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Examining Ankle-Joint Laxity Using 2 Knee Positions and With Simulated Muscle Guarding

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Context: Several factors affect the reliability of the anterior drawer and talar tilt tests, including the individual clinician's experience and skill, ankle and knee positioning, and muscle guarding.

Objectives: To compare gastrocnemius activity during the measurement of ankle-complex motion at different knee positions, and secondarily, to compare ankle-complex motion during a simulated trial of muscle guarding.

Design: Cross-sectional study.

Setting: Research laboratory.

Patients or Other Participants: Thirty-three participants aged 20.2 ± 1.7 years were tested.

Intervention(s): The ankle was loaded under 2 test conditions (relaxed, simulated muscle guarding) at 2 knee positions (0°, 90° of flexion) while gastrocnemius electromyography (EMG) activity was recorded.

Main Outcome Measure(s): Anterior displacement (mm), inversion-eversion motion (°), and peak EMG amplitude values of the gastrocnemius (μV).

Results: Anterior displacement did not differ between the positions of 0° and 90° of knee flexion ($P = .193$). Inversion-eversion motion was greater at 0° of knee flexion compared with 90° ($P < .001$). Additionally, peak EMG amplitude of the gastrocnemius was not different between 0° and 90° of knee flexion during anterior displacement ($P = .101$). As expected, the simulated muscle-guarding trial reduced anterior displacement compared with the relaxed condition (0° of knee flexion, $P = .008$; 90° of knee flexion, $P = .016$) and reduced inversion-eversion motion (0° of knee flexion, $P = .03$; 90° of knee flexion, $P < .001$).

Conclusions: In a relaxed state, the gastrocnemius muscle did not appear to affect anterior ankle laxity at the 2 most common knee positions for anterior drawer testing; however, talar tilt testing may be best performed with the knee in 0° of knee flexion. Finally, our outcomes from the simulated muscle-guarding condition suggest that clinicians should use caution and be aware of reduced perceived laxity when performing these clinical examination techniques immediately postinjury.

Key Words: ankle arthrometer, anterior drawer, talar tilt, electromyography, manual examination

Key Points

- Anterior drawer and talar tilt testing are recommended in the assessment scheme for patients with lateral ankle sprains.
- Proper execution of ligament laxity testing at the ankle joint requires that the patient be relaxed and not guarding against the laxity tests.
- Anterior drawer tests at the ankle joint may be performed with the knee straight or bent. However, the talar tilt test is best done with the knee extended.

Lateral ankle sprains are among the most commonly incurred injuries in the physically active population, with an estimated 28 000 sprains occurring in the United States on a daily basis.[1] After acute ankle injury, it is crucial to recognize mechanical laxity and obtain an accurate diagnosis to guide the treatment and prevent reinjury.[2] In the event of a lateral ankle sprain, the degree of laxity must be assessed to identify any mechanical instability of the ankle joint and therefore the severity of injury. The anterior drawer and talar tilt tests are manual stress tests used by clinicians to assess the ligamentous structures in the ankle joint.[3] These manual stress tests are routinely used to determine the ligamentous integrity of the talocrural and subtalar joints by arbitrary measurement of translation or rotation of the foot compared with the uninvolved limb. The anterior drawer test is performed by applying an anterior load to the foot on a fixed lower leg and stressing the anterior talofibular ligament.[3–5] The talar tilt test is performed by applying an inversion-eversion (IE) torque or rotation to the foot and stressing the calcaneofibular ligament.[3,6] Manual examination of ankle-joint laxity is low in sensitivity and relies heavily on the individual clinician's experience to assess ligamentous end feel.[4,7,8]

Instrumented measurement of the ankle joint allows for a more valid and reliable measure of ankle-ligament laxity compared with manual examination.[4,7–9] Instrumented measurement of ankle-joint laxity has been used extensively since the first publication of ankle arthrometry in 1999.[7] An ankle arthrometer allows for quantitative assessment of the ankle joint, measuring both rotation (IE motion) and anteroposterior displacement of the foot relative to the tibia, similar to the manual stress tests previously mentioned.[3,7–9] Previous researchers[4] have demonstrated that the positioning of the knee joint can cause a significant difference in ankle-complex laxity. Although Kovaleski et al[4] speculated that the differences in ankle-complex laxity are related to the passive tension characteristics (noncontractile components) of the gastrocnemius-Achilles complex, no contemporary evidence supports this notion. We submit that the passive tensioning of these noncontractile structures in the gastrocnemius-Achilles complex refers to the length-tension relationship of the muscle, suggesting that when the knee is fully extended, Achilles tension is increased compared with when the knee is bent. An increase in Achilles tension could reduce the available joint laxity. Electromyography (EMG), an instrumented technique used to record and analyze electrical activity produced when a muscle contracts, provides a convenient way to quantify involuntary muscle activity. Electromyography has been used by Arampatzis et al[10] to detect the change in muscle activation of the gastrocnemius at different knee and ankle positions. Reduced EMG activity of the gastrocnemius at knee-joint angles greater than 80° might be explained by the shortening of the biarticulate muscle at the proximal joint. At knee-joint angles greater than 80° of flexion, the gastrocnemius reaches a critical shortened length at which only minimal force can be generated.[11]

Muscle guarding refers to an involuntary joint stiffening associated with muscle spasm, pain, and swelling in response to ligamentous injury in order to prevent active motion and protect the damaged tissue.[2,3] Muscle guarding inhibits joint movement, making both manual and instrumented examination of ankle laxity extremely difficult. For the purposes of our study, we quantified muscle guarding using a neurologic measurement involving EMG recordings; muscle activity increased to 30% above the resting value served as our indicator of contraction (guarding). After acute ankle sprain, guarding occurs when the foot is held in a neutral position to prevent active and passive motion. The ankle dorsiflexors, including the tibialis anterior, are primarily active in muscle guarding of the ankle joint to prevent stressing the anterior talofibular ligament in plantar flexion. From a clinical perspective, muscle guarding can make manual examination difficult and produce false-negative results on manual stress tests or alter end-feel presentation. According to Lynch and Renström,[11] acute muscle guarding associated with pain and swelling can mask true laxity 4 to 7 days after the injury.

The prevalence of ankle sprains in the active population stresses the need for prompt and accurate diagnosis by the athletic trainer. The anterior drawer and talar tilt tests are 2 of the most common clinical examination techniques used to evaluate acute ankle sprains. Therefore, the primary purpose of our study was to determine which position of the knee joint (0° or 90° of flexion) had the greatest influence on ankle-joint laxity and peak EMG amplitude of the gastrocnemius muscle during ankle-arthrometry assessment. Additionally, to better understand the influence of muscle guarding during these 2 clinical examination techniques, we compared ankle-arthrometry measurements between a relaxed and a simulated muscle-guarding condition. We hypothesized that the 0° of knee-flexion position would elicit greater peak EMG amplitude during the relaxed condition and that voluntary muscle guarding during the arthrometric measurements would result in decreased laxity at both knee positions.

METHODS

Design

We used a repeated-measures design. The dependent variables were anterior displacement (millimeters), IE motion (°), and peak EMG activity (microvolts). The independent variables were knee position (0° and 90° of flexion) and testing condition (relaxed and simulated muscle guarding).

Participants

Thirty-three volunteers (16 men, 17 women, age = 20.2 ± 1.7 years, height = 172 ± 9.7 cm, mass = 68.4 ± 15.6 kg) were recruited from a large university campus community to participate in this study. An a priori power analysis determined that 33 participants were needed to sufficiently power the study. Upon reporting for testing, volunteers were asked to complete an informed consent document (HSIRB # 440092-1) approved by the university institutional review board, which also approved the study; demographic information; injury-history documentation; and the Foot and Ankle Outcome Score (FAOS). To be included in this investigation, volunteers had to score between 90 and 100 on the FAOS, be injury free at the time of study, and have undergone no previous knee or ankle surgery. These criteria were based on the study of Kovaleski et al[4] investigating ankle arthrometry.

Foot and Ankle Outcome Score

The FAOS is a subjective assessment of ankle function in daily activities and recreation.[12] The FAOS consists of 5 subscales: Pain, Other symptoms, Function in daily living, Function in sport and recreation, and Foot- and ankle-related quality of life. The previous week is taken into consideration when answering the questionnaire. Standardized answer options are given (5 Likert boxes), and each question receives a score from 0 to 4. A normalized score (100 indicating *no symptoms* and 0 indicating *extreme symptoms*) is calculated for each subscale. (Additional information on the FAOS can be found at www.koos.nu.)

Ankle Arthrometry

The portable ankle arthrometer (Blue Bay Research Inc, Navarre, FL) was used to measure displacement (anterior drawer) and rotation (talar tilt) of the foot in relation to the leg (Figure 1). The ankle arthrometer consists of an adjustable plate fixed to the foot, a load-measuring handle attached to the footplate through which the load is applied, a tibial pad attached to the tibia, and a spatial kinematic linkage.[4,7–9,13] A *spatial kinematic linkage* is a 6 degrees-of-motion electrogoniometer that measures forces, translations, and rotations applied to the foot. The spatial linkage connects the tibial pad to the footplate, which allows for the measurement of motion from the footplate relative to the tibial pad. The foot is secured to the footplate by a heel cup that grips the calcaneus below the malleoli and a dorsal foot clamp that secures the midfoot to the footplate. A strap placed just above the malleoli on the anterior surface of the leg prevents the tibia from lifting off the table during anterior loading. A fixed load is applied to the handle, and

Figure 1. Ankle-arthrometer placement at 90° of knee flexion.

the position of the footplate relative to the position of the tibial pad is calculated and recorded.[4,7,9,14]

Electromyography

Electromyography allows for the instrumented recording and measurement of electrical activity within a muscle at rest and during contraction. We used a portable EMG dry-surface electrode unit (model DE 2.1; Delsys Inc, Boston, MA). The areas for dry-surface electrode placement were shaved and then cleaned with isopropyl alcohol to reduce skin impedance during testing. Electromyography signals were amplified to correct for gain (×1000), filtered (6–400 Hz bandwidth), and digitized at a sampling rate of 1 kHz.

Procedures

Before we performed the arthrometry measurements, we asked participants which foot they would use to kick a ball. This leg was then used for all measurements. The test leg was prepared for EMG electrode placement. The electrode was placed over the tibialis anterior, and another was placed over the belly of the medial head of the gastrocnemius (Figure 2). Both placements were recommended by the SENIAM project (http://www.seniam.org). A grounding electrode was placed on the patella. Special consideration was given to the electrode placement on the tibialis anterior because the tibial pad of the arthrometer was in a position to compress the electrode. Therefore, the electrode was positioned after the arthrometer's tibial pad was secured (Figure 2).

After EMG electrode placement, the first knee-position condition was selected randomly. For 0° of knee flexion (complete extension), participants were asked to lie supine on the portable treatment table (Figure 2). For the 90° of flexion position, a wooden bolster was placed on the portable treatment table and adjusted to maintain 90° of knee flexion during the arthrometric measurements (Figure 1). We realize that this testing position is not clinically viable; however, it was necessary to accommodate the arthrometric laboratory setup and enable us to recreate the bent-knee test position. The ankle arthrometer was positioned as described by Hubbard et al.[9] Participants' ankles remained in 10° of plantar flexion to isolate the anterior talofibular ligament throughout the testing procedure. We monitored this ankle position by watching the built-in inclinometer on the custom LabVIEW program (National Instruments, Austin, TX) running the ankle arthrometer.

A total of 3 test trials were performed to simulate the anterior drawer and talar tilt tests using the ankle arthrometer. The anterior displacement occurred during loading to 130 N of force, whereas IE motion was loaded to 4 Nm of force. Digital output for both settings was carefully monitored using the arthrometer laptop computer. For each knee position (0° and 90° of flexion), 2 sets of EMG activity were recorded. The order in which the datasets were collected was randomly assigned. The first set of data was collected while the participant was asked to refrain from voluntary muscle contraction (relaxed). During this relaxed condition, only EMG data from the gastrocnemius were collected. Electromyography collection during the relaxed condition was initiated by oral communication from the examiner to "start" and "stop" recording for each testing bout. The second set of EMG data was collected during the simulated muscle-guarding condition. To determine the reference contraction to simulate muscle guarding, the participant was asked to maximally contract and pull the foot upward (dorsiflexion) and hold for a period of 4 seconds. The maximum value derived from this contraction served as the maximal voluntary contraction (MVC) and enabled us to determine the 30% value necessary for each simulated-guarding trial. The 30% MVC value then served as our reference target for the participant to maintain during the simulated muscle-guarding test trials. During each test trial, a line was displayed on the computer screen so the participant could see and maintain the 30% MVC value during the ankle-arthrometry loading.

The average of 3 trials each for anterior displacement and IE motion was taken at each knee position, and this laxity measurement was used for subsequent data analysis. During each trial that included monitoring gastrocnemius activity (relaxed condition), EMG was recorded using an analog-digital converter and custom LabVIEW program. Peak EMG amplitude of the gastrocnemius during each trial was recorded and processed using the LabVIEW program. Raw data were processed by correcting for DC bias, correcting for gain (dividing by 1000), and then taking the root mean square over 100 milliseconds. The values were converted from volts to microvolts. Electromyographic activity during the simulated muscle-guarding condition was used only to

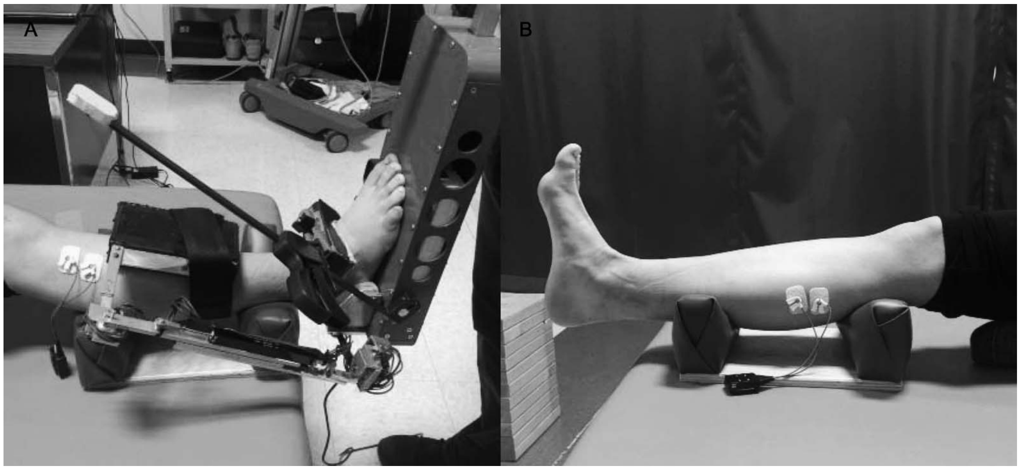

Figure 2. Electrode placement for, A, The tibialis anterior muscle at 0° of knee flexion and, B, The gastrocnemius muscle at 0° of knee flexion.

display the 30% target line and was not used in data analysis.

Statistical Analysis

We used SPSS statistical software (version 20.0; IBM Corporation, Armonk, NY) for the statistical analysis. The dependent variables were anterior displacement (millimeters), IE motion (°), and peak EMG activity (microvolts). The independent variables were knee position (0° and 90° of flexion) and testing condition (relaxed versus simulated muscle guarding). Separate dependent-samples *t* tests were used to compare each of the 3 dependent variables for the 2 knee positions. An additional set of dependent-samples *t* tests was analyzed to compare the anterior-displacement and IE-motion measurements between the relaxed and simulated muscle-guarding conditions at each knee position. The α level was set a priori at .05 for all analyses. The Cohen d statistic was used to calculate effect sizes for all analyses. Effect sizes are interpreted as *small* (0.20), *medium* (0.5), or *large* (0.8).

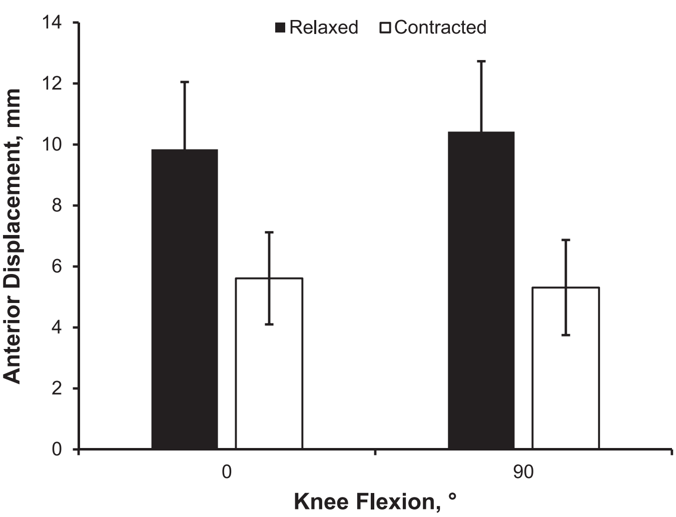

Figure 3. Comparison of anterior displacement between simulated muscle-guarding contracted (30% of maximal voluntary contraction) and relaxed conditions. Anterior displacement decreased in the simulated muscle-guarding contracted condition at 0° of knee flexion (4.23 mm) and at 90° of knee flexion (5.11 mm).

RESULTS

Knee-Joint Position

Contrary to what we had hypothesized, anterior displacement did not differ between the knee-flexion positions of 0° (9.84 ± 2.21 mm) and 90° (10.41 ± 2.31 mm; 95% confidence interval [CI] = 1.46, 0.31; $P = .193$). However, IE motion was greater at 0° of knee flexion (62.64° ± 11.85°) than at 90° of knee flexion (53.52° ± 10.41°; 95% CI = 6.21, 12.03; $P < .001$) with a large effect size (d = 1.1). Resultant peak EMG activity of the gastrocnemius during the anterior-displacement trials was not different at 0° of knee flexion (6.87 ± 4.87 μV) versus 90° of knee flexion (9.01 ± 9.03 μV; 95% CI = –4.74, 0.44; $P = .101$). Despite significant differences in IE motion, gastrocnemius peak EMG activity was not different between the trials at 0° (7.3 ± 6.69 μV) versus 90° (7.29 ± 4.36 μV; 95% CI = –42.73, –2.75; $P = .994$) of knee flexion.

Simulated Muscle-Guarding Trials

As expected, simulated muscle guarding of the tibialis anterior decreased ankle laxity (between 36% and 57%) across all test conditions. This decrease in laxity had a large effect size. Anterior displacement at 0° of knee flexion decreased from 9.84 ± 2.21 mm to 5.61 ± 1.51 mm (95% CI = 3.62, 4.91; $P < .001$, d = 2.1), whereas at 90° of knee flexion, displacement decreased from 10.42 ± 2.31 mm to 5.31 ± 1.56 mm (95% CI = 4.34, 5.86; $P < .001$, d = 2.4; Figure 3). Inversion-eversion motion at 0° of knee flexion decreased from 62.64° ± 11.85° to 23.05° ± 7.76° (95% CI = 35.47, 43.72; $P < .001$, d = 3.4) and at 90° of knee flexion decreased from 53.52° ± 10.41° to 20.76° ± 6.91° (95% CI = 29.57, 35.94; $P < .001$, d = 3.7; Figure 4).

DISCUSSION

The cornerstone of ankle-sprain injury assessment relies heavily on proper execution of both the anterior drawer and talar tilt tests to gauge laxity and determine injury severity.

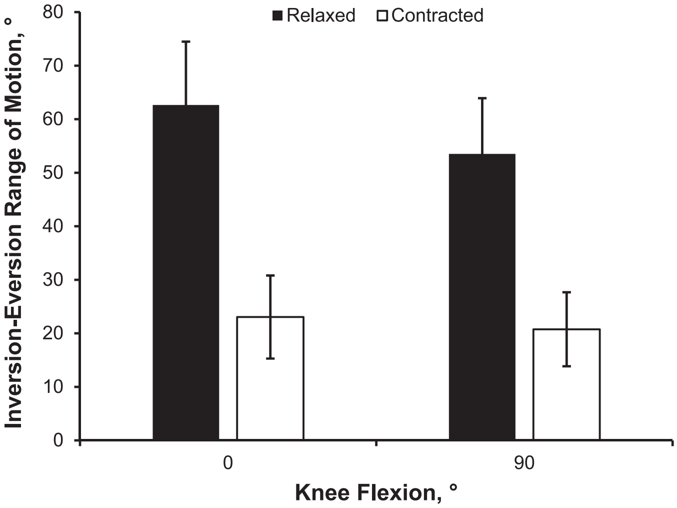

Figure 4. Comparison of inversion-eversion range of motion between simulated muscle-guarding contracted (30% maximal voluntary contraction) and relaxed conditions. Inversion-eversion motion decreased in the simulated muscle-guarding contracted condition at 0° of knee flexion (39.59°) and at 90° of knee flexion (32.76°).

Previous researchers[4] demonstrated that knee and ankle position can alter laxity derived from the anterior drawer test. Using similar methods, we set out to determine whether these differences in laxity were the result of involuntary contraction of the gastrocnemius muscle.[1] Additionally, we were interested in the effect of simulated muscle guarding on these clinical measures. Contrary to what we had hypothesized, it appears that alterations in knee-joint positioning (0° versus 90° of knee flexion) while executing the anterior drawer maneuver at the ankle joint do not affect anterior displacement as measured with precise arthrometry. Additionally, this finding is supported by the fact that the peak EMG amplitude of the gastrocnemius during these trials was not different. Although counter to conventional thought and textbooks on ankle-injury assessment, which recommend the knee be bent to 90° to eliminate tension on the Achilles tendon,[15] we submit that when performing the anterior drawer test in a clinical setting, the position of the knee may be of negligible influence. It is important to keep in mind that *tension* as referred to here could be the result of either muscle guarding or that created by the noncontractile components of the surrounding soft tissue structures.[16] It is also important to note that some mechanical tension on the Achilles tendon may be inherent with the knee in 0° of flexion, which may not be accounted for via our EMG analysis of gastrocnemius muscle activity. It is also important to reiterate that all anterior drawer testing was performed with the talocrural joint in slight plantar flexion; however, we do acknowledge that different ankle-flexion angles may affect laxity and provide an area for future research. Conversely, the 9.12° difference in IE motion between 0° and 90° of flexion may suggest that the talar tilt test is best performed while the knee is in the extended position. Additional evidence to support this recommendation is provided by the lack of differences in peak EMG amplitude of the gastrocnemius during this test condition.

We hypothesized that knee positioning would alter anterior displacement because of involuntary contraction of the gastrocnemius. Our results strongly support the findings of Kovaleski et al,[4] who were the first to investigate differences in ankle laxity with various knee and ankle positions using an ankle arthrometer identical to the one we used. In fact, their differences in anterior displacement between 90° of flexion and 0° of flexion were very close to the differences in our study (1.61 versus 0.57 mm). Additionally, their laxity values at 0° of flexion (8.12 ± 2.1 mm) and 90° of flexion (9.73 ± 2.3 mm) were nearly identical to those we report. Schwarz et al[13] demonstrated normative values for anterior displacement ranging from 8.59–9.95 mm using 125 N of anterior-loading force (with the knee in full extension). The values at 0° of flexion we obtained fall within this range reported by Schwarz et al.[13] These comparative findings point to the importance of standardizing loading forces as well as knee and ankle positioning, especially when we compare research trials.

Our results demonstrating no difference in anterior displacement at the 2 knee-joint positions are further strengthened by the lack of differences in our peak EMG amplitudes. This suggests that the EMG activity of the gastrocnemius muscle had no effect on anterior laxity. In 1999, Davis et al[17] examined Achilles tendon tension and suggested that ankle positioning rather than knee positioning was the primary determinant for tension across the Achilles tendon. Based on their findings, ankle positioning greater than 20° of plantar flexion negates the effect of knee positioning on Achilles tendon tension.[17] Participants in our study were positioned in 10° of plantar flexion; therefore, the knee positions should have affected the EMG activity of the gastrocnemius, but no difference was observed. Conversely, perhaps the 10° ankle plantar-flexion angle negated the effect of knee positioning on EMG activity of the gastrocnemius and other lower leg muscles. Our method of EMG recording involved surface electrodes, which is considered an acceptable method for recording muscle activity. One might argue that indwelling EMG analysis might have provided a more accurate means of recording activity in the medial head of the gastrocnemius. However, using such a technique in conjunction with the ankle arthrometer would have been very difficult from a methodologic standpoint.

An unexpected finding was that IE motion was greater at 0° of knee flexion (62.64°) than at 90° of knee flexion (53.52°). This finding has the potential to affect traditional clinical practice via execution of the talar tilt test. We speculate that, at 90° of knee flexion, involvement of the monoarticular muscles (ie, peroneals) along with increased stiffness from the capsuloligamentous structures surrounding the ankle may have an effect on IE motion. We contend that this is an interesting and unique finding and suggest that additional study is warranted to determine a reasonable explanation. Again, referencing the normative values reported by Schwarz et al[13] (39.9°–42.1°), our values compare favorably with those reported for IE motion using 4 Nm for IE loading; however, testing was performed with the knee in 10° to 20° of flexion. When we compare our 0° of knee-flexion value (62.64°) with that reported by Hubbard et al[9] for full knee extension (59.6° ± 7.5°), our IE motion is quite similar. When compared with our IE-motion value at 90° of knee flexion (53.52°), it becomes apparent that, as the knee joint moves from a position of full extension to a position of flexion, these IE-motion values are changing.

After acute lateral ankle sprain, muscle guarding produces a protective joint stiffness that attempts to resist deviation from the neutral joint position.[16] However, the effect this increased joint stiffness (defined in our project as simulated muscle guarding) has on ankle-complex laxity measurements was not previously investigated. Our test methods enabled us to conveniently add this simulated muscle guarding component to our investigation. We selected 30% MVC of the tibialis anterior for our simulated muscle-guarding condition for several reasons. First, the weight of the arthrometer and pressure from the foot clamps and tibial pad caused the participants to activate the dorsiflexors in some capacity (<15% MVC). Additionally, pilot testing demonstrated that laxity testing with an MVC greater than 40% was unreliable or impossible. The active stiffness generated by the participant past 40% MVC was greater than or equal to the forces applied by the examiner to appropriately move the arthrometer through the testing motions. Hunter and Spriggs[18] described 30% MVC as an accurate representation of active stiffness that allows normal reflex contraction of the lower leg muscles when an external force is applied to the ankle joint. Therefore, we settled on 30% MVC as our simulated muscle-guarding condition. Our results showed that maintaining 30% MVC of the tibialis anterior muscle greatly reduced ankle laxity (both anterior displacement and IE motion). This finding suggests that muscle guarding can significantly reduce ankle-complex laxity. From a clinical perspective, this has implications for performing the anterior drawer and talar tilt tests during ankle-injury evaluation. The clinician should perform these 2 tests early in the acute stages after ankle injury, before muscle guarding takes hold.

We also suggest that ankle arthrometry may be safely used to acutely assess ankle-complex laxity when the joint is guarded, for follow-up measurements that may be compared with initial values to aid in determining the extent of the sprain, and during the later stages of ankle-sprain rehabilitation as a treatment outcome measure.

We acknowledge the following limitations of our study. During the simulated muscle-guarding condition, we did not monitor gastrocnemius EMG activity and acknowledge that the cocontraction of the antagonist muscle could have affected the laxity measurements. Furthermore, due to the inability to synchronize the EMG and arthrometer signals, we instead relied on verbal "start" and "stop" cueing from the examiner to an assistant who controlled the LabVIEW program for EMG recording. This may have resulted in a minor timing error between the signals. However, because peak EMG values were used for comparison, lack of signal synchronization was not a factor in this investigation. Yet future researchers who aim to correlate ankle-complex displacement and muscle contraction should synchronize signals. Baseline MVC of the gastrocnemius was not recorded for comparison with the results of peak EMG amplitude during the relaxed condition. Although we speculate that the low peak EMG amplitude values for the involuntary gastrocnemius muscle are extremely small, without gastrocnemius MVC values, we cannot say with certainty that this is true.

CONCLUSIONS

The high incidence rate at which ankle sprains occur in the athletic population stresses the importance of accurate clinical diagnosis. The anterior drawer and talar tilt tests are often used by athletic trainers to initiate early ankle-sprain treatment. Our results suggest that the anterior drawer test can be performed with the knee either bent or straight. However, talar tilt testing should be performed with the knee extended. Further study is needed to explain the differences in IE motion at each knee position. Research focused on muscle guarding and its effects on ankle laxity is needed to better understand our findings.

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