ORIGINAL ARTICLE

Relationships between differences in the number of fiber bundles of the anterior talofibular ligament and differences in the angle of the calcaneofibular ligament and their effects on ankle-braking function

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Abstract

Purpose The aim was to clarify the relationships between differences in the number of fiber bundles of the anterior talofibular ligament (ATFL) and differences in the angle of the calcaneofibular ligament (CFL) with respect to the long axis of the fibula and their effects on ankle braking function.

Methods The study sample included 110 Japanese cadavers. ATFLs were categorized as: Type I with one fiber bundle; Type II with two fiber bundles with incomplete separation and complete separation; and Type III with three fiber bundles. The CFLs were categorized according to the angles of the CFLs with respect to the long axis of the fibula and the number of fiber bundles. Six categories were established: CFL10° (angle of the CFL with respect to the long axis of the fibula from 10° to 19°); CFL20° (range 20°–29°); CFL30° (range 30°–39°); CFL40° (range 40°–49°); CFL50° (range 50°–59°); and CFL2 (CFLs with two crossing fiber bundles).

Results ATFL was Type I in 34 legs (31%), Type II in 66 legs (60%), and Type III in 10 legs (9%). Five CFL categories were identified: CFL10° in 4 feet (3.7%); CFL20° in 23 feet (20.9%); CFL30° in 34 feet (30.9%); CFL40° in 33 feet (30%); CFL50° in 15 feet (13.6%); and CFL2 in one foot (0.9%). Type III contained mainly CFL40° and CFL50° (7 of 10 feet).

Conclusions ATFL and CFL appear to cooperate in the ankle joint 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. Of them, roughly 66–85% are injuries to the anterior talofibular ligament (ATFL) alone [10, 22, 27]. 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 [15].

The main morphological feature of the ATFL that has been investigated is the number of fiber bundles. Regarding the difference in the number of fiber bundles, there are reports of the existence of types with one, two, and three fiber bundles [16, 24], as well as reports that types with three bundles do not exist [2–4, 17, 20, 23, 26, 28], but in recent years, there have been increasing reports that there are three fiber bundles [6, 9, 16, 24]. The ATFL is reported to serve a major function in ankle plantarflexion and inversion control [14, 18]. 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 [1, 25]. In these earlier studies, the ATFL was mainly the two-fiber bundle type, and the functions of the superior fiber bundle

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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 [25]. 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. 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. Furthermore, in a simulation study [9], we found that the inferior fiber line of Type III (three fiber bundles) was shortened only at plantarflexion 30° and inversion 20°, but in all other types it was stretched. Therefore, it was suggested that Type III was weaker than Type I and Type II in terms of ankle plantarflexion and inversion braking function.

On the other hand, regarding the calcaneofibular ligament (CFL), Ozeki et al. [19] examined cadavers to explore the functional role of the CFL and observed that the CFL becomes taut at dorsiflexion angles ≥ 18°, and it is nearly relaxed at other angles. Furthermore, Leardini et al. [13] argued that it is very likely that the CFL plays a major role in stabilizing ankle flexion and extension. However, although Sarrafian and Kelikian [21] found that the CFL is taut in dorsiflexion and relaxed in plantarflexion, they also noted that some specimens showed reversal of motions, whereas, in others, the tension in this ligament remained constant in all positions. It has been suggested that this may be due to the differences in the angle of the CFL with respect to the long axis of the fibula [19, 21]. In addition, it has also been shown that restrictions on ankle inversion and eversion vary depending on the running angle [21]. Therefore, in our previous study [5], specimens in the CFL20° (angle of the CFL with respect to the long axis of the fibula from 20° to 29°) and CFL30° (range 30°–39°) groups contracted with plantarflexion and stretched with dorsiflexion. In comparison, specimens in the CFL40° (range 40°–49°), CFL50° (range 50°–59°), and CFL2 (CFLs with two crossing fiber bundles) groups stretched with plantarflexion and contracted with dorsiflexion. Furthermore, the other than CFL30° groups stretched with plantarflexion and inversion of 20°.

The lateral ligaments of the ankle are currently considered to consist of the ATFL, CFL, and the posterior tibial ligament (PTFL), and they are thought to form an ankle lateral ligament complex, since each has cross-fibers in some parts [6, 21]. Therefore, regarding the ATFL, it is necessary to verify the relationship with the CFL to determine whether Type III is weaker than Type I and Type II in terms of ankle plantarflexion and inversion braking function.

Therefore, in this study, the aim was to clarify the relationships between the differences in the number of fiber bundles of the anterior talofibular ligament and the differences in the angle of the CFL with respect to the long axis of the fibula and their effect on ankle braking function (Figs. 1, 2).

Materials and methods

Cadavers

A total of 110 legs from 60 Japanese cadavers (mean age at death, 78 ± 12 years; 64 sides from men, 46 from women; 55 sides from the right, 55 sides from the left) were examined. None showed signs of previous major surgery around the ankle. This study was approved by the Ethics Committee at our institution (Table 1).

Methods

One author (first author) dissected the ATFL and CFL alone. The lower limbs were cut 10 cm above the ankle to produce isolated specimens. The ATFLs and CFLs were carefully dissected after removal of skin, subcutaneous tissue, musculotendinous tissue, and crural fascia. In the classification
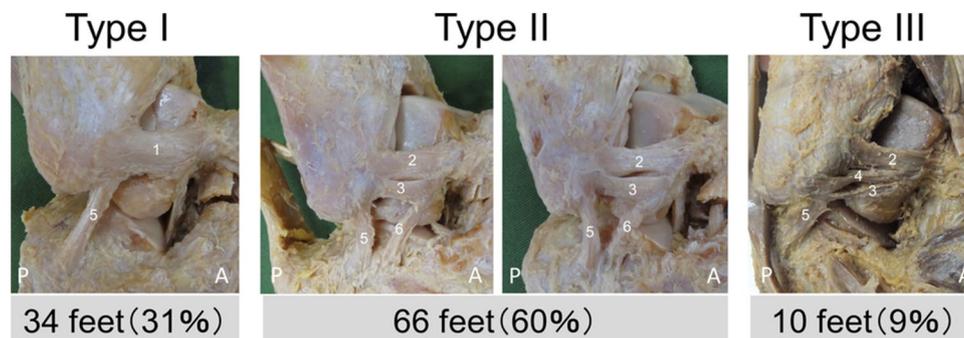

Fig. 1 Anterior talofibular ligament number of fiber bundles classification; right side, anterolateral. Type I: ligament with one fiber bundle. Type II: two fiber bundles with incomplete separation and complete separation. Type III: ligament with three fiber bundles. 1: anterior talofibular ligament, 2: superior fiber bundle, 3: inferior fiber bundle, 4: intermediate fiber bundle, 5: calcaneofibular ligament, 6: lateral talocalcaneal ligament, A: anterior, P: posterior
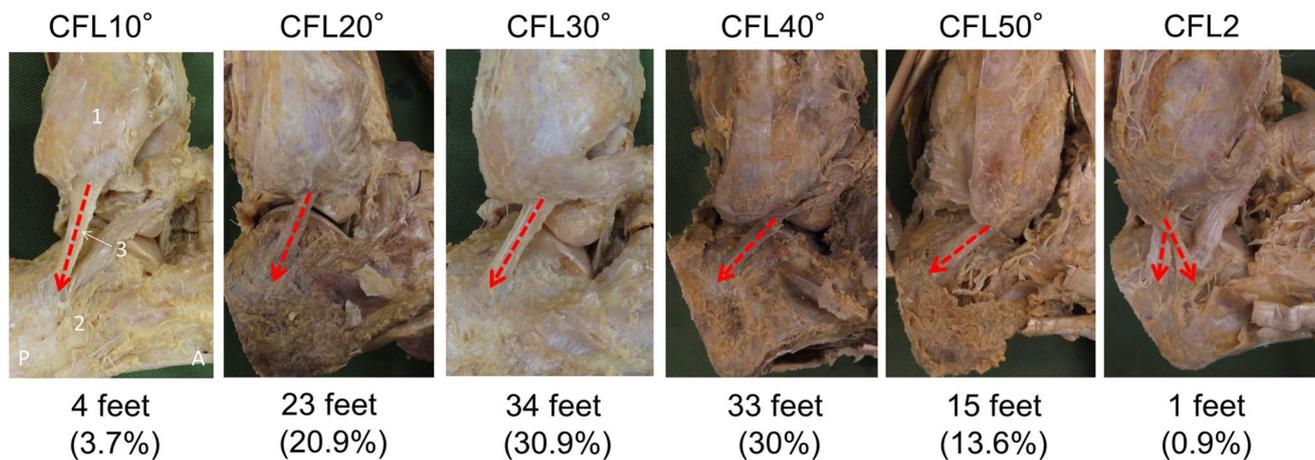
CFL10°   CFL20°   CFL30°   CFL40°   CFL50°   CFL2

4 feet   23 feet   34 feet   33 feet   15 feet   1 feet
(3.7%)   (20.9%)   (30.9%)   (30%)   (13.6%)   (0.9%)

Fig. 2 Classification of calcaneofibular ligaments by running angle, right foot, lateral view. CFL10°, angle of the CFL with respect to the long axis of the fibula from 10° to 19°; CFL20°, angle of the CFL with respect to the long axis of the fibula from 20° to 29°; CFL30°, angle of the CFL with respect to the long axis of the fibula from 30° to 39°; CFL40°, angle of the CFL with respect to the long axis of the fibula from 40° to 49°; CFL50°, angle of the CFL with respect to the long axis of the fibula from 50° to 59°; CFL2, CFLs with two crossing fiber bundles. 1: fibula, 2: calcaneus, 3: calcaneofibular ligament, A: anterior, P: posterior

Table 1 The relationship of the number of fiber bundles of the anterior talofibular ligament with the angle of the calcaneofibular ligaments

	Type I	Type II	Type III	Total
CFL10°	2 (1.8)	2 (1.8)	0 (0)	4
CFL20°	6 (5.5)	14 (12.7)	3 (2.7)	23
CFL30°	14 (12.7)	20 (18.2)	0 (0)	34
CFL40°	7 (6.4)	20 (18.2)	6 (5.5)	33
CFL50°	5 (4.5)	9 (8.2)	1 (0.9)	15
CFL2	0 (0)	1 (0.9)	0 (0)	1
Total	34	66	10	110

Number (%)

Type I: ligament with one fiber bundle; Type II: two fiber bundles with incomplete separation and complete separation; Type III: ligament with three fiber bundles

CFL10° angle of the CFL with respect to the long axis of the fibula from 10° to 19°, *CFL20°* from 20° to 29°, *CFL30°* from 30° to 39°, *CFL40°* from 40° to 49°, *CFL50°* from 50° to 59°, *CFL2* CFLs with two crossing fiber bundles

method, ATFLs with one fiber bundle were taken to be Type I, those with two fiber bundles with incomplete separated and complete 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°. With reference to a previous study [5], the CFLs were categorized according to the angles of the CFLs with respect to the long axis of the fibula and the number of fiber bundles using a stainless 180 goniometer (300 mm CK-S4305-300, Chin Kou Medical Instrument Ltd, New Taipei City, Taiwan).

Six categories were established: CFL10° (angle of the CFL with respect to the long axis of the fibula from 10° to 19°); CFL20° (range 20°–29°); CFL30° (range 30°–39°); CFL40° (range 40°–49°); CFL50° (range 50°–59°); and CFL2 (CFLs with two crossing fiber bundles). All measurements were carefully done in an intermediate position of ankle plantar flexion/dorsiflexion of 0° and foot inversion/eversion of 0°.

Results

Classification by number of ATFL fiber bundles

The ligament type was Type I in 34 legs (31%), Type II in 66 legs (60%), and Type III in 10 legs (9%).

CFL running angle categories

Five categories were identified: CFL10° in 4 feet (3.7%); CFL20° in 23 feet (20.9%); CFL30° in 34 feet (30.9%); CFL40° in 33 feet (30%); CFL50° in 15 feet (13.6%); and CFL2 in one foot (0.9%). The average angle of the CFL with respect to the long axis of the fibula was $36.5 \pm 11.8°$.

Relationships of the number of fiber bundles of the ATFL and the angle of the CFL

The average angle of the CFL with respect to the long axis of the fibula was $35.9 \pm 11.3°$ in Type I; $36.0 \pm 12.3°$ in Type II; $41.6 \pm 9.8°$ in Type III. No significant differences were seen in the angle of the CFL by the number of fiber bundles of the ATFL ($p = 0.357$).

Type I was CFL10° in 2 legs (1.8%), CFL20° in 6 feet (5.5%), CFL30° in 14 feet (12.7%), CFL40° in 7 feet (6.4%), CFL50° in 5 feet (4.5%), and CFL2 in none. Type II was CFL10° in 2 legs (1.8%), CFL20° in 14 feet (12.7%), CFL30° in 20 feet (18.2%), CFL40° in 20 feet (18.2%), CFL50° in 9 feet (8.2%), and CFL2 in one foot (0.9%). Type III was CFL10° in none, CFL20° in 3 feet (2.7%), CFL30° in none, CFL40° in 6 feet (5.5%), CFL50° in one foot (0.9%), and CFL2 in none. No significant differences in the angle of the CFL were seen by the number of fiber bundles of the ATFL ($p = 0.395$).

Discussion

This study clarified the effects of differences in the number of fiber bundles of the ATFL and the differences in the angle of the CFL with respect to the long axis of the fibula on ankle braking function. To the best of our knowledge, no research focusing on the effects of the differences in the ATFL and CFL on ankle joint braking function has been previously reported.

The classification based on differences in ATFL fiber bundles was Type I in 34 legs (31%), Type II in 66 legs (60%), and Type III in 10 legs (9%). Previous studies have reported Type I in 25–100% [3, 4, 6, 16, 17, 20, 23, 24, 26, 28], Type II in 0–75% [3, 4, 6, 16, 17, 20, 23, 24, 26, 28], and Type III in 0–18% [2–4, 6, 16, 17, 20, 23, 24, 26, 28]. One major reason for this is thought to be the very small number of specimens, with 39 legs [2], 26 legs [16], 4 legs [4], 42 legs [23], 22 legs [24], 20 legs [20], 8 legs [17], 46 legs [28], 14 legs [3], 17 legs [26], and 81 legs [6] in the previous studies. Since the present study examined 110 legs, the results are thought to have a higher level of reliability.

In the present study, five categories were identified. The present sample comprised 94 feet (85.5%) with an angle with respect to the long axis of the fibula between 10° and 40°, similar to the finding of 56 feet (74.7%) reported in the previous study [11]. Unlike the previous study, though, the present sample did not include specimens with fan-shaped morphology or with an angle with respect to the long axis of the fibula of 0° and 80–90° [11] or with three bands [12].

In the present study, regarding the relationship of the number of fiber bundles of the ATFL and the angle of the CFL, although there was no significant difference, Type III tended to have a higher angle of the CFL than the other types. Furthermore, Type III contained mainly CFL40° and CFL50° (7 of 10 feet). In our previous 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 anatomical study [6] and the simulation study [9]. Furthermore, in our previous study [5], specimens in the CFL20° and CFL30° groups contracted with plantarflexion

and stretched with dorsiflexion. In comparison, specimens in the CFL40°, CFL50°, and CFL2 groups stretched with plantarflexion and contracted with dorsiflexion. Furthermore, the other than CFL30° groups stretched with plantarflexion and inversion 20°. Therefore, it was suggested that ATFL (Type III) and CFL (CFL40° and CFL50°) appear to cooperate in the ankle joint braking function.

This study did have a number of limitations. First, all cadavers used in this study were Japanese. It is not certain whether the present findings apply to cadavers of 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. Second, although it is thought that the influence is small, the angle of calcaneus and the morphology and biometry of fibula were not considered about the measurement of the angle of the CFL.

In the present study, the ATFL and CFL appeared to cooperate in ankle joint 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 the ATFL. Furthermore, we believe that it would be valuable to confirm whether individual anatomical differences may represent risk factors for ATFL injury.

Compliance with ethical standards

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