Mechanics of the anterior drawer and talar tilt tests

A cadaveric study of lateral ligament injuries of the ankle

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We analyzed the changes in lateral ligament forces during anterior drawer and talar tilt testing and examined ankle joint motion during testing, following an isolated lesion of the anterior talofibular ligament (ATFL) or a combined lesion of the ATFL and calcaneofibular ligament (CFL). 8 cadaver specimens were held in a specially designed testing apparatus in which the ankle position (dorsiflexion-plantarflexion and supination-pronation) could be varied in a controlled manner. Ligament forces were measured with buckle transducers, and joint motion was measured with an instrumented spatial linkage. An anterior drawer test was performed using an 80 N anterior translating force, and a talar tilt test was performed using a 5.7 Nm supination torque with intact ligaments, after sectioning of the ATFL, and again after sectioning of the CFL. The tests were repeated at 10° dorsiflexion, neutral, and 10° and 20° plantarflexion. In the intact ankle, the largest increases in ATFL force were observed during testing in plantarflexion, whereas the largest increases in CFL force were observed in dorsiflexion. Isolated ATFL injury caused only small laxity changes, but a pronounced increase in laxity was observed after a combined CFL and ATFL injury.

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The anterior drawer test and the talar tilt test are used in routine clinical practice to determine the integrity of the lateral ankle ligaments (Renström and Kannus 1994). These tests are performed with application of an anterior load or a supination torque to the foot. It is usually assumed that the ATFL mainly resists anterior translation of the talus and that the CFL resists supination (Korkala et al. 1987, Lassiter et al. 1989). Thus, a positive anterior drawer is taken as an indication of ATFL injury, but a positive talar tilt test is believed to indicate injury to the CFL (Renström and Kannus 1994).

However, it is not known to what extent the different ankle ligaments are involved during the tests or to what extent the displacement occurs in the tibiotalar joint or in the subtalar joints (Renström and Kannus 1994). More information would improve the technique for performing these tests and understanding their potential or limitations for distinguishing between intact ligaments and isolated or combined lesions. Their reliability has been questioned in mechanical (Rasmussen 1985) and clinical studies (Vuust et al. 1984, Ahovuo et al. 1988, Lahde et al. 1988, van Dijk 1994).

We analyzed the changes in lateral ligament forces during anterior drawer and talar tilt testing and examined ankle joint motion during testing, following an isolated lesion of the anterior talofibular ligament (ATFL) or a combined lesion of the ATFL and calcaneofibular ligament (CFL).

Material and methods

The experimental protocol in this study entailed the measurement of ligament force and joint motion during the application of external loads to cadaver ankle specimens. A MTS test machine (Model 858 Bionix Test System, MTS Corporation, Minneapolis, MN, USA) was used to hold ankle specimens in a specially-designed testing apparatus in which the ankle joint could be loaded in a controlled manner (Figure 1).

Specimens

8 fresh human ankle specimens (mean donor age 42 (28–57) years), without evidence of degenerative disease or ligamentous injury, were harvested soon after death, frozen at –20 °C and thawed at room temperature before testing.

Experimental setup

The tibia and fibula were transected with two thirds of the shafts remaining. The end of the tibia was potted in a cylinder of methylmethacrylate cement and mounted in a cylindrical clamp attached to the MTS actuator and load cell. This clamp allowed unconstrained rotation around the long axis of the tibia. The foot was firmly fixed to the foot plate of the testing apparatus by passing two 4 mm diameter wood screws through the foot plate and into the calcaneus, and by a cable tie tightened across the metatarsal heads distally. This allowed rigid fixation of the foot to the foot plate, yet at the same time permitted normal adjustment of the arch of the foot to compressive loading. The foot plate was attached to a frame which could be adjusted to and locked at any desired degree of plantarflexion-dorsiflexion or pronation-supination. The frame was attached to two sets of linear ball-slides (Model S3-6, Del-Tron, Inc., Brookfield, CT, U.S.A.) at right angles to each other, allowing unconstrained anterior-posterior and lateral-medial translation of the foot plate during testing. With the tibia attached to the MTS actuator and load cell, and the foot fixed to the foot plate, the MTS machine was used to adjust the height of the tibia from the testing table to create a condition without compressive or distractive load.

In describing the motion about the foot and ankle, we have adopted the definitions of Broström (Broström 1964, Renström et al. 1988) (Figure 1). The neutral position was defined as the position where the tibia was mounted vertically in the MTS machine, and the foot plate was in a horizontal plane. Internal and external rotation of the foot occurred about a vertical axis (A–A') through the shaft of the tibia. Dorsiflexion and plantarflexion occurred about an axis (B–B') through the lateral and medial malleoli of the ankle (perpendicular to the vertical rotational axis). Supination and pronation occurred about an axis (C–C') which is described by a line centered on the long axis of the foot and perpendicular to the two previous axes.

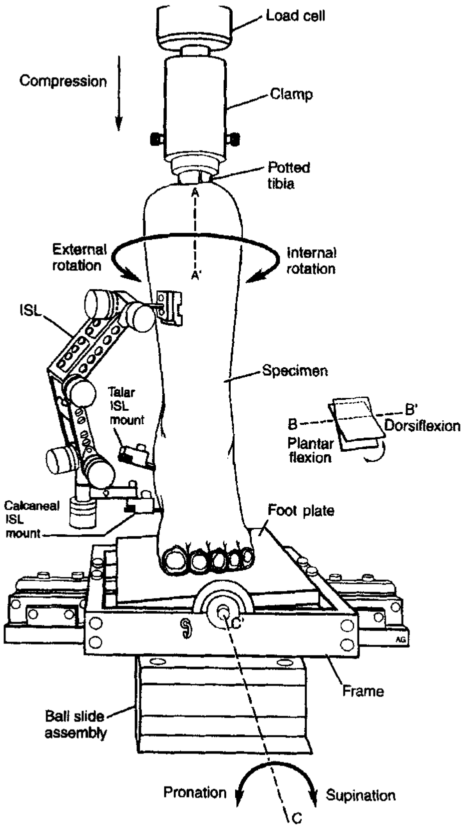

Figure 1. The ankle specimen in the testing apparatus. The ISL was mounted on the tibia proximally and could be attached to mounts which were fixed to the talus or calcaneus distally. The drawing shows the distal end of the ISL attached to the mount in the calcaneus.

Ligament force measurement

The forces in the ATFL and CFL ligaments were measured with buckle transducers (Lewis et al. 1982). The fat pad below the fibula was removed to expose the ATFL. The superior peroneal retinaculum was excised and the peroneal tendons were released to gain access to the CFL. Buckle transducers were installed on the ATFL and CFL and their output was recorded by a computer data acquisition system, using ASYST 4.0 software (Asyst Inc., Rochester, NY, U.S.A.). In a pilot study performed to develop the technique, we were unable to instrument adequately the PTFL, due to space limitations (Cawley and France 1991). Since the PTFL and CFL buckle transducers would probably impinge with each other, the PTFL was kept intact, but was eliminated from further investigation.

Joint motion measurement

Talocrural and ankle joint motion were measured by an instrumented spatial linkage (ISL) (Kirstukas et al. 1992a, Kirstukas et al. 1992b). The ISL (Figure 1) is a six degree-of-freedom electrogoniometer that measures three-dimensional ankle motion. This device consists of seven metal links interconnected by six revolute joints containing electrical potentiometers. The ISL was secured to the medial side of the tibia by means of a mounting block and two 4 mm diameter screws. The distal end of the ISL was fixed either to a mounting block on two 2.5 mm diameter threaded Steinmann pins, which were firmly drilled into the calcaneus, or to an equivalent block and two pins in the talus.

The links and potentiometers of the ISL freely change their relative positions and orientations as the ankle moves. Electrical signals produced by the potentiometers were recorded by the computer data acquisition system, and transformed into three-dimensional joint motion, according to the convention introduced by Grood and Suntay (1983). Joint motion in this study was described in terms of three rotations (dorsiflexion/plantarflexion, supination/pronation, and internal/external rotation) and three translations (anterior/posterior, medial/lateral and compression/ distraction), as defined above. Translations were defined relative to a point in the dome of the talus that moved the least during plantarflexion-dorsiflexion, as determined by a least-squares optimization algorithm.

Testing sequence

Motion and force data were recorded during the application of an anterior translating force from 0 to 80 N using a spring scale (Figure 2). A talar tilt test was also performed by applying a supination torque from 0 to 5.7 Nm using a torque wrench (Figure 2). These anterior drawer and talar tilt tests were performed with the foot plate in 10° dorsiflexion, neutral and 10° and 20° plantarflexion. Throughout the test sequence, the loading apparatus was set to allow unconstrained internal-external rotation of the tibia, as well as unconstrained anterior-posterior and medial-lateral translation of the foot plate. The entire test sequence was performed with the distal end of the ISL mounted first on the calcaneus and then on the talus. This allowed us to measure motion between the tibia and calcaneus (total ankle joint motion) and between the tibia and talus (talocrural joint motion). Subtalar motion was computed as the difference between the total ankle and talocrural joint motions.

After performing the testing sequence with the ligaments intact, the ATFL was sectioned with the surrounding capsular tissue. The entire testing sequence was then repeated. During this sequence, only the CFL was instrumented with a buckle transducer. Finally, joint motion measurements were repeated during the same testing sequence after sectioning the CFL as well.

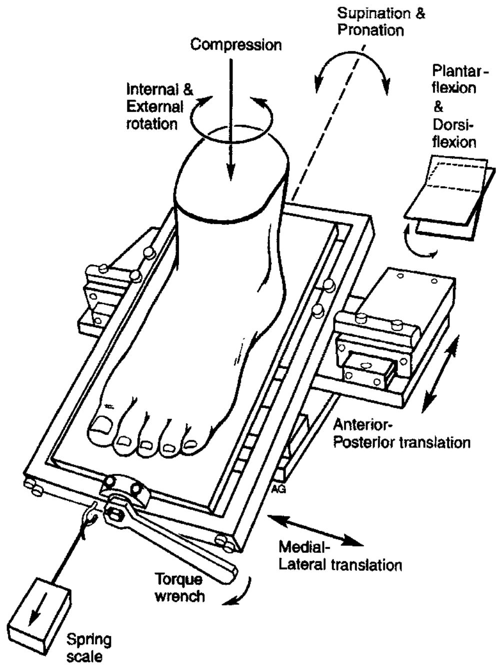

Figure 2. The setup for the anterior drawer test and talar tilt test. The anterior drawer test was performed by pulling on the frame with a spring scale, and the talar tilt test was simulated by applying torque to the foot plate with a torque wrench.

Reproducibility of measurement and data analysis

Calibration of the buckle transducers was performed by excising the end of the ligament from its bony attachment and applying known loads in a direction parallel to the original anatomical position of the ligament. In order to estimate the error introduced by possible variations in the orientation of the applied calibration loads, we also repeated the calibration procedure by applying the calibration loads at angles 15°-20° from the assumed anatomical direction. The resulting standard deviation of the buckle forces was 13.2%. The reproducibility of the ligament force measurements was computed as the means ± standard deviations of the difference between the first (with ISL on calcaneus) and second (ISL on talus) ligament force measurements (Table 1).

Throughout the test sequence outlined above, 15 repeat motion measurements were obtained in the unloaded neutral reference position. The mean of the standard deviations of the motion measurements in the neutral reference position with the ISL on the calcaneus was 0.56° for dorsiflexion/plantarflexion, 0.58° for pronation/supination, 0.61° for internal/ex-

Table 1. Reproducibility of force measurements in different positions during range-of-motion testing, as indicated by the means (SD) of the differences between the recordings from the first test with the ISL on the calcaneus and the second test with the ISL on the talus

Test position [a]	ATFL force (N)	CFL force (N)
Neutral pronation/supination	0.1 (4.1)	4.3 (3.2)
15° pronation	3.7 (8.6)	2.3 (7.7)
15° supination	5.6 (8.5)	11.4 (18.2)

[a] 0° plantarflexion

Table 2. ATFL and CFL force during 80 N anterior drawer testing with the foot plate at different flexion angles. Results are the mean of the two recordings from the buckle transducers made with the ISL on the calcaneus and talus. Force is expressed in N as the change from the reference position, mean (SE)

Test position	ATFL force (N)	CFL force (N)
10° dorsiflexion	33 (6)	40 (6)
Neutral flexion	23 (5)	15 (5)
10° plantarflexion	34 (6)	6 (3)
20° plantarflexion	53 (24)	–3 (2)

Table 3. ATFL and CFL force during talar tilt testing with a 5.7 Nm supination torque. Results are the mean of the two recordings from the buckle transducers made with the ISL on the calcaneus and talus. Force is expressed in N as the change from the reference position, mean (SE)

Test position	ATFL force (N)	CFL force (N)
10° dorsiflexion	26 (4)	123 (19)
Neutral flexion	36 (6)	81 (16)
10° plantarflexion	64 (18)	60 (11)
20° plantarflexion	123 (38)	32 (12)

ternal rotation, 0.59 mm for anterior/posterior translation, 0.65 mm for lateral/medial translation and 0.53 mm for joint distraction compression. The corresponding results for measurements with the ISL on the talus were 0.93°, 0.41°, 0.57°, 0.50 mm, 0.39 mm, and 0.46 mm, respectively.

The force and motion data were analyzed using a two-factor (foot plate angle, ligament status) ANOVA model for repeated measures. First, a MANOVA procedure was performed to check for significant interaction effects ($p<0.10$), i.e., whether the load or motion effects differed at various flexion angles. If a significant interaction was observed, separate t-tests were performed at each flexion angle, using Bonferroni's correction for multiple comparisons. If no significant interaction was observed, the interaction term was deleted from the model and only the main effects were tested by a MANOVA procedure. Except for the interaction test, an alpha level of 0.05 was considered significant. Results are presented as means ± standard errors (SE), unless otherwise noted.

Results

Joint motion and ligament forces with intact ligaments

There was no significant difference in the amount of anterior translation or degree of internal-external rotation between the anterior drawer tests applied at the four flexion angles. ATFL and CFL forces increased with an increasing anterior translating force during anterior drawer testing. This increase was greatest for the ATFL in 20° plantarflexion, whereas the largest increase in CFL force occurred in 10° dorsiflexion (Table 2).

There were no significant differences in the change of supination, internal rotation or plantarflexion resulting from talar tilt tests performed at the four flexion angles. There was no significant effect of flexion angle on ATFL or CFL force during talar tilt testing, although the pattern of ligament force changes was similar to that observed during anterior drawer testing (Table 3).

Joint motion and ligament forces with cut ligaments

There was no significant difference in CFL force during the anterior drawer tests, whether the ATFL was intact or cut. However, there was a small increase in anterior translation between the intact and cut ATFL states during anterior drawer testing in 10° and 20° plantarflexion (Figure 3). When both ligaments had been cut, anterior translation and internal rotation increased at all flexion angles used during testing.

There was no significant difference in CFL force during the talar tilt tests, whether the ATFL was intact or cut. Nor was there any significant increase in supination during talar tilt tests between the intact and cut ATFL states, but supination significantly increased when both ligaments were cut (Figure 4).

Discussion

A frequently asked question is: at what flexion angle should stress-testing of the ankle be performed. In a recent anatomical study, Burks and Morgan (1994)

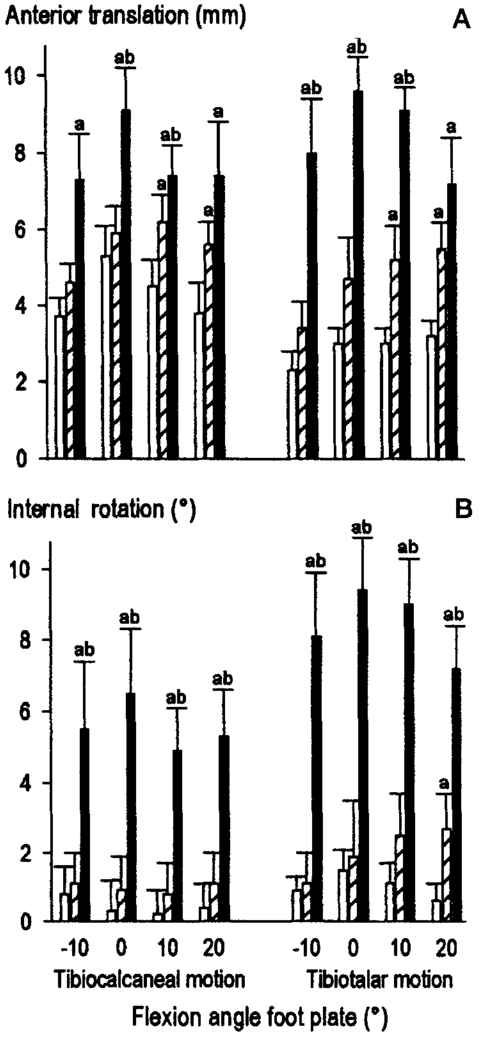

Figure 3. Anterior translation (A) and internal rotation (B) at 10° dorsiflexion (–10), neutral flexion (0) and 10° (10) and 20° plantarflexion (20) during anterior drawer testing with an 80 N anterior translating force with intact ligaments (white bar), after the ATFL had been cut (hatched bar), and after the ATFL and CFL had been cut (black bar). The left set of bars shows the results with the ISL on the calcaneus, and the right set with the ISL on the talus. [a] Significantly different from intact ligaments. [b] Significantly different from ATFL cut. Results are shown as the mean ± SE.

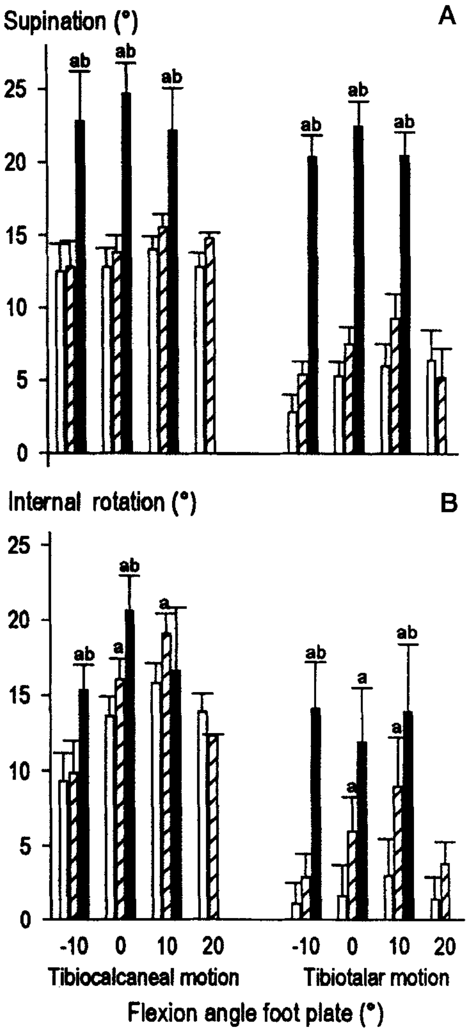

Figure 4. Supination (A) and internal rotation (B) at 10° dorsiflexion (10), neutral flexion (0), 10° (10) and 20° plantarflexion (20) during talar tilt testing with a 5.7 Nm supination torque with intact ankle ligaments (white bar), after the ATFL had been cut (hatched bar), and after the ATFL and CFL had been cut (black bar). The left set of bars shows the results with the ISL on the calcaneus, and the right set with the ISL on the talus. [a] Significantly different from intact ligaments. [b] Significantly different from ATFL cut. Due to limitations in the testing apparatus there are no results from 20° plantarflexion with combined ATFL and CFL injury. Results are shown as the mean ± SE.

showed that the ATFL and the CFL have adjacent attachment sites on the anterior edge of the lateral fibula, 8-10 mm from the distal tip. With the foot in neutral position, the CFL forms a posterior angle of about 130° with the fibula, whereas the fibula-ATFL angle is slightly less than 90° anteriorly. A more precise description of the anatomic locations of these ligaments may help us to understand their function and interpret tension patterns during testing in different ankle positions (Renström and Kannus 1994). When the foot is in dorsiflexion, the CFL assumes a course parallel to the axis of the fibula, thereby functioning as a collateral ligament (Burks and Morgan 1994). The present study is the first to provide direct force measurements during testing, and it supports this view of CFL function, since the highest CFL forces were attained during testing in dorsiflexion. The corresponding ATFL force was low, as expected. On the other hand, when the foot was in plantarflexion, the ATFL became parallel to the long axis of the fibula, and might be expected to function as the main collateral ligament (Burks and Morgan 1994). Again, the force measurements support this hypothesis, as the highest forces in the ATFL were observed with testing in plantarflexion, while CFL tension was low. Previous studies, using strain gauge techniques (Renström et al. 1988, Colville et al. 1990, Cawley and France 1991) or indirect force estimations (Nigg et al. 1990), also support this view.

These results indicate that the largest laxity increases after ATFL injury would be observed with testing in plantarflexion and that additional CFL injury may be more easily detected with testing in dorsiflexion. However, some studies have concluded that the laxity increase resulting from ATFL injury is greater in dorsiflexion than in plantarflexion (Johnson and Markolf 1983, Hollis et al. 1995), whereas others advocate plantarflexion as the best testing position to detect isolated ATFL injury (Tohyama et al. 1995). Kjærsgaard-Andersen et al. concluded that the laxity increase after an isolated ATFL injury are similar throughout the entire flexion range (1991). Similarly, with additional CFL injury, some studies have reported that the greatest laxity increase occurs in dorsiflexion (Kjærsgaard-Andersen et al. 1991, Hollis et al. 1995), while others claim it occurs in plantarflexion (Johnson and Markolf 1983).

Using a testing apparatus which allowed freedom of rotation and medio-lateral displacement during anterior loading, the increase in anterior tibiotalar translation in plantarflexion was about 2 mm after ATFL sectioning alone. When the CFL was sectioned as well, a 2-4 mm further increase in anterior translation was observed across the entire flexion range. During talar tilt testing, ATFL sectioning caused only small supination and internal rotation changes, but a considerable laxity change was observed after combined injuries in all flexion angles.

Several investigators have reported similar increases in laxity after ATFL or CFL sectioning (Kjærsgaard-Andersen et al. 1991, Johnson and Markolf 1983, Hollis et al. 1995, Tohyama et al. 1995), but have reached widely varying conclusions regarding the most sensitive flexion angle for testing. Apart from differences in experimental setup which could, in part, explain the different conclusions reached, the fact remains that individual variations in ligament orientation (Burks and Morgan 1994) may cause different laxity patterns in different patients. In both the present and other mechanical studies, as well as clinical studies (Karlsson et al. 1991), the motion changes vary greatly, depending on the individual specimen or patient. Thus, it may be that testing should be done at several flexion angles, since it is not possible to give universal recommendations as to the best flexion angles for testing.

As mentioned above, a large increase in internal rotation (7–8°) was observed after combined injury during anterior drawer testing. Presumably, a testing technique which limits internal rotation would reduce the sensitivity of the test in detecting ligament injury. Therefore, the technique proposed by van Dijk (1994), where the foot is pulled anteriorly and medially, using the deltoid ligament as a center of rotation, may be preferable to a technique where the foot is pulled straight forward.

In conclusion, ligament function should be examined throughout a range of flexion angles during anterior drawer and talar tilt testing, and free internal rotation of the foot should be permitted during anterior drawer testing. Isolated ATFL injury caused only small laxity changes during testing, which became more pronounced after combined CFL and ATFL injury. However, these changes were so large that it may be difficult to distinguish clinically between intact ligaments and isolated or combined ligament injuries.

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