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The Anatomy and Function of the Individual Bands of the Deltoid Ligament—and Implications for Stability Assessment of SER Ankle Fractures

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Abstract

Background: Deltoid ligament injury occurs often with supination-external rotation (SER) ankle trauma. SER fibula fractures with concomitant deltoid ligament injury are considered unstable—requiring operative fixation. Recent studies have questioned this general practice with emphasis on better defining the medial side ankle ligamentous injury. The function of the individual bands of the deltoid ligament, and the interplay between them, are not fully understood. We undertook this study to develop a better understanding of these complex ligamentous structures and ultimately aid assessment and treatment choice of SER ankle fractures with concomitant deltoid ligament injuries.

Methods: Ten fresh-frozen cadaveric foot and ankle specimens were studied. We identified the various ligament bands and did a functional analysis by assessment of ligament length and tension at predefined angles of ankle dorsi-plantarflexion combined with valgus/varus and rotation. The results were determined by manual evaluation with calipers and goniometers, manual stress, and direct visualization.

Results: We recorded primarily 5 different bands of the deltoid ligament: the tibionavicular (TNL; 10/10) tibiospring (TSL; 9/10), tibiocalcaneal (TCL; 10/10), deep anterior tibiotalar (dATTL; 9/10), and deep posterior tibiotalar (dPTTL; 10/10) ligaments. The tibiospring ligament was tense in plantarflexion, while the tibiocalcaneal and deep posterior tibiotalar ligaments were tense in dorsiflexion. The superficial layer ligaments and the deep anterior tibiotalar ligament length and tension were largely affected by changes in varus/valgus and rotation. The deep posterior tibiotalar ligament length and tension was altered predominantly by changes in dorsi-plantarflexion; varus/valgus positioning had a minor effect on this band.

Conclusions: We confirmed the finding of previous studies that dorsi-plantarflexion affects the tensile engagement of the separate ligament bands differently. Likewise, combined movements with varus/valgus and rotation seem to affect the separate ligament bands differently. Our results suggest that the TNL, TSL, and dATTL are at risk of injury, whereas the TCL and particularly the dPTTL are protected in the event of an SER-type ankle fracture mechanism of injury.

Level of Evidence: Level V, cadaveric study.

Keywords: medial ankle stability, deltoid ligament function, ankle fracture

Introduction

Evaluating function of the deltoid ligament is of key importance when assessing stability of SER fibula fractures.[6,7,12,16,19,21] Traditionally SER fibula fractures with indications of deltoid ligament injury have been considered unstable, and in need for operative fixation[6,7,12,19,21] As shown in recent clinical studies, what is assumed to be complete deltoid ligament tears (SER4b) seem rare with SER fractures, while assumed partial deltoid ligament tears (SER4a) seem to be common.[7,19] It has been theorized that this is because specific components of the deltoid ligament are at risk, and others protected, in SER injury mechanisms.[6-8] Authors have demonstrated that this can influence choice of treatment in these fractures.[6-8]

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Abundant studies have documented the anatomical topographical characteristics of the individual deltoid ligament bands,[1,2,4,5,15,23] but the literature remains unclear about which bands are always present and which are variably present.[1,10,14] Although it is accepted that the deltoid ligament is the primary stabilizing structure in keeping the tibia stable over the talus,[9,18,24] the individual functional roles of the ligament bands are still not fully understood.[22] Clinical and experimental data has led to consensus that the deep layer is the primary stabilizer of the tibiotalar joint, while the superficial layer predominantly stabilizes the subtalar and talonavicular joints.[5,6] Thus, the deep layer is more important when determining the talus stability within the ankle mortise in the event of SER fibula fractures. Deltoid ligament function during physiological dorsiflexion and plantarflexion is previously documented.[3,22] To date, no data exist about the effect of complex movement and ligament stress in all 3 planes. Also, previous studies of the function of the deltoid ligament bands were primarily directed at improving surgical reconstruction techniques.[2,4,20] Adding to the results of previous studies, and relating our results to deltoid ligament injury in SER fractures, may give the surgeon a better understanding of how to examine the patient and determine whether operative treatment is necessary.

The aim of this study is to investigate implications of the SER injury mechanism to the strain of the medial ankle ligaments. We identified the various ligament portions and conducted a functional analysis in cadaveric ankle specimens. The function of the individual ligament bands was analyzed by assessment of ligament length and tension. Because these injuries presumably come from a supination position of the foot (involving plantar flexion of the ankle joint) and external rotation of the talus relative to the tibia and fibula, the effect of these positions on the ligament tensile status was the primary focus in our analysis.

Materials and Methods

Approval from the Regional Comittee for Medical and Health Research Ethics (reference 178067) was obtained before conducting the study.

Ten fresh-frozen human cadaveric foot and ankle specimen (mid crus to toe-tip) (Science Care, Phoenix, AZ, USA) were acquired for this study. Three were female (30%) and 7 were men, with 5 (50%) right and 5 left ankles, respectively. The average age at death was 83 years (range 75-90). No specimen had a recorded medical history of injury or hardware/scars that indicated surgery of the ankle or hindfoot. All specimens were stored at −23 °C and thawed for at least 12 hours before dissection and testing.

Figure 1 displays an example of specimen dissection. In all specimens, a 10 × 10-cm window was established where skin and subcutaneous fat were removed. Subsequently, the flexor retinaculum was opened and the flexor digitorum longus and tibialis posterior tendons were identified and released. We then identified the deltoid ligament structures originating from the anterior and posterior colliculus of the medial malleolus and inserting onto the navicular, talus, and calcaneus. The individual bands were identified based on their origins and insertions and marked with colored sutures according to a predefined color code. The foot was positioned plantigrade on a firm table. To achieve a stable mounting of the specimens during testing, the calcaneus was secured using a vice (Biltema, Jessheim, Viken, Norway) which was fixed to the table, while the forefoot was secured manually.

Anatomical Measurements

After isolation of the individual bands, we descriptively determined their origins and insertions. Subsequently quantitative data were recorded. The length, width, and thickness of each band were measured with a digital caliper (Vogel Digi plus, Kevelaer, North Rine-Westphalia, Germany) in neutral position of the ankle joint in all planes. The width was measured at the origin (most proximal), midpoint, and insertion (most distal) of each band. The thickness was measured at the midpoint. The method of obtaining length measurements is described in the next section.

Functional Evaluation

First, 1.6-mm K-wires with a threaded tip were drilled centrally in the origin and insertion of the ligament band to be evaluated. The distance between the ligament origin and the insertion (outside to outside of the K-wires) was recorded in millimeters using a digital caliper (Vogel Digi plus). Origin-insertion distance was measured in neutral (all planes), with manual varus/valgus and internal/external rotation (of the foot relative to the tibia and fibula) force applied in 3 talocrural joint sagittal plane positions: 0 degrees of dorsiflexion, 10 degrees of dorsiflexion, and 10 degrees of plantar flexion. Because of a fixed foot, the leg was moved to simulate flexion, rotation, and varus-valgus position of the foot. Alignment in the sagittal plane was secured using a universal goniometer (Gymo Kaeu, Norway). A second examiner

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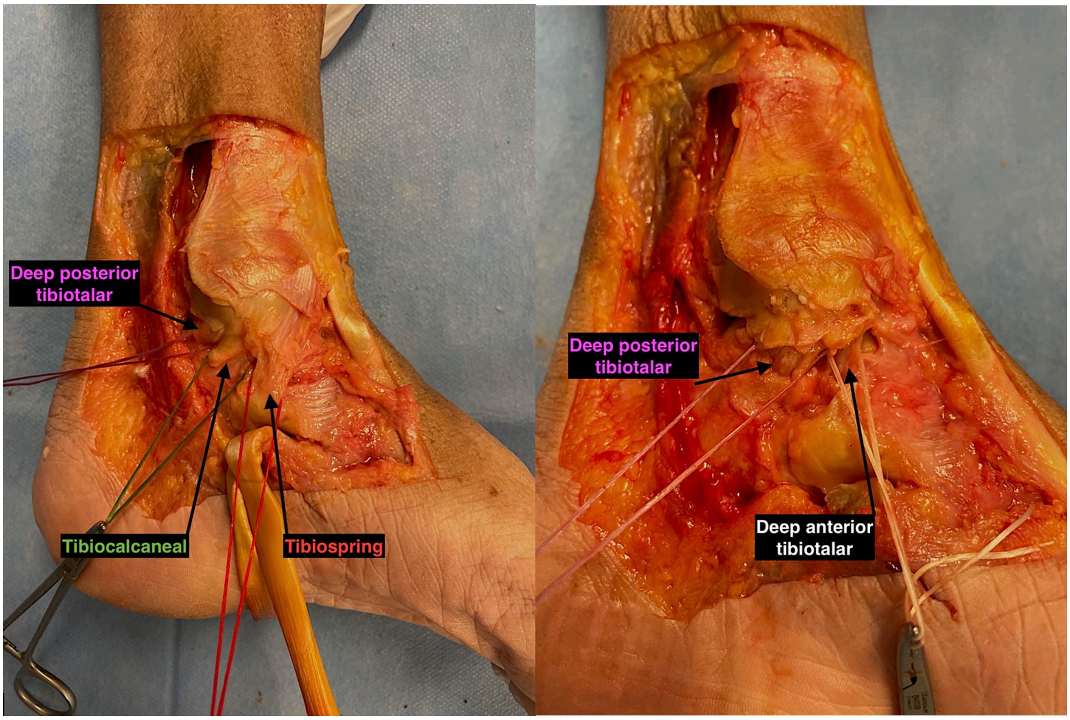

Figure 1. Example of specimen dissection.

Table 1. Anatomical Measurements of the Tibiospring, Tibiocalcaneal, Deep Anterior Tibiotalar, and Deep Posterior Tibiotalar Ligaments in 10 Cadaver Ankle Specimens.

	Tibiospring	Tibiocalcaneal	Deep Anterior Tibiotalar	Deep Posterior Tibiotalar
Width, mm, mean (SD)				
Origin	9.2 (2.4)	8.1 (2.1)	7.9 (2.8)	11.2 (2.3)
Midpoint	8.6 (2.0)	8.4 (1.9)	7.6 (2.7)	10.3 (2.4)
Insertion	12.6 (2.3)	11.1 (1.7)	7.9 (2.8)	10.9 (2.4)
Mean thickness at midpoint, n				
<1 mm	–	–	5	–
1-2 mm	10	9	4	–
>2 mm	–	1	1	10

applied a manual axial load of approximately 5 kilograms through the leg during testing. The primary outcome for the functional evaluation was origin-insertion distance in the 3 sagittal plane positions when no force was applied (neutral), and origin-insertion distance change when varus/valgus and internal-/external rotation forces were applied. An increase of origin-insertion distance indicated tightening of the ligament, whereas a decrease indicated loosening. In addition, we performed a subjective assessment of ligament tension in all test positions using a hook. Tension was graded as tight, neutral, or loose and recorded as 1, 0, or −1, respectively, for the purpose of quantifying the outcomes. Measurements and testing of ligaments were done by 2 observers (skilled surgeons).

IBM SPSS Statistics, version 27, was used for all statistical analysis.

Results

We recorded 5 different bands of the deltoid ligament. All specimens had a deltoid ligament consisting of a superficial and deep layer. Three ligament bands were apparent in all specimens: the tibiospring, tibiocalcaneal, and deep posterior tibiotalar ligaments. The tibionavicular and the anterior tibiotalar ligaments were apparent in all but 1 specimen. We did not note the presence of a superficial posterior tibiotalar ligament in any specimen.

Anatomical measurements are listed in Table 1.

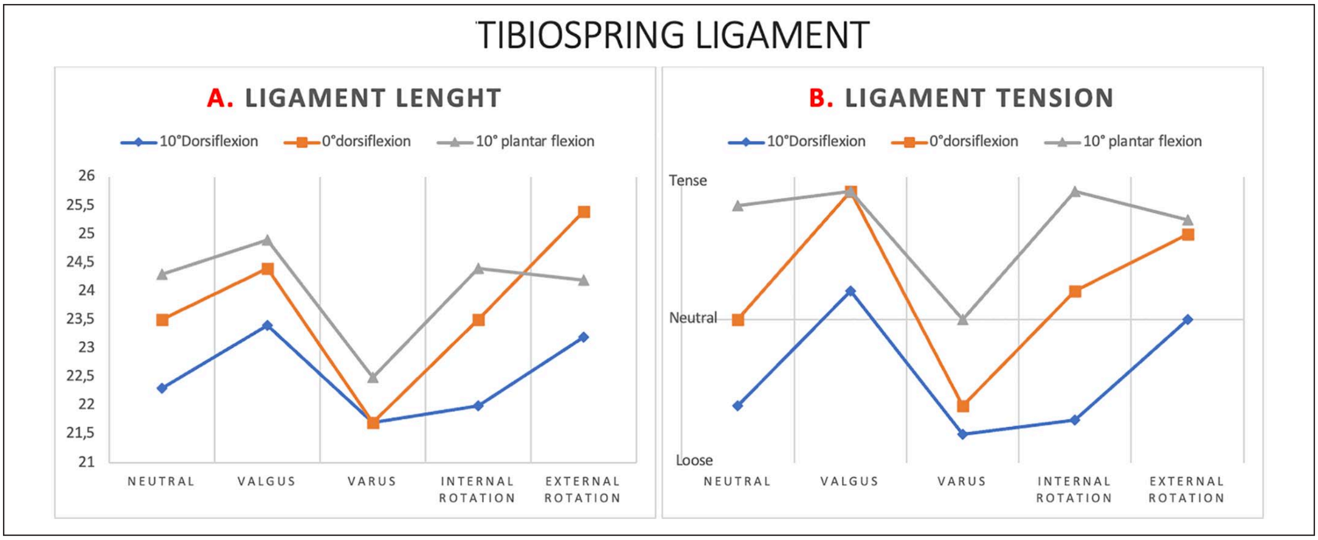

Figure 2. Results of functional evaluation for the tibiospring ligament. (A) Mean measured origin-insertion distance in millimeters (*y* axis) when neutral, varus/valgus, and rotation forces were applied (*x* axis). (B) Mean subjective assessment of ligament tension (*y* axis) when neutral, varus/valgus, and rotation forces were applied (*x* axis). (N = 10)

Tibionavicular Ligament

We recorded fibers corresponding to the course of a TNL in all but 1 specimen. These fibers constituted the most anterior part of the superficial layer of the deltoid ligament. The TNL-corresponding fibers originated from the anterior aspect of the anterior colliculus, then spread fan-shaped to its insertion on the dorsomedial part of the navicular. In 4 specimens, we recorded fibers inserting also to the medial collum tali.

When qualitatively assessing TNL tension, we recorded that the ligament was loose in all test positions and specimens. We noted no tension in the TNL-corresponding fibers until approximately 20 degrees of plantarflexion of the ankle.

Tibiospring Ligament

The TSL was identified in all 10 specimens. It originated from the anterior colliculus, just posterior and proximal to the tibionavicular origin. The TSL inserted at the posterior third of the spring ligament.

Figure 2 presents the functional evaluation of the TSL.

Tibiocalcaneal Ligament

The tibiocalcaneal ligament (TCL) was identified in all 10 specimens. It originated from the most posterior aspect of the anterior colliculus and the anterior aspect of the intercollicular groove. In all specimens, the TCL inserted onto the posterior aspect of the sustentaculum tali on the calcaneus. In 9 of 10 specimens, the TCL had a bifurcate distal course, where some fibers inserted onto the posteromedial process of the talus, just proximal to the subtalar joint.

Figure 3 presents the functional evaluation of the TCL.

Deep Anterior Tibiotalar Ligament

The dATTL was identified in 9 of 10 specimens (90%). The dATTL originated from the anterior colliculus of the medial malleolus immediately deep to the TSL and inserted onto the proximal medial body of the talus.

Figure 4 presents the functional evaluation of the dATTL.

Deep Posterior Tibiotalar Ligament

The dPTTL was identified in all 10 specimens. It was the thickest and largest individual ligament in all specimens. The dPTTL was located deep to the TCL with a broad origin extending from the center of the intercollicular groove and covering most of the posterior colliculus. The dPTTL inserted onto the superoposterior aspect of the medial talus close to the articular cartilage. The thickness of the dPTTL was more than 3 mm in all specimens.

Figure 5 presents the functional evaluation of the dPTTL.

Discussion

The aim of this study was to investigate the anatomy and functional role of individual ligament bands of the deltoid ligament related to the injury of specific bands in the event of SER injury mechanisms. We assessed ligament length and the tensile status at predefined angles of dorsi-plantarflexion and with valgus/varus and rotation forces applied.

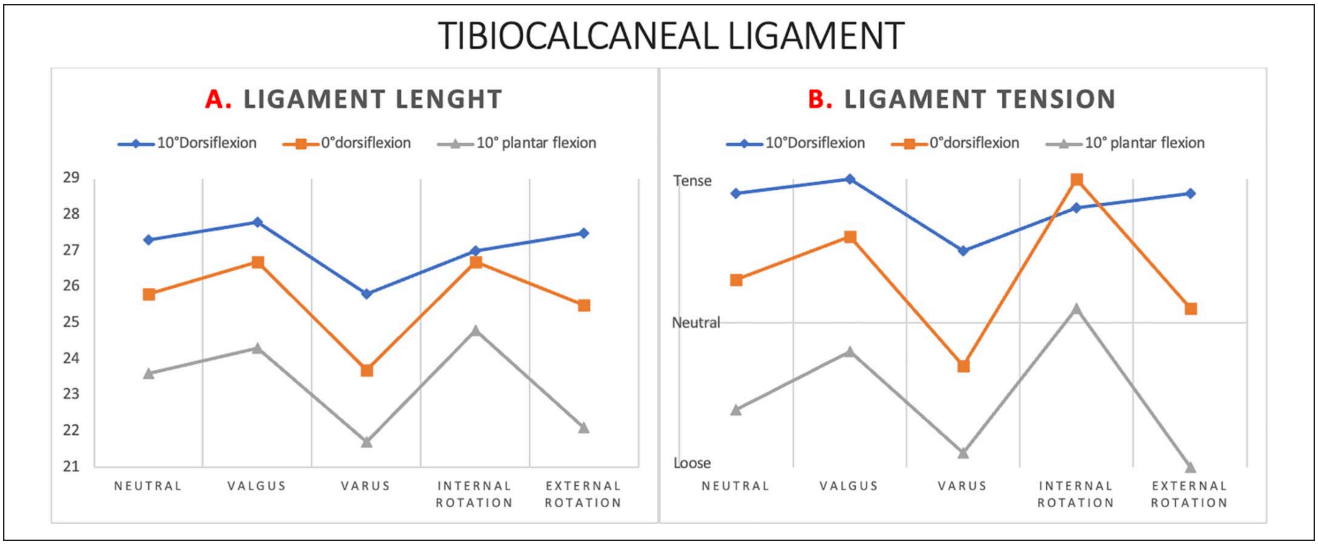

Figure 3. Results of functional evaluation for the tibiocalcaneal ligament. (A) Mean measured origin-insertion distance in millimeters (*y* axis) when neutral, varus/valgus, and rotation forces were applied (*x* axis). (B) Mean subjective assessment of ligament tension (*y* axis) when neutral, varus/valgus, and rotation forces were applied (*x* axis). (N = 10)

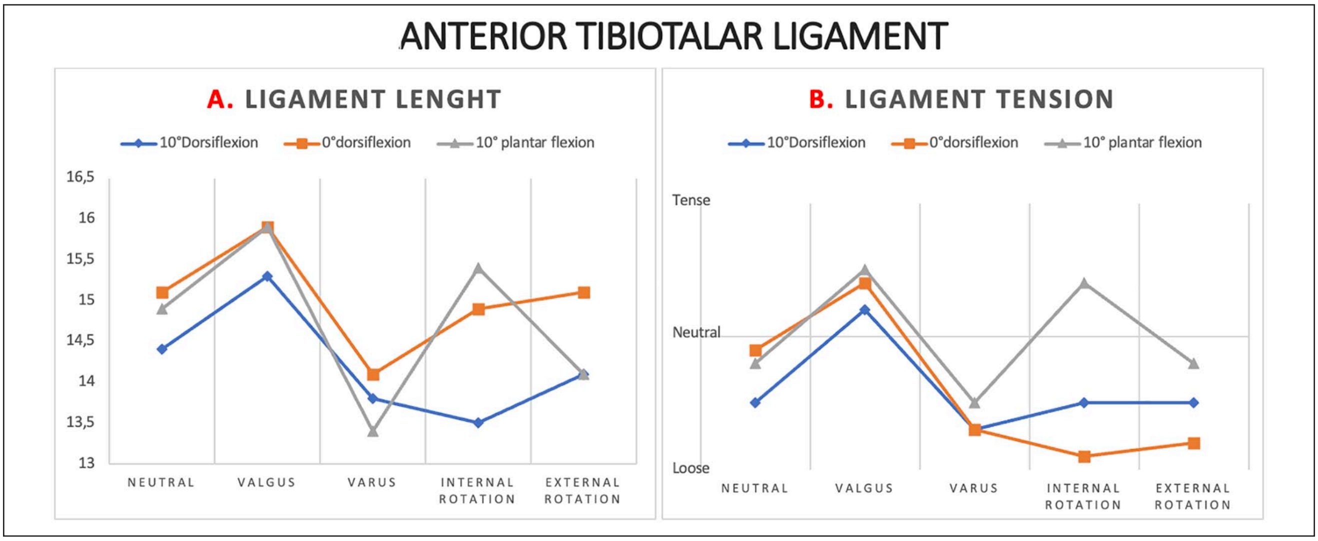

Figure 4. Results of functional evaluation for the anterior tibiotalar ligament. (A) Mean measured origin-insertion distance in millimeters (*y* axis) when neutral, varus/valgus, and rotation forces were applied (*x* axis). (B) Mean subjective assessment of ligament tension (*y* axis) when neutral, varus/valgus, and rotation forces were applied (*x* axis). (n = 9)

The most important results of this study were that dorsi-plantarflexion, but also varus/valgus or rotation, affects the tensile engagement of the separate ligament bands differently. We found that the TSL provides stability (is tense) in plantarflexion, whereas the TCL and dPTTL provide stability (are tense) in dorsiflexion. The dATTL length and tensile status was less affected by changes in dorsi-plantarflexion. Combined movements with valgus/varus or rotation predominantly altered ligament length and tension of the superficial layer ligaments and the dATTL, whereas length and tension of the dPTTL, conversely, was less affected by combined stress with valgus/varus or rotation.

Identification of the ligamentous structures was found to largely agree with commonly accepted descriptions.[1,2,13,14] However, we did not note the presence of a superficial posterior tibiotalar ligament in any specimen of this study. This is in contrast to most previous studies that have identified a superficial component of the posterior tibiotalar ligament in approximately 80% of cases.[23] Also, most previous literature refers to the TNL as an individual ligament, and fibers

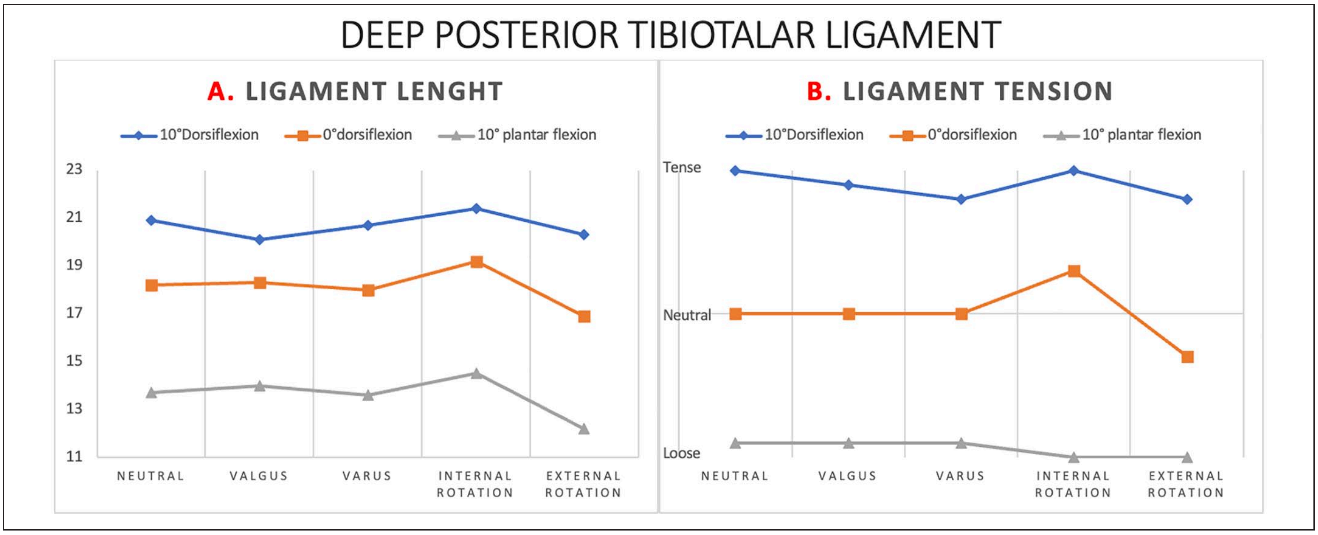

Figure 5. The figure gives a presentation of the results of functional evaluation for the deep posterior tibiotalar ligament. (A) Mean measured origin-insertion distance in millimeters (*y* axis) when neutral, varus/valgus, and rotation forces were applied (*x* axis). (B) Mean subjective assessment of ligament tension (*y* axis) when neutral, varus/valgus, and rotation forces were applied (*x* axis). (N = 10)

corresponding to TNL seem constant in our study and previous anatomical studies.[2,14] However, based on our investigation we would argue not to describe the TNL as a separate ligament because of difficulties separating these delicate fibers from the joint capsule. Our study is not the first to disregard the TNL as a separate ligament band of the deltoid ligament. Boss and Hintermann[1] described the TNL as a thickening of the joint capsule rather than a separate ligament. We found that the TNL was never tense in any tested position. Interestingly, a recent study reported that the TNL begins to tense gradually at increasing angles of plantarflexion after 10 degrees,[22] which corresponds well with our findings.

Comparing our results regarding ligament length with subjective tensile status revealed a large degree of covariation. Figures 2 to 5 shows that increased length covariates with higher ligament tension. Our results show that the TSL and the dATTL were tense in plantarflexion. The dPTTL and the TCL seemed to provide stability in dorsiflexion. Interestingly, the dPTTL was fully tense in all tested positions in dorsiflexion, while completely loose in all tested positions in plantarflexion. Two previous studies have investigated the function of individual ligament bands of the deltoid ligament.[3,22] Takao et al[15] tested ligament bands of the superficial layer, showing that the TNL and TSL becomes tighter at increasing angles of plantarflexion, whereas the TCL and the superficial posterior tibiotalar ligament becomes tenser at increasing ankles of dorsiflexion. Cao et al[3] reported similar results. Also evaluating the deep layer bands, Cao et al[3] found that the dATTL elongated at increasing ankles of plantarflexion and the dPTTL at increasing angles of dorsiflexion. Our results were largely consistent with the findings of those previous studies. Further, our study adds to previous evidence in that we evaluated the function of the ligaments in combined ankle movements about all planes. We have demonstrated that in the superficial layer ligaments, and the deep anterior tibiotalar ligaments, length and tension was affected by changes in varus/valgus and rotation. The TSL got tenser in positions with external rotation. Interestingly, the dPTTL differed from the others in that length and tension was altered predominantly by changes in dorsi-plantarflexion, whereas combined positions with varus/valgus or rotation led to minor changes. Of note, external rotation led to some loosening of the dPTTL in all tested angles of dorsi-plantarflexion.

Assessment of when ligaments are tense or loose is indicative of their normal stabilizing function, but is also suggestive of the potential for ligament damage during certain mechanisms of injury. In acute ankle injuries, injury to ligaments occurs because of excessive strain. Because these injuries presumably come from excessive external rotation of the talus relative to the tibia and fibula when the foot is in a supination position (involving plantar flexion of the ankle joint), the effects of dorsi-plantarflexion and rotations on the ligament tensile status are primarily discussed. Our results support that the TNL, TSL, and dATTL are at risk of injury (because they are tense), whereas the TCL and particularly the dPTTL are protected (because they are loose) when the ankle is plantarflexed with combined external rotation. This may be part of the reason why complete deltoid ligament tears (SER4b) seem rare with SER fractures, whereas partial deltoid ligament tears (SER4a) seem to be common.[7,19] Which specific individual deltoid ligament bands are intact or injured in SER ankle fractures with partial deltoid ligament injury is currently not known. However, authors have proposed theories that both the superficial and the dATTL are damaged whereas the dPTTL is intact in SER4a fractures.[6]

Several previous studies have reported the dPTTL as the largest and most consistently found individual ligament band of the deltoid ligament.[1,2,13,14] This suggests that the dPTTL is a primary medial stabilizer of the talocrural joint. Our finding adds to this by showing that the dPTTL is a stabilizer (as it is tight) in all tested directions at 10 degrees of ankle dorsiflexion, whereas the dPTTL provides no stability (as it is loose) in all tested directions at 10 degrees of plantar flexion. Accordingly, to assess the integrity of the dPTTL, it is mandatory to use methods where the ankle is put in a neutral position to dorsiflexion during testing. The findings of this study would therefore support that stability assessment with the use of weightbearing radiographs is a more valid method for evaluating dPTTL integrity compared to methods such as manual- or gravity stress tests, where angles of plantarflexion are not necessarily controlled for. The understanding gained in this study may also be useful clinically when determining treatment algorithms for SER4a fractures with partial deltoid ligament rupture. According to recent studies, SER4a injuries can be treated nonoperatively.[11] However, there is no evidence supporting one method of nonoperative treatment over another for this fracture type. Some authors argue for cast immobilization whereas others have shown good outcomes with orthoses.[6,7,19] The argument for cast immobilization appears to be fear that treatment involving movement and plantar flexion may result in the injured ligament portions healing “long,” leading to instability and possible increased risk of posttraumatic arthritis.[6] Based on the findings of this present study, and other studies,[3,22] one could argue that the ankle should be kept neutral or dorsiflexed to obtain optimal healing conditions for the superficial layer ligaments and the dATTL after injury. Thus, our results are supportive of cast treatment.

We acknowledge some weaknesses of this study. First, the components of the deltoid ligament are contiguous and difficult to differentiate. This leads to uncertainty when dissecting and recording the individual bands. Previous studies have discussed that the creation of the different fibers may be artificial.[1,5,15,17] This may well be the reason for anatomical inconsistencies and may affect the conclusions of this study. Another concern is that exposure of the dATTL and dPTTL requires excision of the superficial deltoid. It has been pointed out in other studies that excision of the superficial layer may affect the results.[22] However, using our measurement method, one cannot measure the deep layer ligaments without removal of the superficial layer ligaments. Also, the present investigation was based on manual measurements obtained by 2 orthopaedic surgeons. In the absence of inter- and intrarater reliability analyses, the degree of measurement error is unknown and represents some level of uncertainty about accuracy of the results. We recommend that functional testing with precise measuring devices would need to be performed to potentially verify the observations of this study. However, the results of this study may contribute a theoretical framework for planning future studies using more advanced methods for measurement.

Conclusions

We confirmed the finding of previous studies that dorsi-plantarflexion affects the tensile engagement of the separate ligament bands differently. Likewise, combined movements with varus/valgus and rotation seem to affect the separate ligament bands differently. Our results suggest that the TNL, TSL, and dATTL are at risk of injury, whereas the TCL and particularly the dPTTL are protected in the event of an SER-type ankle fracture mechanism of injury.

Ethical Approval

Ethical approval for this study was obtained from the Regional Committee for Medical and Health Research Ethics (ID 178067).

Declaration of Conflicting Interests

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