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Research Article

Comparative Contribution of the Anterior and Posterior Inferior Tibiofibular Ligaments to Distal Tibiofibular Syndesmotic Stability: A Sequential Sectioning Cadaveric Study

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Abstract

Background: Syndesmotic injuries are common and frequently underdiagnosed components of ankle trauma, yet the relative contribution of individual syndesmotic ligaments to overall stability remains incompletely defined. The distal tibiofibular syndesmosis is composed of the anterior inferior tibiofibular ligament (AITFL), the posterior inferior tibiofibular ligament (PITFL), and the interosseous ligament (IOL). The posterior inferior tibiofibular ligament has classically been regarded as the dominant stabilizer, but more recent biomechanical and strain-mapping studies have implicated the anterior inferior tibiofibular ligament as a key restraint against external rotation, leaving the question of relative ligamentous importance unresolved.

Purpose: To compare, in a controlled cadaveric model, the effect of sequential AITFL- and PITFL-first sectioning on distal tibiofibular clear space (TFCS), and to determine whether one ligament contributes disproportionately to syndesmotic stability.

Methods: Sixteen lower extremities from eight fresh-frozen cadavers (2 males, 6 females; mean age 72.5 years, range 55-80) were randomized to one of two sequential sectioning protocols. In Group I (n = 8), the AITFL was sectioned first, followed by the IOL and then the PITFL. In Group II (n = 8), the order was reversed: the PITFL was sectioned first, followed by the IOL and then the AITFL. The IOL was transected 5 cm proximally to the joint line in both groups. With a standardized 100 N lateral force applied to the distal fibula 5 cm above the joint line to reproduce a lateral hook stress test, TFCS was measured 10 mm proximally to the tibiotalar joint line using a calibrated digital vernier caliper, with each measurement averaged over three trials. Paired and unpaired t-tests were used for within- and between-group comparisons, with significance set at $p < 0.05$.

Results: Intact baseline TFCS did not differ significantly between groups (Group I: 3.03 mm, range 2.2-3.55; Group II: 3.17 mm, range 2.56-4.16; p = 0.46). After the first ligament was sectioned, PITFL-first sectioning produced a numerically greater increase in TFCS than AITFL-first sectioning (0.73 mm versus 0.38 mm), a difference that trended toward but did not reach statistical significance (p = 0.056). This pattern persisted after the second sectioning step (p = 0.10) and resolved entirely once all three structures had been divided, with both groups converging on a nearly identical degree of widening (Group I: 1.35 mm; Group II: 1.38 mm; p = 0.78). Within each group, sectioning of the second ligament in the sequence produced the largest and most statistically robust incremental widening: in Group I, AITFL-then-PITFL sectioning increased TFCS significantly beyond AITFL sectioning alone (p = 0.003), and in Group II, PITFL-then-AITFL sectioning increased TFCS significantly beyond PITFL sectioning alone (p = 0.0098).

Conclusion: Both the AITFL and the PITFL make substantial and statistically indistinguishable contributions to distal tibiofibular syndesmotic stability. Although PITFL disruption showed a consistent trend toward greater early widening of the TFCS, complete syndesmotic disruption produced equivalent instability regardless of the order in which the ligaments were sectioned. These findings support a model of syndesmotic stability that depends on the structural integrity of the complex rather than on any single dominant ligament.

Clinical Relevance: Isolated injury to either the AITFL or the PITFL should raise clinical suspicion for syndesmotic instability, and surgical or non-operative management strategies should aim to restore the entire syndesmotic complex rather than prioritizing repair or fixation of a single presumed primary stabilizer.

Level of Evidence: Controlled laboratory study.

Keywords: syndesmotic diastasis; distal tibiofibular clear space; anterior inferior tibiofibular ligament; posterior inferior tibiofibular ligament; ankle syndesmosis; cadaveric biomechanics

Introduction

Injury to the distal tibiofibular syndesmosis occurs in approximately 10% of all ankle fractures, and roughly one quarter of these injuries are severe enough to warrant operative stabilization [1]. Despite this substantial clinical burden, syndesmotic injuries remain among the most frequently underdiagnosed components of ankle trauma, in part because subtle degrees of instability can be difficult to detect on standard radiographs and may only become apparent under dynamic stress [2,3]. Missed or undertreated syndesmotic injury is strongly associated with chronic pain, residual instability, early post-traumatic arthrosis, and inferior functional outcomes, which makes a precise understanding of syndesmotic biomechanics directly relevant to clinical decision-making.

The distal tibiofibular syndesmosis is a fibrous joint stabilized by three principal ligamentous structures: the anterior inferior tibiofibular ligament (AITFL), the posterior inferior tibiofibular ligament (PITFL), and the interosseous ligament (IOL), which is functionally continuous with the more proximal interosseous membrane.[1] (Figure 1) Each of these structures resists a different combination of translational and rotational forces at the distal tibiofibular joint, and injury patterns in clinical practice rarely respect anatomic boundaries cleanly - a single traumatic mechanism, most commonly external rotation and dorsiflexion of the talus within the mortise, can damage one, two, or all three structures depending on the magnitude and direction of force.

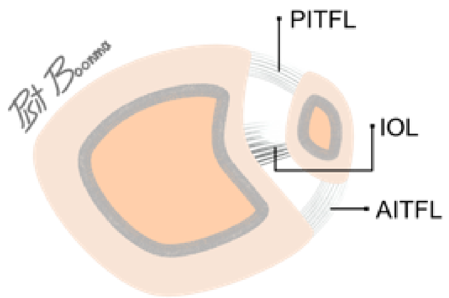

Figure 1: Axial schematic of the distal tibiofibular syndesmotic complex, illustrating the anterior inferior tibiofibular ligament (AITFL), interosseous ligament (IOL), and posterior inferior tibiofibular ligament (PITFL) in relation to the tibial incisura and distal fibula.

The relative importance of these individual ligaments has been debated for more than three decades and remains unresolved. In a frequently cited 1994 biomechanical study, Ogilvie-Harris et al. [4] identified the PITFL as the strongest of the syndesmotic restraints, a finding that shaped clinical teaching for many years and contributed to the perception that the PITFL is the primary stabilizer of the syndesmosis. This view has since been challenged by several lines of more recent evidence. Clanton et al. [5], using a sequential sectioning protocol with rotational loading, found that the AITFL contributed most substantially to resistance against external rotation forces. Using digital image correlation to map strain across the syndesmotic ligaments during simulated external rotation injury, Xu et al. [6] demonstrated disproportionately high strain concentration within the AITFL relative to the PITFL and interosseous membrane, suggesting the AITFL may fail first, and at lower loads, during a rotational injury mechanism. Littlechild et al. [7] reached a similar conclusion in a cadaveric model, proposing that the AITFL, rather than the PITFL, is the more important determinant of syndesmotic stability after ankle fracture. Taken together, this body of work suggests that the relative contribution of each ligament may depend heavily on the mechanism of loading under which it is tested, a possibility that has not been systematically addressed using a single, standardized loading protocol applied identically to both ligaments.

Radiographic and direct caliper-based measurement of the distal tibiofibular clear space (TFCS) remains one of the most widely used and reproducible methods for assessing syndesmotic integrity, both in cadaveric research and in clinical stress testing [2]. Despite the central role TFCS plays in diagnostic algorithms, the literature describing how individual ligament transection translates into TFCS widening is sparse and, where it exists, inconsistent - a gap that is compounded by the small sample sizes characteristic of most cadaveric syndesmosis studies. To our knowledge, no prior comparative cadaveric study has directly examined TFCS widening, measured using a single standardized lateral stress protocol, across two mirrored sequential sectioning groups designed specifically to isolate the relative contribution of the AITFL versus the PITFL.

The purpose of this study was therefore to compare, in a controlled cadaveric model, the effect of AITFL-first versus PITFL-first sequential ligament sectioning on TFCS widening under a standardized lateral stress force. Our primary outcome was the between-group difference in TFCS widening at each stage of sectioning, used as a surrogate for the relative contribution of each ligament to syndesmotic stability. Our secondary outcome was the within-group pattern of TFCS widening as each successive structure was divided, which allows assessment of how instability accumulates as the syndesmotic complex is progressively compromised. We hypothesized, based on the classic biomechanical literature, that PITFL disruption would result in significantly greater TFCS widening than AITFL disruption when each ligament was sectioned first in its respective sequence.

Materials and Methods

Study Design and Specimen Preparation

This was an experimental, comparative cadaveric biomechanical study. Eight fresh-frozen cadaveric specimens (16 lower extremities; 2 male, 6 female; mean age 72.5 years, range 55-80 years) were obtained and thawed to room temperature prior to dissection. All specimens were intact from the knee to the toes, allowing unrestricted access to the proximal tibiofibular joint, the interosseous membrane, the ankle syndesmosis, and the medial and lateral collateral ligament complexes.

Specimens were excluded if there was radiographic or gross evidence of prior fracture, surgical hardware, ligamentous reconstruction, substantial degenerative deformity, or any soft-tissue scarring suggestive of prior injury or operative intervention at the ankle. Each of the sixteen lower extremities included in the final analysis was confirmed grossly free of structural pathology at the time of dissection, and none of the prepared specimens met any exclusion criterion.

Dissection Protocol

A standard anterolateral surgical approach was used to expose the distal tibiofibular syndesmosis in each specimen. The AITFL, IOL, and PITFL were carefully identified and isolated from surrounding soft tissue, with meticulous preservation of all other stabilizing structures, including the proximal tibiofibular joint, the deltoid ligament complex, and the lateral collateral ligaments (anterior talofibular, calcaneofibular, and posterior talofibular ligaments). Maintaining the integrity of these secondary stabilizers was essential to ensure that any measured widening of the TFCS could be attributed specifically to sectioning of the syndesmotic ligaments under study, rather than to incidental injury of adjacent restraints.

The sixteen specimens were allocated using a computer-generated randomization sequence into two groups of eight, with randomization performed at the level of the individual lower extremity rather than the cadaver, so that contralateral limbs from the same donor could be assigned to different groups.

Group I (n = 8): AITFL sectioned first, followed by the IOL, followed by the PITFL (Figure 2).

Group II (n = 8): PITFL sectioned first, followed by the IOL, followed by the AITFL (Figure 3).

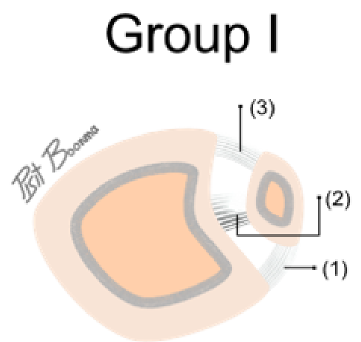

Figure 2: Group I sectioning sequence: AITFL (1) → IOL (2) → PITFL (3). Numbers in parentheses denote the order of ligament sectioning.

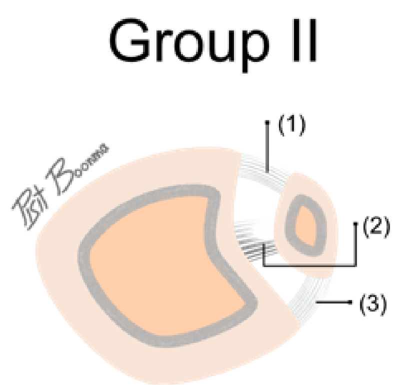

Figure 3: Group II sectioning sequence: PITFL (1) → IOL (2) → AITFL (3). Numbers in parentheses denote the order of ligament sectioning.

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In both groups, the IOL was transected 5 cm proximal to the ankle joint line, consistent with previously described cadaveric methodology for syndesmotic sectioning studies [8]. This sequential, mirrored design was selected specifically so that the structure sectioned first - and therefore the structure whose isolated contribution to TFCS widening could be most cleanly assessed - alternated between the AITFL and the PITFL across the two groups, while the overall order of progression toward complete syndesmotic disruption remained otherwise comparable.

Measurement Protocol

Distal tibiofibular clear space was measured directly using a calibrated digital vernier caliper at a fixed point 10 mm proximal to the ankle joint line, with each measurement obtained from the anterior aspect of the syndesmosis. To minimize measurement error, three independent readings were taken at each stage of sectioning and averaged to yield the value used for analysis.

To reproducibly stress the syndesmosis during measurement, a standardized 100 N lateral force was applied to the distal fibula at a point 5 cm proximal to the ankle joint line, reproducing a lateral hook stress test analogous to techniques described in prior biomechanical literature [8]. (Figure 4) This loading point and magnitude were held constant across all specimens, all groups, and all stages of sectioning, so that any observed difference in TFCS widening could be attributed to the structural consequence of ligament sectioning rather than to variability in applied load.

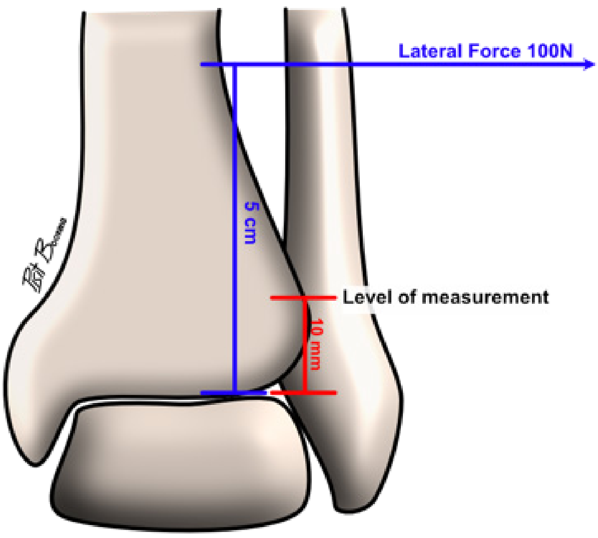

Figure 4: Measurement protocol. A 100 N lateral force was applied to the distal fibula 5 cm proximal to the joint line, and distal tibiofibular clear space was measured 10 mm proximal to the joint line.

Measurements were obtained at four discrete time points for each specimen: with the syndesmosis intact, after sectioning of the first ligament in the assigned sequence, after sectioning of the first ligament plus the IOL, and after complete sectioning of all three structures.

Statistical Analysis

Data was analyzed using SPSS statistical software. Paired t-tests were used to compare sequential measurements within each group, and unpaired (independent-samples) t-tests were used to compare measurements between Group I and Group II at each corresponding stage of sectioning. With eight specimens analyzed per group, statistical significance was defined as a priori as $p < 0.05$.

Results

Demographics

Eight fresh cadavers (16 lower extremities) were included, comprising 2 male and 6 female donors with a mean age of 72.5 years (range, 55-80 years). No specimen demonstrated gross evidence of prior ankle injury, deformity, or surgical intervention (Table 1).

Table 1: Demographic characteristics of the cadaveric specimens.

Characteristic	N = 8 cadavers (16 specimens)
Sex - Male	2
Sex -Female	6
Age, years (mean, range)	72.5 (55–80)

Baseline and Between-Group Comparisons

Intact baseline TFCS did not differ significantly between groups (Group I: 3.03 mm, range 2.2-3.55 mm; Group II: 3.17 mm, range 2.56-4.16 mm; p = 0.46), confirming that the two groups were biomechanically comparable prior to any ligament sectioning.

Following sectioning of the first ligament in each sequence - the AITFL in Group I and the PITFL in Group II - TFCS widening was numerically greater after PITFL sectioning (0.73 mm, range 0.38-1.26) than after AITFL sectioning (0.38 mm, range 0.1-0.77), a difference that approached but did not reach statistical significance (p = 0.056). This same directional trend persisted after the second sectioning step, with combined first-ligament-plus-IOL sectioning producing greater widening in Group II than in Group I (1.09 mm versus 0.88 mm), again without reaching significance (p = 0.10-0.11).

After complete sectioning of all three syndesmotic structures, however, TFCS widening converged to a nearly identical magnitude in both groups (Group I: 1.35 mm, range 0.7-1.7; Group II: 1.38 mm, range 0.53-2.09; p = 0.78), indicating that the order in which the AITFL and PITFL were divided did not influence the final degree of syndesmotic instability once the complex was fully disrupted (Table 2).

Table 2: Comparative widening of distal tibiofibular clear space between Group I and Group II at each stage of sequential ligament sectioning.

Sectioning Stage	Group I, mm (range)	Group II, mm (range)	P value
Intact syndesmosis	3.03 (2.2-3.55)	3.17 (2.56-4.16)	0.46
Δ First ligament cut	0.38 (0.1-0.77)	0.73 (0.38-1.26)	0.056
Δ First ligament + IOL cut	0.88 (0.43-1.34)	1.09 (0.48-1.45)	0.1
Δ All ligaments cut	1.35 (0.7-1.7)	1.38 (0.53-2.09)	0.78

Within-Group Analysis

Within Group I, sectioning of the AITFL alone produced a modest, non-significant increase in TFCS. Combined AITFL-plus-IOL sectioning produced a significant increase in TFCS relative to AITFL sectioning alone (p = 0.003), and complete sectioning of all three structures produced a further highly significant increase relative to baseline (p = 0.0003) (Table 3).

Table 3: Within-group widening of distal tibiofibular clear space in Group I (AITFL → IOL → PITFL sequence).

Sectioning Stage	Group I, mm (range)	P value
Intact syndesmosis	3.03 (2.2-3.55)	-
Δ AITFL cut	0.38 (0.1-0.77)	Reference
Δ AITFL + IOL cut	0.88 (0.43-1.34)	0.003
Δ AITFL + IOL + PITFL cut	1.35 (0.7-1.7)	0.0003

Within Group II, sectioning of the PITFL alone likewise produced an increase in TFCS. Combined PITFL-plus-IOL sectioning produced a significant incremental increase (p = 0.0098), and complete sectioning of all three structures produced a further significant increase (p = 0.0463) (Table 4). Notably, in both groups, the most substantial and statistically robust jump in TFCS widening occurred at the second sectioning step - that is, once the IOL had been divided in addition to the first ligament - suggesting that combined injury to two of the three syndesmotic structures, rather than injury to any single structure in isolation, represents the critical threshold for clinically meaningful instability.

Table 4: Within-group widening of distal tibiofibular clear space in Group II (PITFL → IOL → AITFL sequence).

Sectioning Stage	Group II, mm (range)	P value
Intact syndesmosis	3.17 (2.56-4.16)	-
Δ PITFL cut	0.73 (0.38-1.26)	Reference
Δ PITFL + IOL cut	1.09 (0.48-1.45)	0.0098
Δ PITFL + IOL + AITFL cut	1.38 (0.53-2.09)	0.0463

Discussion

This study evaluated the individual and combined contributions of the AITFL and PITFL to distal tibiofibular syndesmotic stability using TFCS widening as a quantitative, reproducible outcome measure under a standardized lateral loading protocol. The principal finding is that disruption of either ligament contributes meaningfully to syndesmotic instability, and that no statistically significant difference exists between the two ligaments in their overall effect on TFCS once the entire complex has been divided. This finding directly addresses a question that has remained controversial across more than three decades of biomechanical literature: rather than identifying a single dominant stabilizer, our data support a model in which the AITFL and PITFL function as biomechanically comparable, individually necessary, and jointly sufficient restraints against syndesmotic widening.

Although PITFL-first sectioning produced a consistently larger increase in TFCS than AITFL-first sectioning at every intermediate stage of our protocol, this difference did not reach conventional statistical significance at any single time point, instead manifesting as a persistent trend ($p = 0.056$ after the first cut, $p = 0.10$ after the second). This pattern is broadly consistent with the classic biomechanical work of Ogilvie-Harris et al.,4 who identified the PITFL as the strongest single stabilizer of the syndesmosis under their loading conditions, while at the same time our results do not contradict the more recent literature emphasizing the AITFL's importance in resisting external rotation [5,6]. One plausible explanation for this apparent discrepancy across studies is that the relative contribution of each ligament may be loading-mode dependent: the PITFL, by virtue of its more posterior and oblique orientation, may preferentially resist the lateral translational forces isolated in our protocol and in the original Ogilvie-Harris model, whereas the AITFL, oriented more directly across the anterior incisura, may be recruited preferentially during external rotation or dorsiflexion-rotation mechanisms, as suggested by the strain-mapping data of Xu et al.[6] If this is correct, it would imply that no single ligament can be considered universally dominant, and that the clinically relevant 'most important' ligament may depend on the specific mechanism of injury sustained by an individual patient.

A second key observation from our data is the pattern by which instability accumulated within each group. In both Group I and Group II, the largest and most statistically robust incremental increase in TFCS occurred not after sectioning of the first ligament alone, but after the combined sectioning of the first ligament plus the IOL. This observation is consistent with prior cadaveric and arthroscopic work by Massri-Pugin et al.,[8] who demonstrated that meaningful coronal-plane syndesmotic instability emerges only after combined injury to multiple ligamentous structures rather than after isolated injury to any single component. Our results extend this concept by showing that this multi-structure threshold effect holds true regardless of whether the AITFL or the PITFL is the first structure sectioned, reinforcing the interpretation that the syndesmosis behaves as an interdependent structural unit rather than a simple sum of independently acting ligaments. From a clinical standpoint, this has a direct and practical implication: a patient with an isolated, low-grade injury to a single syndesmotic ligament may demonstrate only modest TFCS widening and may be more amenable to non-operative management, whereas any injury pattern involving the interosseous ligament in combination with either the AITFL or the PITFL should raise substantially greater concern for clinically significant instability warranting surgical stabilization.

The convergence of TFCS widening to nearly identical values in both groups after complete syndesmotic disruption (1.35 mm versus 1.38 mm, $p = 0.78$) further reinforces this concept of structural interdependence. Regardless of which ligament failed first, the end state of complete syndesmotic disruption produced equivalent instability. This finding has direct relevance to surgical decision-making in the management of syndesmotic injuries and rotational ankle fractures: it suggests that restoration of the entire syndesmotic complex, rather than selective repair or augmentation of a single ligament presumed to be the primary stabilizer, should be the governing principle of operative treatment. This is consistent with the clinical and biomechanical work of Schottel et al. [9] and little et al.,[10] who demonstrated that anatomic ligament repair - restoring the native ligamentous anatomy of the syndesmosis - can restore rotational stability comparable to that achieved with syndesmotic screw fixation, while additionally preserving the physiologic micromotion of the distal tibiofibular joint and offering superior radiographic reduction in some series. Our data provide additional biomechanical support for this anatomic, complex-restoration-oriented philosophy, as they suggest that no single structure can be relied upon, in isolation, to maintain syndesmotic stability if the remaining structures are compromised.

These findings should also be interpreted in the context of the broader debate regarding optimal fixation strategy for syndesmotic injuries, including the ongoing discussion of suture-button versus screw fixation. While our study did not directly evaluate fixation constructs, the demonstration that both the AITFL and PITFL contribute comparably to stability supports fixation philosophies that aim to recreate physiologic syndesmotic mechanics across the entire complex - for example, by combining direct AITFL repair with suture-button or screw stabilization - rather than relying on a single fixation point to substitute for the function of multiple injured ligaments.

Limitations

This study has several limitations that warrant consideration when interpreting and generalizing our findings. First, the sample size, while comparable to or larger than many previously published cadaveric syndesmosis studies, remains modest at eight specimens per group, which limits statistical power to detect smaller between-group differences and may explain why the consistent trend favoring greater PITFL contribution did not reach statistical significance. Second, our specimens were predominantly elderly (mean age 72.5 years) and predominantly female, a demographic profile that may not fully represent the biomechanical properties of ligamentous tissue in younger, more physiologically representative trauma populations, in whom collagen quality, ligament compliance, and failure characteristics may differ substantially. Third, TFCS was measured exclusively from the anterior aspect of the syndesmosis using a direct caliper technique; prior arthroscopic work has suggested that assessment of the posterior third of the incisura may provide a more sensitive and reliable indicator of syndesmotic instability, and arthroscopic evaluation remains the diagnostic gold standard against which caliper-based measurement is, at best, an indirect surrogate.8 Fourth, our protocol applied a single standardized lateral force vector to simulate stress conditions; the majority of clinical syndesmotic injuries result from external rotation or combined rotation-dorsiflexion mechanisms rather than pure lateral translation, and we are therefore unable to determine from this data alone which ligament would prove more critical under a rotational loading paradigm. Finally, as in all cadaveric biomechanical studies, our model cannot fully replicate the dynamic, weight-bearing, neuromuscular modulated conditions of the in vivo ankle, and the absence of active muscular stabilization may overestimate the degree of instability attributable to passive ligamentous structures alone.

Future investigations using combined rotational and translational loading protocols, posterior incisura measurement techniques, and biomechanically matched younger specimens would help clarify whether the trend toward greater PITFL contribution observed in this study reflects a true, generalizable biomechanical difference or is instead an artifact of the specific loading mode and specimen population studied here.

Conclusion

Both the AITFL and the PITFL are critical stabilizers of the distal tibiofibular syndesmosis. In this cadaveric model, no statistically significant difference was observed between the two ligaments in their overall contribution to TFCS widening, although PITFL disruption demonstrated a consistent, non-significant trend toward greater early widening. The most pronounced increase in instability in both sectioning sequences occurred only after combined injury to multiple syndesmotic structures, indicating that the syndesmosis functions as an interdependent structural unit. These findings suggest that the AITFL and PITFL are similarly important to the maintenance of distal tibiofibular stability, and that clinical and surgical strategies should be directed at restoring the integrity of the entire syndesmotic complex rather than at the repair or fixation of any single ligament in isolation.

Clinical Relevance

Accurate assessment of syndesmotic stability remains essential to the management of both isolated syndesmotic injuries and rotational ankle fractures. This study demonstrates that injury to either the AITFL or the PITFL can produce clinically meaningful widening of the distal tibiofibular clear space, with no clear biomechanical dominance of one ligament over the other. Clinicians should maintain a high index of suspicion for syndesmotic instability whenever injury to either ligament is identified clinically, arthroscopically, or on advanced imaging, and treatment algorithms - whether operative or non-operative - should be designed around restoration of the syndesmotic complex as a functional unit rather than around the assumption that a single ligament bears primary responsibility for stability.

Acknowledgements

None

Conflict of Interest

No Conflict of Interest.

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