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Elongation Behavior of Calcaneofibular and Cervical Ligaments in a Closed Kinetic Chain: Pathomechanics of Lateral Hindfoot Instability

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ABSTRACT

Numerous reconstructive procedures are performed to correct both ankle and subtalar instability after trauma although the precise pathology which results in this chronic instability and pain is not yet known. This study examined the role of the calcaneofibular (CLFL) and cervical ligaments (CRVL) during physiologic loading and demonstrated the effect of CLFL deficiency on the CRVL. Talar and subtalar tilt as well as inversion range of motion before and after CLFL sectioning were studied. Eleven osteoligamentous fresh frozen cadaver legs were used in which each foot was taken through six positions: neutral, 35° plantarflexion, dorsiflexion, inversion, plantarflexion-inversion, and dorsiflexion-inversion. The CLFL and CRVL stretched the greatest in dorsiflexion-inversion. The most interesting finding was that the CRVL was elongated relative to neutral in all other test positions of the foot. However, the CLFL was shortened relative to neutral in plantarflexion and plantarflexion-inversion. In the CLFL deficient state, CRVL ratios demonstrated significant increases in length of the CRVL. Talar tilt increased on average more than 9° with CLFL deficiency ($p<0.008$) while subtalar tilt did not change significantly. The maximum tibiocalcaneal angle, recorded for dorsiflexion-inversion, increased more than 5° after sectioning the CLFL ($p<0.05$).

Key Words: Subtalar Joint; Closed Kinetic Chain; Cervical Ligament; Calcaneofibular Ligament; Lateral Hindfoot

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INTRODUCTION

Functional stability of the subtalar joint is provided by the interplay of ligamentous support, bony congruity and muscular control.[6,18,19,23,24] Trauma can disrupt this delicate balance and lead to a chronic state of instability (recurrent turning over) and pain. The precise pathology that causes these symptoms has yet to be elucidated. Despite this, there are a myriad of reconstructive procedures to correct both ankle and subtalar instability.[1,4,8,11,12,16] It has been previously demonstrated that the calcaneofibular ligament (CLFL) plays a significant role both in ankle and subtalar stability,[1,2,3,5,6,7,8,9,10,13,14,15,17,18] and that in the absence of the CLFL, the cervical ligament (CRVL) is overstretched during inversion range of motion in an unloaded foot.[17] However, those tests were performed in a open kinetic chain (no axial loading). The purpose of the present study was to examine the elongation characteristics of both ligaments under physiologic load (closed kinetic chain) in various functional positions of the foot. The goal was to identify the position or positions of maximal stretch on the CLFL and CRVL and to assess whether

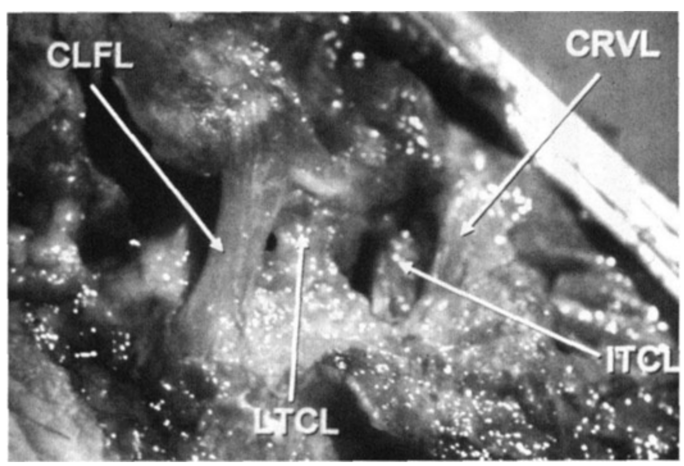

Fig. 1: Dissection of the lateral aspect of the hindfoot illustrating the location of the cervical and calcaneofibular ligaments.
CRVL - Cervical Ligament; CLFL - Cancaneofibular Ligament;
LTCL - Lateral Talocalcaneal Ligament; ITCL - Interosseous Talocalcaneal Ligament

or not load has an effect on the length of the ligaments. To further assess stability, talar tilt, subtalar tilt, and range of motion data (tibiocalcaneal angles) were obtained before and after cutting the CLFL.

Similar studies on the CLFL and CRVL have been performed, but either the foot positions did not involve maximum end range of motion[6,7,13,14,15,18,23] or testing was not done under loaded conditions.[4,19,22] Therefore, the previous studies do not provide enough information about pathomechanics. Specifically, the precise function of these ligaments at or during failure under physiologic load has not been examined. The current study provides information on the role of the CRVL.

MATERIALS AND METHODS

Distal lower extremities were obtained from male and female cadavers with an average age of 62.5 (range, 55 to 79 years). Each cadaver was thawed, and an osteoligamentous dissection was performed from the tibial plateau to the distal midfoot. The anterior talofibular ligament (ATF), posterior talofibular (PTF), CLFL, CRVL, and the ankle and subtalar joint capsules were exposed and preserved (Fig. 1). The inferior extensor retinaculum had to be removed to completely expose the CRVL. The load platform was a custom-cut 5/8″ block of wood attached to a three-way vice via a 3/4″ wood keel. The wood keel was affixed to the block with wood screws. An aluminum, studded friction plate was then attached to the top of the block with nails. This construct was placed in the INSTRON 1321 servohydraulic materials testing equipment (Canton, MA). Before mounting the specimen onto the friction plate, the DVRTs (differential variable reluctance transducer) (Microstrain, Burlington, VT) were calibrated, inserted into the mid-substance of each ligament, and sewn in place with 4.0 silk suture using a figure 8 stitch on each side of each barb (two stitches per barb). Preconditioning of the ligaments was performed by manually taking the foot through the physiologic motions used in the upcoming test.

Our pilot study determined that the maximum range of motion to which we could subject the ankle and subtalar joint without failure was 35° of plantarflexion and dorsiflexion. Inversion was variable as there was some degree of rolling of the heel on the friction plate. This is why tibiocalcaneal angles were measured during testing. We also found in our pilot that these extreme degrees of motion caused the foot to slide off of the friction plate, particularly in inversion. Thus, a 3″ cortical

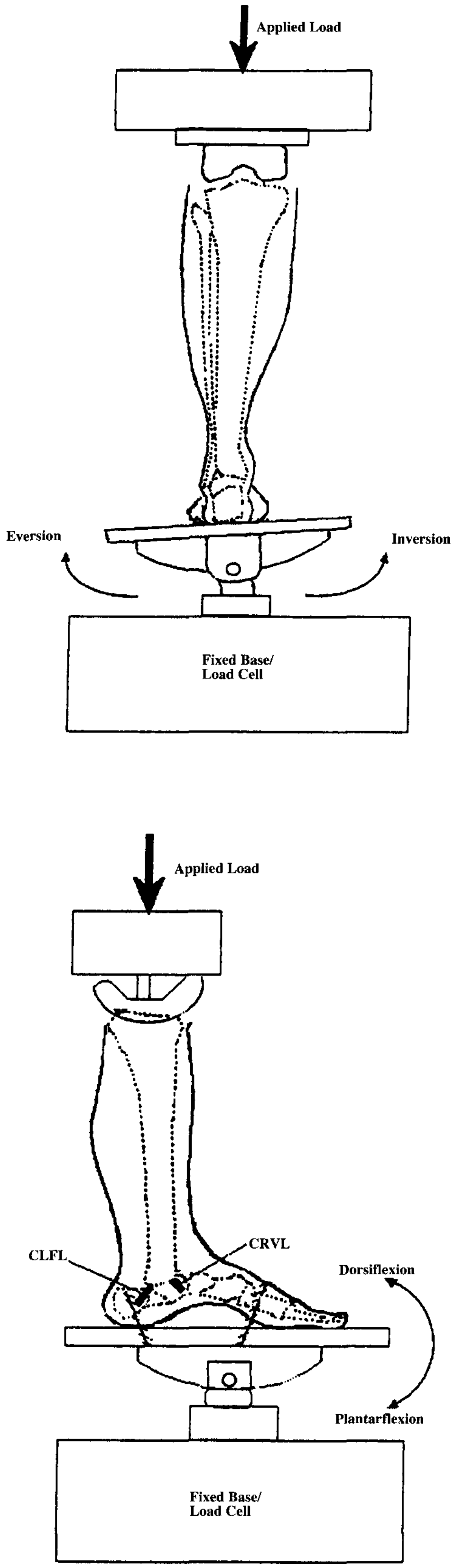

Fig. 2: Schematic of mechanical loading of experimental specimen. A 220N compressive load was applied to the upper tibial plateau via a metallic femoral knee component. A compound angle vise provided the ability to position and fix the foot in eversion/inversion and plantar/dorsiflexion. (**a**) Posterior view, (**b**) Medial view. CRVL - Cervical ligament; CLFL - Calcaneofibular ligament

screw was placed nearly vertically (70° angle) through the tuberosity of the calcaneus into the board. Likewise, to stabilize the forefoot, 2″ wood screws were placed in the second and fourth interspaces at the level of the metatarsal heads. The skin and soft tissues were fully released, and washers were used as a buttress.

At this point the entire construct with the attached foot was placed onto the INSTRON (Fig. 2). Load was applied to the intact tibial condyle through a custom-built adapter made to simulate the radius of curvature of a standard Johnson and Johnson total knee femoral component. There were six positions: neutral, 35° of plantarflexion, dorsiflexion, inversion, plantarflexion-inversion, dorsiflexion-inversion; and two states: unloaded and axially loaded to 220N. Each specimen was placed in the INSTRON in neutral and unloaded to start. Then the test proceeded in the order listed above, performing three runs of the unloaded and loaded state in each of the six positions and returning to neutral between each change of position. Elongation data was obtained in each position for each run of each state.

Once all unloaded and loaded runs in each position were completed, the specimen was removed from the INSTRON and taken for stress radiographs. A stress talar tilt and a subtalar tilt (40° Broden's) were obtained with the foot still attached to the foot plate and the DVRTs still in place, then the CLFL was cut and the stress radiographs repeated. The foot and attached foot plate were then returned to the INSTRON, and all tests were repeated.

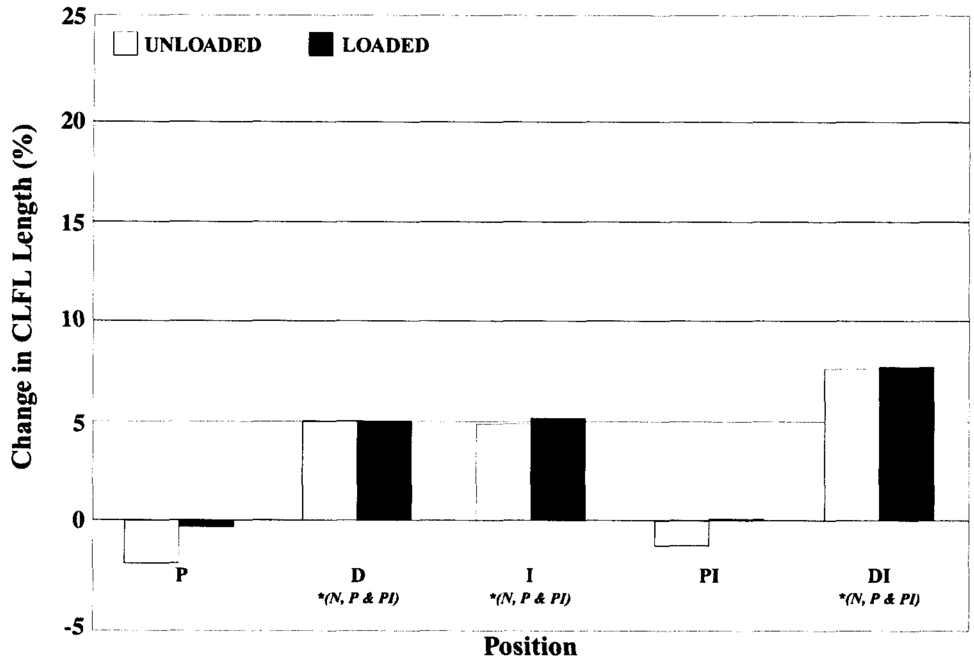

Fig. 3: Percent change in calcaneofibular ligament length change relative to neutral.
N – Neutral; P – Plantarflexion; D – Dorsiflexion; I – Inversion; PI – Plantarflexion/Inversion; DI – Dorsiflexion/Inversion; CRVL – Cervical ligament; CLFL – Calcaneofibular ligament
* denotes significant pairwise differences – $p<0.05$

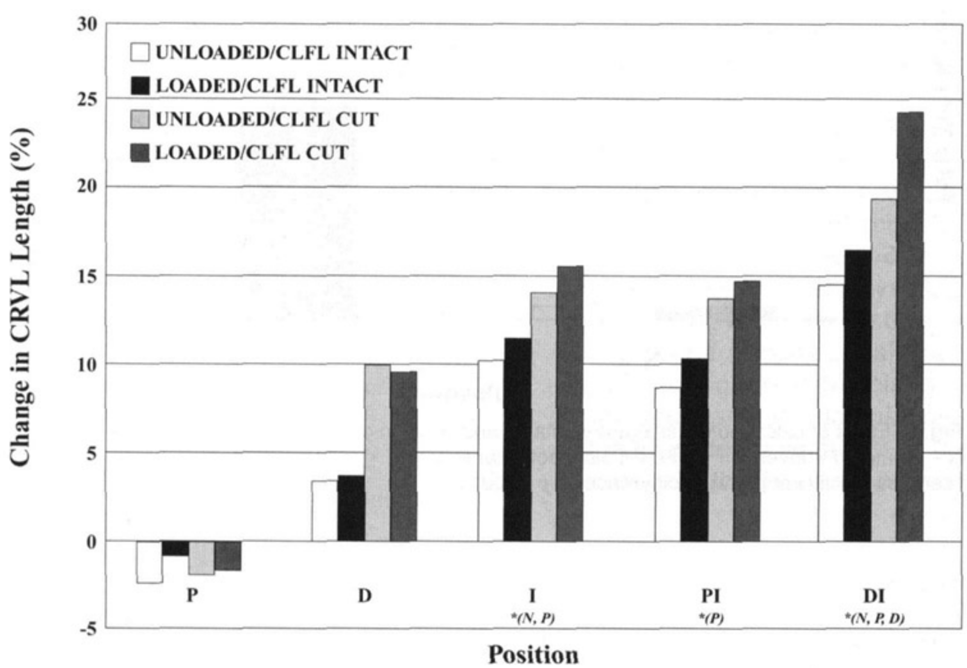

Fig. 4: Percent change in cervical ligament length relative to neutral.
N – Neutral; P – Plantarflexion; D – Dorsiflexion; I – Inversion; PI – Plantarflexion/Inversion; DI – Dorsiflexion/Inversion; CRVL – Cervical ligament; CLFL – Calcaneofibular ligament
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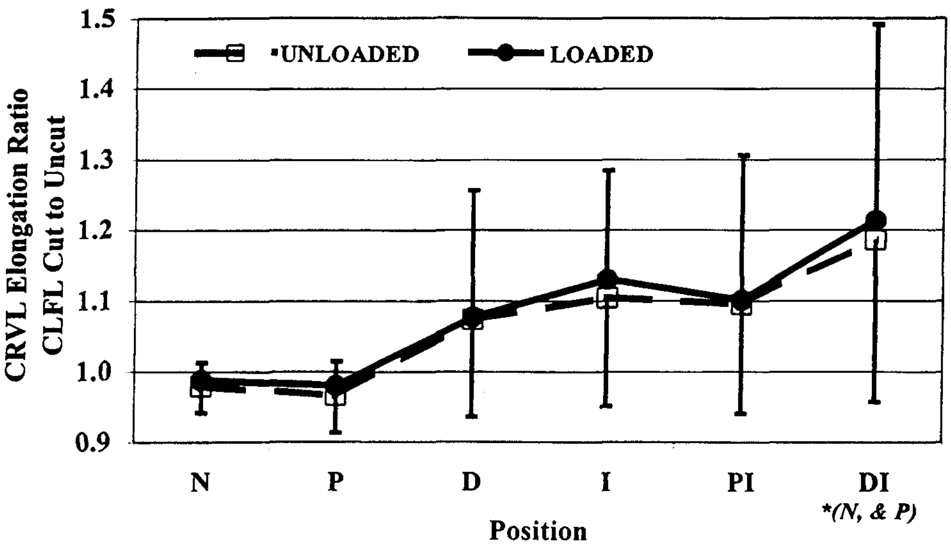

Fig. 5: Effect of the calcaneofibular ligament on cervical elongation.
N – Neutral; P – Plantarflexion; D – Dorsiflexion; I – Inversion; PI – Plantarflexion/Inversion;
DI – Dorsiflexion/Inversion; CRVL – Cervical ligament; CLFL – Calcaneofibular ligament
* denotes significant pairwise differences – $p<0.05$

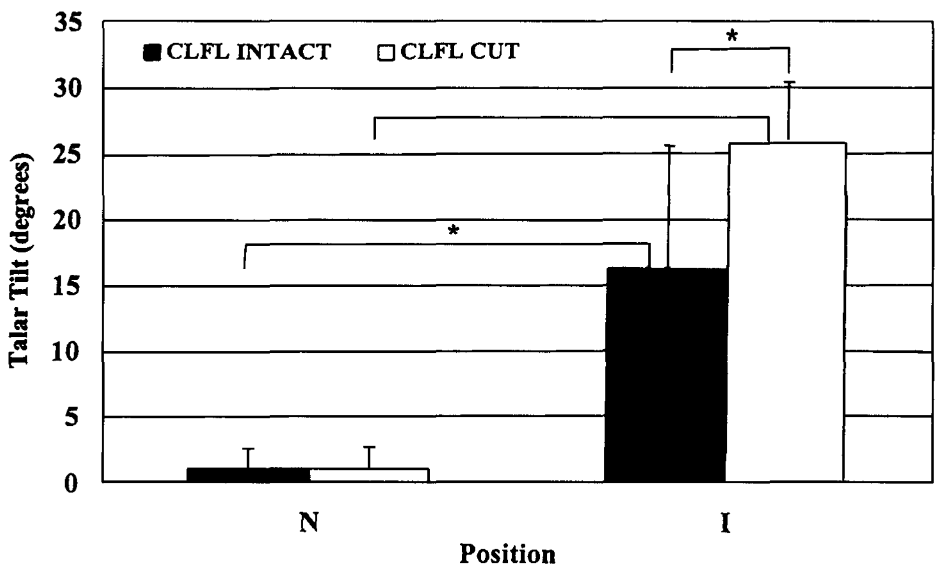

Fig. 6: Effect of calcaneofibular ligament status and position on talar tilt.
N – Neutral; I – Inversion; CLFL – Calcaneofibular ligament
*denotes significant pairwise differences – $p<0.001$

RESULTS

Data from the three runs for each position were averaged, and means and standard deviations were calculated. Two- and three-way ANOVAs followed by post-hoc Tukey analyses were run to examine the differences between the neutral position length and the other five positions in both states (loaded and unloaded). Talar and subtalar tilt averages were generated and analyzed using a Student's t-test. Tibiocalcaneal angles were measured in the neutral position and in maximal inversion during both the unloaded and loaded states.

The CLFL stretched the greatest in dorsiflexion-inversion (Fig. 3) and failed under load in four specimens producing either subluxation (2) or dislocation (2) of the ankle joint. The CRVL also stretched the greatest in dorsiflexion-inversion (Fig. 4). These differences were statistically significant when compared to the neutral length of the respective ligaments ($p<0.05$). The most interesting finding was that the CRVL was elongated relative to neutral in all foot positions. However, the CLFL was shortened relative to neutral in plantarflexion and plantarflexion-inversion.

The CLFL deficient state demonstrated a significant increase in length of the CRVL when studying CRVL ratios (Fig. 5). The CRVL ratio was generated by dividing the length of the CRVL with CLFL cut by the length of the CRVL with the CLFL intact. Specifically, the differences between neutral and dorsiflexion-inversion and between plantarflexion and dorsiflexion-inversion were significant. There was a trend towards increasing length in the loaded state for most test positions. However, statistical significance was not reached.

A significant increase in talar tilt was noted with CLFL deficiency ($p<0.008$) (Fig. 6). Talar tilt averaged 15.1° (±5.0°) with CLFL intact and 24.7° (±4.0°) with the CLFL cut. Subtalar tilt also increased with the CLFL cut although the difference was not significant ($p>0.5$) (Fig. 7). Subtalar tilt averaged 6.6° (±4.5°) with the CLFL intact and 7.7° (±3.7°) with the CLFL cut. The maximum tibiocalcaneal angle was recorded for dorsiflexion-inversion (27.7° ± 3.3°). The CLFL deficient state yielded 33.0° (±3.3°) ($p<0.05$) (Fig. 8).

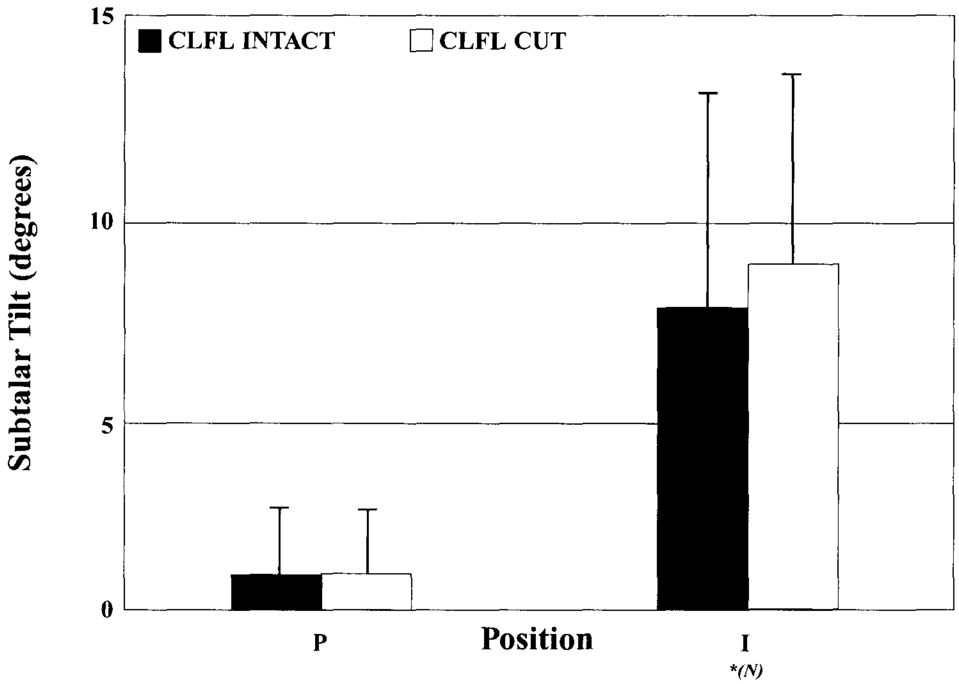

Fig. 7: Effect of calcaneofibular ligament status and position on subtalar tilt.
N – Neutral; I – Inversion; CLFL – Calcaneofibular ligament
* denotes significant pairwise differences – $p<0.05$

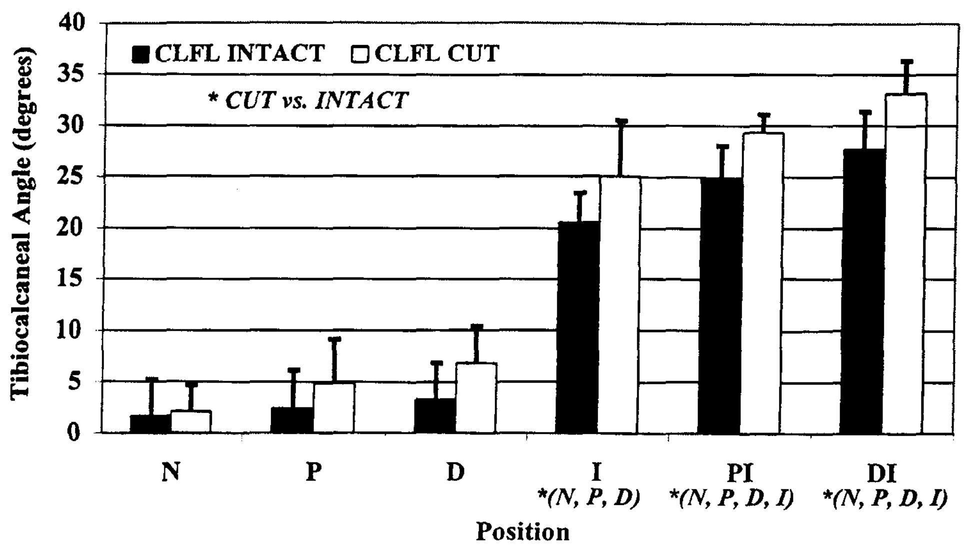

Fig. 8: Effect of calcaneofibular ligament status on tibiocalcaneal angles.
N – Neutral; P – Plantarflexion; D – Dorsiflexion; I – Inversion; PI – Plantarflexion/Inversion;
DI – Dorsiflexion/Inversion; CLFL – Calcaneofibular ligament
* denotes significant pairwise differences – $p<0.05$

DISCUSSION

Because this study was performed in a closed kinetic chain at end physiologic range of motion, it has relevance to pathomechanics. The data indicates that both the CLFL and CRVL are maximally stretched in the dorsiflexed-inverted position. Furthermore, the subtalar joint loses some of the lateral support of the CLFL in the plantarflexed and plantarflexed-inverted positions under study conditions. This fact is novel to the literature. The observations also prove the previous hypothesis that maximum dorsiflexion-inversion can create an isolated CLFL rupture.

Although the data is generated in a closed kinetic chain, there are still several factors that limit direct correlation with pathomechanics. Firstly, this is a static environment; the effect of muscular force is not considered. Secondly, the inferior extensor retinaculum with its three components was removed. This is a support structure to the lateral hindfoot. However, its removal was necessary to completely expose the cervical ligament for DVRT insertion. Its relative contribution to subtalar and ankle stability cannot be contemplated. It is also likely that the osteoligamentous preparation itself destabilizes the joints in question, but this has not been studied.

Further research is still needed. The inferior extensor retinaculum has been examined by Stephens and Sammarco[22] but has never been studied in a functional way under physiologic load. Likewise, the inaccessibility of the talocalcaneal interrosseous ligament to this type of biomechanical study has precluded in-depth analysis of the function of this ligament as well.

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