Biomechanical analysis of load sharing in deltoid ligament using a 6 degrees-of-freedom robotic system

Katsunori Takahashi[1], Atsushi Teramoto[1], Yasutaka Murahashi[1], Kosuke Shiwaku[1],
Tomoaki Kamiya[1], Kota Watanabe[2], Toshihiko Yamashita[1]
[1]Department of Orthopaedic Surgery, Sapporo Medical University School of Medicine, Sapporo, Hokkaido, Japan,
[2]Department of Physical Therapy, Sapporo Medical University School of Health Sciences, Sapporo, Hokkaido, Japan
Email of Presenting Author: black_minder_k@yahoo.co.jp

Disclosures: Katsunori Takahashi (N), Atsushi Teramoto (N), Yasutaka Murahashi (N), Kosuke Shiwaku (N), Tomoaki Kamiya (N), Kota Watanabe (N), Toshihiko Yamashita (N)

INTRODUCTION: The medial collateral ligament of the ankle (deltoid ligament) attaches from the medial malleolus to the navicular, calcaneus, and talus. There are only few biomechanical studies about function of deltoid ligament, and none of them evaluated the function of each ligamentous band directly. The purpose of the present study is to evaluate the load sharing of each ligamentous band of the deltoid ligament during eversion and external lotation of the ankle.

METHODS: This study was approved by our institution's ethics review board. Eight normal fresh-frozen cadaver legs (6 males and 2 females) that were donated to our university's department of anatomy were used. The specimen was fixed with acrylic resin molds and aluminum clamps and connected to the end-effector of a robotic testing system (FRS2015; Technology Service). This mechanical testing system consisted of a 6-degrees of freedom (DOF) manipulator, servomotor controllers, and a control computer. The eversion and external rotation moments were applied for the intact ankle joint complexes at 15° of dorsiflexion (15°DF), at the neutral position (0°) and 15° and 30° of plantarflexion, and 6-DOF ankle motion during the test were recorded. The tibionavicular ligament (TNL) , tibiospring ligament (TSL) , tibiocalcaneal ligament (TCL) , anterior tibiotalar ligament (ATTL) , superficial posterior tibiotalar ligament (sPTTL) and deep posterior tibiotalar ligament (dPTTL) were completely transected respectively. We reproduced the recorded intact ankle mortion before and after each transection of ligamentous band, and measured the 6-DOF force/torque data to determine the in-situ force (ISF) of each ligamentous band. The normality of all outcome data was confirmed using the Shapiro-Wilk test. Post-hoc analysis of the differences between the models was performed using Bonferroni's test. A p value of 0.05 was chosen as the level of significance.

RESULTS: During eversion, the ISF of sPTTL was significantly larger than all others at 15° DF, and the ISF of TCL was significantly larger than others at 0°, 15° and 30° DF. During external rotation, the ISF of sPTTL was significantly larger than all others at 15° DF, and the ISF of TNL/dPTTL was significantly larger than other 1-2 ligamentous bands at 15° and 30° DF.

DISCUSSION: The results of our study showed that function of each ligamentous bands in the deltoid ligament. In particular, the TCL and sPTTL were shown larger ISF than other ligamentous bands when applied eversion force. On the other hand, the sPTTL was shown similarly larger ISF when applied external rotation force at 15°DF, but the TNL and dPTTL were shown larger ISF when applied external rotation force at 15° and 30°PF.

SIGNIFICANCE/CLINICAL RELEVANCE: This is the first study in the world to directly evaluate the function of each 6 ligamentous bands in the deltoid ligament, and there have been no similar studies to date. We would like to conduct further study to investigate the effects on the talonavicular and talocalcaneal joints, or to apply the treatment protocols of deltoid ligament injuries.

IMAGES AND TABLES:

Table 1. The ISF of each ligamentous bands during eversion of the ankle.
ISF, in-situ force; DF, dorsiflexion; PF, plantarflexion;
TNL, tibionavicular ligament; TSL, tibiospring ligament; TCL, tibiocalcaneal ligament; ATTL, anterior tibiotalar ligament;
sPTTL, superficial posterior tibiotalar ligament; dPTTL, deep posterior tibiotalar ligament
*, significantly larger than all other ligamentous bands ($p<0.05$)

ISF (N)	15°DF		0°		15°PF		30°PF	
	Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)	
TNL	1.7 (1.1)		2.6 (1.5)		3.4 (3.2)		3.7 (3.0)	
TSL	3.5 (2.8)		3.5 (2.8)		5.4 (2.2)		9.3 (5.4)	
TCL	10.8 (8.5)		**21.9 (11.0)**	*	**20.9 (7.4)**	*	**19.4 (7.6)**	*
ATTL	1.8 (0.5)		2.1 (1.6)		1.8 (1.1)		2.4 (1.6)	
sPTTL	**21.6 (10.8)**	*	10.1 (10.6)		4.3 (7.8)		1.7 (1.6)	
dPTTL	4.9 (5.3)		1.9 (1.1)		1.6 (0.7)		2.5 (0.6)	

Table 2. The ISF of each ligamentous bands during external rotation of the ankle.
ISF, in-situ force; DF, dorsiflexion; PF, plantarflexion;
TNL, tibionavicular ligament; TSL, tibiospring ligament; TCL, tibiocalcaneal ligament; ATTL, anterior tibiotalar ligament;
sPTTL, superficial posterior tibiotalar ligament; dPTTL, deep posterior tibiotalar ligament
*, significantly larger than all other ligamentous bands ($p<0.05$)
†, significantly larger than sPTTL ($p<0.05$)
‡, significantly larger than ATTL and sPTTL ($p<0.05$)

ISF (N)	15°DF		0°		15°PF		30°PF	
	Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)	
TNL	2.5 (1.4)		4.6 (3.0)		**9.8 (4.8)**	†	**11.3 (5.5)**	‡
TSL	2.8 (1.9)		5.3 (2.9)		6.2 (2.4)		7.5 (3.0)	
TCL	9.3 (5.9)		10.4 (5.0)		6.3 (2.9)		5.3 (3.5)	
ATTL	2.8 (1.3)		7.1 (3.7)		6.5 (5.2)		2.9 (1.7)	
sPTTL	**15.3 (11.0)**	*	6.8 (8.4)		3.0 (3.5)		1.2 (0.5)	
dPTTL	3.5 (3.7)		2.8 (1.5)		5.7 (4.4)		**12.2 (7.9)**	‡