle.

The hypothesis of this study was that ATFL's superior fascicle is a structure that can be visualized in the normal ultrasonography exploration of the ankle. This could be important in helping early diagnosis of partial and complete ATFL's superior fascicle injuries, and therefore facilitate prompt treatment of ankle instability and microinstability.

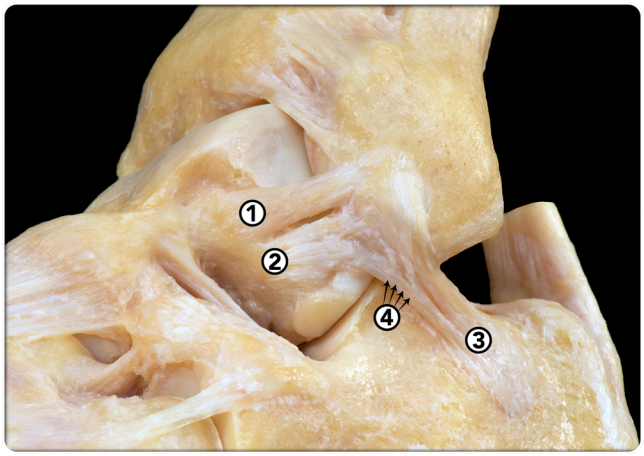

FIGURE 1 Lateral view of an osteoarticular dissection of a human ankle. This image demonstrates the anatomy of the lateral fibulotalocalcaneal ligament complex (LFTCLC), formed by ATFL's inferior fascicle (2), the CFL (3) and the connecting arciform fibres (4). Note that ATFL's superior fascicle (1) is an intra-articular structure, and not part of the LFTCLC. Reproduced with permission from Hong CC, Lee JC, Tsuchida A, Katakura M, Jones M, Mitchell AW, Dalmau-Pastor M, Calder J. Individual fascicles of the ankle lateral ligaments and the lateral fibulotalocalcaneal ligament complex can be identified on 3D volumetric MRI. *Knee Surg Sports Traumatol Arthrosc* 2023;31(6):2192-2198. ATFL, anterior talofibular ligament; CFL, calcaneofibular ligament.

MATERIALS AND METHODS

This study was performed using 20 fresh frozen ankles amputated below the knee, and approval was granted by the local Institutional Review Board of the University of Barcelona (IRB 00003099). All specimens were Caucasian specimens with a median age of 64 years (mean: 62; range: 51−76 years). Ankles with deformities, stiffness and scars indicating previous surgery were excluded from the study. If an ATFL injury was detected during the study, that specimen was excluded, as the goal of the study was the ultrasonographic exploration of the normal ATFL superior fascicle.

The specimens were thawed in water at room temperature for a minimum of 6 h before the ultrasound examination. All ultrasound images were obtained using a General Electric Logiq E BT12 R7 device (GE) with a high-resolution probe (L10-22 RS; 10−22 MHz), set at

22 MHz. A small footprint probe was chosen as it was easier to visualize the ligament.

The study was divided into four phases.

Phase 1. All the ultrasound examinations were carried out by a sonographer with more than 10 years' experience. The specimens were placed on the table resting on the medial side of the leg under plantar flexion of the ankle to achieve a certain degree of tension on the superior fascicle of the ATFL and thus ensure optimal visualization of the ligament. The images were obtained in longitudinal and transverse planes. The longitudinal images were obtained by placing the probe parallel to the axial axis of the ligament. The reference point for placement of the probe was the posterior angle of the anterior margin of the peroneal malleolus, as previously described [24]. Using this reference point, the probe was moved anteriorly and slightly inferiorly to reach the insertion of the neck of the talus, very close to the joint surface of the talar dome. Lastly, small adjustments were made until the ligament was visible and three images from proximal to distal on the long axis were obtained, together with a transverse image of the superior fascicle of the ATFL at its medial portion. To do so, we turned the probe 90° in order to place it perpendicular to the longitudinal axis of the ligament. All the specimens were rigorously examined using the described protocol (Figure 2). Each specimen was then moved to the second phase for arthroscopy and placement of a suture in the superior fascicle of the ATFL. Data were duly recorded and stored.

Phase 2. Arthroscopy technique

All procedures were performed by an experienced surgeon. The specimen was fixed to the table with a grasper holding the tibia. The foot and the ankle were outside the table to have free ankle movement. A 4 mm diameter scope, a 3.5 mm shaver, an arthroscopic suture retriever clamp and a suturelasso bending 70° (Arthrex) were used for the procedure. Through a dorsiflexion and non-distraction ankle arthroscopic procedure, anterolateral and anteromedial portals were established. An accessory lateral portal was established at about 1.5 cm proximal to the fibular tip, and just anterior to the fibular. In a first step, the scope was introduced through the anteromedial portal and directed to the lateral gutter. ATFL superior fascicle was observed occupying the floor of the lateral gutter [6]. Next, the suturelasso was introduced through the anterolateral portal, and the ATFL superior fascicle was penetrated. The nitinol of the suturelasso was pulled out through the lateral accessory portal. The nitinol was changed to a suture doubled in the middle. One of the ends of the suture was introduced

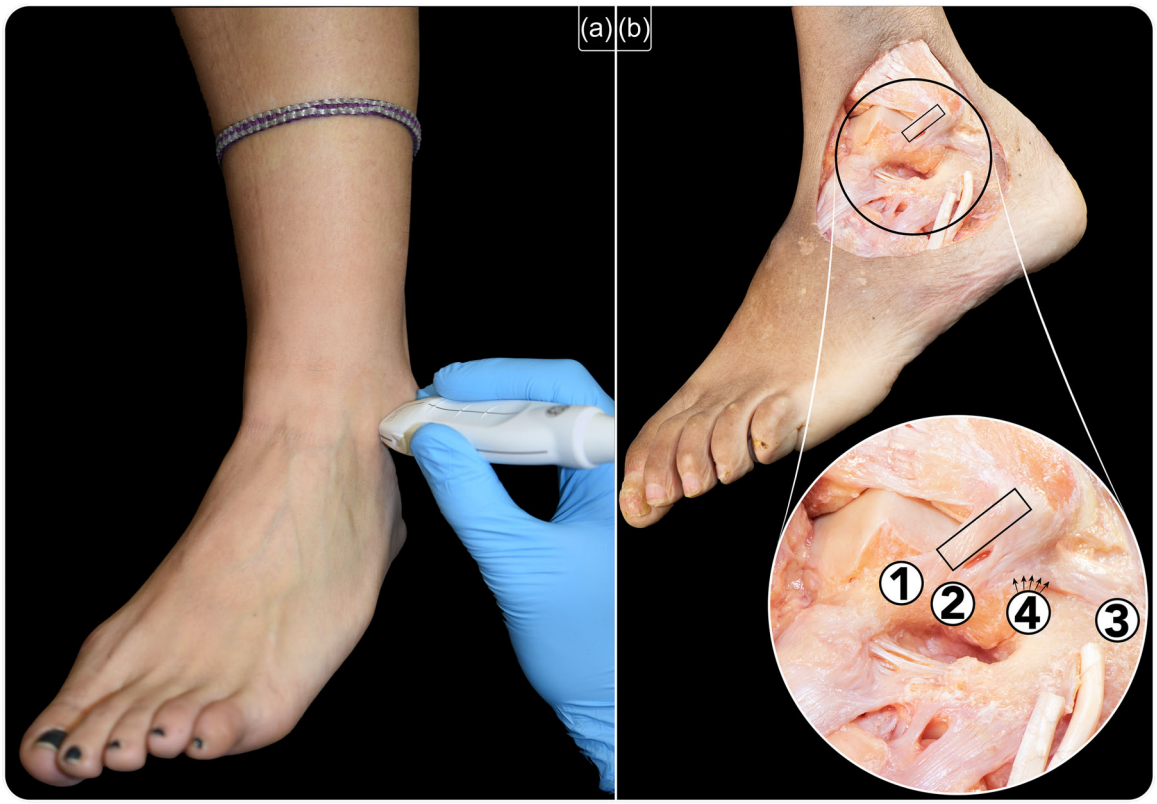

FIGURE 2 Position of the probe for examination of ATFL's superior fascicle. (a) Position during patient examination. (b) Black rectangle shows probe position relative to the position of LFTCLC structures: (1) ATFL's superior fascicle. (2) ATFL's inferior fascicle. (3) CFL. (4) Connecting arciform fibres between 2 and 3. ATFL, anterior talofibular ligament; CFL, calcaneofibular ligament; LFTCLC, lateral fibulotalocalcaneal ligament complex.

inside the loop and by pushing the ends, the loop was introduced inside the joint and the ATFL superior fascicle grasped as the consequence.

Phase 3. After arthroscopy, all specimens underwent a second ultrasound examination to identify the suture placed in the superior fascicle of the ATFL using arthroscopy and to verify that it corresponded to the images obtained during the first examination. The protocol followed was that of the first phase. The three images were obtained following the longitudinal axis of the ATFL before obtaining a transverse image of the ligament. The images were recorded, and the results noted.

Phase 4. All the specimens were dissected to ensure that the sutures were in the appropriate structure. The ankles were all dissected by a single researcher with experience and specific training in anatomical plane-per-plane dissection. A window was created on the anterolateral part of the ankle, and the tendons in the anterior compartment of the leg and anterior capsule of the ankle were removed. That allowed to visualize the ligaments and sutures. The results were noted and photographs taken. The dissections were recorded using a digital camera (Nikon D810; 105 mm Micro Nikon F 2.8 lens) in raw format.

RESULTS

Pre-arthroscopy ultrasound, arthroscopic suture, post-arthroscopy ultrasound and dissection were performed in the twenty specimens. In all cases, the structure observed on ultrasound, sutured arthroscopically and then identified by dissection was the superior fascicle of the ATFL.

The longitudinal image of the superior fascicle of the ATFL was visualized with a high-frequency probe (16−22 MHz), we found a slightly flattened, hyperechoic ligament, the echogenicity of the ligament can vary due to anisotropy, becoming more hypoechoic depending on the perpendicularity of the ultrasound beam with respect to the disposition of the ligament. The ligament had a well-defined fibrillar pattern that coursed anteriorly and slightly medially until its insertion distal to the level of the neck of the talus (Figure 3). The superficial fibres were longer than the deeper fibres, thus indicating an oblique placement at the level of the insertions. The proximal insertion had a broader surface than the distal insertion, which was markedly smaller. In other words, the superficial fibres expand proximally along the peroneal malleolus, thus widening the insertion surface (Figure 4).

Both the superficial and deep margins of ATFL's superior fascicle were well defined. At the level of the superficial margin, we can see a fine hyperechogenic layer that covers the ligament, compatible with the joint capsule, consistent with data from Dalmau et al. [6]. The deep margin is in contact with the intra-articular synovial fluid, and a thin hyperechogenic line is visible, compatible with the synovial membrane of the joint.

On examining the transverse image at the mid portion of the superior fascicle of the ATFL with a high-frequency probe (16−22 MHz), we observed an ellipsoid, hyperechogenic ligament, not as well defined as in the longitudinal image (Figure 5).

In the post-arthroscopy ultrasound study (with the sutured ATFL's superior fascicle) we identified the suture placed as a hyperechoic artefact with a posterior acoustic shadow generated by the suture material (Figure 6). In 100% of cases, dissection of the ankle enabled us to confirm that the suture was in the superior fascicle of the ATFL, which was an intra-articular structure covered by the joint capsule.

DISCUSSION

The most important finding of our research was proving that ATFL superior fascicle is visible on ultrasound. A 100% correlation was found between the structure

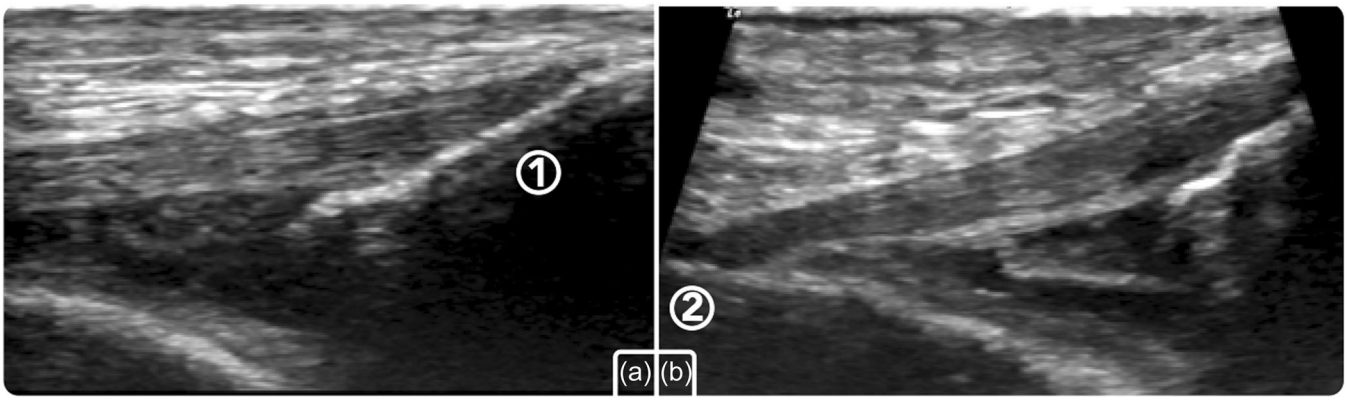

FIGURE 3 (a) Ultrasound image at the fibular malleolus showing the fibular insertion of ATFL's superior fascicle (1). (b) Ultrasound image at the lateral talus malleolus showing the talar insertion of ATFL's superior fascicle (2).

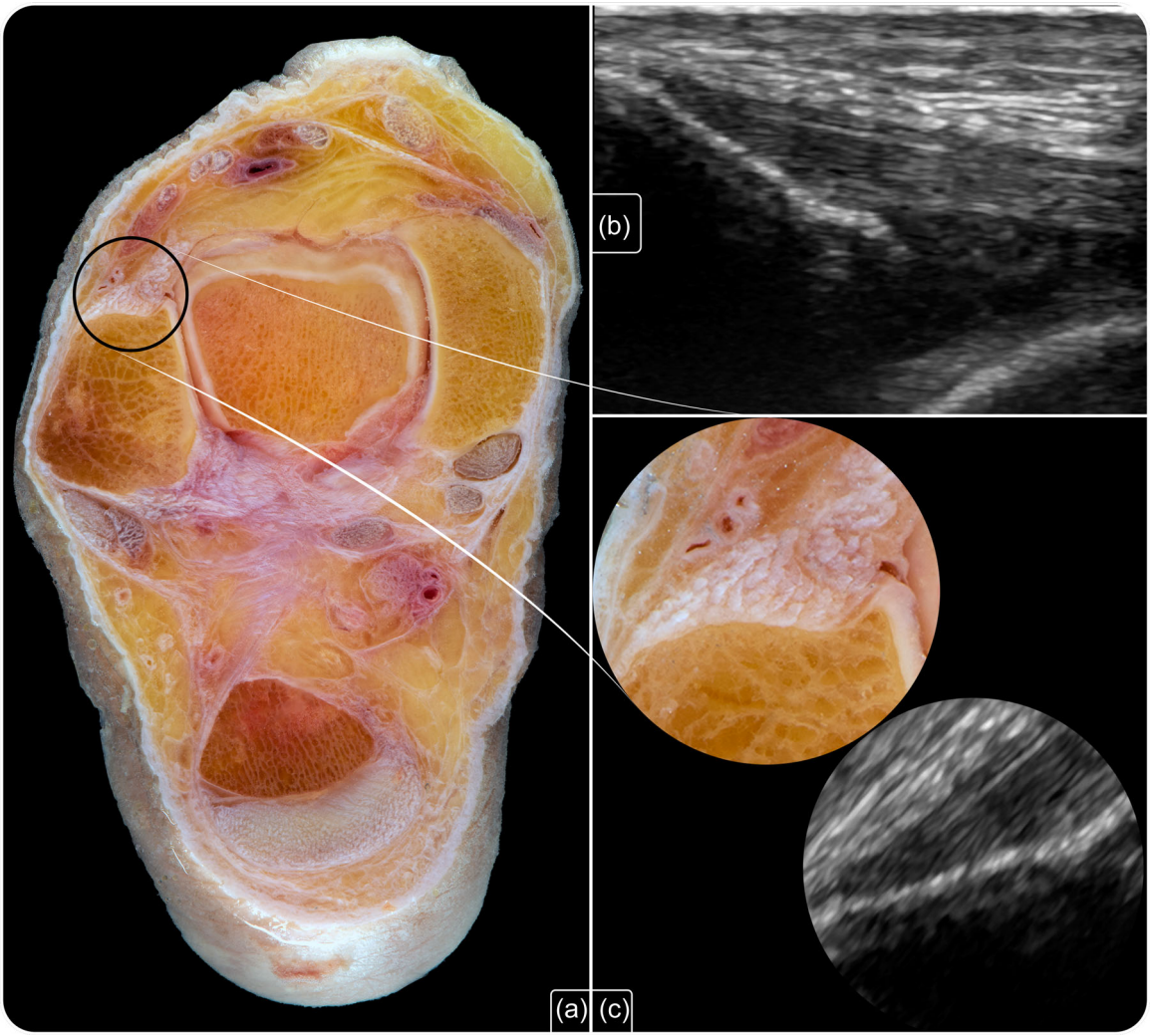

FIGURE 4 Comparative image (c) between a transverse cross-section of the ankle (a) and the ultrasound image (b) showing the detailed morphology of ATFL's fibular insertion. ATFL, anterior talofibular ligament.

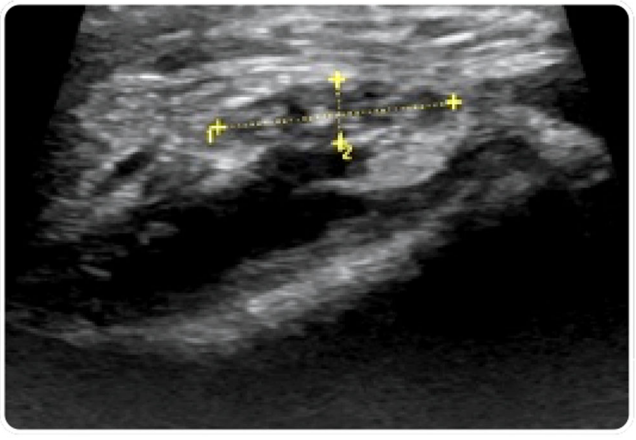

FIGURE 5 Transverse image of the superior fascicle of the ATFL. Note the transverse area of the ligament (yellow lines). ATFL, anterior talofibular ligament.

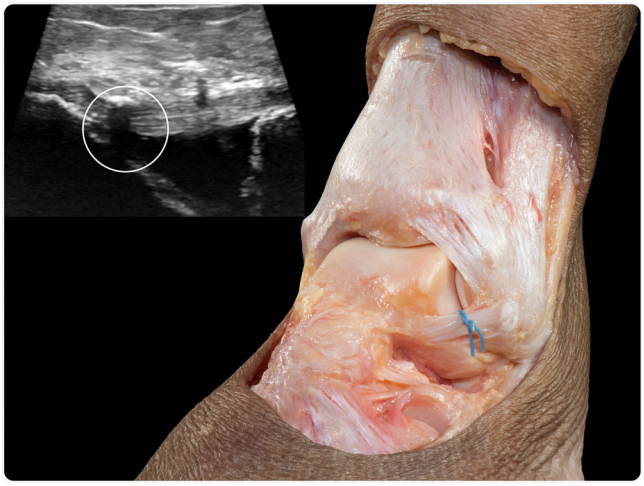

FIGURE 6 Image showing an anatomical dissection of one of the specimens, with the suture placed on ATFL's superior fascicle, and the US image with the suture (white circle). ATFL, anterior talofibular ligament.

seen on ultrasound before and after arthroscopy, and later confirmed by dissection. In addition, it appears that the structure traditionally described as the ATFL [24–26, 28] belongs only to the superior fascicle, and that the inferior fascicle should be explored separately.

It is well known that the superior fascicle of the ATFL is an intra-articular structure, although extrasynovial, both from anatomical studies [5, 6] and clinical studies that show how this structure can be repaired arthroscopically to treat chronic lateral ankle instability [29–34]. The intra-articular location of the superior fascicle of the ATFL has significant clinical implications, as healing of intra-articular ligaments is impaired due to the presence of synovial fluid, as seen in other intra-articular ligaments such as the anterior cruciate ligament [35–38].

The intra-articular nature of ATFL's superior fascicle has been used as a possible explanation to the fact that between 30% and 40% of all patients who undergo conservative treatment for ankle sprain experience residual symptoms such as pain, muscle weakness, or instability [2]. Soft tissue impingement, chronic mechanical instability [39, 40] and the recently reported concept of ankle microinstability [8, 9, 11, 41] have all been considered potential complications of ankle sprain causing considerable pain after injury. Microinstability has been associated with injuries affecting the superior fascicle of the ATFL [8, 9, 11], and these injuries have recently been classified into four types [41], which range from a loss of tension in the ligament to complete disinsertion, and resorption of the ligament in chronic cases. It is worth noting that a key element of all partial lesions or disinsertions of the superior fascicle of the ATFL is that in most cases the injury affects the fibular insertion, with no connective tissue abnormality at the distal talar insertion. In addition to causing microinstability, isolated injuries of the superior fascicle are very difficult to diagnose using clinical tests such as the anterior drawer test or talar tilt test, since the result is often negative owing to the absence of marked instability as the inferior fascicle of the ATFL is preserved.

A recent biomechanical study has reported isolated ATFL superior fascicle injuries to cause microinstability in talar internal rotation [7], which is believed to be difficult to diagnose using current clinical tests.

Li et al. reported on the reverse anterolateral drawer test and compared it with the classic anterior drawer test and anterolateral drawer test, concluding that the reverse anterolateral drawer test increases diagnostic accuracy in ATFL injury, irrespective of whether the CFL is involved [13]. However, they did not consider the possibility of an isolated lesion of the superior fascicle, stressing that sensitivity is reduced depending on the experience of the examiner and that there is no correlation with the results of arthroscopy-based tests.

Given that ankle sprain is one of the most common injuries, not only in athletes but also in the wider population [1–3], the ligaments of the lateral aspect have been and continue to be, one of the most widely studied structures in the literature, and sonographic anatomy of the ankle ligaments has received considerable attention during the last 30 years [19–21, 24, 26, 42–45]. Despite the wealth of information surrounding this topic, this is the first paper confirming that the ATFL superior fascicle is visible on ultrasound, with dedicated pre-arthroscopic and post-arthroscopic imaging.

Both magnetic resonance imaging and high-resolution ultrasound are considered valid examination techniques for detection of ATFL injuries [24, 26, 28, 46, 47]. Ultrasound technology has advanced enormously in recent years, as has the image quality. Several studies have confirmed the validity of ultrasound in determining the degree of involvement of the ligaments in ankle injury, thus enabling an effective criterion for surgery when necessary [19–23]. Moreover, it has proven useful in the evaluation not only of patients with acute injury, but also in those with chronic injury [22]. Ultrasound is highly sensitive (98.9%) and specific (96.2%) in ATFL injury [19, 21]. The reliability of ultrasound examination of the ATFL is influenced by the device being equipped with a high-frequency probe and the examiner's experience [22]. However, recent data show high inter/intra-examiner reliability, even when the examiner's experience is minimal, with only 6 weeks' training being necessary to ensure substantial reliability [48].

Typically, the sonographic anatomy of the ATFL is described generically, without dividing it into a superior and an inferior fascicle [19, 24–26]. Only one study to date has performed an ultrasound study identifying ATFL's fascicles [27]. Nevertheless, the study by Kakegawa et al. [27] was performed using ultrasonography and dissection, without performing a suture of the ligament to be visualized; in our opinion, suturing the ligament and taking a second ultrasonographic image, plus dissecting the specimen, is a further advancement that increases the validity of the study, as it allows to ascertain whether the visualized structure was indeed ATFL's superior fascicle and indeed if what is visualized at the time of arthroscopy corresponds to the sonographic findings.

Recent studies indicate that the superior fascicle of the ATFL is a consistent finding, and that it is intra-articular [6]; furthermore, the clinical relevance of an injury of ATFL's superior fascicle differs from that of an injury to ATFL's inferior fascicle [7]. These findings have rendered the need of assessing ATFL's fascicles separately. As a matter of fact, when identifying ATFL's superior fascicle the superficial and deep margins were well defined. A fine hyperechogenic layer that covers the ligament and could be compatible with the joint capsule was observed on the superficial margin, and another

hyperechogenic layer was seen on the deep margin, which we believe is compatible with the synovial membrane of the joint (Figure 5).

This is, to the best of our knowledge, the first study to describe visualization of the superior fascicle of the ATFL in isolation using ultrasound, after marking the fascicle on arthroscopy. The arthroscopic appearance of ATFL's superior fascicle has been recognized for some time [29–31, 33], and therefore arthroscopic recognition of the fascicle was used to confirm its ultrasonographic appearance in our study.

Regarding clinical relevance, it should be highlighted that despite being a very common ankle injury, microinstability is currently underdiagnosed. This study provides a solid clinical basis for ultrasound-based diagnosis of this injury. Furthermore, ATFL's superior fascicle partial or complete injury is considered a cause of chronic anterolateral ankle pain, microinstability and the origin of recurrent ankle sprains producing even greater instability, that in time will produce intra-articular injuries (soft-tissue impingement, anterior joint impingement and osteochondral defects of the talus) [41, 49].

Limitations of this study include the fact that only 20 specimens were used, and that they were old specimens. However, the finding was constant in the 20 specimens; hence in the author's opinion, 20 specimens were sufficient to prove our hypothesis. Another limitation was the fact that ATFL's inferior fascicle was not studied. This was because reaching this fascicle during ankle arthroscopy and suturing it is technically difficult. Further studies should be conducted to assess the ultrasonographic aspect of ATFL's inferior fascicle.

CONCLUSIONS

Ultrasound visualization of the superior fascicle of the ATFL is possible and has been validated by arthroscopy and dissection in all specimens. A description of the normal sonographic anatomy of ATFL's superior fascicle is provided, which will facilitate ultrasound diagnosis of partial or complete injury lesions of the superior fascicle of the ATFL, a very common injury following ankle sprains, which will likely increase the amount of ankle microinstability diagnosis, impacting clinical management of ankle sprain consequences.

AUTHOR CONTRIBUTIONS

Jordi Esparó: Methodology, investigation, data analysis, writing. **Jordi Vega:** Conceptualization, methodology, investigation. **Guillaume Cordier:** Conceptualization, methodology, investigation. **Rowena Johnson:** Conceptualization, writing—review and editing. **Benjamin Dallaudière**: Methodology, investigation. **Xavier Gasol-Santa:** Methodology, investigation. **Miki Dalmau-Pastor:** Methodology, investigation, data analysis, writing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS STATEMENT

Ethics approval was obtained at the University of Barcelona as disclosed in the manuscript, IRB 00003099.

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