Measurement of Ankle Dorsiflexion: A Comparison of Active and Passive Techniques in Multiple Positions

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Context: Limited ankle DF (DF) range of motion (ROM) resulting from restricted gastrocnemius and soleus mobility is associated with a variety of lower extremity pathologies. Several techniques are used clinically to measure ankle DF. Objectives: To evaluate the reliability and minimal detectable change of DF ROM measurement, determine whether there is a difference in measured DF between techniques, and quantify the electromyographic (EMG) activity of the soleus and tibialis anterior muscles associated with the techniques. Design: Repeated measures. Setting: Controlled laboratory setting. Participants: 39 healthy subjects, age 22–33. Main Outcome Measures: DF measurements using 5 different techniques including active and passive DF with the knee extended and flexed to 90° and a modified lunge. EMG activity of the soleus and anterior tibialis muscles. Results: Intrarater reliability values (ICC3,1) ranged from .68 to .89. Interrater reliability (ICC2,1) ranged from .55 to .82. ICCs were the greatest with the modified lunge. The minimal detectable change (MDC95) ranged from 6° to 8° among the different techniques. A significant difference in DF ROM was found between all methods. Measurements taken with active DF were greater than the same measures taken passively. The lunge position resulted in greater DF ROM than both active and passive techniques. EMG activity of the soleus was greater with active DF and the lunge than with passive DF. Conclusions: The modified lunge, which demonstrated excellent intrarater and interrater reliability, may best represent maximal DF. Active end-range DF was significantly greater than passive end-range DF when measured at either 0° or 90° knee flexion. Greater active DF was not explained by inhibition of the soleus. Finally, using the modified lunge, a difference between 2 measurements over time of 6° or more suggests that a meaningful change has occurred.

Keywords: testing and measurement, goniometry, range of motion

Adequate ankle mobility is necessary for normal gait, as well as participation in many sporting and recreational activities. Limited dorsiflexion (DF) may be caused by factors such as heel-cord tightness or posterior arthrokinetic restrictions.

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Inadequate DF range of motion (ROM) is reported to predispose athletes to a variety of conditions including Achilles tendinitis, anterior knee pain, plantar fasciitis, and proximal second-metatarsal stress fractures. There are inconsistencies in the literature as to what constitutes heel-cord tightness. Kaufman et al reported a significant association between heel-cord tightness and Achilles tendinitis. They defined tightness as DF <11.5° with full knee extension and <18.5° with knee flexion (KF) of 90°. DiGiovanni et al reported that limited DF ROM was correlated with an increased risk of forefoot and midfoot pain. Limited DF was defined as <5° with the knee extended and <10° with the knee flexed 90°. Malliaras et al measured maximal DF using a modified lunge and found that when DF was less than 45°, lower extremity biomechanics and the ability to absorb load were compromised, thus increasing the risk of patellar tendinopathies.

Several techniques are used clinically to measure ankle DF. Common techniques include using a universal goniometer or an inclinometer to take non-weight-bearing measurements in varying angles of KF and weight-bearing positions such as the modified lunge. The position of the knee influences ankle DF ROM. Variations in measurements resulting from knee position likely reflect the influence of the gastrocnemius as it crosses both the knee and ankle joint. Consequently, DF measurements taken with 90° KF are greater than measurements taken with the knee extended. The modified-lunge technique, a weight-bearing method of measuring ankle DF, produces a greater value for ankle DF than any of the aforementioned positions. The multiple methods available to measure ankle DF ROM pose the question of which method is most reliable and clinically valid.

Clinical application of goniometer and inclinometer methods for measuring ankle-joint ROM has been evaluated for both reliability and responsiveness. Reliability refers to the degree of consistency, whereas responsiveness is the ability of a measurement to detect change not resulting from measurement error. Investigators report moderate to high intrarater reliability and poor to moderate interrater reliability using a standard goniometer to measure DF ROM. High interrater and intrarater reliability are reported when using an inclinometer to measure ankle DF in a modified-lunge position.

The responsiveness of sagittal-plane ankle goniometric measurements to accurately document functional progress has been questioned. Wilson et al reported a minimal detectable change of 11.3° when measuring maximum DF to maximum plantar flexion in the prone position with the knee flexed 90°. They concluded that goniometric measurements of sagittal-plane motion deficits did not reach an acceptable level of responsiveness.

Measuring ROM actively versus passively is another factor that can influence reliability. Passive ROM (PROM) measurements have the potential to be less reliable because of variability of the applied force. Although differences between active ROM (AROM) and PROM values are reported, the reasons for the differences have not been fully explored.

In addition to applied force, another factor that may contribute to differences is reciprocal inhibition. Reciprocal inhibition is relaxation of the antagonist secondary to contraction of the agonist. Thus, with active DF, contraction of the dorsiflexors produces relaxation of plantar flexors and possibly greater DF ROM than passive techniques. Several authors have examined reciprocal inhibition between dorsiflexors and plantar flexors, with a specific focus on the tibialis anterior and soleus.
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muscles,19–24 Results have varied. For example, Crone et al21 reported increased disynaptic Ia soleus motoneuron inhibition with dynamic DF but not with tonic DF, whereas Shindo et al24 reported increased soleus inhibition with tonic DF.

Purposes of this study included evaluating intrarater and interrater reliability of multiple ankle-DF measurement techniques; determining the responsiveness, or minimum detectable change (MDC), of each technique; determining whether there is a difference in amount of measured DF between the techniques; and proposing a possible explanation for differences in measured values through electromyographic (EMG) analysis. Results will provide clinicians insight into the reliability of different clinical ankle-DF measurement techniques, as well as MDC values to evaluate repeated measurements.

Methods

Design

The study was a repeated-measures design with DF ROM the dependent variable and measurement technique the independent variable. Subjects were tested on a single occasion and were tested across conditions in a randomized order.

Patients or Participants

Thirty-nine (13 men, 26 women) healthy subjects age 22 to 33 years (mean age 24.2 ± 2.72 y, mean height 170.51 ± 9.73 cm, mean weight 69.01 ± 12.96 kg) volunteered to participate in the study. Exclusion criteria included current or past history of ankle injuries or conditions that would limit ankle DF. The study was approved by our institutional review board.

Procedures

Examiners were second-year doctoral physical therapy students under the supervision of a physical therapist with over 20 years of clinical experience and certified as a specialist in orthopedics. Two examiners were responsible for performing measurements, and a third examiner was responsible for positioning the foot for passive measurements and recording all measurements. The measurement order was randomized for both examiner and test-position sequence. On arrival, subjects were provided with consent documents and given an opportunity to ask questions and consent to or decline participation. Before testing, subjects walked for 5 minutes as a warm-up. The tested leg was the self-reported leg used to kick a ball. Sites for EMG electrodes over the soleus and tibialis anterior on the test leg were cleaned with an alcohol wipe. Placement of EMG electrodes was based on techniques described by Cram et al.25 Recording electrodes were applied to the tibialis anterior just lateral to the tibia approximately one-quarter to one-third of the distance between the knee and ankle and the medial aspect of the soleus distal to the muscle belly of the gastrocnemius. These muscles were selected because previous research examining reciprocal inhibition associated with DF of the ankle specifically monitored them.19–24 The ground electrode was placed on the bony prominence of the anterior aspect of the distal tibia. All EMG measurements were
recorded at a sampling rate of 1000 Hz. Raw EMG signals were collected with D-100 bipolar surface electrodes (Therapeutics Unlimited, Inc, Iowa City, IA). The active Ag–AgCl electrodes had an interelectrode distance of 22 mm and were encased in preamplifier assemblies measuring 35 × 17 × 10 mm. The preamplifiers had a gain of 35. Conductive gel (Signa Cream Electrode Cream, Parker Laboratories, Inc, Fairfield, NJ) was used to conduct the electrical signal from the skin to the electrodes. Electrode leads from the preamplifiers were connected to a GCS67 main amplifier system (Therapeutics Unlimited, Inc). The combined amplification permitted a gain of 100–10,000 with a bandwidth of 40 Hz to 6 KHz. The common-mode rejection ratio was 87 dB at 60 Hz, and input impedance was >15 MV at 100 Hz. Raw EMG signals were processed with WinDaq data-acquisition software (DATAQ Instruments, Inc, Akron, OH).

In a long-sitting position, a manual muscle test of ankle DF was performed to determine an appropriate individualized gain setting and prevent saturation of the EMG signal. The subject then stood and performed a single-leg heel raise to determine an appropriate individualized gain setting for the soleus. Both tests were then repeated to determine maximum voluntary isometric contraction for the tibialis anterior and soleus. Muscle tests were based on techniques described by Hislop and Montgomery.26

Five DF measurements were taken by 2 examiners for a total of 10 measurements. The 5 DF measurements included PROM 0° KF, PROM 90° KF, AROM 0° KF, AROM 90° KF, and a modified lunge (Figures 1 and 2). Starting position for PROM and AROM measurements was a resting foot position. As a result, the foot was plantar flexed to begin tests performed in 0° KF. Examiner order and measurement order were randomized. The examiner and technique order were kept the same for measurements taken a week later. PROM and AROM DF measurements were performed with the subject lying prone on an examination table. A universal goniometer (NexGen Ergonomics, Inc, Point Claire, Quebec, Canada) was used for AROM and PROM measurements. The goniometer was covered such that examiners 1 and 2 were blinded to the results. The stationary arm of the goniometer was positioned in line with the fibular head and lateral malleolus. The moving arm was parallel to the longitudinal axis of the fifth metatarsal, with the fulcrum just distal to the lateral malleolus.27 For PROM measurements, examiner 3 positioned the subject’s ankle in subtalar neutral, avoiding pronation or supination, as described by Tiberio.28 A 6.4-kg (14-lb) force was applied with a MicroFET 2 handheld dynamometer (Hoggan Health Industries, Inc, West Jordan, UT) over the second metatarsal head by examiner 3. The magnitude of applied force was determined through trial and error before actual testing. Investigators applied a “typical” force to the plantar aspect of the foot with the handheld dynamometer while the subject performed passive DF. From this process, 6.4 kg was selected as the standard force for all subjects. While examiner 3 maintained subtalar neutral and DF with the 6.4-kg force, examiners 1 and 2 measured the subject’s PROM. For AROM measurements, the subject was instructed to actively dorsiflex the foot. The examiners visually monitored this motion to ensure that it was performed in the sagittal plane avoiding pronation or supination. The modified lunge was performed as described by Denegar et al.29 Subjects were instructed to step forward with the non-test leg while keeping the test foot in line with the long axis of the leg, knee in extension, and heel on the ground. The subject leaned forward and flexed the hip and knee of the non-test leg as needed to allow for maximal ankle DF of the test
leg. The maximal position was the point at which the heel began to lift from the floor. Foot pronation and supination were again monitored. A digital inclinometer (Saunders Group, Chaska, MN) was used for this measurement. The precision of the inclinometer was checked against computer-generated angles; the instrument demonstrated exact agreement. To establish the amount of DF during the modified lunge, the inclinometer was positioned in line with the fibular head and lateral malleolus. All testing positions were held for a total of 8 seconds for EMG data collection. Raw EMG data recorded during the 5 exercises were processed with the root-mean-square algorithm at a 55-millisecond time constant, then normalized and expressed as a percentage of the maximum voluntary isometric contraction. Examiners 1 and 2 performed the measurements while examiner 3 read and recorded the resulting DF value. The entire procedure including warm-up, electrode placement, and measurements was repeated 1 week later for each subject to establish intrarater reliability.

Figure 1 — (A) passive range of motion at 0° of knee flexion, (B) passive range of motion at 90° of knee flexion, (C) active range of motion at 0° of knee flexion, and (D) active range of motion at 90° of knee flexion.

Figure 2 — Modified lunge.
Statistical Analysis

Intrarater and interrater reliability coefficients (ICCs) for the 5 DF test positions were estimated with the ICC described by Shrout and Fleiss. Intrarater reliability was estimated with model 3 of the ICC:

\[ \text{ICC}_{3,1} = \frac{BMS - EMS}{BMS + (k - 1)EMS}. \]

Interrater reliability was estimated with model 2 of the ICC:

\[ \text{ICC}_{2,1} = \frac{BMS - EMS}{BMS + (k - 1)EMS + \frac{k(RMS - EMS)}{n}}. \]

Although ICC labels are somewhat arbitrary, we analyzed our reliability as follows: ICC >.75 excellent reliability, ICC .40–.75 fair to good reliability, and ICC <.40 poor. MDC at the 95% confidence level (MDC95), an index of a measure’s responsiveness, was calculated with the following equation:

\[ \text{MDC}_{95} = z \times SD \times \sqrt{2(1 - ICC)} \]

with \( z \) representing the \( z \)-score (1.96) at the 95% confidence level and SD representing the standard deviation of the first measurement distributions. Standard errors of measurement

\[ \text{SEM} = SD \times \sqrt{1 - ICC} \]

were also reported.

Repeated-measures analyses of variance (ANOVA) were conducted to assess the effect of testing technique on DF ROM and on normalized EMG activity in the soleus and tibialis anterior. In the first analysis, ankle ROM was the dependent variable and testing technique (5 levels) was the independent variable. In the subsequent analysis, normalized EMG was the dependent variable. Soleus and tibialis anterior EMG analyses were conducted separately. In all analyses, data from examiner 1 were used. Post hoc Bonferroni-corrected \( t \) tests were used to examine multiple comparisons when the ANOVAs were significant. Data were analyzed with SPSS 15.0 statistical software (SPSS Inc, Chicago, IL). Statistical significance was established at an alpha of .05.

Results

Intrarater reliability coefficients (ICC3,1) for both examiners are presented in Table 1. Intrarater reliability ranged from .68 to .89, with the modified lunge resulting in the greatest reliability. Table 2 displays the interrater reliability coefficients (ICC2,1). Interrater reliability was the greatest for the modified-lunge position, at .82. ICCs for all other positions ranged from .55 to .79.
The MDC for each individual examiner is presented in Table 1. The MDC for examiner 1 ranged from 6° to 7°, and for examiner 2 the range was 6° to 8°. For examiner 1, the modified lunge had the lowest MDC value, and AROM 90° KF resulted in the lowest MDC value for examiner 2.

Results for the ANOVA indicated a significant effect of testing technique ($F_{4,156} = 388.29$, $P < .001$). Based on the post hoc analysis, each comparison was statistically significant. Modified-lunge DF ROM was greater than ROM with active or passive techniques. AROM was greater than PROM in both 0° and 90° KF. PROM was greater with 90° KF than with 0° KF. Likewise, AROM was greater in 90° KF than in 0° KF. Descriptive data are presented in Table 3.

Normalized EMG (% of maximum voluntary isometric contraction) data are presented in Figure 3. EMG for both the soleus ($F_{4,152} = 106.27$, $P < .001$) and tibialis anterior ($F_{4,152} = 54.50$, $P < .001$) was significantly greater in the AROM and lunge conditions than the passive conditions.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Intrarater Reliability Coefficients, Standard Errors of Measurement (SEM), and Minimal Detectable Change (MDC) for the 5 Test Positions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test position</td>
<td>ICC$_{3,1}$</td>
</tr>
<tr>
<td>Examiner 1</td>
<td></td>
</tr>
<tr>
<td>active range of motion at 0° knee flexion</td>
<td>.82</td>
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<tr>
<td>active range of motion at 90° knee flexion</td>
<td>.68</td>
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<tr>
<td>passive range of motion at 0° knee flexion</td>
<td>.70</td>
</tr>
<tr>
<td>passive range of motion at 90° knee flexion</td>
<td>.83</td>
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<tr>
<td>modified lunge</td>
<td>.88</td>
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<tr>
<td>Examiner 2</td>
<td></td>
</tr>
<tr>
<td>active range of motion at 0° knee flexion</td>
<td>.81</td>
</tr>
<tr>
<td>active range of motion at 90° knee flexion</td>
<td>.81</td>
</tr>
<tr>
<td>passive range of motion at 0° knee flexion</td>
<td>.76</td>
</tr>
<tr>
<td>passive range of motion at 90° knee flexion</td>
<td>.78</td>
</tr>
<tr>
<td>modified lunge</td>
<td>.89</td>
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</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Interrater Reliability Coefficients and Standard Errors of Measurement (SEM) for the 5 Test Positions</th>
</tr>
</thead>
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<tr>
<td>Test position</td>
<td>ICC$_{2,1}$</td>
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<tr>
<td>Active range of motion at 0° knee flexion</td>
<td>.62</td>
</tr>
<tr>
<td>Active range of motion at 90° knee flexion</td>
<td>.55</td>
</tr>
<tr>
<td>Passive range of motion at 0° knee flexion</td>
<td>.67</td>
</tr>
<tr>
<td>Passive range of motion at 90° knee flexion</td>
<td>.79</td>
</tr>
<tr>
<td>Modified lunge</td>
<td>.82</td>
</tr>
</tbody>
</table>
Table 3  Descriptive Statistics for the 5 Ankle-Dorsiflexion Testing Techniques for Examiner 1 and Examiner 2

<table>
<thead>
<tr>
<th>Test position</th>
<th>Time 1, mean ± SD, °</th>
<th>Time 2, mean ± SD, °</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examiner 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>active range of motion at 0° knee flexion</td>
<td>6.72 ± 6.00</td>
<td>5.32 ± 5.65</td>
</tr>
<tr>
<td>active range of motion at 90° knee flexion</td>
<td>14.64 ± 4.22</td>
<td>15.69 ± 4.52</td>
</tr>
<tr>
<td>passive range of motion at 0° knee flexion</td>
<td>−3.49 ± 4.65</td>
<td>−3.92 ± 5.49</td>
</tr>
<tr>
<td>passive range of motion at 90° knee flexion</td>
<td>11.03 ± 5.60</td>
<td>10.83 ± 6.21</td>
</tr>
<tr>
<td>modified lunge</td>
<td>32.77 ± 6.63</td>
<td>33.59 ± 7.90</td>
</tr>
<tr>
<td>Examiner 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>active range of motion at 0° knee flexion</td>
<td>7.28 ± 6.12</td>
<td>6.73 ± 6.53</td>
</tr>
<tr>
<td>active range of motion at 90° knee flexion</td>
<td>18.15 ± 4.85</td>
<td>17.90 ± 4.79</td>
</tr>
<tr>
<td>passive range of motion at 0° knee flexion</td>
<td>−1.61 ± 5.07</td>
<td>−3.35 ± 5.51</td>
</tr>
<tr>
<td>passive range of motion at 90° knee flexion</td>
<td>13.79 ± 6.08</td>
<td>11.83 ± 6.31</td>
</tr>
<tr>
<td>modified lunge</td>
<td>33.36 ± 6.70</td>
<td>33.23 ± 7.48</td>
</tr>
</tbody>
</table>

Figure 3 — Percent maximal voluntary isometric contraction (MVIC) of the tibialis anterior and soleus in the 5 test positions: passive range of motion (PROM) at 0° of knee flexion, PROM at 90° of knee flexion, active range of motion (AROM) at 0° of knee flexion, AROM at 90° of knee flexion, and modified lunge.
Discussion

Reliability
The first purpose of our study was to determine the reliability of measuring DF in 5 different positions. Examiner 1’s reliability was excellent with AROM 0° KF, PROM 90° KF, and the modified lunge. Reliability was fair to good with PROM 0° KF and AROM 90° KF. Examiner 2’s intrarater reliability for all 5 positions was excellent. Our findings for intrarater reliability of DF measurements are comparable to those of previous studies. Youdas et al reported an ICC range of .64 to .92 (median .83) using a standard goniometer to measure active DF. Jonson and Gross reported an ICC of .74. Measurements were performed using a standard goniometer with subjects prone and the knee extended. Motion was active, with the examiner providing additional passive assistance.

Interrater reliability was excellent in PROM 90° KF and the modified-lunge position. The reliability in the other positions, AROM and PROM 0° KF and AROM 90° KF, was fair to good. Similar to our findings, Jonson and Gross reported interrater reliability of .65, whereas Youdas et al reported an interrater ICC of .28. Our findings suggest that repeated DF measures using either the modified lunge or PROM 90° KF may be reliably performed by multiple examiners.

The modified-lunge position demonstrated the greatest interrater and intrarater reliability. One factor for this difference may have been use of the digital inclinometer for the measurement. When using a standard goniometer, the examiner must monitor both the stationary arm and the moveable arm of the device. With the digital inclinometer, there is less potential for error because only the inclinometer, the equivalent of the goniometer’s movement arm, must be monitored.

Responsiveness
MDC95 indicates the responsiveness of a measurement, or the extent to which a change in measurement across time can be accounted for by factors beyond measurement error. For clinicians, this is meaningful because a difference between 2 subsequent measurements equal to or greater than the MDC95 value indicates meaningful, or true, change. Clinicians can evaluate the effectiveness of treatment based on this knowledge. As stated previously, the MDC95 of measurements taken by individual examiners (intrarater) ranged from 6° to 8°. Using the modified lunge as an example, a difference between repeated measures of approximately 6° would indicate that true change had occurred. Youdas et al likewise reported an MDC95 of 6° when measuring DF AROM in 0° KF.

Effect of Knee Position and Weight Bearing
Another purpose of this study was to determine whether different knee positions or a weight-bearing position would result in different values for DF measurements. All 5 tested positions were significantly different from one another. This is consistent with previous research illustrating the influence of knee position on measured values of DF. It has been reported that in the knee-extended position, plantar flexion of the foot likely increases the passive tension in the gastrocnemius.
and the general stiffness of the ankle via the effects of the stretched muscle on the series and elastic components of the muscle–tendon unit. Consistent with this, DF PROM 0° KF resulted in the least amount of measured DF, and the modified lunge with the knee flexed resulted in the greatest.

In addition to the effects of knee position, the lunge was performed in weight bearing, and as a result, the applied force was likely greater than with the non-weight-bearing techniques. As stated previously, the lunge position demonstrated excellent interrater and intrarater reliability. For a measurement to be clinically useful, it should be valid in addition to being reliable. Given the weight-bearing nature of the lunge position, it may represent functional DF requirements such as walking, stair climbing, and squatting more accurately than the other techniques.

Given the differences between test positions, repeated clinical measures should use a consistent technique to measure ankle DF. If not contraindicated, we recommend the lunge position because of the functional weight bearing involved, as well as the reliability of the technique.

**EMG Activity During Active and Passive Techniques**

A final purpose of this study was to determine whether active and passive DF values were different, and if so, might reciprocal inhibition account for a portion of the difference. Our initial hypothesis stated that soleus activity would be minimal with active contraction of the tibialis anterior. Although we found active measures significantly greater than passive measurements for a given knee position, if reciprocal inhibition were a mediating factor, one would expect decreased EMG activity of the soleus with AROM. Our results, however, demonstrated a significantly greater amount of soleus activation during AROM than PROM. Based on our data, reciprocal inhibition does not appear to explain the differences between AROM and PROM. Another possible explanation might be differences in ankle arthrokinematics. Specifically, applying a long lever force to the second metatarsal head may not allow posterior glide of the talus, which has been reported to be a component of normal DF ROM.

**Limitations and Future Research**

The design of this study lent it to limitations. The inclusion of only healthy subjects limits the ability to generalize the results to a more diverse population. A second limitation relates to the technique for providing an external force during PROM. In our attempt for consistency, using a constant force (6.4 kg), it is likely that not all subjects reached end-range motion because of the inherent stiffness of the gastrocnemius and soleus muscles. Based on our ROM and reliability results, this appears to have been more impactful on measurements taken with the knee extended than those taken with the knee flexed. A final limitation was the inability to fully investigate the arthrokinematics of the ankle joint to assess posterior glide of the talus while performing the various measurement techniques. Suggestions for future research include using subjects with lower extremity pathologies and analyzing the biomechanics of the ankle joint, specifically the influence of talar glide in passive and active ankle ROM and function.

In conclusion, limited ankle DF has been associated with sport-related injuries of the lower extremity. As such, it is important to accurately assess this motion.
and assess progress during rehabilitation. Our findings demonstrate that DF ROM measurements may be performed with acceptable intrarater reliability in all test positions examined, with the modified lunge being the most reliable position. In addition, the modified lunge may best represent maximal ROM of the ankle joint; it produced the greatest ROM values. Increased ROM with active techniques was not explained by inhibition of the soleus. Finally, using the modified lunge, a minimum difference of 6° between 2 measurements over time indicates that a meaningful change in ROM has occurred.

References