LIGAMENTOUS RESTRAINTS OF THE SECOND TARSOMETATARSAL JOINT: A BIOMECHANICAL EVALUATION.

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Introduction

Low-energy injuries to the tarsometatarsal joint are often sustained during sports and recreational activities, resulting in midfoot sprains.[1,2,4-6,9] Two large ligaments maintain the relationship of the second metatarsal base to the medial cuneiform. The interosseous (Lisfranc) ligament attaches to the lateral aspect of the medial cuneiform and the medial aspect of the second metatarsal base. The plantar ligament attaches to the lateral aspect of the medial cuneiform and the plantar aspect of the base of the second and third metatarsals. The relative strength and importance of these two closely related ligaments are not known. The purpose of this study was to determine the mechanical properties of the plantar and Lisfranc ligaments.

Methods

Thirteen pairs of elderly cadaveric feet were obtained from the state anatomy board. Before testing, the feet were wrapped in saline-soaked towels and stored in sealed bags at -20^0C. Specimens were thoroughly defrosted for 24 hours before preparation. From each foot, the second and third metatarsals and the first cuneiform were dissected. There was no evidence of previous trauma or arthrosis in any specimen. The Lisfranc and plantar ligaments were left intact, as was the intermetatarsal ligament between the second and third metatarsals. All other ligaments were excised.

Each specimen was potted in two pieces of PVC pipe using a common epoxy resin. The cuneiform was additionally secured by passage of crossed Kirschner wires, placed before potting, with care to ensure that the wires were not close to the ligamentous attachments. A Kirschner wire was also placed through the heads of the two metatarsals to maintain their near-parallel relationship. Each specimen was mounted on an Instron testing machine so that the applied load was along the longitudinal axis of the ligament fibers. Specimens were preloaded to 7 N and then elongated at a rate of 0.1 mm/sec until a load of 100 N was reached. The specimen was then unloaded and one ligament was sectioned. In one of each pair of specimens, the Lisfranc ligament was sectioned; the plantar ligament was sectioned in the contralateral specimen. Assignment of Lisfranc ligament sectioning was alternated between right and left feet to minimize any potential right/left limb bias. The loading test was then repeated, but elongation was continued until rupture of the remaining ligament. Load and displacement data were recorded throughout the test. The ultimate strength of the each ligament was thus determined from one specimen from each pair of feet.

The difference in failure strength between Lisfranc and plantar ligaments was analyzed using a paired Student t-test. The effect of condition (intact versus sectioned) and ligament (Lisfranc versus plantar) on stiffness was analyzed using a repeated measures ANOVA. Post hoc comparisons were conducted using Tukey's test. Unless otherwise specified, results were considered significant at $p < 0.05$.

Results

Table 1 provides a summary of the data. The mean ultimate strength was significantly greater for the Lisfranc ligament than for the plantar ligament. The average stiffness of the intact specimens assigned to the plantar group was greater than that of the Lisfranc group, although this difference was not significant. Once the Lisfranc ligament was sectioned, stiffness decreased significantly, whereas sectioning the plantar ligament produced no significant change in stiffness.

TABLE 1

Group	Stiffness (N/mm)*	Strength (N)*
Plantar intact	86.9 ± 2.6	NA
Plantar sectioned	90.0 ± 2.6	449.4 ± 57
LisFranc intact	75.2 ± 2.6	NA
LisFranc sectioned	62.4 ± 2.6	305.2 ± 38

* n = 13; values are mean ± SEM.

Discussion

The results show that, under the loading conditions used in the current study, the Lisfranc ligament is stronger and stiffer than the plantar ligament. Saraffian[8] and de Palma et al[3] noted that both the Lisfranc and plantar ligaments were large and strong, but their assessments of the mechanical properties of these ligaments were based on anatomical observation and not quantitative measurement.

The results of the current study elucidate the relative importance of each ligament and serve as baseline data for choosing a suitable graft material for the reconstruction of the tarsometatarsal joint ligaments. Until recently, soft tissue injuries of the second tarsometatarsal joint were treated without distinguishing which ligament was involved. Magnetic resonance imaging now allows the diagnosis of isolated injuries,[7] and treatments may need to be modified accordingly.

In the past, the distinction between Lisfranc and plantar ligaments has not always been clearly made. Contrary to the descriptions in anatomical studies,[3] authors often refer to plantar ligament and Lisfranc ligament as two bundles of the "Lisfranc ligament."[7] Interpretation of the results of other studies may also be influenced by clarification of the anatomy.

The cadaveric specimens used in the current study were from an elderly age group, and demographic details were incomplete. Measurements of ultimate load of the ligaments are therefore likely to be underestimates when considering young athletic patients. However, the specimens were paired, and thus the relative strength of the two ligaments is likely to be accurate because both would have undergone similar age-related changes.

This biomechanical study measured the relative strength and stiffness of the two major ligaments of the second tarsometatarsal joint, providing a foundation from which reconstruction techniques can be developed to more accurately restore this joint's functional anatomy.

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