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original research

Knee and Ankle Position, Anterior Drawer Laxity, and Stiffness of the Ankle Complex

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Context: Anterior drawer testing of the ankle is commonly used to diagnose lateral ligamentous instability. Our hypothesis was that changing knee and ankle positions would change the stability of the ankle complex during anterior drawer testing.

Objectives: To assess the effects of knee and ankle position on anterior drawer laxity and stiffness of the ankle complex.

Design: A repeated-measures design with knee and ankle position as independent variables.

Setting: University research laboratory.

Patients or Other Participants: Bilateral ankles of 10 female (age = 19.8 ± 1.1 years) and 10 male (age = 20.8 ± 1.2 years) collegiate athletes were tested.

Intervention(s): Each ankle complex underwent loading using an ankle arthrometer under 4 test conditions consisting of 2 knee positions (90° and 0° of flexion) and 2 ankle positions (0° and 10° of plantar flexion [PF]).

Main Outcome Measure(s): Recorded anterior laxity (mm) and stiffness (N/mm).

Results: Anterior laxity of the ankle complex was maximal with the knee positioned at 90° of flexion and the ankle at 10° of PF when compared with the knee positioned at 0° of flexion and the ankle at 10° or 0° of PF ($P < .001$), whereas ankle complex stiffness was greatest with the knee positioned at 0° of flexion and the ankle at 0° of PF ($P < .009$).

Conclusions: Anterior drawer testing of the ankle complex with the knee positioned at 90° of flexion and the ankle at 10° of PF produced the most laxity and the least stiffness. These findings indicate that anterior drawer testing with the knee at 90° of flexion and the ankle at 10° of PF may permit better isolation of the ankle capsuloligamentous structures.

Key Words: lateral ankle sprains, physical examination

Key Points

- Differences in ankle laxity and stiffness during anterior drawer loading of the ankle complex were found in various knee and ankle positions.
- Alterations in the passive tension characteristics acting through the Achilles tendon complex and the ankle capsulo-ligamentous structures should be considered when assessing ankle ligament laxity.

Inversion ankle sprain often results in injury to the anterior talofibular (ATFL) and calcaneofibular (CFL) ligaments.[1–3] As part of the physical examination to evaluate the extent of damage, anterior displacement of the talus in the ankle mortise is assessed.[4–7] To evaluate ATFL integrity, the anterior drawer test is performed with the patient lying supine with the leg relaxed and foot held in neutral or plantar flexion as an anterior load is applied at the ankle.[5,7–9]

Using in vitro studies, researchers have extensively investigated the anterior drawer test as a diagnostic method by examining the lateral ligamentous structures at various ankle positions for their individual and combined contributions to the mechanical stability of the joint.[10–15] Changing the position of the foot relative to the tibia changes the contributions of the ATFL and CFL to ankle stability. In dorsiflexion, the posterior talofibular ligament is maximally stressed and the CFL is taut, while the ATFL is loose. In plantar flexion, the ATFL is taut, and the CFL and posterior talofibular ligament become loose.[16–18] Because the ankle complex becomes more lax from neutral to plantar flexion with anterior loading, a complex interaction must exist among ligamentous laxity, the bony constraints of the joint, and ankle plantar flexion (PF).[16]

Experimental measurement of ankle complex laxity at different knee flexion angles has not been previously reported. The anterior drawer test described in physical examination textbooks is commonly depicted with the knee positioned in flexion or extension.[5,7–9,16] In the flexed knee position, the gastrocnemius becomes slackened.[5] The gastrocnemius, with its medial and lateral heads, arises from the posterior aspect of the femoral condyles and, along with the soleus muscle, attaches to the posterior surface of the calcaneus via the Achilles tendon. Because the muscle crosses the knee, ankle, and subtalar joint, placing the gastrocnemius in a shortened position could reduce the passive tension effects (tightness) of the muscle acting through the Achilles tendon on the ankle complex.[5,19,20] When anterior drawer loading of the ankle is performed with the knee extended, ankle complex laxity and stiffness are more likely to be affected by the noncontractile components of the gastrocnemius-Achilles tendon complex, which could be under increased tension due to musculotendinous unit elongation.[21] In biological tissues, the elasticity of the tissue is quantified by its stiffness and is calculated as the change in applied force divided by the resulting change in length.[21] Laxity describes the freedom of movement within a joint and is measured as joint translation at a given force load.[6,11,15,21]

The knee position in which a clinical measurement would most likely demonstrate increased laxity and decreased stiffness of the ankle complex is unknown. If laxity decreases and ankle stiffness increases during anterior drawer loading with the knee extended, then knee extension would be considered to reduce ankle complex laxity during anterior drawer loading. Positioning the ankle at 0° of PF could further increase this effect. Thus, the purpose of our study was to quantify the effect of different knee and ankle positions on anterior drawer laxity and stiffness of the ankle complex. We hypothesized that positioning the knee at 90° of flexion would increase laxity and decrease stiffness of the ankle complex during anterior drawer loading by altering the passive tension characteristics acting through the gastrocnemius-Achilles tendon complex. Positioning the ankle at 0° of PF should result in even greater ankle complex laxity and reduced stiffness.

METHODS

Design

We used a repeated-measures design. Independent variables were knee position (90° and 0° of flexion) and ankle position (neutral [0°] and 10° of PF). Dependent variables were anterior drawer laxity and stiffness of the ankle complex.

Participants

Ten female (age = 19.8 ± 1.1 years, height = 165.9 ± 7.7 cm, mass = 57.3 ± 11.5 kg) and 10 male (age = 20.8 ± 1.2 years, height = 179.6 ± 4.7 cm, mass = 88.7 ± 15.9 kg) National Collegiate Athletic Association Division I athletes participating in volleyball, soccer, or basketball consented to participate. None of the athletes reported a history of injury to either ankle or knee within the previous 12 months. The institutional review board approved this study, and each athlete provided informed consent.

Ankle Arthrometer

Testing was conducted using a portable ankle arthrometer (Blue Bay Research Inc, Navarre, FL) consisting of a spatial kinematic linkage, an adjustable plate fixed to the foot, a load-measuring handle attached to the footplate through which the load was applied, and a reference pad attached to the tibia.[15,22–24] Ankle arthrometry is a method for assessing translatory and uniplanar rotary displacements of the foot in relation to the leg that result from the combined motions within the talocrural and subtalar joints.[11,15,22] A spatial kinematic linkage is a 6 degrees-of-freedom electrogoniometer used for measurements of applied forces and moments and the resultant translations and rotations of the ankle complex.[11,15,25] The arthrometer spatial linkage connected the tibial pad to the footplate and measured the motion of the footplate relative to the tibial pad. Ankle flexion angle was measured from the plantar surface of the foot relative to the anterior tibia and determined by the 6 degrees-of-freedom electrogoniometer within the instrumented linkage. A computer with an analog-to-digital converter was used to simultaneously record and calculate the resulting displacement (mm) and corresponding load (N). We used a custom software program written in LabView (National Instruments Corp, Austin, TX) for data collection.

The ankle arthrometer has been previously shown to be both valid and reliable in the measurement of ankle complex laxity. High validity of measurement has been derived via comparison with concurrent measurement of tibial-calcaneal bone motion in cadaver specimens for sagittal-plane translation (r = 0.88) and frontal-plane rotation (r = 0.86).[15] Groups studying in vitro and in vivo ankles have established high values for intratester and intertester reliability for both anterior and posterior translation and frontal-plane rotation (intraclass correlation coefficients 2,1 = 0.80 to 0.99), along with high measurement precision (SEM = 0.58 to 1.76 mm).[15,22–24,26]

Procedures

Ankle anterior drawer laxity and stiffness were evaluated using 4 test conditions combining 2 knee positions (90° and 0° of flexion) and 2 ankle positions (neutral [0°] and 10° of PF). Thus, the 4 testing conditions were as follows: (1) knee at 90° of flexion, ankle at 0° of PF; (2) knee at 90° of flexion, ankle at 10° of PF; (3) knee at 0° of flexion, ankle at 0° of PF; and (4) knee at 0° of flexion, ankle at 10° of PF.

The athletes participated in one testing session, during which all anterior drawer measurements were obtained using ankle arthrometric procedures previously described.[22–24,26,27] A restraining strap was secured around the distal lower leg 1 cm above the malleoli to prevent lower leg movement during testing. The examiner secured the arthrometer to the foot by placing the bottom of the foot onto the footplate and adjusting the heel and dorsal clamps. The heel clamp prevented the device from rotating on the calcaneus, while the dorsal clamp secured the foot to the footplate. The tibial pad was then positioned 5 cm above the ankle malleoli and secured to the lower leg. To minimize variation, the arthrometer was oriented and positioned on all participants in a similar manner for all tests, and the same examiner (J.E.K.) performed all tests. Test order was counterbalanced and randomly assigned between right and left ankles and by knee position (90° or 0° of flexion) and ankle position (0° or 10° of PF). After the ankle measurements were obtained, the device was removed and the testing procedure repeated on the opposite ankle.

With the athlete lying supine on the table, the knee was positioned at 90° of flexion using a bolster or extended straight (0° of flexion) (Figure 1). Knee flexion angle was determined using a handheld goniometer and measured with the athlete lying supine. The fulcrum was centered over the lateral femoral epicondyle, the stationary arm was centered over the midline of the femur, and the movement arm was centered over the midline of the fibula.[8] By visualizing the computer screen display, the ankles were positioned at zero anteroposterior load and zero inversion-eversion moment at the 0° and 10° of PF angles, which were defined as the measurement reference positions.[11,22,25] The other degrees of freedom (internal-external, medial-lateral, and proximal-distal) were also maintained at the zero load position during testing. Thus, the measurement reference position represents zero moment and force loads.[11,15,25] Starting at the measurement reference posi-

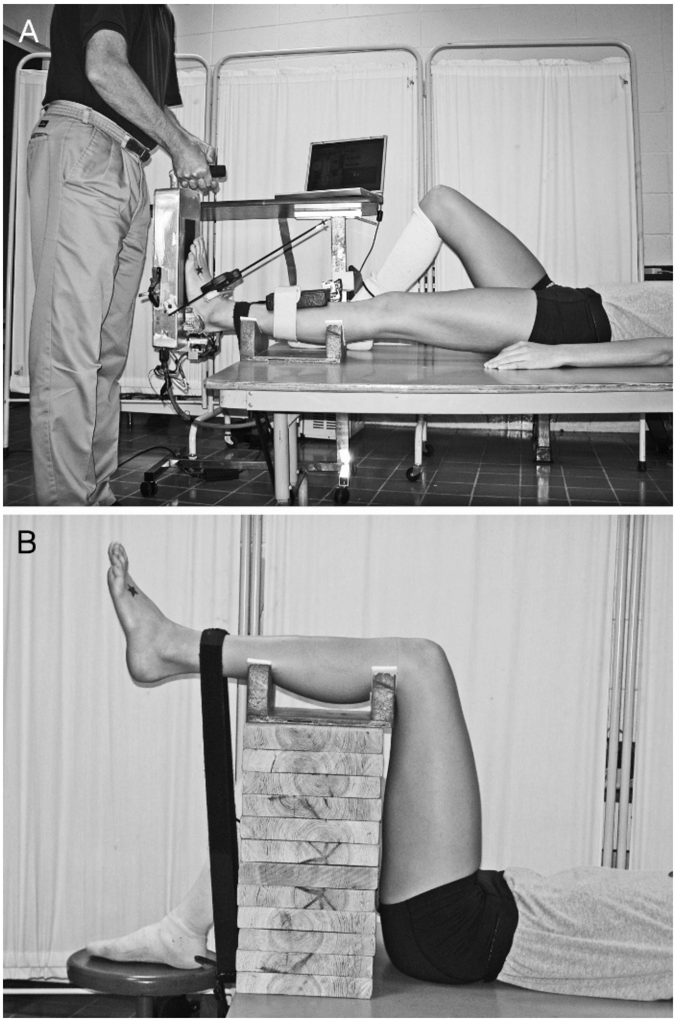

Figure 1. Ankle anterior-drawer test. A, Attached ankle arthrometer with the knee positioned at 0° of flexion and the ankle at 0° of plantar flexion. B, Participant lying supine with the knee positioned at 90° of flexion and the ankle at 10° of plantar flexion.

tion, loading was applied through the load handle in line with the footplate. By watching the computer monitor, the examiner could visualize the applied load to obtain a maximum of 100 N. Anterior displacement (mm) of the ankle complex from a single trial was recorded along with the load.

Data Reduction and Statistical Analysis

The load-displacement relationship is characterized in Figure 2. In all tests, the ankle joint demonstrated a nonlinear load-displacement relationship. To quantify the elasticity of the ankle complex, secant stiffness was calculated as the change in applied force divided by the resulting change in displacement.[21] As the magnitude of the applied anterior load increased beyond 50%, the ankle joint became less lax (more stiff).[12,21,25,28] To measure the stiffness of the ankle complex, these data were plotted as the applied load versus the displacement over the end-range of loading (50 to 100 N). Stiffness was defined as force per displacement (N/mm) and was calculated by dividing 50 N (load difference between 50 N and 100 N) by the anterior displacement between the 50 N and 100 N force loads. Ankle complex motion at 100 N anterior to the measurement reference position (zero N load) was defined as anterior displacement (mm) and recorded as ankle complex laxity.[29–31]

Separate 2 × 2 repeated-measures analyses of variance were used to determine the effect of knee and ankle position on ankle complex laxity and stiffness. Statistical significance was set at .05. The within-subjects factors were knee position with 2 levels (90°, 0°) and ankle position with 2 levels (0°, 10° PF). Post hoc analyses consisted of paired t tests corrected for α inflation by the Bonferroni procedure, which established .0125 as the adjusted α level for determination of statistical significance. All statistical analyses were performed with SPSS software (version 14.0; SPSS Inc, Chicago, IL).

RESULTS

The knee-by-ankle position interaction effects were significant for both laxity ($F_{1,39} = 4.48$, $P = .04$; Figure 3) and stiffness ($F_{1,39} = 9.24$, $P = .004$; Figure 4). The knee angle main effect was significant for laxity ($F_{1,39} = 36.85$, $P < .001$) and stiffness ($F_{1,39} = 4.65$, $P = .037$), as was the ankle angle main effect for laxity ($F_{1,39} = 34.79$, $P < .001$). The ankle angle main effect was not significant for stiffness ($F_{1,39} = 1.303$, $P = .261$).

Changing the ankle angle with the knee positioned at 0° or 90° of flexion and changing the knee angle with the ankle positioned in 0° or 10° PF influenced laxity. Greater laxity was observed at 90° of knee flexion, 10° of ankle PF when compared with either 0° of knee flexion, 10° of ankle PF or 90° of knee flexion, 0° of ankle PF ($P < .002$; Table). Greater ankle complex laxity occurred at 90° of knee flexion, 0° of ankle PF and 0° of knee flexion, 10° of ankle PF than 0° of knee flexion, 0° of ankle PF ($P < .001$).

Changing the ankle angle position with the knee at 0° or 90° of flexion influenced stiffness. Changing the knee angle position with the ankle in 0° of flexion influenced stiffness but not with the ankle in 10° of PF. Ankle complex stiffness was greater at 0° of knee flexion, 0° of ankle PF than at 0° of knee flexion, 10° of ankle PF or 90° of knee flexion, 0° of ankle PF ($P < .009$; Table). In addition, 90° of knee flexion, 10° of ankle PF produced greater stiffness than 90° of knee flexion, 0° of ankle PF ($P = .012$). No difference in stiffness was found between 0° of knee flexion, 10° of ankle PF and 90° of knee flexion, 10° of ankle PF ($P = .730$).

DISCUSSION

Assessment of lateral ligament laxity after inversion ankle sprain injury is critical to accurate diagnosis and treatment. The ATFL is the major ligamentous structure preventing forward subluxation of the talus, so a tear of the ligament allows the talus to slide forward relative to the tibia.[11] Although the clinician becomes skilled in evaluating ligamentous injuries and develops a quantitative "feel" for ankle laxity, manual examination is largely subjective, with accuracy depending on the skill and experience of the examiner.[32] Ankle arthrometry provides instrumented measurement of the load-displacement characteristics of the ankle complex.[11,15,25] Laxity measurement describes the normal or pathologic joint movement and represents the

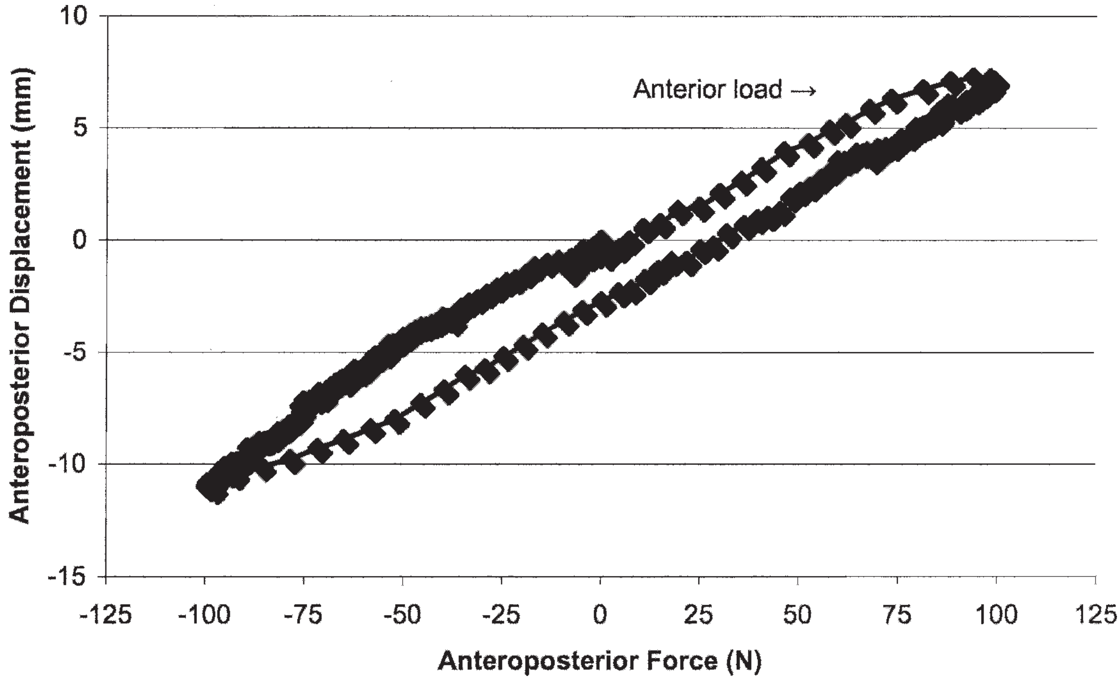

Figure 2. Anteroposterior force-displacement curve from one ankle. A negative load value represents posterior load, and a negative displacement value represents posterior displacement. Ankle complex laxity is the anterior displacement (mm) between 0 and 100-N force loads.

structural integrity of the capsuloligamentous tissues surrounding the joint.[15,21,33,34]

With anterior loading of the ankle, the clinician also assesses the end-feel of joint movement, identifying the resistance felt at the limits of the joint's end range of motion.[33,34] In the ATFL-deficient ankle, end-feel reflects the secondary constraints to anterior motion. Because anterior drawer loading is passively performed in the sagittal plane, it likely is affected by the noncontractile components of the gastrocnemius-Achilles tendon complex, which could be under increased tension due to musculotendinous unit elongation in the extended knee or the neutral foot position.[21] We defined stiffness as the change in applied force divided by the resulting change in displacement.[21] The load range between 50 and 100 N was chosen as a measure of the terminal range of the load-

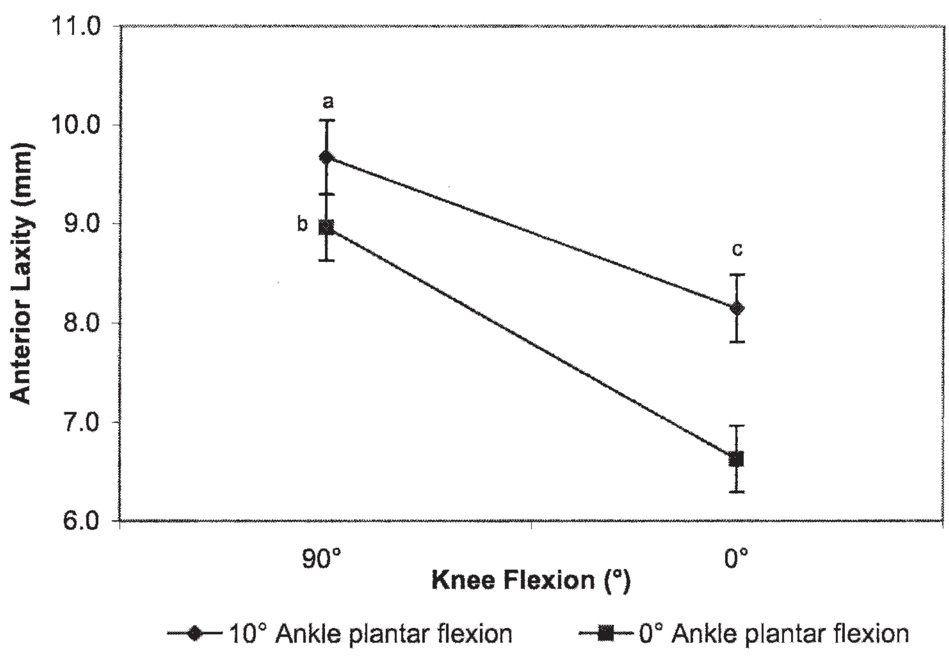

Figure 3. Knee-by-ankle comparisons for ankle complex laxity. [a] Indicates knee at 90° of flexion, ankle at 10° of plantar flexion > knee at 90° of flexion, ankle at 0° of plantar flexion and knee at 0° of flexion, ankle at 10° of plantar flexion ($P \leq .002$); [b] Knee at 90° of flexion, ankle at 0° of plantar flexion > knee at 0° of flexion, ankle at 0° of plantar flexion ($P < .001$); [c] Knee at 0° of flexion, ankle at 10° of plantar flexion > knee at 0° of flexion, ankle at 0° of plantar flexion ($P < .001$).

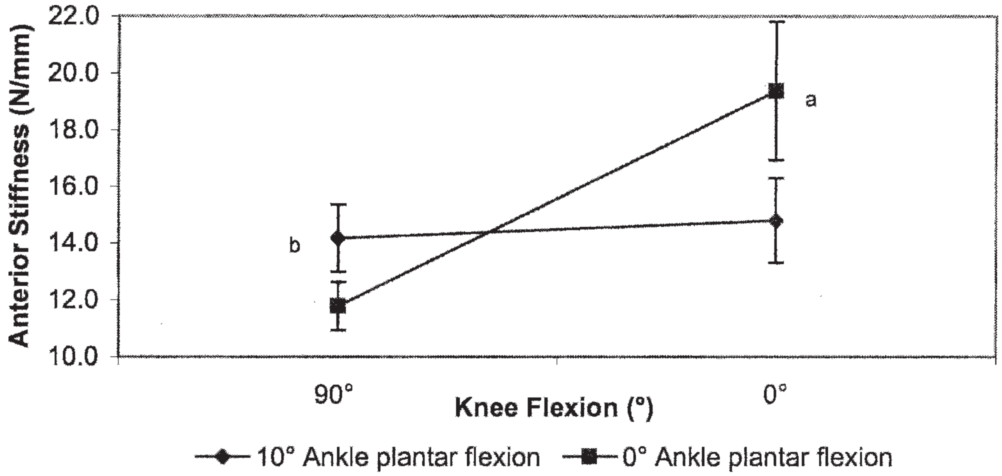

Figure 4. Knee-by-ankle comparisons for ankle complex stiffness. [a] **Indicates knee at 0° of flexion, ankle at 0° of plantar flexion > knee at 0° of flexion, ankle at 10° of plantar flexion and knee at 90° of flexion, ankle at 10° of plantar flexion ($P \leq .009$);** [b] **Knee at 90° of flexion, ankle at 0° of plantar flexion > knee at 90° of flexion, ankle at 10° of plantar flexion ($P = .012$).**

displacement curve to provide an assessment of the end-range of the supporting tissues elasticity (stiffness). Because soft tissue is more compliant (ie, has lower stiffness) at low loads, higher force levels cause the tissues to become stiffer as unit increases in force are produced. Thus, when performing an anterior drawer test, the lack of a solid endpoint (laxity) implies that the ligamentous structures are injured and any resulting end-feel (stiffness) is likely produced by the intact secondary structures supporting the joint.[33] Authors performing in vitro ankle research have shown that during anterior drawer loading of the intact ankle, displacement and stiffness increased, but after sectioning the lateral ligaments, stiffness did not change ($P > .05$).[30] The lack of change in stiffness in the ligament deficient-ankles indicated that bony and other soft tissues maintained anterior stiffness after pathologic joint displacement.

Effects of Knee Positioning

The effects of knee positioning on ankle complex laxity and stiffness have not previously been quantified. When anterior drawer loading the ankle, we found increased laxity of the ankle complex in 90° compared with 0° of knee flexion at both ankle PF angles. These findings indicate that the 90° of flexion knee position may better contribute to isolating the ankle capsuloligamentous structures by reducing the influence of the calf musculature on laxity. Flexing the knee likely relaxed the gastrocnemius-Achilles tendon complex and decreased its tightness at the ankle.[5] When stretched (ie, the knee extended versus the knee flexed), passive tension increases in a muscle as it displays viscoelastic behavior. This passive tension effect of muscle is created by the parallel elastic component of the tissue and anatomically includes the fascia that surrounds the fibers and the muscle itself.[21,35,36]

The largest difference in stiffness was found between the knee flexed to 90° and to 0° with the ankle in 0° of PF. At 0° of PF, the hindfoot likely maintained tension on the Achilles tendon, and when the knee was positioned at 0° of flexion, the ankle complex was tightened. However, ankle complex stiffness was almost identical between the knee at 90° of flexion, ankle at 10° of PF and the knee at 0° of flexion, ankle at 10° of PF conditions. Thus, PF of the ankle alone appears to loosen the Achilles-tendon complex, and any further loosening produced by flexing the knee may not have resulted in any additional effect. This finding is supported by Davis et al,[20] who measured the passive tension forces in the Achilles tendon at various knee and ankle positions and reported that positioning the hindfoot in at least 15° of PF effectively eliminated tension in the Achilles tendon. When examined with the knee in full extension, tension within the Achilles tendon was eliminated at 30° of PF.[20]

Table. Summary of the Interaction Comparison Analyses for Knee by Ankle Position (Mean ± SD)

Knee Flexion	Ankle Plantar Flexion	Anterior Laxity, mm	P Value	Anterior Stiffness, N/mm	P Value
0°	0°	6.63 ± 2.1	< .001[a]	19.37 ± 15.4	.006[a]
90°	0°	8.96 ± 2.1		11.78 ± 5.4	
0°	10°	8.12 ± 2.1	< .001[a]	14.81 ± 9.4	.730
90°	10°	9.73 ± 2.3		14.20 ± 7.6	
0°	0°	6.63 ± 2.1	< .001[a]	19.37 ± 15.4	.009[a]
0°	10°	8.12 ± 2.1		14.81 ± 9.4	
90°	0°	8.96 ± 2.1	.002[a]	11.78 ± 5.4	.012[a]
90°	10°	9.73 ± 2.3		14.20 ± 7.6	

[a] $P \leq .05$.

Effects of Ankle Positioning

We found increased ankle complex laxity at 10° of PF when compared with 0° of PF in both 90° and 0° of knee flexion. Testing with the ankle in PF is reported to increase the contribution of the ATFL, whereas testing with the ankle perpendicular (neutral) to the tibia principally stresses the CFL.[17,37] Findings from in vitro studies indicate ankle complex laxity changes at different ankle flexion angles when only the passive structures are present.[11–14,17,38] These structures include the bone articulations and their osseous shapes, the joint capsule, and related ligamentous tissues.[16]

In an in vivo analysis of ankle complex laxity using an instrumented arthrometer, Hubbard et al[23] reported anterior laxity of 11.1 mm at 125 N in uninjured ankles in 0° of PF, which was greater than the 9.73 mm we found at the 100-N load with the ankle in 10° of PF. The difference in findings between these 2 studies could have been caused by the different ankle positions or the greater anterior load used by Hubbard et al. It is also possible that at an anterior load above 100 N, a greater nonlinear load displacement occurred than that observed at the 100-N load. In addition, in vitro assessment of the ankle complex has also shown greater laxity in the neutral versus the PF position.[11]

We found that placing the ankle in 0° of PF with the knee at 0° of flexion (19.37 N/mm) increased stiffness over the ankle placed in 10° of PF (14.81 N/mm). This finding illustrates that PF of the ankle with the knee extended likely reduced the passive tension effect of the calf musculature acting through the Achilles. In contrast, with the knee positioned at 90° of flexion, the ankle complex showed greater stiffness in 10° of PF. By reducing or eliminating the passive tension effects of the calf musculature by flexing the knee, the ankle complex may be inherently stiffer in PF because the ankle capsuloligamentous structures are placed under greater strain. Tohyama et al[12] reported that the ATFL is under maximum strain with the ankle in a PF position. Taga et al[39] observed that the stiffness of the normal ankle at 50 N of anterior-directed load was an average of 24 N/mm with the ankle in PF. We found lower stiffness values at 10° of PF for both the 90° (14.20 N/mm) and 0° (14.81 N/mm) of knee flexion angles. Differences in findings may be explained by the experimental setup and type of test device used in loading the ankle. The method we used, in which the talus was free to move, probably more nearly represents the in vivo situation.[11,15] In several studies,[10–12,39] some devices did not allow freedom of rotation of the foot, which occurs during normal anteroposterior loading of the ankle complex. Test procedures performed while limiting internal rotation of the foot could reduce the ability to detect laxity, which could explain why some investigators found greater ankle complex laxity with the foot in dorsiflexion after sectioning both the ATFL and CFL.[10–12]

Limitations

We recognize the following limitations to our study. Sex differences were not examined for possible effects on ankle complex laxity and stiffness. Muscle activation was not measured and could also be considered a limiting factor. When performing the anterior drawer test, controlling for muscle activation (relaxation) was important because we wanted to examine the effect of knee position and the corresponding passive tension effects (influence) of the musculotendinous unit on ankle complex laxity and stiffness. During testing, all participants were instructed to relax their leg muscles. To ensure muscle relaxation, the leg and ankle were supported, so that muscle force was not required to maintain the desired joint angle during testing. None of our participants reported or appeared to experience any noticeable reflexive muscle tightening, which could have contributed to increased stiffness. In addition, the 100-N anterior loading was selected as the standard test force to ensure that the magnitude of loading was both sufficient to detect joint laxity and also tolerated by the subject. We have routinely used loading as high as 125 N, even though the literature has shown loading as low as 10 N can be used to detect ankle complex laxity.[18,22–24,38]

We did not measure passive dorsiflexion range of motion in this study, which could also be considered a limitation. DiGiovanni et al[19] described gastrocnemius equinus as maximum ankle dorsiflexion of 5° or less with the knee in full extension and Achilles tightness with maximum ankle dorsiflexion of 10° or less with the knee in 90° of flexion. The effects maximum ankle dorsiflexion and other ankle and knee positions may have had on gastrocnemius-Achilles tendon tension are unknown. In addition, the effects of ankle positioning on ankle complex laxity and stiffness that we examined may not be solely attributed to musculotendinous length-tension changes. Without the use of indwelling strain transducers, it is impossible to determine exactly how much difference in laxity and stiffness was attributable to musculotendinous changes and how much was due to capsuloligamentous changes at the different ankle positions.

CONCLUSIONS

Knee and ankle positioning influenced ankle complex laxity and stiffness. Our findings indicate that anterior drawer testing of the ankle complex with the knee positioned in 90° of flexion and the ankle in 10° of PF produced the greatest laxity and least amount of stiffness.

FINANCIAL DISCLOSURE

J. Marcus Hollis, PhD, holds a patent on the Ankle Arthrometer.

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