THE EFFECT OF DAMAGE TO THE LATERAL COLLATERAL LIGAMENTS ON THE THREE DIMENSIONAL FLEXIBILITY CHARACTERISTICS OF THE ANKLE COMPLEX

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Lateral ankle sprains are arguably the most prevalent orthopedic injury.[1-6] They often result in partial or complete rupture of the anterior talofibular and/or calcaneofibular ligaments. Following the initial insult, recurrence is common especially in athletes, leading to chronic instability, pain, swelling and arthritic conditions.[1,4,7-11] The mainstay of diagnosis today is still clinical assessment. The ankle is manually stressed in inversion and anterior drawer directions to subjectively assess increases in flexibility or motion of the ankle. Stress radiographs involving talar tilt and anterior drawer are often performed in an attempt to objectively quantify increases in flexibility.[11-37]

Among the difficulties involved with stress radiographs are the methods of load application.[1,23,24,27,33,38,39] Various methods have been reported to standardize the method of stressing the ankle. Among these is the Telos device which attempts to apply reproducible loads in the inversion, eversion, and anterior drawer directions to the ankle. However, interpretation of stress radiographs remains controversial with the abnormal and normal values reported in the literature overlapping each other.[14,15,21,25,38,40-46] In addition, many claim that stress radiography cannot differentiate between single and double ligament involvement.[11,27,46-49] The diagnosis of lateral ankle sprains remains subjective with a margin for error.

Mechanical devices have been developed to stress and measure the resulting flexibility or motion for the purpose of diagnosing soft tissue injuries to joints. Most of these devices were developed for the knee.[50-52] Their inability to produce reliable results or differentiate between the types of soft tissue injuries to the knee have been documented.[53-55] A new device, the Ankle Flexibility Tester (AFT), has been developed to stress and measure the flexibility of the ankle joint. The reliability, accuracy, effects of loading rate on flexibility, and symmetry between left and right ankles of normal subjects have been reported in a prior study.[56] The topic of this paper is the effect of ligamentous injury on the flexibility of the ankle and subtalar joints.

METHODOLOGY

Experimental Procedure

A six degrees of freedom instrumented linkage, the Ankle Flexibility Tester (AFT), was used to measure the flexibility characteristics of the ankle (Fig. 1). The system measures the relative motion between the calcaneus and the tibia/fibula in response to stress applied manually across the ankle and subtalar joints. A description of the principle of operation, accuracy, and repeatability of the AFT as well as data comparing the left to right symmetry in the normal population was provided by Siegler.[56]

Cadaver Tests. Six fresh cadaver lower limbs were tested intact and after serial sectioning of the ATFL followed by the CFL. The minimally required soft tissue dissection was performed to expose the ATFL and the CFL prior to testing.

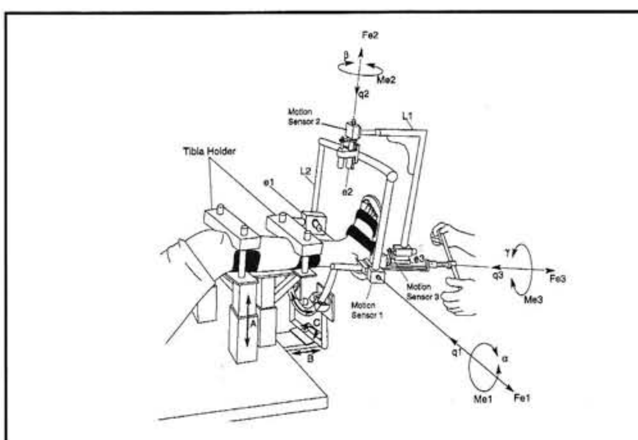

Figure 1. Schematic drawing of the experimental system used to measure the three dimensional flexibility characteristics of the ankle complex. (Siegler, 1996)

Each test consisted of stressing the rearfoot for six continuous cycles. For example when testing in inversion/eversion, the ankle was loaded in inversion, unloaded, loaded in eversion and unloaded once again to complete one cycle. At each extreme of the range of motion, loading was increased until no further motion occurred.

Subject Testing. Five patients with various lateral ankle pathologies were examined with the aid of the Ankle Flexibility Tester. Both the injured ankle and the intact contralateral joint, which served as a control, were examined. Each complete test was repeated on two different occasions. The experimental procedure was essentially identical to that used on the cadaver specimens.

Data Processing. Flexibility was defined as the amount of motion resulting from a given amount of load applied to the rearfoot. Two flexibility values were calculated for two regions in each direction of motion. One region starts from neutral to one half of the maximum load applied, and is termed early flexibility. The second region is from one half of the maximum load to end range of motion (Fig. 2). Calculations of flexibility were based on the following definitions. Primary flexibility was defined as the change in position in the direction of the applied load. Coupled flexibility was defined as the amount of motion in the internal/external rotation direction as a result of stressing in the inversion/eversion direction. Total flexibility was defined as the average of early and late flexibility.

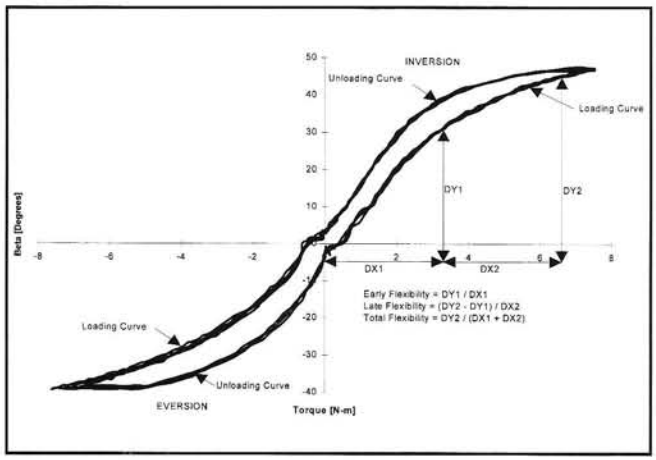

Figure 2. Primary load displacement characteristics in inversion/eversion obtained from one specimen. The definition of early, late and total flexibility are as indicated in the figure.

RESULTS

Examples of raw data obtained from one specimen showing the effect of sectioning of ligaments on the load displacement curves are shown in Figures 3A-3C. The means for the flexibility parameters in anterior drawer, inversion and coupling are graphed in Figures 4, 5, and 6 respectively.

Repeated measures analysis of variance (ANOVA) was performed on the cadaver data at the significance level of $p < 0.05$. The purpose of this statistical analysis was to determine whether ligament injury significantly affected the flexibility of the ankle. Following the ANOVA, linear contrast tests were performed at the same significance level to determine which conditions were significantly different from each other.

Results from the Cadaver Tests

The greatest change caused by cutting the ATFL was in the direction of anterior drawer. The early flexibility parameter was increased by an average of 109%. The changes in anterior drawer late flexibility were not significant. No other significant changes in flexibility were statistically significant with isolated sectioning of the ATFL.

Cutting the CFL in addition to the ATFL caused significant increases in early flexibility in the inversion direction. This increase averaged 86% when compared to the intact condition. The double ligament injury model resulted in significant increases in coupling. The greatest percent increase was seen when inversion stresses produced increases in internal rotation by 190% (increased coupling).

Results from Subject Testing

Case #1. A forty-three-year-old white male sustained a right ankle sprain after missing a stair. During the clinical examination, pain on palpation was present over the ATFL and the CFL. The patient was being treated with strengthening exercises and proprioception training by a physical therapist at the time of the tests. The results of the flexibility tests revealed an increase in inversion early flexibility of 90% when the affected side was compared to the contralateral ankle.

Case #2. A twenty-three-year-old female presented with recurrent sprains since December of 1986, following an acute sprain of the right

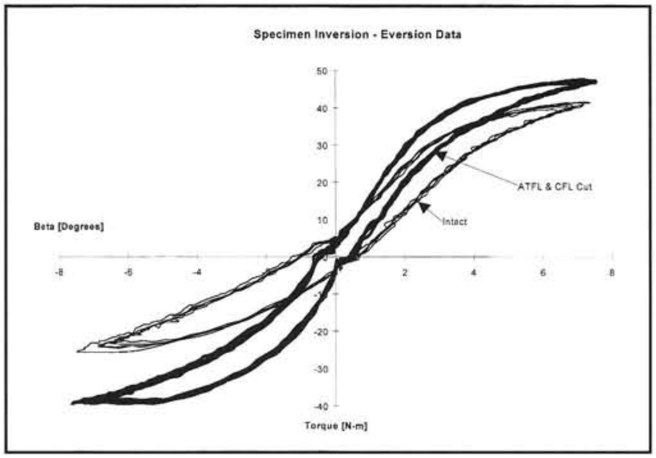

Figure 3A. Primary load-displacement characteristics and coupling obtained from one specimen showing the effect of sectioning of both the ATFL and the CFL on the inversion/eversion characteristics of the ankle.

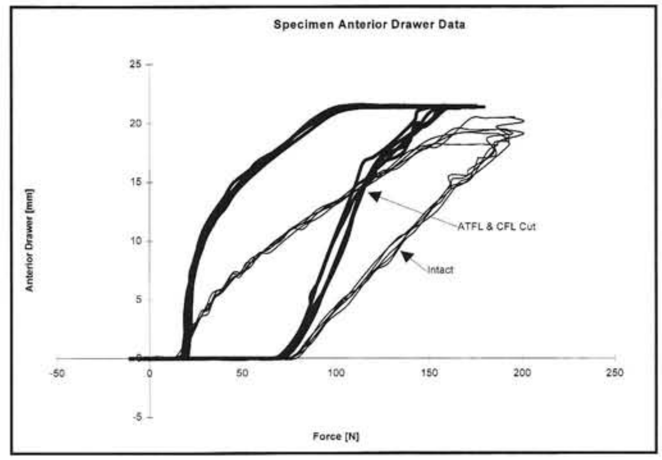

Figure 3B. Load displacement plot for one cadaver showing the effects of a double ligament rupture on the anterior drawer characteristics.

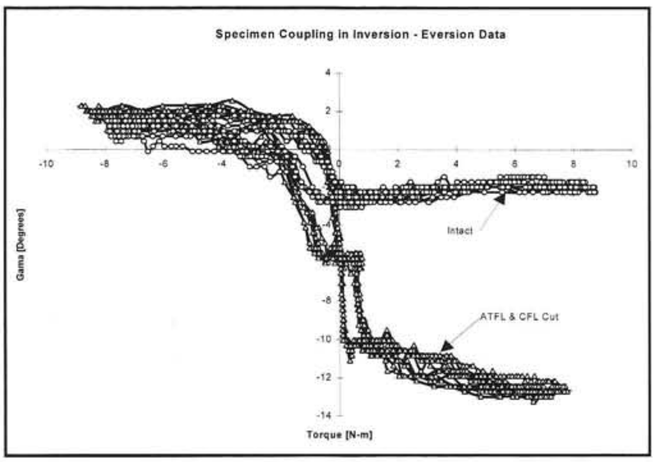

Figure 3C. Load displacement plot for one cadaver showing the effects of a double ligament rupture on the coupling characteristics when an inversion/eversion load is applied.

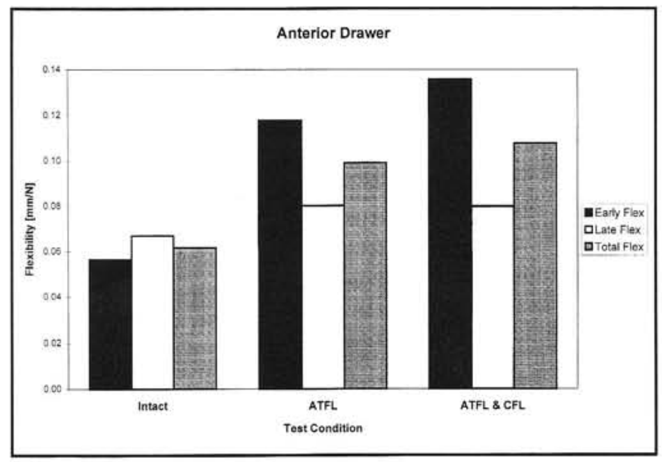

Figure 4. Average flexibility values obtained from all six specimens in the direction of anterior drawer. Early, late and total flexibility values are shown for the intact specimens and for the specimens with isolated ATFL damage and a combined rupture of both the ATFL and the CFL.

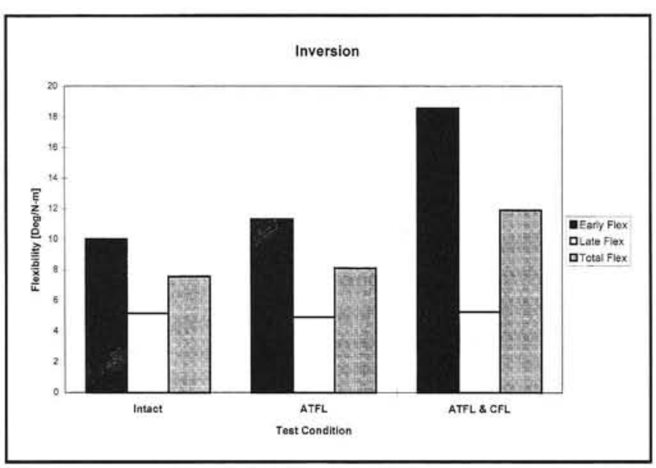

Figure 5. Average flexibility values and the results of the statistical analysis obtained from all six specimens in the direction of inversion. For further details see caption to Figure 4.

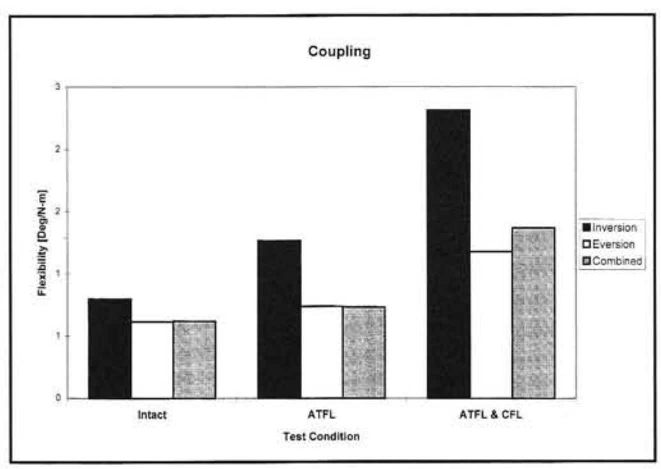

Figure 6. Average flexibility values and the results of the statistical analysis obtained from all six specimens in the direction of eversion. For further details see caption to Figure 4.

ankle. The patient complained of instability and of pain at the extreme range of motion in inversion. Radiographs, stress studies, MRI and bone scans were negative. These diagnostic studies were taken over a four-year period from 1986 to 1990. The flexibility test was conducted in February of 1992. The results showed increased inversion early flexibility of 94%.

Case #3. An active, twenty-six-year-old female complained of repeated giving way in her left ankle subsequent to an acute sprain while playing soccer. Pain was present only at the extreme ranges of motion in the left ankle. The stress radiographs taken were negative for talar tilt and anterior drawer. The results of the inversion flexibility testing showed no difference between the two limbs. Anterior drawer testing showed a 118% increase in early flexibility on the injured side as compared to the contralateral side.

Case #4. A thirty-six-year-old female had recurrent ankle sprains with the first acute injury occurring in 1976. After six years of conservative treatment and continued instability, a Watson-Jones reconstruction was performed. In 1986, the ankle was re-injured and the plantaris tendon was used to reconstruct the lateral ankle ligaments. The patient did not complain of instability at the time of testing, but did relate pain after walking, and a stiff ankle. Early flexibility in inversion showed a negligible difference (7%) between the reconstructed and contralateral ankles. However, a 57% decrease in flexibility was noted in inversion late flexibility.

Case #5. A thirty-five-year-old female complained of right ankle pain while walking and fully loading the rearfoot. The patient had several episodes of acute ankle sprains. X-rays, stress radiographs, MRIs, CT scans, a bone scan, arthrogram and a tenogram were all negative. On arthroscopy, the diagnosis was hypertrophy of synovium, chip fracture of the posterior process and an osteochondral defect of the fibular tip. No injury to the lateral ankle ligaments was found. Following the arthroscopy, an MRI was taken which showed a residual bone fragment near the posterior process of the talus. The results showed that early flexibility was decreased by 17% and late flexibility by 105% on the injured side as compared to the intact contralateral side.

DISCUSSION AND CONCLUSIONS

The cadaver study was performed to determine whether rupture of the lateral collateral ligaments of the ankle would produce significant changes in the flexibility characteristics and if so, could these changes in flexibility be used to differentiate between the two most common ankle ligament injuries. Cutting either the ATFL alone, or the ATFL and CFL combined produced significant changes in flexibility. Furthermore, these changes can be used to differentiate between a single or double ligament rupture. In an isolated ATFL injury, a significant increase in anterior drawer flexibility without a significant increase in inversion flexibility occurs. Further significant increase in flexibility in inversion occurs after damage to the CFL. Coupling flexibility is not significantly increased until after cutting both ligaments which is similar to the results of inversion flexibility.

From the cadaver study it was concluded that the parameters most sensitive to the presence of damage to the lateral collateral ligaments of the ankle are early flexibility in anterior drawer, early flexibility in inversion, and coupling. These results are in agreement with previous studies[39,57] which showed that the larger changes in flexibility following rupture of a lateral ankle ligament occurs about the neutral position.

The patient population was tested to determine whether changes in flexibility could be detected with various ankle lateral pathologies, and if these changes would correlate with the cadaver results. The first three case studies were referred for testing because their stress radiographs and other diagnostic studies did not correlate with their clinical presentation of lateral ankle ligament injuries. In the first two cases, increases in inversion early flexibility were 90% and 94%. This correlates with the average increase of 86% seen with the double ligament rupture in the cadaver study. The third patient had no increase in inversion flexibility, which ruled out a double ligament rupture when comparing the results to the cadaver study. However, anterior drawer early flexibility was increased in this patient by 118%. This did correlate with the isolated ATFL rupture which produced an increase of 109% in the cadaver study. The final two case studies involved types of injury not evaluated in the cadaver studies. The fourth case, involving lateral ankle ligament reconstruction, showed no difference in early flexibility when compared to the contralateral ankle. However, there was a decrease of flexibility at the end range of motion in inversion, indicating a stiffer ankle following the surgery. The last case involved a mechanical block on motion caused by an osteochondral bone fragment verified by arthroscopy. The late flexibility was decreased by over 100% in inversion late flexibility without affecting early flexibility. In both of the latter cases, there were decreases in late inversion flexibility. Flexibility may prove helpful in diagnosing other injuries not involving the lateral ankle ligaments. Further studies need to be conducted in the patient population in this area. It is interesting to note that the mechanical restraints caused by the ligament reconstruction and the talar dome fracture did not affect early flexibility. Otherwise these injuries may have confounded the results obtained in the cadaver ligament injury model.

In all the five case studies, changes in flexibility between the injured joint and the intact contralateral joint were consistent with the clinical presentation. Furthermore, for the three case studies involving ligament injuries, large changes in flexibility were noted. These changes were consistent with those seen in the cadaver study. They greatly exceeded the left to right variation in flexibility in a normal population.[57]

The Ankle Flexibility Tester differs from stress radiography. Stress radiographs assess the increase in end range of motion. The flexibility technique measures the flexibility about neutral and the end range of motion. This work and prior studies have shown that early flexibility is more sensitive than range of motion for detection of lateral ankle ligament ruptures. Stress radiographs permit loading in inversion and anterior drawer. The AFT allows loading in all six degrees of freedom, specifically inversion/eversion, external/internal rotation, dorsiflexion/plantarflexion, compression/distraction, anterior/posterior drawer and medial/lateral distraction. The AFT permits the operator to apply any combination of loads and can measure the flexibility in all of the directions, but stress radiographs cannot. Stress radiographs assess the changes seen at the level of the ankle joint. The AFT measures changes seen at both the ankle and subtalar joint. Nerve blocks should be performed when performing stress radiographs because it cannot be determined if the patient is guarding. The real time on-line display provided by the AFT demonstrates if the patient is guarding by sharp increases or decreases in position without any increases or decreases in loading. In the case of patient guarding the test can be repeated at a later date or the patient may be anesthetized. The AFT does provide a consistent method of load application which does not vary with position of the rearfoot in relation to the leg, and has been shown to be reliable. Stress radiographs require a Telos device or an external method of load application to obtain repeatable results. In the case of the Telos device the load application may not be consistent from test to test.[16] The disadvantage of the AFT is the instrumentation needed to perform the test is not readily available. Radiographs are available at any hospital, clinic and private practice making them easily accessible.

In summary, based on the results presented, the mechanical properties of the ankle and specifically changes in flexibility as defined and measured in this study may ultimately provide a useful clinical test for early diagnosis of ankle ligament injuries. Further testing of ankle flexibility is needed to validate the ability of this technique in diagnosing lateral ankle ligament injuries in the patient population. The AFT may also provide a method of diagnosing other types of injuries such as osteochondral defects and assessing the success of treatment.

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