THE LATERAL FIBULOTALOCALCANEAL LIGAMENT COMPLEX: AN ANKLE ISOMETRIC STABILIZING STRUCTURE.

Introduction

Injury to the lateral collateral ligament complex of the ankle is a common finding in ankle sprains, frequently leading to ankle instability, either chronic or microinstability. Chronic ankle instability is a well-known problem, where the pathomechanism involves an isolated tear of the anterior talofibular ligament (ATFL) in 80% of cases and a combined rupture of ATFL and calcaneofibular ligament (CFL) in 20% of cases [2]. In contrast to chronic ankle instability, microinstability is an emerging concept in the ankle joint, and the current proposed pathomechanism is a partial tear of the ATFL affecting the superior fascicle of the ligament. Although partial tears of the ATFL can affect the whole superior fascicle of the ligament, quite often only a subtle tear of the superior fascicle is observed, especially during arthroscopic procedures [27-29].

Ankle ligaments have been the focus of multiple studies, particularly the ATFL and CFL, as these are the most commonly injured ankle ligaments [9,10,18,21]. The lateral collateral ligament complex of the ankle is formed by the ATFL, CFL and posterior talofibular ligament (PTFL). According to the literature, the ATFL is most commonly formed by two fascicles, while the CFL is a single ligament. However, there are no specific descriptions of how these ligaments are related or connected to each other as part of the same complex. Some biomechanical and clinical studies have already proved that isolated ATFL repair yields excellent results in cases of ankle instability with injuries to both ATFL and CFL [12,13,16]. To date, no anatomical observations are available to explain this fact.

The purpose of this study was to describe in detail the components of the lateral collateral ligament complex -ATFL and CFL- and determine its anatomical relationships, if any. The PTFL was not included in the study because of its rare contribution to ankle instability unless ankle dislocation is present.

It was hypothesized that the two fascicles of the ATFL -superior and inferior- are, from an anatomical point of view, two different structures, and that anatomical connections exist between the inferior ATFL fascicle and the CFL.

Material and methods

Thirty-two fresh-frozen below-the-knee ankle specimens were used for this study. The specimens were provided by and dissected at the Department of Anatomy of our Institution.

No specimens had any foot and ankle deformities, or cutaneous incisions that suggested any foot and ankle trauma, fracture or surgery. Specimens with ankle joint stiffness and ankle instability were also excluded, as were those where a lateral collateral ligament injury was identified during dissection.

Each specimen was dissected in a protocolized manner. As previously suggested by the literature [5], all dissections were performed by an experienced anatomist in collaboration with an orthopaedic surgeon specialized in foot and ankle pathology. After thawing the specimens by submersion in room temperature water, an anterolateral skin window was created, big enough to allow full visualization of the lateral ankle structures. A plane-by-plane anatomical dissection was performed until the anterior ankle joint capsule was reached. At this point it is critical to dissect with care in order to resect the capsule off the lateral collateral ligaments to expose them. Due to the intimate relation between the capsule joint and the ligaments, air insufflation of the ankle joint with a needle is very useful in order to clearly visualize its limits. (**Figure 1**) An understanding of ligamentous structure and experience in anatomical dissection will enable accurate exposure of the true ligament and its fibers. Overdissecting the area just distal to the inferior fascicle of the ATFL must be avoided, as it would alter the original morphology of the ligaments and the connecting fibers between them. Examples of this can be seen on **Figure 2**.

After careful dissection of the lateral collateral ligament, the specimen was inspected. The characteristics of the ATFL and CFL, as well as any connecting fibers between them were recorded including length, width and number of ATFL fascicles present. Measures were obtained with a calibrated electronic ruler. Ligament length was referred to the distance between its proximal and its distal insertion. The midpoint of the insertional area was used as the reference for measurements in all specimens. Ligament width was obtained at the midpoint of the ligament. Measurements are illustrated in **Figure 3**.

To investigate the dynamics of the ligamentous complex, the distance between the proximal and distal insertions of each ATFL fascicle and of the CFL were measured in full plantarflexion and dorsiflexion of the ankle.

Two observers performed each measurement on the specimens and the average of those was used as the final figure for analysis.

IRB Approval: IRB approval was obtained at the University of Barcelona with IRB number: IRB00003099.

Statistical analysis.

Descriptive statistics were used to evaluate the distribution of continuous variables. The obtained measures of ATFL and CFL length were tested for normal distribution using the Kolmogorov-Smirnoff test. All measurements were found to be normally distributed and were analyzed using paired Student *t* tests to test for significant differences between plantarflexion and dorsiflexion. The significance level was set at 5%. (SPSS 11.0, SPSS Inc, Chicago, IL.)

A power size calculation was performed using previously published data on the lateral ankle ligaments that served as the known population parameters [19]. A continuous endpoint and a one-sample study were considered with an alpha value of 0.05 and a power of 80%. The sample size calculation was performed separately for the three measured ligaments: ATFL superior fascicle, ATFL inferior fascicle, and CFL. The results suggested a sample size for the study group of 11, 0, and 2 respectively. To achieve a more robust conclusion and to account for potential measuring errors, it was decided to include 30 subjects in our study.

Results

A total of 32 ankles were carefully dissected down to the lateral ligamentous structures. Two specimens were excluded because a single ATFL fascicle with a synovialized appearance was found, suggesting a prior traumatic injury.

The total number of specimens included in the study was 30 with a mean age of 68,7 years (range 42-89 years). There were 16 male and 14 female specimens. The right ankle was dissected in 13, and the left ankle in 17 specimens.

A complete list of the measurements obtained from the ligaments is summarized in **table 1**.

The ATFL was observed as a two-fascicle ligament in all 30 specimens. (**Figure 4**) No single-fascicle or three-fascicle ATFL were observed in any specimen.

The ankle joint capsule was observed as a thin structure at the level of the anterolateral ankle joint. The capsule limits were evidenced after air insufflation of the joint. After carefully removing the capsule, it became evident that the ATFL's superior fascicle was an intra-articular structure in the ankle. The ATFL's inferior fascicle was an extra-articular structure in close relationship with the lateral part of the subtalar joint capsule that was found to be the part of its insertion area. An evident gap between both fascicles was observed in all cases. The gap was constantly filled with fatty fibrous tissue, and a small diameter artery running through the gap. Both the artery and the fatty tissue were removed in order to obtain a more accurate measurement of the ATFL fascicles. The superior ATFL fascicle had a fibular origin distinct from its inferior fascicle. The fibular insertion of the superior ATFL fascicle was located just below the distal insertion of the anterior tibiofibular ligament at the anterior aspect of the fibula, and just above the insertion of the inferior ATFL fascicle. From its fibular insertion, with the ankle in neutral position, the superior ATFL fascicle runs anteriorly and horizontally to attach on the talar neck, close to the talar dome articular surface. From dynamic observations, the superior ATFL fascicle becomes lax in ankle dorsal flexion, and taut in plantar flexion. In consequence, the mean distance measured between insertions increases in plantar flexion when compared to dorsal flexion (median 19.2mm in plantar flexion, and 12.6mm in dorsal flexion, $p<0.001$). (**Figure 5**)

The inferior ATFL fascicle and the CFL had a common fibular origin located at the anterior aspect of the lateral malleolus, proximal to the fibular tip, and just below the fibular insertion of the superior ATFL fascicle. From this common point of origin, the inferior ATFL fascicle runs parallel to the superior ATFL fascicle, and was directed anteriorly to attach to the talar neck just below the talar insertion of the superior ATFL fascicle. (**Figure 6**) The distance between talar and fibular insertions of the inferior ATFL fascicle remained unchanged throughout ankle range of motion (median 10.6mm in plantar flexion, and 10.6mm in dorsal flexion, p=0.59,n.s.). (**Figure 5**)

With the ankle in a neutral position, and from its fibular insertion, the CFL runs obliquely downwards and backwards to attach to the posterior aspect of the lateral calcaneal surface. The CFL becomes horizontal in plantar flexion and vertical in dorsal flexion without any change in length between these two positions (median 20.1mm in plantar flexion, and 19.9mm in dorsal flexion, p=0.32,n.s.).

The inferior ATFL fascicle and the CFL were connected by arciform fibers. These arciform fibers were arc-shaped ligamentous fibers joining the inferior border of the ATFL inferior fascicle and the anterior border of the CFL. The arciform fibers originated from the inferior border of the ATFL inferior fascicle and the lateral part of the talar body. They were then directed posteriorly and distally forming an arc or parabola in order to join the anterior border of CFL and lateral part of the calcaneus (just anterior to the CFL calcaneal insertion). (**Figure 7**) These fibers were an intrinsic reinforcement of the subtalar joint capsule, meaning that the subtalar joint capsule is inserted in the ATFL inferior fascicle and in the anterior border of the CFL.

The length of the inferior ATFL fascicle was larger (median 10.6mm, range 5.4mm-15.4mm) than that of the arciform fibers (median 6.4mm, range 4.8mm-11.5mm), demonstrating that the presence of the fibers was limited to the posterior part of the inferior fascicle of the ATFL, not including its talar insertion. In contrast, the CFL length (median 20.1mm, range 11.7mm-28.7mm) was similar to that measured for the arciform fibers (median 18.6mm, range 12.2mm-28.3mm), demonstrating how the fibers arrive to the CFL insertion on the calcaneus.

A separate structure constituting the lateral talocalcaneal ligament was never identified. However, talocalcaneal fibers were found to be present as part of the complex connecting the ATFL and CFL.

Discussion

The most important contributions of the present study are: 1. The inferior ATFL fascicle, the CFL, and the arciform fibers that connect them represent a single functional structure that acts as a ligamentous complex. Thus, lateral fibulotalocalcaneal ligament (LFTCL) complex is a more accurate terminology for this structure. 2. ATFL's superior fascicle is an intra-articular structure while ATFL's inferior fascicle is extra-articular.

Ankle sprains are one of the commonest injuries in orthopaedics [3,7]. In ankle inversion sprains the ATFL is the first ligament to be injured, and usually the only one injured [20]. This is due to the fact that the ATFL is the weakest component of the lateral collateral ligament complex of the ankle, in particular its superior fascicle [9,10]. With higher deforming forces, the injury continues to propagate rupturing the inferior ATFL fascicle and the CFL [1,2]. Finally, continuous energy will rupture the PTFL causing the ankle to dislocate laterally. Injury to these ligaments -ATFL and CFL- will cause mechanical ankle instability.

Previous ATFL descriptions by Milner and Soames report variable presentations with one (38%), two (50%), or three (12%) fascicles [18]. In the present study, a two-fascicle ATFL was observed in all specimens. Many other authors have found the two-fascicle ligament to be the most common ATFL-type in their descriptions [4,9,15]. As observed in the present study, the two fascicles of the ATFL are separated by a gap containing a vascular branch of the fibular artery [8,17,21,23]. The two fascicles of the ATFL differ in their morphological features. First, both fascicles have a contiguous footprint on the anterior border of the distal fibula, however, their distal insertion on the talus is located apart from each other. (**Figure 6**) The ATFL superior fascicle inserts at the body-neck junction of the talus and it is an intra-articular structure of the ankle, whereas the ATFL inferior fascicle inserts more plantarly in the talar body and it is an extra-articular structure [4,14,19]. Second, the length of the superior ATFL fascicle varies depending on ankle plantar or dorsal flexion whereas the inferior remains unchanged. Thus, it can be assumed that the inferior fascicle is an isometric fascicle, in contrast with the superior fascicle that changes its length through the range of motion. (**Figure 5**) These observed anatomical differences suggest that each ATFL fascicle has a different function and therefore the pathology resulting from an isolated injury to the superior fascicle or a combined superior and inferior fascicle injury will also be functionally different. Microinstability of the ankle has been described as the result of an injury affecting the superior fascicle of the ATFL [27-29], while the injury affecting the superior and inferior ATFL fascicles will result in chronic ankle instability as classically described. Our results would support these definitions and provide the anatomical basis to support the classification of chronic ankle instability into its different variants of the classic (ATFL+/- CFL injury) or the microinstability (isolated ATFL superior fascicle injury). The anatomical findings of this study support the use of the term microinstability; it has to be considered as an initial instability produced by an isolated injury of ATFL's superior fascicle, that will probably evolve to chronic ankle instability as it makes easier for the patient to have recurrent ankle inversion sprains, which will ultimately injury ATFL's inferior fascicle +/- CFL.

Furthermore, the inferior ATFL fascicle and the CFL share similar anatomical features according to our observations. They are both isometric ligaments and share the same fibular origin. (**Figure 7**) The direction that each ligament takes from their fibular origin is different. However, these two ligaments are joined by arciform fibers resulting in a single functional anatomical structure. The landmarks of this triangular shaped structure are the inferior fascicle of the ATFL -superior border-, the CFL -posterior border-, the common insertional area of the ligaments at the lateral malleolus -apex-, and the longest and most distal fibers of the arciform fibers -base-. The existence of arciform fibers connecting the inferior ATFL fascicle and the CFL has already been mentioned in the anatomical descriptions by Golanó et al and others [6,9,10,25], although no detailed anatomical studies of his static and dynamic morphology and behavior had been performed to date. These fibers link the inferior ATFL fascicle with the CFL and its length does not vary when measured in plantar or dorsal ankle flexion. Thus, the authors suggest that they play a mechanical role of transferring tension between the two ligaments allowing them to work in tandem in their function of stabilizing the ankle and subtalar joints. As a consequence, the inferior ATFL fascicle and the CFL share anatomical characteristics and are interconnected, allowing both ligaments to work together as a functional unit. We have named this anatomical and functional unit the lateral fibulotalocalcaneal ligament (LFTCL) complex in contrast to the fibulotalocalcaneal ligament, or Rouviére and Canela ligament, located in the posterior part of the ankle.

The lateral talocalcaneal ligament, a non-constant structure described to be medial and anterior to the calcaneofibular ligament [11,22,24,30], has never been found as a separate structure in this study. Results of the current study indicate that the lateral talocalcaneal ligament is a part of the LFTCL complex. It is always present, and variations in the reported incidence in anatomical studies [11,25] are probably a consequence of the commonly practiced overdissection that has led to the LFTCL complex being unnoticed in previous anatomical studies.

After an inversion ankle injury, the superior fascicle of the ATFL is the first ligament to be torn, and ankle initial instability or microinstability is the result. When symptomatic, patients complain of a feeling of instability with a negative anterior drawer test, associated to a history of repetitive ankle sprains, antero-lateral ankle pain, or a combination of them. However, if the force of injury continues, after the ATFL -superior fascicle of the ATFL- is torn, the LFTCL complex -inferior fascicle of the ATFL and the CFL- is injured next, and the patient develops mechanical ankle instability. Patients will usually complain of the ankle giving way and will have a positive anterior drawer test and/or a positive talar tilt test. In addition, a very important point to consider is the finding of ATFL's superior fascicle being an intra-articular structure. If we extrapolate data from other intra-articular ligaments it seems clear that intra-articular ligaments do not heal by themselves (Murray MM. Current status and potential for primary ACL repair. Clin Sports Med 2009;28(1):51-61). This would mean that after a mild ankle sprain with an isolated rupture of ATFL's superior fascicle patients would not have symptoms of chronic instability, but the fact that ATFL's superior fascicle would not be able to heal will produce an initial instability or microinstability, augmenting the risk of sprain recurrence and formation of degenerative intra-articular injuries, and causing the subjective feeling of instability of the patient.

This would also explain why some patients with a severe ankle sprain (ATFL's superior and inferior fascicle injury +/- CFL) improve their symptoms after immobilization (REFERENCIA GINO KERKHOFFS): extra-articular acute ATFL's inferior fascicle injury will heal if not completely teared, and major instability symptoms will reduce. However, ATFL's superior fascicle will remain teared, and this could be the etiology of the high index of chronic pain after an ankle sprain. These patients usually improve with immobilization (ATFL's inferior fascicle +/- CFL are healing) but they continue to feel pain (ATFL's superior fascicle is not stabilizing the ankle joint). Diagnosis in these patients is unclear and will become a new field of research, since when some of these patients have recurrent ankle sprains and develop a chronic ankle instability, they show a very high index of intra-articular injuries during surgical intervention (long-term injuries that start to develop by the time of initial instability or microinstability, i.e. anterior bony impingement, soft-tissue impingement, or talar osteochondral defect).

Also, the descriptions of ATFL as a single-fascicled ligament could be explained by the fact that ATFL's superior fascicle is an intra-articular ligament. In anatomical studies specimens used are usually of an advanced age. It seems fair to assume that some of those specimens had ankle sprains during their lives. If some of them had an isolated injury of ATFL's superior fascicle, this intra-articular ligament did not heal and eventually it was reabsorbed by the body, demonstrating at dissection a single-fascicled ATFL that is indeed pathological, and should not be reported as a variation but excluded from the study.

The presence of the LFTCL complex is the basis that may explain the fact that an isolated repair of the ATFL has excellent results in the treatment of chronic ankle instability even when an injury of both the ATFL and CFL exists. Although in the present study no lateral ligament repair was performed, Lee et al have reported the biomechanical benefits of an isolated ATFL repair finding no differences between open and all-inside arthroscopic techniques in terms of torque to failure, degree to failure or working construct stiffness [12]. This has been supported clinically by the literature, and patients with chronic ankle instability undergoing isolated ATFL repair have shown excellent results at follow-up [13,16]. On the basis of these findings, the authors also hypothesize that aggressive soft tissue dissection during surgery that would disrupt the arciform fibers could disconnect both ligaments requiring each ligament to be repaired or reconstructed individually in the case they were both torn. From a clinical point of view, an injury of the LFTCL complex, either complete or partial, would result in an unstable ankle.

The so-called anatomical repair (Brostrom procedure) includes repair of the injured structures i.e. ATFL and CFL with the possible addition of the inferior extensor retinaculum plication (Gould augmentation). This concept was transferred to modern arthroscopic ligament repair techniques and in some instances only the ATFL is addressed [26]. This study suggests that despite repairing only the ATFL the procedure is in fact a truly anatomical repair as it indirectly addresses all the injured structures (ATFL and CFL) because the CFL has anatomical continuity with the inferior fascicle of the ATFL due to the presence of the arciform fibers.

This study is limited by the fact that a relatively small number of specimens were included. An evaluation of a larger series would certainly improve the validity of the study. Another limitation of our study lies in the intrinsic difficulty of dissecting this anatomic area, although all the dissections were performed by an anatomist highly experienced in the plane-by-plane dissection technique to try and replicate the genuine anatomy. The arciform fibers connecting the inferior ATFL fascicle and CFL are sometimes poorly defined, and it may be possible to inadvertently remove part of this structure. Nevertheless, given that in the present study the LFTCL complex has been found in 100% of the cases it is certain that care taken during dissection technique has successfully avoided overdissection [5]. Finally, histological and mechanical characteristics of the arciform fibers were not studied in the present study and warrant future investigation with regards to their function. Also, ankles without laxity were used for this study to describe the normal anatomy of the lateral ligament complex which may differ slightly in pathological cases.

The clinical relevance of this study is that the superior fascicle of the ATFL is anatomically a distinct structure from the inferior ATFL fascicle and it is in turn functionally different. The superior fascicle is an intra-articular ligament, that will most probably not be able to heal after a rupture, explaining why it is so frequent for patients to have chronic symptoms after an ankle sprain, especially if an isolated rupture of this fascicle is present. The inferior ATFL fascicle and the CFL are isometric ligaments but the superior ATFL fascicle is not. In addition, the inferior ATFL fascicle is connected to the CFL by arciform fibers, forming a ligament complex, the LFTCL complex. As discussed above, this has implications in the etiopathology of ankle sprains and chronic instability as well as in the surgical treatment of these; in addition, development of clinical tests to assess an isolated injury of ATFL's superior fascicle is necessary, as this will become one of the basis in ankle sprains diagnostics.

Conclusions

The superior fascicle of the ATFL is an intra-articular and a distinct anatomical structure, whereas the inferior ATFL fascicle and the CFL share some features being both isometric and extra-articular ligaments, having a common fibular insertion, and being connected by arciform fibers. Because of these anatomical and dynamic characteristics, the inferior ATFL fascicle, the CFL and the connecting arciform fibers form, as a whole, a functional and anatomical entity, and its injury should be diagnosed as two different entities. This has been described in the current study for the first time and has been named the lateral fibulotalocalcaneal ligament complex of the ankle.

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