Clinical and epidemiological studies have identified limitation in ankle dorsiflexion and increased ankle stiffness as key contributors to the evolution of foot and ankle pathology. A lack of robust measurement techniques to quantify ankle range of motion (ROM) and stiffness, however, has limited our ability to assess the functional consequences of relatively small changes in ankle ROM. Treatment strategies ranging from stretching exercises to surgical lengthening of the gastrocnemius-soleus complex are prescribed based on assessments of dorsiflexion ROM, despite the less-than-adequate reliability of these assessments. Recent research has identified the importance of being able to accurately measure relatively small changes in ankle ROM to accurately identify impairments.

A New Device for Assessing Ankle Dorsiflexion Motion: Reliability and Validity

**STUDY DESIGN:** Clinical measurement.

**OBJECTIVE:** To determine the validity and reliability of measures obtained using a custom-made device for assessing ankle dorsiflexion motion and stiffness.

**BACKGROUND:** Limited dorsiflexion has been implicated in the evolution of foot pain in a number of clinical populations. Assessment of ankle dorsiflexion range of motion (ROM) is, therefore, commonly performed as part of a foot and ankle examination. Conventional goniometric assessment methods have demonstrated limited intertester reliability, while alternative methods of measurements are generally more difficult to use. The Iowa ankle range of motion (IAROM) device was designed in an attempt to develop a simple, clinically relevant, and time- and cost-effective tool to measure ankle dorsiflexion range of motion and stiffness.

**METHODS:** Validity and intertester reliability of dorsiflexion range-of-motion measures using the IAROM device were assessed at 10, 15, 20, and 25 Nm of passively applied dorsiflexion torque, with both the knee extended and flexed approximately 20°. Stiffness (change in torque/change in dorsiflexion angle) values were determined using the angular change obtained between the 15- and 25-Nm torque levels. Convergent validity (n = 12) was assessed through comparison of ankle dorsiflexion angles measured simultaneously with the IAROM device and an optoelectronic motion analysis system. Intertester reliability (n = 17) was assessed by 2 testers who took measurements within the same day.

**RESULTS:** Validity testing demonstrated excellent agreement (intraclass correlation coefficient [ICC] values ranging from 0.95 to 0.98). Reliability testing demonstrated good to excellent intertester agreement (ICC values ranging from 0.90 to 0.95). The ICCs for ankle joint dorsiflexion stiffness were .71 and .85 for the knee in an extended and flexed position, respectively.

**CONCLUSION:** The IAROM device provides valid and reliable measurement of ankle dorsiflexion ROM. The IAROM device also allows calculation of stiffness by measuring ROM at multiple torque levels, although the reliability of the measurement is not optimal.

**KEY WORDS:** IAROM, plantar flexors, stiffness, talocrural joint
methods of assessing ankle dorsiflexion ROM have been recently proposed. One functional approach for assessing ankle ROM has been to ask patients to perform a controlled lunge. While this approach has been shown to be reliable, weight-bearing methods of assessing dorsiflexion may have limited applicability in certain clinical situations, such as the early phases of ulcer healing or in postsurgical or conditions in which weight bearing is restricted.

An alternative, relatively direct method of assessing ankle dorsiflexion ROM has been to photograph the foot and leg as a given force is applied to the metatarsal heads, then to measure the orientation of the foot relative to the leg. Beyond the practical difficulties of applying this technique in a clinic, failure to stabilize the foot and the localized application of force may not adequately replicate loading of the foot during functional tasks. Computerized approaches that isolate ankle joint motion and measure the applied external torque, making it possible to measure not only ankle ROM but ankle stiffness (changes in ankle dorsiflexion angle as a function of applied external torque), have also been proposed. However, the increased accuracy of these more sophisticated measurement approaches comes at a financial cost. These systems also tend to be difficult to transport and complicated to use, raising questions as to their clinical usefulness and cost effectiveness. Most importantly, few of these ROM devices have demonstrated reliability and none, to our knowledge, has demonstrated validity. Further, while most studies report ankle ROM data from an average of 3 readings, none has quantified the potential benefit of single versus average measures (as to answer the question, “Do I need to take and average of 3 measures, or is 1 sufficient?”) and, second, to determine the intertester reliability and convergent validity of measures obtained with a new, portable, practical, and cost-effective device for testing ankle dorsiflexion ROM and stiffness.

**METHODS**

**Participants**

This study was approved by the University of Iowa Institutional Review Board for Experimentation on Human Subjects, and consent was obtained from all participants. For validity testing, 12 participants (6 male, 6 female; mean ± SD age, 23 ± 3 years; height, 1.7 ± 0.1 m; body mass, 72 ± 12 kg) were simultaneously evaluated using the IAROM device and a motion analysis system (Optotrac 3020; Northern Digital Inc, Waterloo, ON, Canada). To evaluate intertester reliability, dorsiflexion ROM was assessed in 17 participants (7 male, 10 female; mean ± SD age, 52 ± 15 years; height, 1.7 ± 0.1 m; body mass, 88 ± 21 kg). Patients receiving orthopaedic care for unilateral foot or ankle injury or pathology at the University of Iowa Hospitals and Clinics were recruited to participate in the study. The limb contralateral to the one requiring orthopaedic care was tested.

**Instrumentation**

The IAROM device (Figure 1) was designed to be easy to assemble, inexpensive to produce, and easy to use. The device consisted of a 30-by-30-cm Plexiglas footplate, attached to a 30-by-40-cm base plate. Two 10-cm-wide Velcro straps, passed through lateral slots in the base plate, secured the lower leg during testing. A 3-cm-high semirigid foam block was placed under the distal leg to support the tibia in a position perpendicular to the foot plate. Adjustable supports on the proximal end of the device allowed knee flexion angle to be increased to approximately 20° during testing.

**Procedures**

Participants were positioned in the device with the long axis of their tibia perpendicular to the foot plate, with the foot vertical and the sole in contact with the transparent Plexiglas foot plate. The axis of rotation of the device was then adjusted in the anterior/posterior and superior/inferior directions to approximate the ankle axis of rotation, as determined by palpation of the distal tips of the medial and lateral malleoli. To ensure that the participant was properly aligned in the device, to precondition the soft tissue, and to minimize potential measurement variability due to previous activity, 25 Nm of external dorsiflexion torque was applied approximately 20 times prior to testing. The rate of external torque application was kept extremely low to replicate the quasi-static testing procedures used clinically and to avoid eliciting a stretch reflex. The total time for each torque repetition took up to 5 seconds.

Angular measurement was performed using a digital inclinometer (Checkpoint Inc, Torrance, CA), zeroed on the middle third of the tibial crest to provide a consistent anatomical reference point (perpendicular to the crest was used as 0° dorsiflexion) and then mounted on the foot plate. The moment of force (torque) about the ankle joint was controlled by applying 45, 67, 89, and 111 N of force (10, 15, 20, and 25 lb of force) perpendicular to the foot plate with a handheld force gauge (FDK 40; Wagner Instruments,
Intrarater Reliability of Single Versus the Average of 3 Measures and 95% Confidence Intervals for Ankle Dorsiflexion Measured by the 2 Raters

<table>
<thead>
<tr>
<th></th>
<th>10 Nm</th>
<th>15 Nm</th>
<th>20 Nm</th>
<th>25 Nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single measure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1</td>
<td>0.964 (0.859, 0.990)</td>
<td>0.978 (0.883, 0.995)</td>
<td>0.988 (0.898, 0.997)</td>
<td>0.992 (0.957, 0.998)</td>
</tr>
<tr>
<td>Rater 2</td>
<td>0.946 (0.775, 0.985)</td>
<td>0.985 (0.882, 0.987)</td>
<td>0.963 (0.906, 0.988)</td>
<td>0.988 (0.946, 0.997)</td>
</tr>
<tr>
<td>Average of 3 measures</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1</td>
<td>0.988 (0.948, 0.997)</td>
<td>0.992 (0.920, 0.998)</td>
<td>0.996 (0.963, 0.999)</td>
<td>0.997 (0.985, 0.999)</td>
</tr>
<tr>
<td>Rater 2</td>
<td>0.981 (0.912, 0.995)</td>
<td>0.985 (0.933, 0.996)</td>
<td>0.987 (0.967, 0.996)</td>
<td>0.996 (0.981, 0.999)</td>
</tr>
</tbody>
</table>

Table 1

Greenwich, CT) at a distance of 22.5 cm from the axis of rotation. Testing was performed by using one hand to apply the external torque, and placing the other hand on the participant’s lower leg to palpate for any muscle activation and ensure participant relaxation. The sequential application of external dorsiflexion torque from 10 to 25 Nm was considered a single trial. Following 3 trials, with the knee in an extended position, the device was inclined to approximately 20° of knee flexion. Flexing the knee reduced the ability of the bi-articular gastrocnemius to passively resist dorsiflexion of the ankle relative to the unaffected mono-articular soleus muscle. Inclination of the IAROM base alters the orientation of the tibia, which serves as the reference point for calculating ankle position. To account for this change in position, the inclination of the tibial crest was remeasured with the digital inclinometer.

Reliability Testing
To evaluate intertester reliability, participants were tested by a physical therapist and a research assistant who was trained in the use of the measurement system but had no previous experience in ROM assessment. Training for the inexperienced tester consisted of a total of approximately 1 hour of data collection, under direction, and discussion of proper alignment and data recording using the device. Same-day reliability testing was performed such that tester order alternated with each consecutive participant to minimize any potential order effect. To assess intratester reliability of single versus average measures, each tester performed 3 consecutive trials (each including all 4 force levels), first with the knee extended, then repeated the testing with the knee flexed. Testing was then performed by the second tester, after the device was completely removed and reset so that cues could not be taken from prior testing.

Validity Testing
For validity testing, ankle dorsiflexion motion was simultaneously evaluated using the IAROM device and an optoelectronic motion analysis system (Optotrak 3020; Northern Digital, Inc, Waterloo, ON, Canada). Three markers on the tibial crest and 3 markers on the foot (fifth metatarsal, dorsum, and lateral heel) were used to generate a rigid-body representation for both segments, to determine the dorsiflexion angle of the foot relative to the tibia. Markers were placed over bony areas, where movement of underlying soft tissue could be minimized, to provide accurate measures of ankle ROM. Simultaneous measurements of ankle dorsiflexion ROM were acquired with the IAROM device and motion analysis system for 3 trials (all 4 force levels) at each of the 2 knee flexion angles. Using motion analysis as a reference, we assessed the convergent validity of our dorsiflexion ROM measures using the IAROM.

Controlling for Bias
We controlled for selection bias by recruiting a random selection of patients who were seeking care from a foot and ankle orthopaedic specialist. Both the digital inclinometer and handheld dynamometer in the IAROM device can be zeroed to a person’s specific reference prior to starting data collection, thus eliminating the introduction of calibration errors or instrument bias. Expectation bias was minimized by having the testers use the device in random order, and by blinding the second tester to the measures obtained by the first tester. Verification bias was minimized by testing the contralateral ankle of patients who were seeking care from an orthopaedic foot and ankle specialist, and by not restricting recruitment to patients with a specific pathology or diagnosis. In addition, bias was minimized through randomization, blinding, prospective design, and consecutive recruitment.

Dependent Variables
Ankle dorsiflexion angle values were recorded for each force application level. Stiffness was computed as change in torque divided by change in ankle dorsiflexion angle over the 15-to-25-Nm interval. The 15-to-25-Nm torque interval was selected for calculating stiffness to avoid the more nonlinear “toe” region that exists at lower torque levels.¹⁹

Data Analysis
Mean, SD, and standard error of the measurement (SEM) were used to summarize dependent variables. SEM was calculated as follows: \( \text{SEM} = \text{SD} \times (1 - r^{1/2}) \), where \( r \) is the reliability coefficient. The 90% confidence bound of the minimal detectable change (MDC₁⁹) was used...
Intertester Reliability of Ankle Range of Motion (deg) and Stiffness (Nm/deg) Measurements, With the Knee Extended and Flexed

<table>
<thead>
<tr>
<th>Knee extended</th>
<th>Mean ± SD</th>
<th>ICC_{2,1} (95% CI)</th>
<th>SEM</th>
<th>MDC_{90}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle dorsiflexion at 10 Nm</td>
<td>1.0 ± 8.8</td>
<td>0.924 (0.886, 0.961)</td>
<td>2.4</td>
<td>5.6</td>
</tr>
<tr>
<td>Ankle dorsiflexion at 15 Nm</td>
<td>10.5 ± 7.5</td>
<td>0.943 (0.875, 0.967)</td>
<td>1.8</td>
<td>4.2</td>
</tr>
<tr>
<td>Ankle dorsiflexion at 20 Nm</td>
<td>16.9 ± 6.8</td>
<td>0.901 (0.861, 0.922)</td>
<td>2.1</td>
<td>5.0</td>
</tr>
<tr>
<td>Ankle dorsiflexion at 25 Nm</td>
<td>21.2 ± 6.7</td>
<td>0.943 (0.876, 0.984)</td>
<td>1.6</td>
<td>3.7</td>
</tr>
<tr>
<td>Stiffness</td>
<td>1.04 ± 0.15</td>
<td>0.711 (0.518, 0.852)</td>
<td>0.08</td>
<td>0.19</td>
</tr>
<tr>
<td>Knee flexed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle dorsiflexion at 10 Nm</td>
<td>6.6 ± 7.8</td>
<td>0.904 (0.834, 0.954)</td>
<td>2.4</td>
<td>5.6</td>
</tr>
<tr>
<td>Ankle dorsiflexion at 15 Nm</td>
<td>15.6 ± 8.1</td>
<td>0.951 (0.891, 0.970)</td>
<td>1.8</td>
<td>4.2</td>
</tr>
<tr>
<td>Ankle dorsiflexion at 20 Nm</td>
<td>21.3 ± 8.5</td>
<td>0.944 (0.901, 0.972)</td>
<td>2.0</td>
<td>4.7</td>
</tr>
<tr>
<td>Ankle dorsiflexion at 25 Nm</td>
<td>25.7 ± 8.7</td>
<td>0.962 (0.853, 0.990)</td>
<td>1.9</td>
<td>4.4</td>
</tr>
<tr>
<td>Stiffness</td>
<td>1.00 ± 0.18</td>
<td>0.851 (0.696, 0.921)</td>
<td>0.07</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimum detectable change; SEM, standard error of the measurement.

RESULTS

Reliability

Intratester Reliability of Single versus the average of 3 measures is summarized in Table 1 and indicates excellent reliability (greater than 0.94) for single measures. Therefore, single measures were used for subsequent analyses.

The mean ± SD RMS differences in peak dorsiflexion between testers at 10, 15, 20, and 25 Nm were 2.5° ± 0.5°, 2.3° ± 0.5°, 2.7° ± 0.6°, and 2.5° ± 0.5° with the knee extended and 2.9° ± 0.4°, 2.8° ± 0.4°, 3.4° ± 0.4°, and 3.7° ± 0.3° with the knee flexed, respectively. Mean ± SD, ICC_{2,1}, SEM, and MDC_{90} values are presented in Table 2, and demonstrate high levels of intertester agreement. Low SDs indicate that ankle joint stiffness was very homogenous within the group of participants tested. Though intertester differences were small for the calculation of ankle joint stiffness, the ICCs (95% confidence intervals) were 0.711 (0.518, 0.852) and 0.851 (0.696, 0.921) for the knee extended and knee flexed, respectively (Table 2).

Validity

For convergent validity, we noted mean ± SD RMS differences in peak dorsiflexion, at 10, 15, 20, and 25 Nm of 1.7° ± 0.4°, 1.3° ± 0.3°, 1.4° ± 0.4°, and 1.7° ± 0.4° with the knee extended and 2.1° ± 0.3°, 1.8° ± 0.4°, 1.5° ± 0.4°, and 1.5° ± 0.4° with the knee flexed, respectively, between testing methods. ICC_{2,1} and 95% confidence intervals for peak dorsiflexion measured with the knee extended and flexed to approximately 20° are summarized in Table 3.

DISCUSSION

The IAROM device was developed in an attempt to provide a level of accuracy similar to that of more technologically advanced ankle ROM testing systems, while being more affordable and easier to use. We determined that the IAROM device provides both valid and reliable assessment of ankle dorsiflexion ROM. The IAROM’s design characteristics, which include the application of predetermined levels of external dorsiflexion torque and the ability to monitor foot positioning and the distribution of surface contact along the sole of the foot, likely contributed to the high validity and reliability measures seen in this study. To our knowledge, this is the only ankle passive dorsiflexion ROM device that has been evaluated for both reliability and validity.

Preliminary testing with the IAROM device identified a few difficulties in testing certain populations that are likely common to other ROM testing methods. The ability to accurately measure ankle ROM was compromised in participants who were morbidly obese (body mass index greater than 50 kg/m²), as it was not...
possible to adequately stabilize the leg in these participants. In addition, a small subset of participants initially had difficulty relaxing, as detected with palpation of the dorsiflexor tendons and increased trial-to-trial variability, and required some coaching to ensure the absence of muscle activation. Finally, a few elderly and frail participants, typically with a body mass of less than 55 kg, were unable to tolerate an applied torque of greater than 20 Nm.

The validity testing demonstrated the importance of selecting landmarks when defining segments (APPENDIX). Using the crest of the tibia, as opposed to the long axis of the shank, as is typical in goniometric testing, resulted in an offset of approximately 5° between measures, which has been previously observed by Stebbins et al.\textsuperscript{19} After accounting for this offset, mean values obtained with the knee extended closely matched the goniometric values reported by Kaufman et al.,\textsuperscript{14} as well as the device-measured values reported by Moseley et al.\textsuperscript{18}

The IAROM device provided superior intertester reliability compared to previously reported values (ICCs ranging from 0.50 to 0.80) obtained from goniometric methods of ankle dorsiflexion ROM assessment.\textsuperscript{1,2,13-15,20,28} Intertester reliability noted with the IAROM device was comparable to that of other computerized systems\textsuperscript{3,32} and to the weight-bearing lunge methods.\textsuperscript{4,21} The poor reliability of ankle dorsiflexion assessment is problematic when deciding on a treatment or assessing treatment effects, as it provides the false perception of intervention effectiveness or obscures actual differences. The digital inclinometer has a resolution of 0.1°, and the handheld dynamometer has a resolution of 0.45 kg (1 lb). Given the high accuracy of the instruments, we anticipated that between-trial variability would constitute a greater source of measurement error. Consistent with this expectation, we noted an overall intertester reliability of 0.96, SEM of 2°, and MDC\textsubscript{90} of approximately 5°. SEM values obtained during reliability testing of the IAROM device were less than a fourth of those determined in the previously published goniometric study showing the best intertester reliability,\textsuperscript{20} which underscores the greater precision with the IAROM. One reason for the better intertester reliability values reported in this study may be the IAROM protocol’s standardized application of external dorsiflexion torque. Such control is likely key to the collection of reliable and clinically relevant measures, as this study data and others\textsuperscript{19} have shown that a 5-Nm change in torque can result in a 5° to 10° change in measured ankle dorsiflexion ROM. This magnitude of difference can represent as much as 25% of the total motion available in dorsiflexion. The application of predetermined torque levels, as compared to determining the torque required to reach the predetermined dorsiflexion angle, is also more practical for the assessment of a wide variety of patient populations in which ROM may be limited.

The ability to determine ankle dorsiflexion ROM through a range of predetermined force levels also has the advantage of documenting ankle stiffness,\textsuperscript{19,32} Ankle stiffness can be calculated from the dorsiflexion angle change as a function of applied torque. While the stiffness values obtained using the IAROM device are in agreement with those reported in the literature,\textsuperscript{27,29,30,33} reliability coefficients were not as high and had wider 95% confidence intervals (TABLE 2). For stiffness, we noted low SD and SEM, as well as low ICC values. This counterintuitive combination of low SD and low ICCs may be due to the intrinsic homogeneity of the stiffness measure in our sample.\textsuperscript{23} Consistent with this contention, the intersubject variability in the stiffness measures was less than 10% in our sample. Perhaps recruiting participants from a population with greater variability in stiffness, such as individuals with diabetes or other clinical populations, would result in improved ICC values.

A limitation of this study was that the reliability data were not obtained from ankles with a documented pathology. In our experience, the device has served well in determining ankle ROM limitations and changes in joint stiffness in patients with diabetes.\textsuperscript{22} Further study in participant groups with differing impairments is needed. As in all other ROM approaches, the measures obtained with the IAROM device may be affected by patients who have foot or ankle pain and/or muscle splinting. However, because one hand is free when obtaining the measures, it is possible to monitor the soft tissue around the ankle to detect soft tissue changes. The acrylic footplate also allows the investigator to monitor changes in foot contact that might be associated with secondary compensations. We, therefore, believe that the reliability demonstrated in this study substantiates the potential value of this approach for assessing ankle ROM; however, as with any other assessment, tester attentiveness is required to obtain valid results.
CONCLUSION

Ankle dorsiflexion ROM can be reliably and validly measured in clinical or research settings using the IAROM device. The device’s simple and relatively low-tech design allows individuals who have minimal previous knowledge and skill in range-of-motion assessment to use the IAROM device to determine ankle dorsiflexion ROM, with little training, and to do so with a higher level of reliability and confidence than is possible with conventional goniometry.

REFERENCES

The standard method for measuring ankle dorsiflexion using a goniometer uses the fibula as a reference for the stationary arm and the plantar aspect of the heel or fifth metatarsal for the moving arm (solid black lines). The Iowa ankle range of motion device uses the tibia crest as a reference (dashed black line), similar to the reference used by Stebbins et al., and the plantar aspect of the foot for the moving arm. The angular difference between using the lateral aspect of the fibula versus the tibial crest as a reference is approximately 5°. The offset does not affect our measurements but helps in interpreting our results relative to those reported in the literature.

This image depicts the Iowa ankle range of motion device setup and the position of the tibial crest, with the knee extended (solid line) and knee flexed (dashed line). Position of the tibia relative to the device does not change. However, change in inclination of the IAROM base flexes the knee by about 20° and also changes inclination of the tibial crest relative to the foot plate.