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ORIGINAL ARTICLE

The effect of differences in the number of fiber bundles of the anterior tibial ligament on ankle braking function: a simulation study

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Abstract

Purpose The aim was to clarify the effect of differences in the number of fiber bundles of the anterior tibial ligament (ATFL) on ankle braking function.

Methods The study sample included 81Japanese cadavers. ATFLs were categorized as: Type I with one fiber bundle; Type II with two fiber bundles that were completely separated; and Type III with three fiber bundles. Three-dimensional reconstructions of a single specimen from each category were then created. These were used to simulate and calculate ATFL strain during dorsiflexion (20°) and plantarflexion (30°) on the talocrural joint axis and inversion (20°) on the subtalar joint axis.

Results Almost all types of superior fiber lines were stretched with dorsiflexion and plantarflexion. Regardless of Type, the inferior fiber line was shortened with plantarflexion and stretched with dorsiflexion. The inferior fiber bundle of Type III was shortened only at plantarflexion 30° and inversion 20°, but in all others it was stretched.

Conclusions The results suggest that Type III was weaker than Type I and Type II in terms of ankle plantarflexion and inversion braking function.

Keywords Lateral ankle ligament injury · Ankle inversion restriction · Lateral ankle ligament complex

Introduction

Injury to the lateral ligaments of the ankle is one of the most frequent sports injuries in both competitive and recreational sports, and roughly 70% of them are injuries to the anterior talofibular ligament (ATFL) alone [20, 26]. The morphological features of the lateral ligaments of the ankle are thought to be heavily involved in these injuries, and many anatomical studies of the ATFL in particular have been reported [13, 25].

The main morphological features of the ATFL that have been investigated are the number of fiber bundles, fiber bundle length, fiber bundle width, and fiber bundle angle. Regarding the difference in the number of fiber bundles, there are many reports that two fiber bundles are common, and there are not three fiber bundles [3, 4, 16, 21, 24, 25, 27], but, in recent years, there are increasing reports that there are three fiber bundles [6, 14, 22]. The ATFL is reported to serve a major function in ankle plantarflexion and inversion control [12, 17]. It has been reported that, during plantarflexion, the superior fiber bundle tenses and the inferior fiber bundle relaxes, and that, during dorsiflexion, the superior fiber bundle relaxes and the inferior fiber bundle tenses [2, 23]. In these earlier studies, the ATFL was mainly the two fiber bundle type, and the functions of the superior fiber bundle and of the inferior fiber bundle differed. In other earlier studies, however, the fiber bundle length and total fiber bundle width were the same even when the number of fiber bundles differed, and so it was thought that functional differences were unlikely [23]. Therefore, in previous research [6], we examined the differences in morphological characteristics due to the difference in the number of fiber bundles of the ATFL using large-scale specimens. Consequently, it was suggested that there is a difference in the braking function of the ankle due to the difference in the number of fiber bundles. However, this hypothesis is limited to consideration

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based on morphological features, and it has not actually been verified.

Therefore, in this study, the aim was to clarify the effects of differences in the number of fiber bundles of the ATFL on ankle braking function.

Materials and methods

Cadavers

This investigation examined 81 legs from 43 Japanese cadavers(mean age at death, 77 ± 12 years; 51 sides from men, 30 from women; 41 sides from right, 40 sides from left) were used in the previous study [6]. None showed signs of previous major surgery around the ankle. This study was approved by the Ethics Committee at our institution.

Methods

One author (first author) dissected the ATFL alone. The lower limbs were cut 10 cm above the ankle to produce isolated specimens. The ATFLs were carefully dissected after removal of skin, subcutaneous tissue, musculotendinous tissue, and crural fascia. In the classification method, ATFLs with one fiber bundle were taken to be Type I, those with two fiber bundles that were completely separated were Type II, and those with three fiber bundles were Type III [6]. All measurements were carefully done in an intermediate position of ankle plantarflexion/dorsiflexion at 0° and foot inversion/eversion at 0°. A single specimen from each category was then selected, and three-dimensional reconstructions were created from 3 feet, using the MicroScribe system (G2X-SYS, Revware, NC, USA) to digitize six points, the origin, and the terminus of the ATFL (Fig. 1). The Rhinoceros 3D software program (McNeel, Seattle, WA, USA) was used to construct the three-dimensional models. The talocrural joint (the line connecting the inferior borders of the medial and lateral malleoli) and the subtalar joint (the line connecting the lateral border of the calcaneal tuberosity and the midpoint of the talar head) were designated as the joint axes [9, 10, 15, 18]. The simulations were then used to calculate ATFL strain (%) during dorsiflexion (20°) and plantarflexion (30°) on the talocrural joint axis and during inversion (20°) on the subtalar joint axis. Using the following formula, ATFL strain was expressed as the percentage

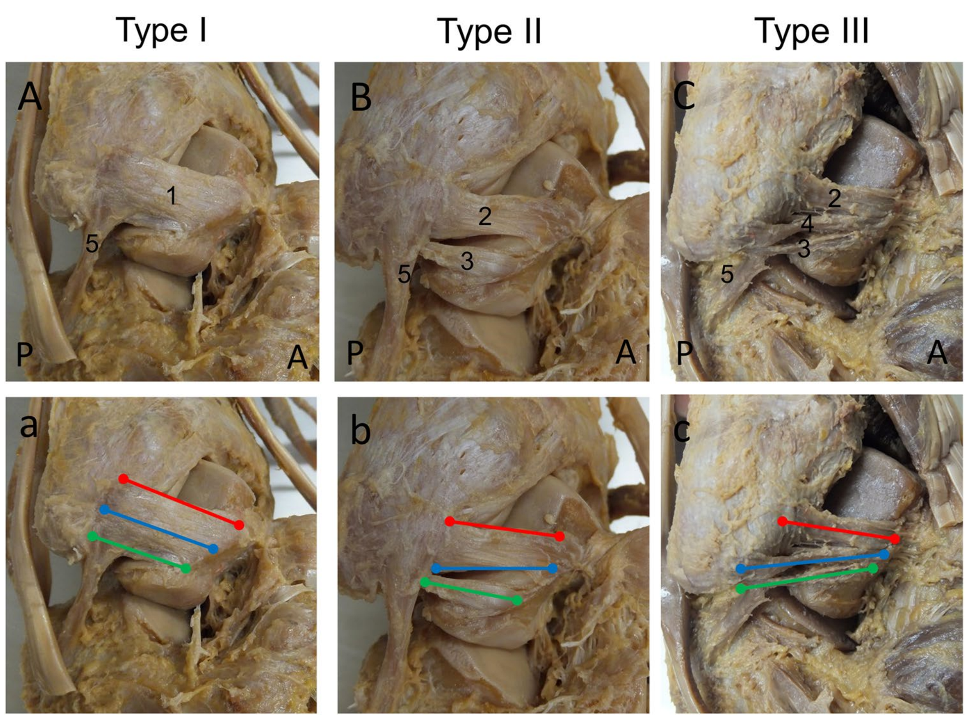

Fig. 1 Classification of anterior talofibular ligament number of fiber bundles; right side, anterolateral. Type I: ligament with one fiber bundle. Type II: ligament with two fiber bundles with complete separation. Type III: ligament with three fiber bundles. 1: anterior talofibular ligament, 2: Superior fiber bundle, 3: inferior fiber bundle, 4: intermediate fiber bundle, 5: calcaneofibular ligament, *A* anterior, *P* posterior. Superior fiber line (red line): Type I and Type II are the upper edge of the fiber bundle, and Type III is the center line of the superior fiber bundle. Intermediate fiber line (blue line): Type I is the center line of the fiber bundle, Type II are the lower edge of the fiber bundle, and Type III is the center line of the intermediate fiber bundle. Inferior fiber line (green line): Type I is the lower line of the fiber bundle, Type II are the center line of the inferior fiber bundle, and Type III is the center line of the inferior fiber bundle

of change of ligament length from the initial limb position (LTS), when both flexion/extension and inversion/eversion were 0°, to the final position after motion [11].

$$\text{Strain}(\%) = \left[\left(\frac{L^{T} - L_{S}^{T}}{L_{S}^{T}}\right) \times 100\right]$$

The MicroScribe system is an instrument with high precision (manufacturer's specifications, measurement precision of 0.23 mm). However, measurements must be performed manually. In addition, although the study cadavers were thoroughly fixed to the examination table such that they did not move, it was necessary to test whether they had moved, since the measurements entailed dissection of the ligament tissue. A previous study by the authors found the intraclass correlation coefficient (1, 1) to be 0.97–0.99 [5], which indicates a high level of reliability and reproducibility.

Results

Changes in strain for each Type during dorsiflexion and plantarflexion (Table 1)

Almost all types of superior fiber lines were stretched with dorsiflexion and plantarflexion. Regardless of Type, the inferior fiber line was shortened with plantarflexion and stretched with dorsiflexion.

Changes in strain when ankle inversion (20°) was added at the ankle joint with plantarflexion/dorsiflexion for each ATFL category (Table 2).

The inferior fiber line of Type III was shortened only at plantarflexion of 30° and inversion of 20°, but in all other types it was stretched.

Discussion

This study clarified the effect of the number of ATFL fiber bundles on ankle joint braking function. To the best of our knowledge, no research focusing on ATFL fiber bundle number and function has been previously reported.

In the present study, almost all types of superior fiber lines were stretched with dorsiflexion and plantarflexion. However, regardless of Type, the inferior fiber line was shortened with plantarflexion and stretched with dorsiflexion. In a previous study [6], in comparisons of morphological features within each type, significant differences were seen in fiber bundle length, fiber bundle width, and fiber bundle angle with the sagittal plane between superior fiber bundles and inferior fiber bundles of Type II. Furthermore, among superior fiber bundles and inferior fiber bundles of Type III, significant differences were seen in the fiber bundle width and the angle with the sagittal plane. From these findings, the possibility is suggested that the superior and inferior fiber bundles in Type II and Type III have different ankle control functions. Therefore, one must consider the possibility that the differences in the morphological features may affect the strain of ankle joint plantarflexion and dorsiflexion.

In the present study, the inferior fiber line of Type III was shortened only at plantarflexion 30° and inversion 20°, but in all other types it was stretched. In a previous study [6], it was reported that there was no significant difference between

Table 1 Changes in the strain of ankle joint plantarflexion and dorsiflexion for each anterior talofibular ligament classification

	Plantarflexion				Dorsiflexion	
	− 30°	− 20°	− 10°	0°	10°	20°
Superior fiber line						
Type I	12.3	6.5	2.3	0	− 0.1	1.9
Type II	8.1	4.3	1.5	0	− 0.2	1.0
Type III	7.6	3.2	0.6	0	1.5	4.9
Intermediate fiber line						
Type I	1.5	0	− 0.5	0	1.5	3.9
Type II	0.8	− 0.2	− 0.5	0	1.2	3.0
Type III	− 8.3	− 6.1	− 3.3	0	3.7	7.5
Inferior fiber line						
Type I	− 10.9	− 8.7	− 5.0	0	5.9	12.3
Type II	− 11.6	− 9.0	− 5.0	0	5.8	12.0
Type III	− 17.2	− 12.1	− 6.3	0	6.4	12.9

Value: strain at plantarflexion and dorsiflexion

Type I with one fiber bundle, *Type II* with two fiber bundles that were completely separated, *Type III* with three fiber bundles

Table 2 Changes in strain when ankle inversion (20°) is added to ankle joint plantarflexion/dorsiflexion for each anterior talofibular ligament classification

	Plantarflexion				Dorsiflexion	
	– 30°	– 20°	– 10°	0°	10°	20°
Superior fiber line						
Type I	26.0	19.2	13.9	10.3	8.7	9.4
Type II	19.2	15.1	12.0	9.9	9.0	9.4
Type III	21.4	16.0	12.3	10.4	10.6	12.9
Intermediate fiber line						
Type I	14.9	12.8	11.6	11.5	12.3	14.1
Type II-b	11.1	9.9	9.4	9.5	10.2	11.6
Type III	1.9	3.6	6.0	9.1	12.6	16.4
Inferior fiber line						
Type I	6.4	7.5	10.2	14.2	19.4	25.3
Type II	5.1	6.5	9.1	12.9	17.6	23.0
Type III	– 3.6	0.8	6.2	12.3	18.7	25.3

Value: strain at inversion

Type I with one fiber bundle, *Type II* with two fiber bundles that were completely separated, *Type III* with three fiber bundles

Type II and Type III fiber bundle length and fiber bundle width. Therefore, although the difference in the ultimate failure of each type is unknown, it was suggested that Type III was weaker than Type I and Type II in terms of ankle plantarflexion and inversion braking function.

This study did have a number of limitations. First, it involved simulations with cadavers. Therefore, gravity, weight-bearing, muscle activity, and the posture of the foot were not considered. Furthermore, the value of strain exceeds the ultimate failure of the ligament. In the future, we believe that it will be necessary to perform biomechanical research using our basic data with in vivo samples. Second, the variations in the morphology of the talus [19], subtalar joint facets [1], and its joint axis [18] were not considered. Third, all cadavers used in this study were Japanese. It is not certain whether the present findings apply to cadavers from other ethnicities. Many studies have raised the possibility of skeletal muscle and tendon variations across ethnicities [7, 8], and this could be true for ligaments as well. Thus, future studies will need to investigate variations based on ethnic origin.

In the present study, it was suggested that Type III was weaker than Type I and Type II in terms of ankle plantarflexion and inversion braking function. In the future, we believe that it will be necessary to perform biomechanical research using our basic data with in vivo samples, which may lead to the elucidation of the functional role of ATFL. Furthermore, we believe that it would be valuable to confirm whether individual anatomical differences may represent risk factors for ATFL injury.

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Authors' contributions ME and TT contributed to study design and data correction, and drafted the manuscript; TI and TK contributed to data analysis and made critical revisions to the manuscript; WI, EN, RH, MI and FK made critical revisions to the manuscript; IK supervised the study, contributed to analysis and interpretation of data, and made critical revisions to the manuscript. All authors read and approved the final manuscript prior to submission.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The methods were carried out in accordance with the 1964 Declaration of Helsinki and the cadavers were legally donated for the research by the Nippon Dental University of Life Dentistry at Niigata in Japan.

Informed consent Informed consent was obtained from the families of all subjects.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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