Comparison of Treatment Methods for Syndesmotic Injuries With Posterior Tibiofibular Ligament Ruptures

A Cadaveric Biomechanical Study

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Background: Studies on ankle syndesmosis have focused on anterior inferior tibiofibular ligament (AITFL) and interosseous membrane injuries; however, the characteristics of posterior inferior tibiofibular ligament (PITFL) ruptures remain unclear.

Purpose/Hypothesis: This study evaluated the biomechanical characteristics of syndesmotic instability caused by PITFL injury and compared various treatment methods. We hypothesized that PITFL injury would lead to syndesmotic internal rotational instability and that the stability would be restored with suture tape (ST) PITFL augmentation.

Study Design: Controlled laboratory study.

Methods: Ten uninjured fresh-frozen cadaveric leg specimens were tested via forces applied to the external and internal rotation of the ankle joint. The fibular rotational angle (FRA) related to the tibia, anterior tibiofibular diastasis (aTFD), and posterior tibiofibular diastasis (pTFD) were measured using a magnetic tracking system. Six models were created: (1) intact, (2) AITFL injury; (3) AITFL + PITFL injury; (4) suture button (SB) fixation; (5) SB + anterior ST (aST) fixation; and (6) SB + aST + posterior ST fixation. The FRA, aTFD, and pTFD were statistically compared between the intact ankle and each injury or fixation model.

Results: In the intact state, the changes in FRA and aTFD were 1.09° and 0.33 mm when external rotation force was applied and were 0.57° and 0.41 mm when internal rotation force was applied. In the AITFL injury model, the changes in FRA and aTFD were 2.38° and 1.51 mm when external rotation force was applied, which were significantly greater versus intact ($P = .032$ and .008, respectively). In the AITFL + PITFL injury model, the changes in FRA and pTFD were 2.12° and 1.02 mm when internal rotation force was applied, which were significantly greater versus intact ($P = .007$ and .003, respectively). In the SB fixation model, the change in FRA was 2.98° when external rotation force was applied, which was significantly higher compared with intact ($P < .001$). There were no significant differences between the SB + aST fixation model and the intact state on any measurement.

Conclusion: PITFL injury significantly increased syndesmotic instability when internal rotation force was applied. SB + aST fixation was effective in restoring syndesmotic stability.

Clinical Relevance: These results suggest that SB + aST fixation is sufficient for treating severe syndesmotic injury with PITFL rupture.

Keywords: ankle syndesmotic injury; biomechanics; posterior tibiofibular ligament; suture tape augmentation

The distal tibiofibular syndesmosis (ankle syndesmosis) is the complex that comprises the anterior inferior tibiofibular ligament (AITFL), posterior inferior tibiofibular ligament (PITFL), and interosseous membrane.[7] Approximately 7% to 25% of ankle injuries are syndesmotic injuries.[6,8,26] Syndesmotic instability may cause chronic pain and can lead to osteoarthritis of the ankle.[14] Surgical treatment is necessary to restore syndesmotic stability. However, the surgical technique to address this injury remains controversial.

Various biomechanical studies on syndesmotic treatment have been reported. Syndesmotic screw fixation is a rigid surgical method for which some disadvantages have been reported, such as obstructed physiological syndesmosis motion, screw loosening, screw breakage, and the need for screw removal.[3,12,17,18] Syndesmotic suture button (SB)

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fixation allows for some syndesmotic motion and does not require implant removal. However, some studies have reported that SB fixation could not restore physiological syndesmotic stability.[2,3,24] Suture tape (ST) augmentation of the AITFL in additional to SB fixation has been documented to improve external rotation stability in contrast to SB-only fixation.[21,23,27]

Most previous studies on syndesmotic injury have addressed only AITFL and interosseous membrane injuries, and the biomechanical effects of PITFL injury remain unclear. It is believed that syndesmotic injury results from external rotation forces. Hence, AITFL first ruptures, but PITFL injury certainly exists in cases in which the distal tibia and fibula are clearly separated. It has been reported that severe ankle sprain is associated with a high rate of PITFL injuries.[19] A clinical study has stated the outcomes of surgical treatment for syndesmotic injury with PITFL rupture.[16] Nevertheless, it is unknown whether stabilization of the syndesmosis should be performed with or without a procedure for PITFL rupture. Moreover, the biomechanical effect of treating PITFL injury is unknown. Thus, we considered that studying the role and treatment effect of PITFL is important.

In this study, we aimed to evaluate the biomechanical characteristics of syndesmotic instability caused by PITFL injury and compare various treatment methods. We hypothesized that PITFL injury leads to syndesmotic internal rotational instability and that the stability would be recovered with ST augmentation of the PITFL.

METHODS

Cadaveric Preparation

This study was approved by our institutional ethics committee. Before commencing the present study, we performed a power analysis. With an α error of .05 and power (β error) of 80%, the required minimum sample size was estimated to be 10 specimens based on a previous study.[21]

The study specimens were 10 fresh-frozen cadaveric legs (4 male, 6 female) that were donated to the Department of Anatomy of our institution. The mean age at the time of death was 85.2 years (range, 70-101 years). The exclusion criteria were cadavers with osteoarthritis of the ankle or subtalar joint and a history of fracture or lower leg surgery. Two assessments were made before and after testing to ensure the specimen integrity. Before testing, a plain radiographic examination was performed to confirm the absence of ankle or subtalar osteoarthritis. After testing, macroscopic assessment was performed to ensure that there were no degenerative changes in the ankle or subtalar joint.

In preparation for testing, each leg was cut at the distal third of the femur, with no disruption of soft tissue. The specimens were stored at -20°C and thawed overnight at room temperature before use. The legs were mounted on a customized wooden fixture, and the feet were fixed with 3.0 mm–diameter titanium Steinmann pins placed at the calcaneus and the metatarsals. The knee joint was fixed in the extended position via external joint fixation with a wooden bar and 3.0 mm–diameter titanium Steinmann pins. To measure the 3-dimensional (3D) movement of each bone, electromagnetic sensors were attached to the middle of the tibial and fibular shafts via an acrylic stylus and small stainless screws. To avoid soft tissue disruption around the ankle joint, the skin incision was kept minimal.

Measures and Loading System

The 3D movements of the tibia and fibula relative to a coordinate system were acquired using a magnetic tracking system (3 Space Fastrak; Polhemus) as 3D coordinates (x, y, and z) and angles (azimuth, elevation, and rotation). The coordinate system was fixed on the calcaneus, with the origin at the midpoint between the tips of the malleoli in the neutral position. The axes were located as follows: z-axis along the tibial shaft via the midpoint between the tips of the malleoli; x-axis parallel to the line connecting the center of the heel and the second toe and perpendicular to the z-axis; and y-axis perpendicular to both the z- and the x-axes, as per the right-hand rule. The three axes (x, y, and z) were also used to construct 3 mutually perpendicular planes: frontal (y-z plane), sagittal (x-z plane), and transverse (x-y plane).

The 3D data were collected using Medis-3D software (Medisens). The motion of each sensor was transformed to the anatomic points on each bone by digitizing the constant x-y-z offset from each sensor's origin to each anatomic point. Thus, as each sensor moved in space, the motion of the anatomic point was recorded. The digitized points of the tibia were the anterior and posterior edges of the medial malleolus and the distal anterolateral and anterior edges of the tibia. The digitized points of the fibula were the anterior and posterior edges of the lateral malleolus. To minimize soft tissue disruption, every digitization was performed via a small skin incision. The measurements and loading system used only nonmagnetic materials to prevent the magnetic environment from being affected. Within 250 mm of the magnetic source, the translational

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Ethical approval for this study was obtained from Sapporo Medical University (ref No. 2-1-19).

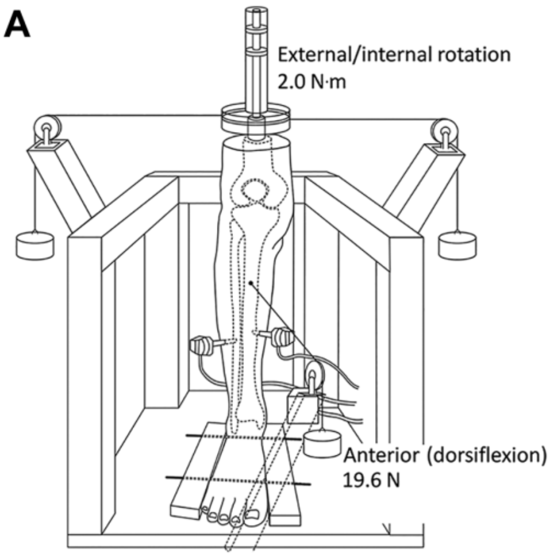

Figure 1. (A) Front and (B) side views of the measurement and loading system.

accuracy was 0.2 mm root mean square and the angular resolution was 0.5°.[11]

The specimens were tested while anterior traction forces of 19.6 N were applied to the proximal tibia 30 cm from the sole. In addition, 2.0-N·m internal and external rotation forces were applied to the femur. These forces were selected based on previous biomechanical studies on the same experimental system.[9,21,22,25] These anterior, internal rotation, and external rotation forces represented dorsiflexion, external rotation, and internal rotation of the ankle joint, respectively. Each of these forces were loaded separately. All forces were applied horizontally with a pulley-and-weight system. The rotation forces were applied using a 10 cm–diameter disk, which was fixed to the femoral diaphysis, thus providing a constant moment arm with force applied tangentially via a cable (Figure 1). All forces were applied in sequence.

The fibular rotational angle (FRA) related to the tibia, the anterior tibiofibular diastasis (aTFD), and the posterior tibiofibular diastasis (pTFD) were measured by calculating the anatomic points using the magnetic tracking system while each load was applied. The FRA was estimated from the angle created by 2 lines drawn between the anterior edge of the medial malleolus and the distal anterolateral edge of the tibia and the anterior and posterior edges of the lateral malleolus. The aTFD was computed from the distance between the distal anterolateral edge of the tibia and the anterior edge of the lateral malleolus. The pTFD was determined from the distance between the distal posterolateral edge of the tibia and the posterior edge of the lateral malleolus (Figure 2).

Reliability analysis was not performed for coordinate measurement evaluation because the evaluation could not be blinded owing to knowledge of the intended point in the actual experiment. From previous biomechanical studies using the same experimental system, it was evident that elongation did not occur in the soft tissue under this load.[25]

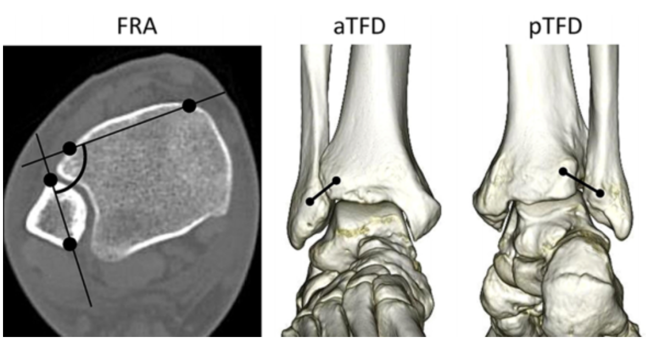

Figure 2. Measuring the fibular rotation angle (FRA), anterior tibiofibular diastasis (aTFD), and posterior tibiofibular diastasis (pTFD). The FRA represents the angle created by 2 lines drawn between the anterior edge of the medial malleolus and the distal anterolateral edge of the tibia and the anterior and posterior edges of the lateral malleolus; the aTFD represents the distance between the distal anterolateral edge of the tibia and the anterior edge of the lateral malleolus; and the pTFD represents the distance between the distal posterolateral edge of the tibia and the posterior edge of the lateral malleolus.

A total of 6 trials were performed for each loading test, and the mean value of the last 3 trials was used. Each trial lasted 5 seconds, and a 5-second recovery period was allowed. The 6 trials were completed in 1 minute.

Surgical Methods

After the initial loading test of the intact specimens, the AITFL, the distal 15 cm of the interosseous membrane, and the deltoid ligament were completely transected to create an AITFL injury model. The ligament cuts were performed carefully to minimize the disruption of the surrounding soft tissue. Clinically, the deltoid ligament is also injured

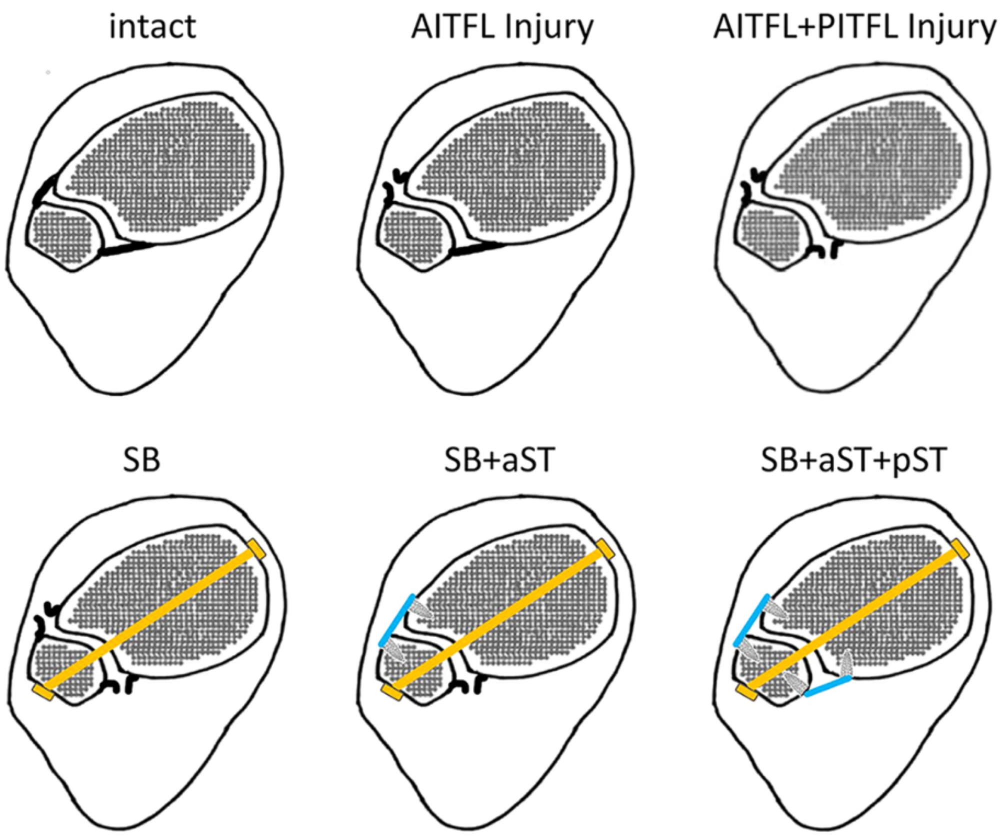

Figure 3. Schematic representation of each study model. The suture button (SB) is indicated in yellow, and the suture tapes (STs) are indicated in blue. For SB fixation, the SB device (Tightrope; Arthrex) was inserted from the lateral aspect of the fibula to the medial aspect of the tibia at a level 2 cm proximal from the ankle joint line. For ST fixation, a 2 mm–wide FiberTape (Arthrex) was used for AITFL and PITFL augmentation, and a 3.5-mm BioComposite SwiveLock (Arthrex) was inserted in the anterior or posterior aspect of the distal tibia and fibula. The ST was oriented in the same direction as the AITFL and PITFL fibers. AITFL, anterior inferior tibiofibular ligament; PITFL, posterior inferior tibiofibular ligament; aST, anterior suture tape; pST, posterior suture tape.

in severe syndesmosis injuries. After the same loading tests with AITFL injury models, the superficial and deep PITFLs were completely transected to create an AITFL + PITFL injury model, and the same loading tests were performed. Subsequently, the following 3 ankle states were evaluated for each specimen in the same order: SB only, SB fixation with anterior ST augmentation (SB + aST), and SB fixation with anterior and posterior ST augmentation (SB + aST + pST) (Figure 3).

For SB fixation, 3.5 mm drilling was performed at a level 2 cm proximal from the ankle joint line at a 30° angle to the frontal plane from the posterolateral aspect of the fibula toward the anteromedial aspect of the tibia to provide a 4-cortex hole. The SB device (Tightrope; Arthrex) was inserted from the lateral aspect of the fibula to the medial aspect of the tibia. A lateral SB was pushed into the fibula, with the ankle at 30° of plantarflexion. For ST augmentation, an ST device (InternalBrace; Arthrex) was used for AITFL and PITFL augmentation, and a 2.7-mm drilling was performed over the anterior or posterior aspect of the fibula at a level 5 mm proximal from the ankle joint line. A 3.5-mm BioComposite SwiveLock (Arthrex) suture anchor with a 2 mm–wide FiberTape (Arthrex) was inserted. Subsequently, 2.7-mm drilling was performed in the anterior or posterior aspect of the lateral tibia at a level 15 mm proximal from the ankle joint line such that the folded back part of the ST was oriented in the same direction as the AITFL and PITFL fibers. A 3.5-mm SwiveLock was then inserted (Figure 4). To avoid overtensioning, a small, curved hemostat was placed between the ST and lateral tibia while inserting the tibial anchor. All surgical procedures were performed by a board-certified orthopaedic surgeon (K.T.)

The same measurement protocol was applied for each surgical method. Coordinate analysis and surgical interventions were performed by the same researcher.

Statistical Analysis

All required data and sample size were analyzed using EZR (Saitama Medical Center, Jichi Medical University), which is a graphical user interface for R (Version 4.0.3; The R Foundation for Statistical Computing). The normality of all outcome data was confirmed using the Shapiro-Wilk test.

One-way repeated-measures analysis of variance was used to evaluate the relationship of the angles or the diastasis among each model. Post hoc analyses for differences among the parameters were performed using the Dunnett test. Significance was set at $P < .05$.

RESULTS

Anterior Traction Force (Ankle Joint Dorsiflexion)

Compared with the intact state, FRA was significantly increased in the AITFL injury model ($P = .015$). In the AITFL + PITFL injury model, both FRA and aTFD were significantly increased ($P = .009$ and .049, respectively). However, after SB fixation, FRA and aTFD did not differ significantly compared with intact (Table 1).

External Rotation Force

Compared with the intact state, both FRA and aTFD were significantly increased in the AITFL + PITFL injury model ($P = .026$ and $P < .001$, respectively), and in the SB fixation model, FRA was increased significantly compared with intact ($P < .001$). In the SB + aST and SB + aST + pST fixation models, neither FRA nor aTFD differed significantly compared with intact (Table 2).

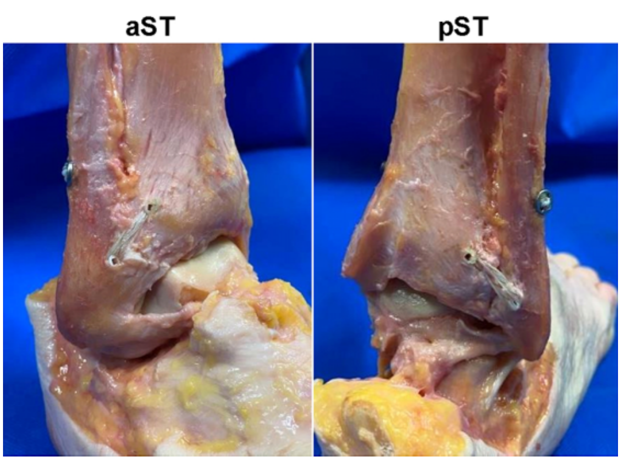

Figure 4. Anterior (aST) and posterior suture tape (pST) augmentation. The soft tissue was removed to enable visualization the ST in this figure.

Internal Rotation Force

Compared with the intact state, FRA and pTFD did not differ significantly in the AITFL injury model. In the AITFL + PITFL injury model, FRA and pTFD were significantly increased compared with intact ($P = .007$ and .003, respectively). However, after SB fixation, FRA and pTFD did not differ significantly compared with intact (Table 3).

DISCUSSION

The results of our study showed that PITFL injury increased laxity to an internal rotation torque. For the treatment of syndesmotic injury, the SB + aST model did not exhibit a significant difference in FRA and TFD compared with the intact state with any traction or rotational force applied at the ankle, and pST did not cause significant decrease in FRA or TFD.

Previous studies have focused on the PITFL function. Feller et al[5] reported arthroscopic quantification of syndesmotic stability and showed that PITFL injury affected syndesmotic instability. Krähenbühl et al[13] evaluated syndesmotic instability using weightbearing computed tomography and similarly established that PITFL injury caused syndesmotic widening. Schottel et al[20] reported that anatomic PITFL repair was beneficial for restoring syndesmotic stability. However, the researchers only loaded external rotational force and stability when the applied internal rotational force was unknown. Clanton et al[2] created stepwise syndesmotic injury models and then applied axial loading force and external and internal rotational force at the ankle for each model. They reported that PITFL primarily provided internal rotational stability. These results agree with those from the present study, but their measurement methods were different from ours. Clanton et al[2] monitored the axial rotation of the fibula and the coronal and sagittal translation of the fibula. In contrast, we monitored

TABLE 1
Changes in FRA and aTFD With Dorsiflexion Force at the Ankle[a]

Model	FRA, deg[b]	*P* vs Intact	aTFD, mm[c]	*P* vs Intact
Intact	–0.10 ± 0.33	—	0.15 ± 0.18	—
AITFL injury	0.82 ± 0.58	**.015**	0.47 ± 0.28	.335
AITFL + PITFL injury	0.87 ± 0.71	**.009**	0.64 ± 0.42	**.049**
SB	–0.07 ± 0.94	.999	–0.08 ± 0.54	.710
SB + aST	–0.50 ± 0.92	.615	–0.24 ± 0.47	.181
SB + aST + pST	–0.13 ± 0.65	.999	–0.13 ± 0.41	.491

[a]Data are reported as mean ± SD. Boldface *P* values indicate statistically significant difference compared with intact ($P < .05$). AITFL, anterior inferior tibiofibular ligament; aST, anterior suture tape; aTFD, anterior tibiofibular diastasis; FRA, fibular rotation angle; PITFL, posterior inferior tibiofibular ligament; pST, posterior suture tape; SB, suture button. Dashes indicate not applicable.

[b]An FRA >0° indicates external rotation.

[c]An aTFD >0 mm indicates increased diastasis.

TABLE 2
Changes in FRA and aTFD With an External Rotation Force at the Ankle[a]

Model	FRA, deg[b]	*P* vs Intact	aTFD, mm[c]	*P* vs Intact
Intact	1.09 ± 0.50	—	0.33 ± 0.13	—
AITFL injury	2.38 ± 1.25	**.032**	1.51 ± 0.79	**.008**
AITFL + PITFL injury	2.41 ± 1.14	**.026**	2.78 ± 1.79	**<.001**
SB	2.98 ± 1.81	**<.001**	1.14 ± 0.73	.129
SB + aST	1.58 ± 0.74	.801	0.58 ± 0.40	.973
SB + aST + pST	1.45 ± 0.76	.945	0.58 ± 0.42	.971

[a]Data are reported as mean ± SD. Boldface *P* values indicate statistically significant difference compared with intact ($P < .05$). AITFL, anterior inferior tibiofibular ligament; aST, anterior suture tape; aTFD, anterior tibiofibular diastasis; FRA, fibular rotation angle; PITFL, posterior inferior tibiofibular ligament; pST, posterior suture tape; SB, suture button. Dashes indicate not applicable.
[b]An FRA $>0^\circ$ indicates external rotation.
[c]An aTFD >0 mm indicates increased diastasis.

TABLE 3
Changes in FRA and pTFD With an Internal Rotation Force at the Ankle[a]

	FRA, deg[b]	*P* vs Intact	pTFD, mm[c]	*P* vs Intact
Intact	–0.57 ± 0.34	—	0.41 ± 0.21	—
AITFL injury	–1.33 ± 0.89	.404	0.40 ± 0.21	.999
AITFL + PITFL injury	–2.12 ± 1.63	**.007**	1.02 ± 0.41	**.003**
SB	–1.78 ± 0.89	.055	0.46 ± 0.45	.999
SB + aST	–1.74 ± 1.26	.066	0.54 ± 0.58	.952
SB + aST +pST	–1.19 ± 1.12	.612	0.32 ± 0.58	.991

[a]Data are reported as mean ± SD. Boldface *P* values indicate statistically significant difference compared with intact ($P < .05$). AITFL, anterior inferior tibiofibular ligament; aST, anterior suture tape; FRA, fibular rotation angle; PITFL, posterior inferior tibiofibular ligament; pST, posterior suture tape; pTFD, posterior tibiofibular diastasis; SB, suture button. Dashes indicate not applicable.
[b]An FRA $>0^\circ$ indicates external rotation.
[c]A pTFD >0 mm indicates increased diastasis.

anterior and posterior diastasis of the syndesmosis. In our study, PITFL injury increased anterior diastasis during dorsiflexion of the ankle and fibular rotation and posterior diastasis during internal rotation of the ankle. Therefore, PITFL appears to play an important role in stabilizing the distancing of the syndesmosis and the internal rotation of the fibula.

Regarding the effects of the surgical procedures, SB-only fixation did not alleviate external rotation instability in the case of severe syndesmotic injury with PITFL rupture, and the instability decreased significantly with aST fixation. Thus, aST seems to play a key role in providing external rotation stability. There are several reports that SB fixation provides better clinical outcomes than screw fixation, but inferior results have also been reported with SB fixation in severe cases.[4] In addition, several studies have reported that SB-only fixation by itself is unable to restore normal syndesmotic stability.[2,3,24,27] We believe that SB fixation is not the perfect treatment method for syndesmotic injury, and it is beneficial to establish a better treatment method. In a clinical study, good patient outcomes have been reported with ST augmentation.[10] In contrast, internal rotation instability decreased statistically with SB-only fixation. Based on the results of the present study, we believe that SB + aST fixation is sufficient to restore syndesmotic stability when treating severe syndesmotic stability with PITFL rupture and that pST is not always needed.

The strong point of our study is the PITFL treatment model. This study is the first to observe the biomechanics of syndesmosis in detail using a PITFL augmentation model. The SB + aST model did not exhibit a significant difference in syndesmotic stability compared with the intact state without PITFL augmentation. This finding was different from our hypothesis. Several factors may account for this result. First, aTFD was larger than pTFD in the AITFL + PITFL injury model. Because the posterior instability was less than the anterior instability before treatment, the same trend might have been observed with the treatment models. Second, the bone and joint shape differ between the medial and lateral talomalleolar joint; specifically, the width of the trochlea tali anterior is greater than that of the posterior.[1] Owing to this difference, talofibular compression and syndesmosis instability may be more effective in external than in internal rotation. Third, the tibiotalar joint rotational range of motion may be affected. In the healthy volunteer group, tibiotalar rotational angle was greater in external than in internal rotation.[15] Although we used syndesmotic injury models, the same trends might have been observed. Fourth, SB direction may affect posterior stability. We created a 30° angle from the posterolateral aspect of the fibula toward the anteromedial aspect of the tibia to perform SB fixation; however, the use of another angle may result in another stability pattern.

Limitations

This study has several limitations. First, our cadaveric biomechanical model could not reflect axial load. Applying axial loading may cause more syndesmotic instability. Second, we could not simultaneously apply dorsiflexion and rotational force. For example, different syndesmotic kinematics may occur when external rotation force is applied to the ankle in the neutral position or in dorsiflexion. Third, the applied forces were relatively low compared with in vivo forces. The magnitudes of the applied forces were determined following previous studies.[21,22,24] Fourth, we could not assess an in vivo ligament injury pattern. We created the ligament injury via sharp transection of the AITFL and PITFL. In addition, we also transected the deltoid ligament. Thus, our injury model represented a worst case of syndesmosis injury. Fifth, due to the nature of the study, a reliability analysis could not be performed. Although these limitations were difficult to overcome, we conducted the present study in as close to clinical conditions as possible. Finally, the sample size of this study was too small. Although a power analysis was performed, when internal rotational force was applied, FRA in the SB + aST model was less than that in the intact state ($P = .066$). Despite these limitations, this biomechanical study is the first to assess the stability of syndesmosis with a PITFL-injury treatment model. The results of the present study are likely to be helpful in determining the treatment protocol for patients with severe syndesmotic injury.

Some caution may be needed while interpreting the results. In the condition of internal rotation force's being applied, the absolute values of FRA and pTFD in the SB + aST model were still higher than those in the AITFL injury model although the values were not statistically different from those of the intact state. In some severely injured cases, there is a possibility of residual instability following SB + aST fixation. Internal rotation force should be useful in evaluating syndesmotic instability caused by PITFL injury to confirm the efficacy of stabilizing procedures during operation.

CONCLUSION

PITFL plays an important role in stabilizing the tibiofibular syndesmosis, and PITFL injury causes significant syndesmotic rotational laxity when internal rotation force is applied at the ankle. SB + aST fixation should be sufficient to restore syndesmotic stability when treating syndesmotic injury with PITFL rupture.

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