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The Attachment Sites and Attachment Areas of Deltoid Ligament Related to Clinical Implications: A Cadaveric Study

Los Sitios y las Áreas de Inserción del Ligamento Deltoideo Relacionadas con las Implicaciones Clínicas: Un Estudio Cadavérico

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SUMMARY: Currently, the treatment for patients with deltoid ligament injuries who require surgical treatment are anatomical repair and reconstruction. The clinicians should understand the exact knowledge of attachment areas of individual bands of deltoid ligament for a successful treatment. We studied 46 ankles of fresh frozen cadavers. The individual bands of deltoid ligament were divided to small fibers. Afterwards, each small fiber of each band was cut and marked with acrylic color on the origin and insertion followed by photo taking. Lastly, the photos of individual origin and insertion were used to calculate the attachment areas. We found six bands of deltoid ligament in all ankles except tibionavicular ligament. Moreover, we discovered deep to tibiocalcaneal and posterior to sustentaculum tali ligaments in 3 cases. Regarding the attachment area, the deep posterior tibiotalar ligament had the largest proximal and distal attachment areas which were 87.36±23.15 mm^2 and 88.88±24.24 mm^2, respectively. The anterior tibiotalar ligament had the least proximal and distal attachment areas which were 23.12±8.25 mm^2 and 33.16±14.63 mm^2, respectively. Hence, the accuracy and exact areas of attachment of deltoid ligament are important as it can help clinicians to select the suitable treatments including injury prevention.

KEY WORDS: Medial Collateral ligament of ankle joint; Deltoid ligament; Attachment area; Attachment site;

INTRODUCTION

The treatment procedures of deltoid ligament injury are both conservative and surgical treatments. Most acute deltoid ligament injury patients are also treated with conservative or non-operative treatment. However, the chronic patients including the ineffective conservative treatment and chronic instability medial ankle cases are treated with the surgical treatments which are repair or reconstruction. Currently, the concept of repair and reconstruction is based on the anatomical knowledge of deltoid ligament (Campbell *et al*., 2014; Wenny *et al*., 2015).

The anatomical document of deltoid ligament represents the origin and insertion from medial malleolus to navicular, spring ligament, talus and calcaneus bones (Milner & Soames, 1998). The function of deltoid ligament is primary stabilizing of medial side of ankle and restraint valgus tilting and anterior translation of talus (Michelson *et al*., 2004), restraint lateral translation and tibiotalocalcaneal joint complex stability (Gluck *et al*., 2010) including preventing lateral talar subluxation in ankle fracture case (Hogan *et al*., 2013). Deltoid ligament consists of two layers which are superficial and deep layers (Milner & Soames; Boss & Hintermann, 2002). The roles of superficial layer are maintaining talus and medial malleolus alignment including resisting external rotation of talus to tibia and valgus stress (Beals *et al*., 2010). The roles of deep layer are primary stabilizing of ankle to resist plantar flexion and secondary restraint external rotation, preventing lateral displacement, external rotation of talus (Jelinek & Porter, 2009) and axial rotation of talus (Harper, 1987).

Hence, the accuracy of anatomical knowledge of deltoid ligament is important and can help to select the suitable treatments. There are benefits for the restoration of the exact anatomy of deltoid ligament including an advantage for the clinician to apply with several injuries and surgery of ankle in a 0 suitable structure for preventing other injuries of any kind.

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MATERIAL AND METHOD

Forty-six fresh ankles, donated from Department of Anatomy, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand, were randomly dissected. This study was ethically approved by the Research Ethics Committee, Faculty of Medicine, Chiang Mai University (Study code: ANA-2561-05229). The cadavers were sufficient in quality and had no evidence of surgical intervention at the ankle. The superficial structures were carefully removed to identify the location of origin and insertion of deltoid ligament. The deltoid ligament was separated into superficial and deep layers. The superficial layer had 4 bands and deep layer had 2 bands. Each band of the deltoid ligament was evaluated and divided into small bundles, for approximately 2-5 bundles per each band followed the orientation of ligament fiber. After dividing ligament, the distal attachment of each small bundle was cut and marked with the acrylic color followed by color blowing. After the color dried, the steel balls size 3 mm were embedded in the closed origin and insertion attachment areas. For the image process, the origin and insertion of each band were set in the perpendicular direction with the camera followed by taking a photo. The size of steel balls in all pictures of attachment areas was measured out to be the pixel value. The attachment areas were marked with color at each attachment area by using Adobe Photoshop program, and the attachment areas of deltoid ligament were measured using Image J program. The data of steel balls size and attachment areas were recorded and calculated using Microsoft Excel. Later, the results were shown mean±SD, range of minimum and maximum values.

RESULTS

In all forty-six ankles, we found 6 bands of deltoid ligament and 2 variational bands namely tibionavicular ligament (TNL), tibiospring ligament (TSL), tibiocalcaneal ligament (TCL), superficial posterior tibiotalar ligament (sPTTL), anterior tibiotalar ligament (ATTL) and deep posterior tibiotalar ligament (dPTTL) including deep to tibiocalcaneal ligament (dTCL) and posterior to sustentaculum tali (PST). The deltoid ligament was separated into superficial and deep layers by adipose tissue in all ankles. The 6 bands of deltoid ligament were identified in forty-six ankles (100 %) except TNL. TNL which was identified only 26 ankles (56.52 %). Moreover, dTCL found 2 ankles (4.35 %) and PST found only 1 ankle (2.17 %).

Attachment sites: The proximal attachment of deltoid ligament attached from medial malleolus to insert at the different distal attachments was shown in Tables I and II. The proximal attachments of each band of the superficial layer overlapped with each other. Moreover, the distal attachment sites overlapped some bands namely TNL, TSL, sPTTL and dPTTL.

Attachments areas: The most proximal and distal attachment areas of individual bands of deltoid ligament at the tibia was dPTTL. The least proximal and distal attachment areas was ATTL. All bands of deltoid ligament had more the distal attachment areas than the proximal attachment areas except TSL. More information of attachment areas in our study was shown in Figures 1, 2 and 3.

Table I. Proximal attachment sites of individual bands of deltoid ligament.

Ligament	Proximal attachment sites		
	Milner & Soames, 1988	Panchani *et al*., 2014	Our study, 2019
TNL	Ant. border of Ant. colliculus	Ant. aspect of medial malleolus	Anteromedial aspect of Ant. colliculus
TSL	Medial malleolus	Between TCL&TNL	Ant. aspect of Ant. colliculus
TCL	Medial surface of Ant. colliculus	Medial aspect of medial malleolus	Ant. aspect of Ant. colliculus
sPTTL	Medial surfaces of Post. colliculus & Post. part of Ant. colliculus	Posteromedial aspect of medial malleolus	Post. part of Ant. colliculus to anteromedial part of Post. colliculus
ATTL	Ant. colliculus & intercollicular groove	Anteromedial aspect of medial malleolus	Most Inf. aspect of Ant. colliculus
dPTTL	Intercollicular groove, Post. surface of Ant. colliculus & Ant. surface of Post. colliculus	Deep to sPTTL and shared Prox. attachment with sPTTL	Post. aspect of Ant. colliculus, intercollicular groove & Ant. aspect of Post. colliculus
dTCL	-	Between ATTL & dPTTL	Between ATTL and sPTTL (1 ankle) Post. to ATTL, deep to sPTTL & TNL
PST	-	Shared proximal attachment with TCL	Deep and Post. to TCL

Abbreviations: Ant. = anterior; Inf. = inferior; Post. = posterior.

Table II. Distal attachment sites of individual bands of deltoid ligament.

Ligament	Distal attachment sites		
	Milner & Soames, 1988	Panchani *et al.*, 2014	Our study, 2019
TNL	Dorsomedial aspect of navicular and spring lig.	Dorsomedial aspect of navicular	dorsomedial aspect of navicular and spring lig. (deep to TSL)
TSL	Sup. margin of spring lig.	Sup. margin of spring lig.	Sup. margin of spring lig.
TCL	Medial margin of sustentaculum tali (some fiber: spring lig.)	Sup. aspect of sustentaculum tali.	Sup. aspect of sustentaculum tali. (some case: talus)
sPTTL	Medial talar tubercle and sustentaculum tali	Supero-posterior aspect of talus.	Postero-inferior aspect at medial tubercle of talus
ATTL	Medial surface of talus.	Supero-anterior aspect of talus	Ant. part of body of talus
dPTTL	Medial surface of talus under tail of articular facet (posteromedial talar tubercle)	Shared Dis. attachment with sPTTL	Medial tubercle of talus (deep to sPTTL)
dTCL	-	Supero-medial aspect of talus between ATTL & dPTTL	Between ATTL & sPTTL
PST	-	Medial surface of calcaneus	Medial side of calcaneus for Ant. part and Inf. to distal attachment of sPTTL for Post. part

Abbreviations: Ant. = anterior; Inf. = inferior; lig. = ligament; Post. = posterior.

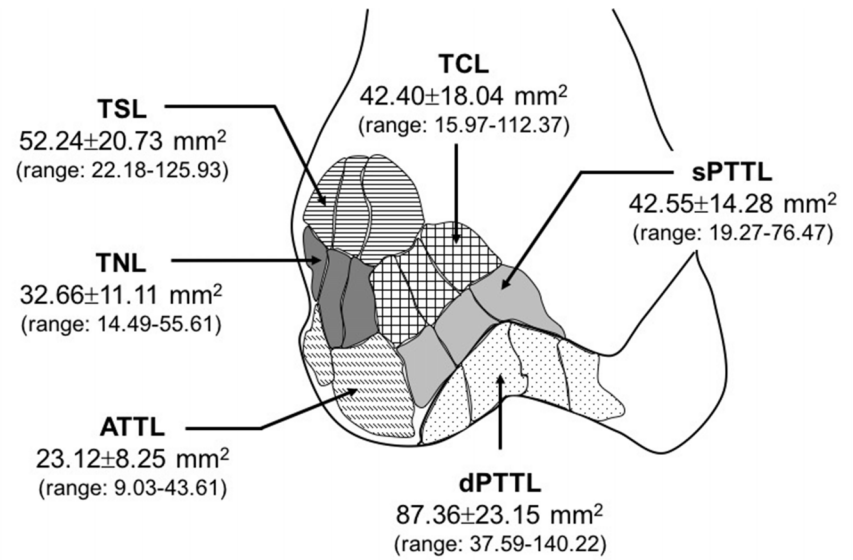

Fig. 1. The proximal attachment of deltoid ligament on tibia.

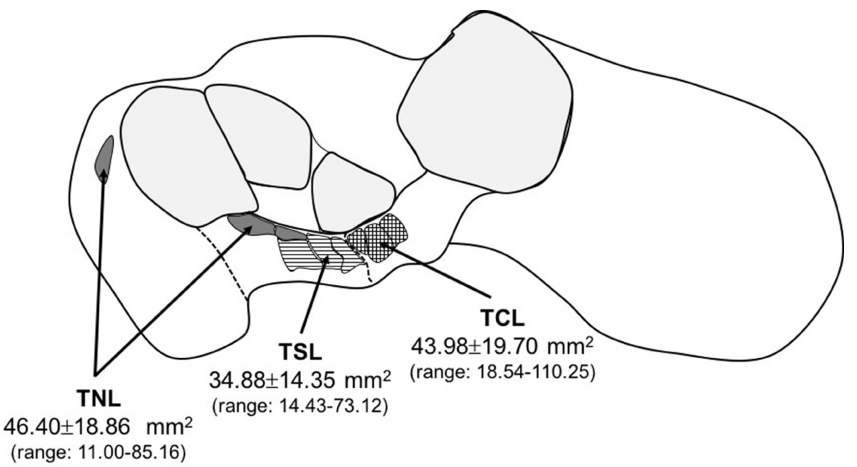

Fig. 2. The distal attachment of deltoid ligament on navicular, spring ligament and calcaneus.

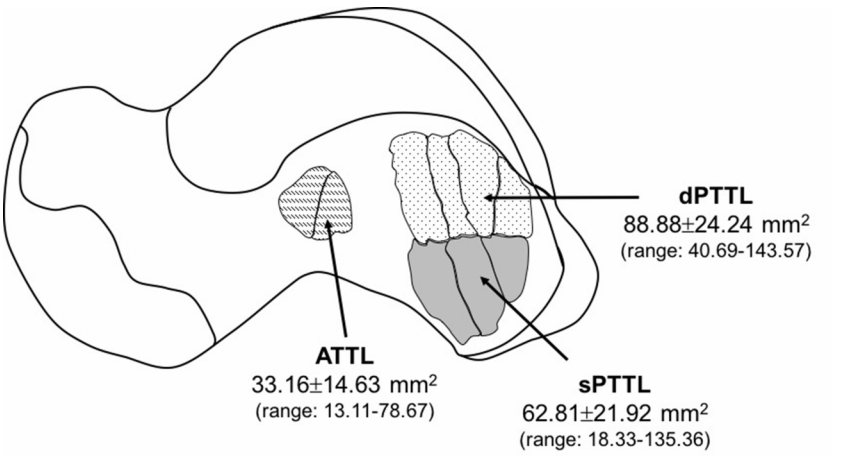

Fig. 3. The distal attachment of deltoid ligament on talus.

DISCUSSION

The number of individual bands of deltoid ligament showed some differences. We found that the superficial layer was composed of 4 individual bands which were TNL, TSL, TCL and sPTTL. In the deep layer, 2 bands which were ATTL and dPTTL were found. There are constant findings in all ankles except TNL. The results had different information from the previous studies (Milner & Soames; Boss & Hintermann; Campbell *et al*.; Panchani *et al*., 2014; Cromeens *et al*., 2015). Furthermore, we found the additional bands such as dTCL and PST which were similar to Panchani *et al*. They found more dTCL and PST than in our studies.

Attachment sites of individual bands of deltoid ligament and variation bands were attached from tibia to navicular, spring ligament, calcaneus and talus. The results of the previous studies compared to ours were shown in Tables I and II. The most attachment sites of deltoid ligament in the previous studies and our study showed the similar attachment sites. However, some bands of deltoid ligament had the different attachment sites. The similarity and difference of attachment sites of several studies may lead to change the functions of ankle joint (Hogan *et al*.).

Attachment areas of individual bands of deltoid ligament in our study compared to previous results were shown in Table III. In my opinion, the reason of different attachment areas of deltoid ligament can probably be due to the different method and the number of ankles in these studies (Cromeens *et al*.). Although our study used similar dissection method (Boss & Hintermann), it had the different point as our study divided the individual bands of deltoid ligament to small fibers, which was easy and not complicated to study. Therefore, the results of attachment areas showed the different values; however, these results had the same directions. Furthermore, the divided small fibers may improve the knowledge of clinicians for apply to biomechanics, repair or reconstruction of deltoid ligament in the future.

The patients who have large or complete deltoid ligament tears including primary failure patients and chronic medial ankle instability will be treated with the surgical deltoid ligament repair or reconstruction (Haddad *et al*., 2010). Furthermore, the posterior tibial tendon dysfunction or pathology which leads to dynamic instability can reach to failure of deltoid ligament repair (Hintermann, 2003). The patients of posterior tibial tendon injury, total ankle arthroplasty and adult-acquired flatfoot deformity require the surgical treatment in order to manage the deltoid ligament (Bluman & Myerson, 2007; Haddad *et al*., 2007; Ellis *et al*., 2010). The surgical treatment leads to the correct position of foot, whereas post-operate patients of surgical treatment may have the deformity. This reason leads to the anatomical knowledge of deltoid ligament, which is interesting (Patil *et al*., 2007). The reconstruction procedure focuses on each band of deltoid ligament. Currently, the clinicians do not know what the most important individual bands of deltoid ligament for repair or reconstruction are. Moreover, the success rate of deltoid ligament reconstruction is unpredictably and has not shown in clinical aspect. The lack of knowledge and data of the exact origin and insertion areas of individual bands of deltoid ligament leads to low reliability of treatment results. Therefore, the clinicians should know and understand the normal anatomy and the exact attachment areas of deltoid ligament for correct deltoid ligament, which in turn leads to successful treatment and apply with the clinicians to biomechanics, repair or reconstruction of deltoid ligament in the future.

Table III. Attachment areas of individual bands of deltoid ligament[1].

Ligament	Studies							
	Boss & Hintermann, 2002		Campbell *et al.*, 2014		Cromeens *et al*., 2015		Our study, 2019	
	Prox. areas	Dis. areas	Prox. areas	Dis. areas	Prox. areas	Dis. areas	Prox. areas	Dis. areas
TNL	NR	NR	54.0	109.5	Tibiocalcaneo-navicular lig.	Tibiocalcaneo-navicular lig.	32.66±11.11	46.40±18.86
TSL	21.3±10.1	34.2±17.7	59.1	NR			52.24±20.73	34.88±14.35
TCL	17.1±9.4	19.8±10.9	29.4	52.1			42.40±18.04	43.98±19.70
sPTTL	13.8±5.5	16.7±7.3	31.7	38.3	32.34±17.68	26.39±17.42 (Calcaneus: 21.27±2.25)	42.55±14.28	62.81±21.92
ATTL	14.8±14.5	25±25.8	54.5	87.6	14.85±5.37	20.61±12.71	23.12±8.25	33.16±14.63
dPTTL	24.3±21.9	38.8±38.7	102.0	129.6	111.65±27.42	140.89±41.93	87.36±23.15	88.88±24.24
dTCL	NR	NR	NR	NR	NR	NR	14.56±12.99	19.57±12.01
PST	NR	NR	NR	NR	NR	NR	8.87	13.42

Abbreviations: Dis. = distal; lig. = ligament; NR = not reported; Prox. = proximal.
[1]Values are in square millimeters (mm^2) and presented as mean±SD.

CONCLUSION

We found 6 bands of deltoid ligament in all ankles except TNL. Furthermore, we found variation ligaments such as dTCL and PST. The deltoid ligament attached from medial malleolus to navicular, spring ligament, calcaneus and talus. The most proximal and distal attachment areas were dPTTL, whereas the ATTL had the least proximal and distal attachment areas. The detailed data in this study will help the clinicians about biomechanics, diagnosis and improving knowledge of anatomical repair and anatomical reconstruction techniques of deltoid ligament.

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RESUMEN: Actualmente, el tratamiento para pacientes con lesiones del ligamento colateral medial de la articulación talocrural (ligamento deltoideo), que requieren tratamiento quirúrgico es la reparación y reconstrucción anatómica. Los médicos, para un tratamiento exitoso, deben conocer exactactamente las áreas de inserción de las partes de ligamento deltoideo. Estudiamos 46 tobillos de cadáveres congelados frescos. Las bandas individuales del ligamento deltoideo se dividieron en fibras pequeñas. Posteriormente, cada pequeña fibra de cada banda se cortó y marcó con color acrílico en el origen y la inserción, seguido de la toma de fotografías. Por último, las fotos de origen e inserción individuales se utilizaron para calcular las áreas. Encontramos seis bandas de ligamento deltoides en todos los tobillos, excepto el ligamento tibionavicular. Además, descubrimos en profundidad hasta los ligamentos tibiocalcaneaos y posteriores al *sustentaculum tali* en 3 casos. Con respecto al área de inserciónn, la parte tibiotalar posterior profundamente tenía las áreas de inserción proximal y distal más largas, que eran 87.36 ± 23.15 mm^2 y 88.88 ± 24.24 mm^2, respectivamente. La parte tibiotalar anterior del ligamento deltoideo tpresentaba áreas de unión menos proximales y distales 23.12 ± 8.25 mm^2 y 33.16 ± 14.63 mm^2, respectivamente. Por lo tanto, la precisión y las áreas exactas de inserción del ligamento deltoideo de la articulación talocrural son importantes, ya que pueden ayudar a los médicos a seleccionar los tratamientos adecuados, incluida la prevención de lesiones.

PALABRAS CLAVE: Ligamento colateral medial de la articulación talocrural; Ligamento deltoides; Área de inserción.

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