Arthroscopy: The Journal of Arthroscopic and Related Surgery 8(4):469—173
Published by Raven Press, Ltd.

Ligament Strain and Ankle Joint Opening During Ankle Distraction

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Summary: To determine the efficacy of ankle distraction and to investigate possible complications of the procedure, the strain on four ankle ligaments and the tibiotalar joint opening resulting from distraction force and various foot positions were studied. We mounted strain gauges on the deltoid, calcaneofibular, tibiofibular, and anterior talofibular ligaments of six fresh human cadaver ankles. An Acufex ankle distractor was used to apply forces of 45, 90, 135, and 180 N at 20° dorsiflexion, neutral, and 10° plantar flexion. The ankle distractor proved to be effective in opening the joint space for better visualization, but complications of pin bending, excessive ligament strain, and bony destruction did occur within the clinically recommended range. Based on the observed results, the safest method of distraction was to use forces < 135 N in the neutral position. **Key Words:** Ankle distraction—Ankle joint—Ligament strain.

The purpose of this study was to determine ankle ligament strain and tibiotalar joint opening as a function of distraction force and relative foot position.

Ankle arthroscopy has advanced from a medical curiosity to a valuable diagnostic and surgical procedure. The ankle joint presents a significant challenge to the arthroscopist because it is a small joint surrounded by neurovascular structures.

Distraction during arthroscopic surgery creates more space for visualization and maneuverability of instruments. Two methods of distraction are the simple Kerlix gauze sling (1) and the Acufex small-joint distractor, which utilizes a tibia and calcaneal pin for fixation. Potential complications are broken pins, infection, ligament injury, neurovascular damage, and fractures.

Guhl introduced an invasive distraction technique and found that the ankle joint could be distracted 7 to 8 mm for 45 to 60 min without significant injury to the ankle ligaments (2). Other studies have addressed the biomechanical properties of ankle ligaments but have not correlated them to ankle distraction (3,4).

MATERIALS AND METHODS

Eight fresh foot and ankle specimens were used for this study. We used two in preliminary analysis to determine strain gauge placement, distractor mounting, and correct foot-ankle orientation for data collection.

The specimens varied in length and fibular and tibial shaft diameters. The length from the distal to the proximal end of the feet ranged from 18 to 29.5 cm, and tibia diameters ranged from 2.6 to 3.31 cm. The following four ligaments from each specimen were tested: anterior tibiofibular, anterior talofibular, and calcaneofibular on the lateral side; and the deltoid on the medial side. The posterior talofibular ligament was not tested because it would involve a technically difficult procedure requiring a larger dis-

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section than the other ligaments, which could have changed the data.

The strain gauges used in this study were liquid metal strain gauges (LMSG) (Parks Medical Electronics, Aloha, OR, U.S.A.) with an open length of 0.5 cm (5). Each LMSG was individually calibrated with the use of a dial caliper (Starrett, Athol, MA, U.S.A.) attached to the strain gauge. A bridge amplifier (Honeywell Accudata 218, Denver, CO, U.S.A.) provided gauge excitation voltage and amplification of the output voltage of the LMSG. An analog-to-digital converter (MetraByte, Taunton, MA, U.S.A.) installed in an IBM AT computer was used to collect and store analog voltages.

We made medial and lateral incisions transverse to the length of the foot and ~10 cm in length. These incisions were for access to the ligaments and for LMSG attachment. Each gauge was securely attached with a combination of 4-0 Dexon surgical suture and 22-gauge needle anchors. Care was taken in orienting the gauges so that the longitudinal gauge direction was parallel to the principle fiber directions of each ligament. In addition, each gauge was prestretched ~1 mm (20% strain) so that changes in the baseline strain could be measured for each ligament.

With the use of a handheld cannula and power drill, the ankle distractor (Acufex, Norwood, MA, U.S.A.) was attached 18 cm proximal to the ankle joint just behind the anterior tibial crest. Another 3/16 in pin was drilled distal to the ankle into the lateral aspect of the os calcis. This pin was placed adjacent to the peroneus longus tendon and into the os calcis ~13 mm anterior to its posterior border and ~13 mm above the inferior border. The ankle was drilled with a 20° distal inclination so that the pins were nearly parallel when distraction was complete. The pins were drilled only until good purchase was obtained and did not penetrate the medial cortex. The purpose of the cannula was to protect the soft tissues while drilling the pins. The distractor was positioned and secured with the locking nuts (Fig. 1).

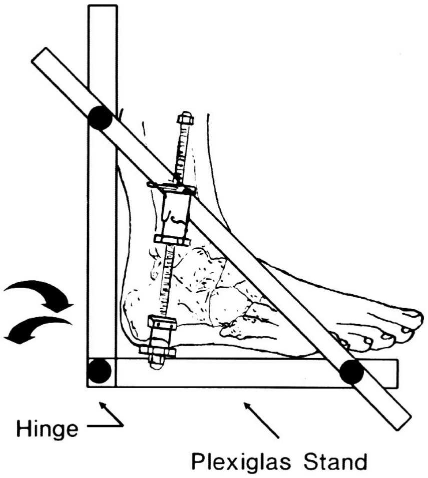

FIG. 1. Ankle Holder

We then placed the specimen into a Plexiglas holder capable of three preset positions: 10° plantar flexion; 20° dorsal flexion; and neutral position (90° orientation). The specimen was velcro-strapped to the holder for stability. The mercury strain gauge wires were then attached to the bridge amplifiers and coupled to the IBM computer for data collection. A 900 N load cell ring (A. L. Design, Amherst, NY, U.S.A.) was inserted between the tightening ring and bottom face of the force scale on the distractor to obtain accurate and reproducible forces from the ankle distractor. While the specimen was strapped to the Plexiglas holder in a 90° orientation, the distractor ring was rotated until 45 N of distractor force was obtained on the load ring meter. It was held in this position for 10 s and then brought back to 0 N force and held again for 10 s. This procedure was repeated nine times to obtain ligament stabilization as verified from previous work (4). With the strain gauges and load ring voltages zeroed, the computer was programmed to collect data from the mercury strain gauges for 60 s. At time equal to 15 s, the distractor ring was rotated until 45 N of distractor force was obtained. The distractor was held at this position for 30 s, and then brought back to 0 N. At this point, the computer had finished data collection. The digitizing rate was 167 Hz with a 25-point running average routine for filtering. For a digitizing period of 60 s, this resulted in 100 data points per collected channel.

With the specimen in the same orientation as outlined above, the distractor ring was again rotated until 45 N of distractor force was obtained. A series of pins, incrementally ranging from 1 to 8 mm, were used as feeler gauges to determine ankle joint porthole opening.

The same procedure as outlined above was performed at 10° plantar flexion, 20° dorsal flexion, and at 90 and 135 N distraction forces.

RESULTS

A total of 24 ligaments were tested. Strain results are summarized in Table 1. Strain in the deltoid was

TABLE 1. Ligamentous strain (%)

	Dorsiflexion 20			Neutral			Plantar flexion 10˚		
	45 N	90 N	135 N	45 N	90 N	135 N	45 N	90 N	135 N
Deltoid	–1.3	–1.8	– 6.6	0.4	2.0	4.3	– 0.5	0.8	0.8
Calcaneofibular	5.2	7.6	4.4	4.2	3.2	6.6	3.5	5.4	6.2
Tibiofibular	1.2	2.6	4.6	0.3	0.7	2.1	1.4	1.2	4.4
Anterior talofibular	–2.2	0.2	2.5	– 0.2	0.4	0.6	– 0.6	– 0.3	0.8

higher at each different force in the neutral position than in the 10° plantar flexion and 20° dorsiflexion positions. The strain was least in the dorsiflexed position and actually produced negative strain values because the ankle was inverted and closed down along the medial joint space. The differences in the strain of the deltoid were statistically significant ($p < .02$).

The strain in the calcaneofibular ligament progressively decreased as the ankle went from 20° dorsiflexion to 10° plantar flexion. As the force increased at each given position, the strain on the calcaneofibular ligament also increased except in the 20° dorsiflexion position at 135 N. In this case, the strain went from a high value of 7.6% to 4.4%, respectively. In one of the ankles tested, the calcaneofibular ligament reached a high strain of 18.2% in the dorsiflexion position at 90 N.

The strain patterns for the tibiofibular ligaments showed a direct relationship to force of distraction applied. As the force increased, the strain also increased. The highest mean strain values occurred in the 20° dorsiflexion position; the lowest strains were in the neutral position. In one specimen, the maximum strain on the tibiofibular ligament was 10.3% in 20° dorsiflexion at 135 N.

The strain in the anterior talofibular ligament was lowest (- 2.2) in the 20° dorsiflexion position at 45 N. But when the force reached 135 N, the strain on the anterior talofibular ligament became the highest (2.5).

Table 2 shows the results of portal opening in millimeters. The maximum joint space opening, 4.6 mm, was attained in the neutral position at 135 N.

TABLE 2. *Opening (mm)*

	Neutral	Plantar flexion 10°
45 N	2.4 (0.21)	1.7 (0.55)
90 N	3.3 (0.67)	2.6 (0.31)
135 N	4.6 (0.97)	4.1 (0.77)

Standard deviations given in parentheses.

allowed a statistically significant, larger joint space opening at each given force of distraction when compared to the dorsiflexion and plantar flexion positions. When forces were increased in the neutral and plantar flexion positions, the increases in joint space opening were also significant ($p < 0.05$). Pin bending and bony destruction of the calcaneus were consistent complications encountered with forces ≥140 N.

DISCUSSION

Ankle arthroscopy is a valuable and prevalent surgical procedure. Ankle distraction is used to enhance the efficiency of the arthroscopic procedure. Different means of distraction, such as simple sling or invasive pin distraction, can be used. At the present time, no published studies describe the effects and impact of ankle distraction on ankle ligaments. This study was designed to determine the amount of joint space opening and to measure the strain on four ankle ligaments in three separate positions while subjected to various forces of distraction using the Acufex small-joint distractor.

The results of the forces and strains on the ankle ligaments are shown in Table 1. Strain in the calcaneofibular ligament increased when the ankle was dorsiflexed to 20°. These findings are consistent with Colville (6) and Rasmussen (7). An interesting significant clinical finding was a strain decrease of 3.2% (from 7.6 to 4.4%) while forces increased from 90 to 135 N. This indicated that the ligament reached yielding and that a ligamentous injury had occurred. However, it was not determined whether this injury occurred at the ligament-bone interface or within the substance of the ligament.

Therefore, it appears important for the arthroscopist to avoid distraction forces >90 N while distracting the ankle in the 20° dorsiflexion position.

The strain pattern of the anterior tibiofibular ligament was highest in the 20° dorsiflexion position. This finding was consistent with the Kleiger study, which demonstrated disruption of the anterior tibiofibular ligament with dorsiflexion and external rotation of the ankle (8).

Strain in the anterior talofibular ligament was highest in the dorsiflexed position, just opposite the pattern of strain found by Colville (6) but similar to the report by Rasmussen (7). Negative strain patterns in the deltoid ligament in dorsiflexion suggested that the ankle distractor inverted the ankle. Neutral positions had similar but higher strain patterns than the plantar flexion positions.

The strain patterns of the four ligaments indicated that no damage was done while distracting the ankle in the three positions at the various forces. The exception was the calcaneofibular ligament, which developed strains sufficient to produce ligamentous injury in the 20° dorsiflexion position when forces applied were between 90 and 135 N. In addition, because the 20° dorsiflexion position resulted in the least amount of ankle joint opening, we suggest that this position be avoided during arthroscopic procedures.

The highest and safest force of distraction applied was 135 N. Beyond that point, pin bending and bony failure occurred in the calcaneus. However, because this experiment used cadaver bone, it may not reflect the possible differences in bony mechanics that depend on age and quality of bone. Pin bending, though, is independent of the specimen type.

The larger joint space openings in the neutral position, as compared with dorsiflexion and plantar flexion position, were significant using paired statistics. The maximum joint space opening obtained was 4.7 mm using 135 N in the neutral position. A further increase in the distraction forces did not increase the joint opening, which was probably due to the pin bending and bony failure. The bones of some specimens were experimentally supplemented with cement; however, failure still occurred at forces >135 N. In addition, we found that distraction techniques using less force still obtained joint opening measurements equal to and sometimes greater than those obtained with Acufex pin distraction. This happened because manual distraction applies a straight longitudinal force; Acufex distraction is a combination of longitudinal and inversional forces.

Based on these findings, we recommend that the arthroscopist avoid use of forces > 135 N to prevent complications. In addition, the ankle distractor calibration scale was found to be nonlinear—forces <220 N were higher than actual readings and forces were lower than the actual readings >220 N.

Another important consideration is the size of the scope. The joint could only be safely distracted to <5 mm, which indicates that a 2.5-mm arthroscope would be less likely to cause articular cartilage damage than a 5.5-mm arthroscope. Also, manipulation of the ankle was difficult with the distractor in place.

In summary, this study addressed the biomechanical properties of ankle ligaments and correlated them with the clinical situation of ankle distraction. Joint distraction was found to be effective, with limitations. Specific parameters were defined for safe, effective joint distraction. This study required a considerable investment of time to define each plotted point on the stress-versus-strain graph. Therefore, only three positions and three forces on six cadaveric specimens were studied. However, this study provided a method for further investigation of ligamentous behavior during ankle distraction.

CONCLUSIONS

1. The Acufex distractor was effective in opening the tibiotalar joint space for better visualization; complications did, however, occur.
2. Manual distraction was as effective as the Acufex distractor without the risks of pin bending and calcaneal bone destruction.
3. When using an invasive pin ankle distractor, forces >135 N should be avoided to prevent pin bending and bony calcaneal damage.
4. The neutral position of the ankle allowed statistically significant, larger joint space openings than did dorsiflexion or plantar flexion at the same given forces.
5. The 20° dorsiflexion position allowed the least amount of joint space opening.
6. Distractor forces >90 N in the 20° dorsiflexion position resulted in strains large enough to damage the calcaneofibular ligament.
7. Based on the data observed in the study, arthroscopes <4 mm should be used in ankle arthroscopy when using a small joint pin distractor.

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