The anatomy of the ankle (talocrural) joint is complex and detailed knowledge of the ligaments that stabilize this joint is clinically important for the effective treatment of traumatic ankle injuries. Nearly 14,000 people are diagnosed with ankle fractures in the United States each day. Excessive foot eversion can tear the medial collateral ligament, also called the deltoid ligament (DL), of the ankle and accounts for 10-15% of ankle sprains. Advanced imaging studies and arthroscopy have increased the diagnosis of DL tears in complex ankle injuries, which may have otherwise been missed during the history and physical examination. A literature review was conducted to compare our data to those of previous studies.

The DL should always be considered when evaluating a supination-external rotation (SER) fracture, which is the most common type of ankle fracture. According to the Lauge-Hansen classification system, the more advanced stage of a SER fracture involves fracture of the medial malleolus, DL tear, or both. Along with tearing of the DL, degeneration or attenuation of this ligament is found in the most advanced stage of adult-acquired flatfoot deformity, which leads to a valgus talar tilt. The ligaments of the medial ankle should also be evaluated when assessing the lateral ligaments in patients with lateral ankle instability. Some cases where both ligaments are torn may necessitate operative repair to re-establish ankle stability but this operative approach is not universally accepted. A recent, evidence-based update on orthopedic operative research of the ankle and foot frequently mentioned the DL, which underscores the importance of the anatomy of the DL in relation to ankle stability and unstable Type-IV SER fractures with concomitant tears of the DL.

Keywords: anatomy, deltoid ligament, medial collateral ligament, surgery, morphology
Most authorities agree that the DL is composed of superficial and deep layers.\textsuperscript{6,12,13,28} Despite the anatomic, clinical, and operative relevance of the ligamentous bands of the DL, there is conflicting evidence and no consensus in the literature regarding the number and morphology of these bands.\textsuperscript{1,2,20,21} The DL is a strong stabilizer of the ankle and along with the more distal termination of the lateral malleolus, restricts excessive eversion of the foot.\textsuperscript{27,28} Anatomical texts and previous cadaveric studies reported that the DL is composed of 5 to 6 distinct bands, along with variations.\textsuperscript{1,3,20,21,24}

The purpose of this cadaveric study was to describe the morphology and variations of the DL to reach an evidence-based consensus about its constituent ligamentous bands. These data should help surgeons better evaluate and manage ankle fractures. The number of ligamentous bands is not consistently reported in anatomy textbooks\textsuperscript{1,24,28} and the paucity of information on the DL was reported by studies with small sample sizes. Like clinical practice, modern anatomic research employs more sophisticated technology (eg, use of a digital caliper to obtain precise measurements) and statistical methods to analyze data. This is in stark contrast to anatomic studies in the past that were usually descriptive in nature and devoid of inferential statistics.

Materials and Methods

To examine the ligamentous architecture of the DL, blunt and sharp dissections were performed on 33 ankles from 17 formalin-fixed cadavers with a mean age at death of 76.6 years (range, 55-103 years). Seventeen right ankles and 16 left ankles were dissected from 8 male and 9 female cadavers. Ankles with trauma or a previous history of surgery were excluded from the study, assessed by the presence of operative scars or gross lower limb deformities. All structures superficial to the DL (tendons, muscles, vessels, and adipose tissue) were removed using a sharp-dissection technique by removing any fat plugs interposed between the superficial and deep layers, and the different bands.\textsuperscript{17} After the bands were isolated, we recorded the number of bands in each ankle. The length, width, and thickness of each band was measured with a digital caliper (Hawk, Inc, Cleveland, OH) and recorded. The length was measured from the most proximal attachment to the most distal attachment. The width and the thickness were measured at the midpoint of each band.

Statistical analyses were performed using SPSS for Windows version 22.0 (IBM; Armonk, NY). The average values of the left and right feet measurements were calculated, and were used in the analysis. The Mann–Whitney U test for independent samples and Wilcoxon signed-rank test for dependent samples were respectively used to assess differences between sexes, and between right and left limbs. Spearman rho correlation coefficient was obtained to estimate the association between age and measurements. A P value of less than .05 was considered statistically significant.

Results

We found 8 different bands of the DL. Six of 8 bands (anterior tibiotalar ligament, tibionavicular ligament, tibiocalcaneal ligament, fibers to spring ligament, superficial posterior tibiotalar ligament, and deep posterior tibiotalar ligament) were more frequently encountered than the 2 additional variants (band deep to tibiocalcaneal ligament and band posterior to sustentaculum tali). All ankles (100%) had a DL that consisted of superficial and deep layers. An anterior tibiotalar ligament, tibionavicular ligament, tibiocalcaneal ligament, fibers to spring ligament, superficial posterior tibiotalar ligament and deep posterior tibiotalar ligament were observed bilaterally in 13, 13, 15, 5, 15, and 16 cadavers, respectively. The band deep to tibiocalcaneal ligament and band posterior to sustentaculum tali were found unilaterally on the left foot (n = 2 and 1, respectively) and on the right foot (n = 2 and 1, respectively). In 1 of the examined cadavers, only the right foot was available for dissection.

From anterior to posterior, the superficial layer of the DL consisted of the following bands: tibionavicular ligament (TNL), fibers to spring ligament (FSL), tibiocalcaneal ligament (TCL), and superficial posterior tibiotalar ligament (sPTTL) (Figure 1).

Tibionavicular Ligament

The proximal attachment of the TNL was the anterior aspect of the medial malleolus and the distal attachment was the dorsomedial aspect of the navicular. Due to its close proximity to the ankle joint capsule, the TNL was difficult to separate entirely from the capsule, but was isolated in 29 of 33 (89%) ankles. We found that the TNL was, on average, the longest of the 8 bands (mean length, 36.9 mm).

Fibers to Spring Ligament

The proximal attachment of the FSL was between the TCL and TNL proximal attachments, and the distal attachment was the superior aspect of the spring ligament. Although the FSL was difficult to separate from the TCL and TNL, we were able to carefully separate and measure it in 15 of 33 (46%) ankles.

Tibiocalcaneal Ligament

The proximal attachment of the TCL was the medial aspect of the medial malleolus and the distal attachment was the superior aspect of the sustentaculum tali. The TCL was found in 31 of 33 (94%) ankles. The TCL and TNL shared fibers with the FSL.
Superficial Posterior Tibiotalar Ligament

The proximal attachment of the sPTTL was the posteromedial aspect of the medial malleolus and the distal attachment was the superoposterior aspect of the talus. The sPTTL was found in 32 of 33 (97%) ankles.

The deep layer of the DL consisted of the anterior tibiotalar ligament (ATTL) and deep posterior tibiotalar ligament (dPTTL) (Figure 2).

Anterior Tibiotalar Ligament

The proximal attachment of the ATTL was the anteromedial aspect of the medial malleolus inferior to the FSL proximal attachment and the distal attachment was the superoanterior aspect of the talus. The ATTL was found in 30 of 33 (86%) ankles.

Deep Posterior Tibiotalar Ligament

The dPTTL was immediately deep to the sPTTL and shared similar proximal and distal attachments with the sPTTL. The dPTTL was found in all 33 (100%) ankles. This band was the widest (mean width 10.4 mm) and thickest (mean thickness 0.6 mm) of the 6 common bands we dissected.

We found 2 rare variant bands of the DL. The first was a deep-layer band located immediately deep to the TCL and we called this the deep to tibiocalcaneal ligament (dTCL) band and the second was a superficial-layer band located posterior to the sustentaculum tali (PST).
Deep to Tibiocalcaneal Ligament

This band, part of the deep layer of the DL, was located between the ATTL and dPTTL (see Figure 2). The proximal attachment of this band was between the ATTL and dPTTL proximal attachments (distal tip of the medial malleolus) and the distal attachment was the superomedial aspect of the talus between the ATTL and dPTTL distal attachments.

Posterior to Sustentaculum Tali

The PST, part of the superficial layer of the DL, attached directly posterior to the sustentaculum tali on the medial surface of the calcaneus (Figure 3). This band shared a proximal attachment with the TCL and split after the TCL attached to the sustentaculum tali and coursed directly posterior to the sustentaculum tali to attach to the medial surface of the calcaneus.

Data related to the 6 common bands were further analyzed. TCL, sPTTL, and dPTTL were longer in males compared to females. No significant differences were found between the right and left sides with respect to the length, width and thickness of the 6 common bands (Wilcoxon signed-rank test, \( P > .1 \)). dPTTL became narrower with increasing age (Spearman rho = –.505, \( P = .046 \)). Age was not associated with any other measurements (\( P > .1 \)).

Discussion

According to Gray’s Anatomy, the DL is a triangular ligamentous complex that attaches the medial malleolus to multiple bony areas of the medial ankle and is composed of different bands located in superficial and deep layers.\(^{28}\) The superficial layer consists of the tibionavicular, tibiocalcaneal, and posterior tibiotalar ligaments, whereas the deep layer consists only of the anterior tibiotalar ligament.\(^{28}\) We found 8 distinct bands comprising the DL in 33 ankles. Six of these bands were consistently found and included the TNL, FSL, TCL, sPTTL, ATTL, and dPTTL. The TCL, sPTTL, dPTTL, and ATTL were reported as 4 distinct bands in previous cadaveric studies, but the TNL and FSL were not described as separate bands in all of them.\(^{3,20,21}\) Barnes described the appearance of the DL as sheet-like with a variable number of bands.\(^{1}\) Sarrafian reviewed the literature from 1822 to 1998 and reported 8 different described bands of the DL.\(^{24}\) These included the tibiocalcaneal ligament, tibionavicular ligament, anterior talotibial ligament, superficial posterior talotibial ligament, deep posterior talotibial ligament, fibers to spring (plantar calcaneonavicular) ligament, band deep to tibiocalcaneal that attached to the talus, and a band posterior to the sustentaculum tali.\(^{24}\) In 1979, Pankovich and Shivaram\(^{21}\) dissected 16 cadaveric ankles and reported that the superficial layer had 3 bands (naviculotibial, calcaneotibial, and superficial talotibial ligaments) and the deep layer had 2 bands (deep anterior talotibial and deep posterior talotibial ligaments).\(^{21}\) The authors stated that the superficial layer attached to the navicular, spring (plantar calcaneonavicular) ligament, and the sustentaculum tali, but they did not consider the fibers to the spring ligament as a separate band.\(^{21}\) Milner and Soames performed a similar study on 40 cadaveric ankles and described 6 different bands.\(^{20}\) Three bands (tibiospring, tibionavicular, and deep posterior tibiotalar ligaments) were present in all of the ankles.\(^{20}\) The superficial posterior tibiotalar, tibiocalcaneal, and deep anterior tibiotalar ligaments were considered additional bands because they were not present in all ankles.\(^{20}\) However, the authors were not able to find a common pattern in the various bands. In their cadaveric study of 12 ankles, Boss and Hintermann found that the superficial layer consisted of the tibiospring, tibiocalcaneal, and superficial posterior tibiotalar ligaments, whereas the deep layer consisted of the anterior...
deep tibiotalar and posterior deep tibiotalar ligaments. Along with identification of these bands, the authors measured the length, width, and thickness of each band. They found that the tibiocalcaneal and tibiospring ligaments were the longest bands, and the tibiocalcaneal and posterior deep tibiotalar ligaments were the thickest.

Boss and Hintermann reported that the TCL and FSL were the longest bands. However, we found that the TNL was the longest, which is in agreement with Siegler et al., however the length of TNL was not statistically significant. We also found that the TNL was difficult to dissect because of its close proximity to the joint capsule, and therefore, we were unable to separate it in all the ankles but we did note its presence. The average lengths of TCL, sPTTL, and dPTTL were statistically significant. The FSL was not reported as a separate band by Pankovich and Shivaram because these authors considered that fibers to the spring ligament were part of the TNL. We found fibers attaching to the spring ligament in all ankles, but we were only able to separate them in 15. Many studies do not consider the FSL to be a separate band; however, its clinical relevance was noted by Siegler et al., who stated that the FSL provides a significant amount of stabilization to the ankle joint. These authors found that the FSL was the most resistant to strain and deformation compared to the other bands of the DL and they suggested that this finding could be due to its unique attachment to another ligament.

We found that the dPTTL was the widest (mean width 10.4 mm) and thickest (mean thickness 0.61 mm) band out of the 6 common bands, but not statistically significant. In their study, Boss and Hintermann reported that the TCL was the thickest band. However, in our study we found the dTCL to be the thickest (mean thickness 0.81 mm) band when comparing all of the bands collectively. This difference may be due to our large sample size compared to those in previous cadaveric studies.

The 2 variants (dTCL and PST) that we found were not reported in any of the 3 aforementioned cadaveric studies. Our large sample size allowed us to find both of these rare bands multiple times. The dTCL was found in 4 of 33 (12%) ankles. In his textbook, Sarrafian illustrated a similar band (reported by Yashar in 1961) but provided no other data or information. The PST was found in 2 of 33 (12%) ankles. In his textbook, Sarrafian illustrated a similar band (reported by Poirier in 1899 and Paturet in 1951) but provided no other data or information.

We believe these variant bands may have been overlooked in previous studies due to their close proximity to other ligamentous or non-ligamentous structures and the technical difficulty of the dissection. This underscores the continued importance of modern anatomic research that employs current technologies and analyses.

The clinical relevancy of knowing the variations of the DL becomes paramount when assessing the mechanism of ankle sprain or fracture. Each layer of the DL provides a specific supportive function to the ankle joint, and collectively, the bands of the DL prevent lateral subluxation of the talus in severe ankle fractures. Bands in the superficial layer prevent excessive eversion of the ankle, whereas those in the deep layer prevent axial rotation of the talus. Separate studies conducted by Earll et al., Harper, and Tornetta came to a similar conclusion that all of the bands are necessary to establish significant medial talar tilt. Few studies describe the importance of each layer, however, Tornetta noted that it was necessary to operatively fixate all fractured bony fragments that attached to the bands of the superficial and deep layers (where they attached to the medial malleolus) to ensure long-term stabilization of the ankle. Recently, Jeong et al conducted a magnetic resonance study to investigate the relationship between ankle fracture and DL tear and they found that 58.3% of patients with acute ankle injuries had tears of the superficial and deep ligaments of the DL. The operative finding by Tornetta suggests that each band provides support to the ankle joint. To prevent chronic ankle instability, repairing the proper stabilizing structures of the ankle joint requires thorough knowledge of these bands and all known variations. Therefore, our morphometric data can help orthopedic surgeons plan more accurate operative corrections to prevent long-term ankle instability. Many orthopedic surgeons now use minimally invasive approaches to minimize soft-tissue damage. Jeng et al. stated that reconstruction techniques for correcting stage IV adult-acquired flatfoot deformity was difficult due to the complex anatomy of the DL. These authors described a minimally invasive technique to reconstruct the DL along with triple arthrodesis to achieve better patient satisfaction and functional stability compared to triple arthrodesis alone.

Because acute ankle injuries are often associated with tears of the DL, during clinical evaluation the significant difference in the length of TCL, sPTTL, and dPTTL between males and females should aid in formulating an appropriate treatment strategy. However, age does not play a significant role in the measurement of the bands, but other age-related concerns for healing would be important.

Conclusions

This study contributes to an evolving understanding of the anatomy of the DL and its operative implications. Our robust sample enabled us to report more morphometrics of each band along with 2 rare variants. Each layer of the DL plays a critical role in establishing functional stability of the postinjury ankle. Future studies assessing functional stability after operative correction need to be conducted for a better evidence-based understanding of the anatomy of the DL and its constituent bands.
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References
2. Bluman EM. Deltoid ligament injuries in ankle fractures: should I leave it or fix it? Foot Ankle Int. 2012;33(3):236-238.