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Validated Method for Measuring Functional Range of Motion in Patients With Ankle Arthritis

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Abstract

Background: Total range of motion between the tibia and the floor is an important outcome measure following ankle surgery. However, there is wide variation in its measurement: from clinical evaluation, to radiographic metrics, and gait analysis. The purpose of this study was to present and validate a simple, standardized technique for measurement of functional total range of motion between the tibia and the floor using a digital goniometer.

Methods: Institutional review board approval was obtained. Forty-six ankles from 33 participants were recruited into 2 groups: Group 1 (healthy controls) comprised 20 ankles from 10 participants. None had any musculoskeletal or neurologic pathology. Group 2 (ankle osteoarthritis) comprised 25 ankles from 23 patients. Ankle pathology had been treated with ankle arthrodesis (n = 5), total ankle replacement (n = 6), and nonoperative treatment (n = 14). Measurement was performed by 2 testers according to a standardized protocol developed for the Total Ankle Replacement Versus Arthrodesis (TARVA) randomized controlled trial. Intra- and interrater reliability was calculated using intraclass correlation coefficients (ICCs).

Results: Group 1 (healthy controls): the median difference for all measurements within an observer was 1.5 (interquartile range [IQR] 0.7-2.5) degrees, and the intraclass coefficients (ICCs) for inter- and intrarater total ankle range of motion were excellent: 0.95 (95% confidence interval [CI] 0.91-0.97, $P < .001$) and 0.942 (95% CI 0.859-0.977, $P < .001$), respectively. Group 2 (ankle osteoarthritis): the median difference for all measurements within an observer was 0.6 (IQR 0.2-1.3) degrees, and the ICCs for inter- and intrarater total ankle range of motion were excellent: 0.99 (95% CI 0.97-1.0), $P < .001$) and 0.99 (95% CI 0.96-1.0), $P < .001$), respectively.

Conclusion: This technique provided a reliable, standardized method for measurement of total functional range of motion between the tibia and the floor. The technique required no special equipment or training. It provided a valid functional assessment for patients with or without ankle osteoarthritis, including those who had undergone operative treatment.

Level of Evidence: Level II, prospective comparative study.

Keywords: range of motion, ankle fusion, ankle replacement, TARVA, ankle arthritis

Introduction

There is no standardized method for measuring range of motion before and after ankle surgery. Four main methods have been described in the literature. These include clinical impression, the use of a goniometer, radiographic measurement, and gait analysis.[4,7,10,12] Although most studies focus on isolated tibiotalar motion, the most important determinant of outcome is the functional total range of motion between the leg and the floor as this is what the patient experiences and should become an important outcome measure for any clinical studies pertaining to ankle arthritis patients. Indeed, even in patients who have undergone ankle arthrodesis, a study has suggested that sagittal range of motion can increase after surgery because of a compensatory increase in range of motion at the adjacent joints.[9]

Clinical assessment is very subjective, especially when performed supine as the range of motion depends on the force applied by the tester.[1,2,3,6,8] Measurement of great toe distance to wall during the lunge test relies on a consistent foot length to leg length ratio, which is clearly a source of

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error.[1] An inclinometer may introduce error through the choice of position and angle of application of the device in 3 dimensions and movement of the device during testing. Gait analysis offers more in-depth assessment but is cumbersome and difficult to carry out in routine clinical practice.[10]

The aim of this study was to present a technique for standardized measurement of total range of motion from the tibia to the floor using a digital goniometer and a standardized and reproducible methodology.

Method

Study Design

Ethical approval was obtained for a randomized control trial comparing Total Ankle Replacement Versus Arthrodesis. This study formed part of the pilot work for the larger pivotal study. Forty-six ankles from 33 participants were recruited into 2 groups. In the first group of healthy controls, 20 ankles of 10 participants were measured. None of the participants had any musculoskeletal or neurologic pathology. In the second (pathology) group, we measured 26 ankles from 23 patients with ankle osteoarthritis, some of whom were preoperative (n = 14) and some post–ankle fusion (n = 6), or post–ankle replacement (n = 6).

Measurement was performed by 2 testers. Neither tester had any previous experience with a digital goniometer. Both testers read a standardized methodology in the use of a digital goniometer for the measurement of ankle range of motion according to the TARVA study protocol (as described in this article). Each tester measured both legs of each subject twice, with a half hour interval between testing. Intra- and interrater reliability was calculated using intraclass correlation coefficients using SPSS v22.0 (IBM, Chicago, IL, 2014). The strength of agreement was reported according to nomenclature from Landis and Koch.[5] Each tester was blinded to the results of their counterpart.

Pre-Priori Power Calculation

Pre-priori sample size estimation was performed and 44 ankles were required in total, based on $\alpha = 0.05$, $\beta = 0.20$, and expected intraclass correlation coefficient (ICC) = 0.90, with the minimum value in a 1-sided 95% confidence interval (CI) of 0.80 using 2 testers and 2 repetitions of each measurement.[11]

Measurement Technique

A standardized digital goniometer was used in all cases (Trend Manufacturing and Cutting Tools Ltd, United Kingdom). This goniometer was made of metal and had limbs of 50 cm in length, meaning it would reach up toward the knee. The test could equally be carried out with a standard orthopedic goniometer made of transparent plastic. To ensure reproducibility of measurement 2 marks were made on the limb one over the center of the fibular head and the second over the tip of the fibula (lateral malleolus). A line was drawn along the longitudinal axis of the fibula continuing to the floor (Figure 1), which was referred to as the fibula line. Because our goniometer was metallic and not translucent, we then drew a second parallel line 2 cm posterior to the first line over a length of approximately 15 cm in the midcalf region (Figure 1), which was to correspond to the posterior border of the vertical limb of the goniometer, so that the fibula line corresponded to the bisection of the vertical limb of the goniometer. This step could have been omitted if a transparent goniometer was used. A nonpermanent marker was used, and these marks were removed between testers. The subject then stood facing a wall with the unmarked contralateral limb behind the limb to be measured, ensuring the knee of the measured limb was as straight as possible (Figure 2). One arm of the goniometer was then placed flat on the floor and the vertical arm rested against the outer surface of the calf of the leg to be measured, with the central point of the vertical limb of the goniometer corresponding to the fibula line (Figure 3). This corresponded to the subject's neutral standing position and the goniometer reading was approximately 90 degrees (Figure 4A). For

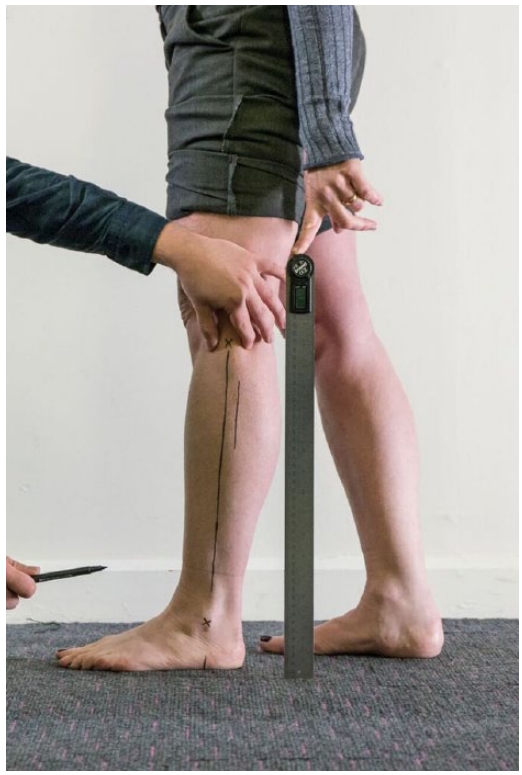

Figure 1. Photograph demonstrating the marking of the reference lines for measurement. The fibula line extends from the center of the head of the fibula to the center of the lateral malleolus.

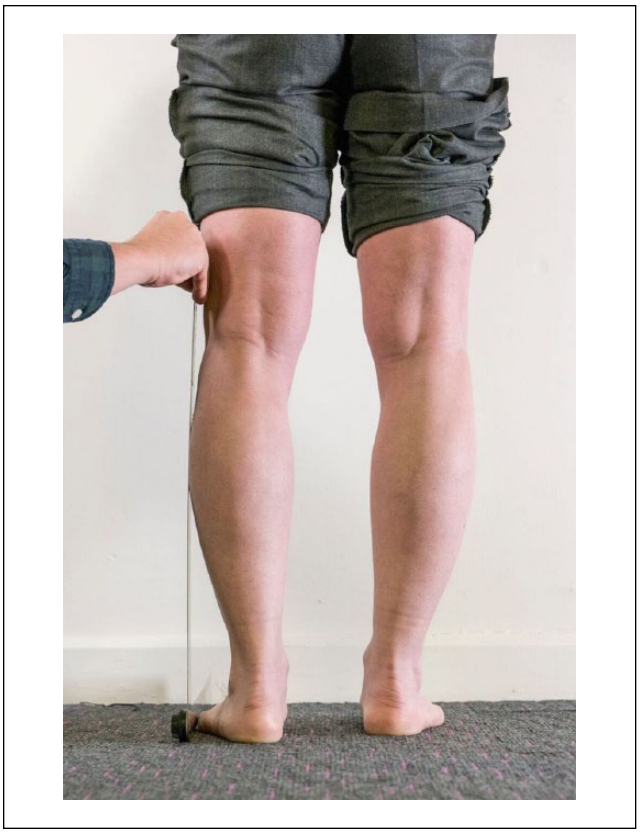

Figure 2. Photograph demonstrating the patient from behind facing a wall. The horizontal limb of the goniometer is at right angles to the wall, and sits flat on the floor touching the outer border of the foot. The vertical limb sits against the widest part of the calf.

Figure 3. Photograph demonstrating the same as Figure 2 but from a side on view. The posterior border of the vertical limb corresponds to our posterior line, whereas the center of the goniometer corresponds with the fibula line.

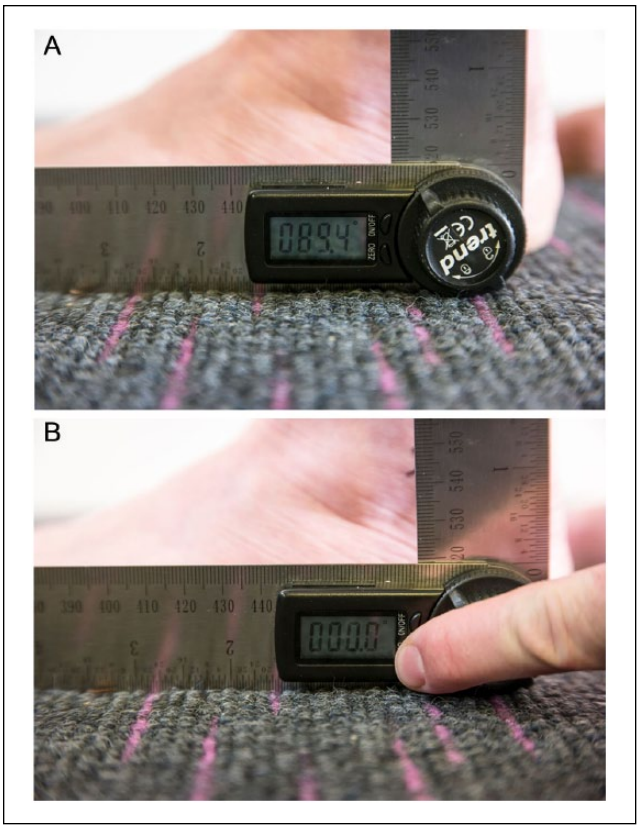

Figure 4. (A) Photographs showing a close up of the digital goniometer in Figure 3. With the knee extended the reading is 89.4 degrees. (B) At this point the reader presses reset to zero the reading.

consistency, the horizontal limb of the goniometer was touching the widest point of the fifth metatarsal head and was at right angles to the wall in front of the patient (Figure 2). In patients with significant hindfoot varus, the horizontal limb of the goniometer touched the fifth metatarsal but the hinge of the goniometer was further away from the heel than in patients with normal hindfoot alignment (Figure 5). In patients with hindfoot valgus the horizontal limb may stand off slightly from the lateral border of the foot, as the key aim is to ensure the horizontal limb of the goniometer continues to be at right angles to the wall in front (Figure 6). At this point, the goniometer was zeroed, setting the baseline for measurement (Figure 4B). The subject was then asked to bring the measured knee forward by bending both knees to produce maximal dorsiflexion of the foot relative to the tibia on the measured side (Figure 7). If unsure as to whether the heel was rising off the floor, the tester could place a piece of paper under the heel to ensure it remained flat and prevented pull out. The patient was informed that it did not matter if the contralateral heel raised from the floor.

To measure maximal tibia to floor plantarflexion, the subject sat on the edge of a chair and was instructed to place both heel and forefoot flat on the floor with the knee straight (Figure 8). If the knee was not fully straight, the patient was instructed to move their bottom forward on the chair to enable the knee to be straightened. The angle subtended

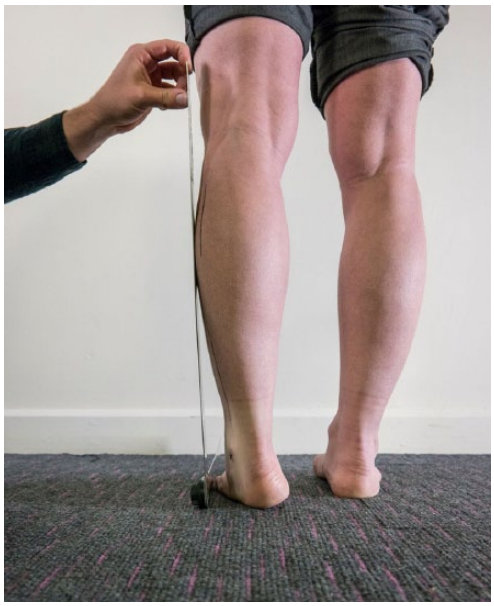

Figure 5. Photograph illustrating that in a patient with hindfoot varus the horizontal limb of the goniometer sits further away from the heel than normal (as seen in Figure 2). The horizontal limb remains positioned at 90 degrees to the wall in front of the patient rather than being angled to the heel.

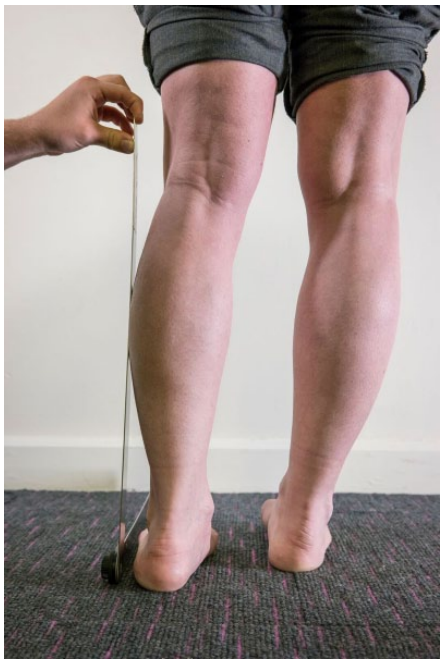

Figure 6. Photograph illustrating that in a patient with hindfoot valgus the horizontal limb of the goniometer sits closer to the heel and the horizontal limb remains positioned at 90 degrees to the wall in front of the patient. This may mean that the anterior aspect of the horizontal limb does not touch the most prominent part of the fifth metatarsal.

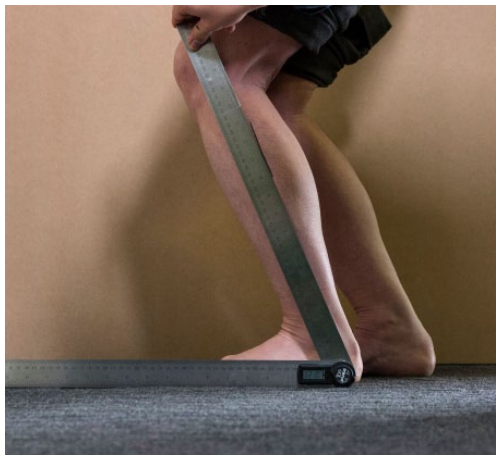

Figure 7. Photograph illustrating the subject bending the knee of the ankle to be measured to obtain maximal dorsiflexion. The posterior border of the vertical limb corresponds to our posterior marked line. The reader must ensure the heel remains on the floor. The reading is measured and recorded.

Figure 8. Photograph demonstrating the patient sitting on a wheeled chair with the knee fully extended on the side to be measured. The horizontal limb sits on the floor, whereas the vertical limb corresponds to the posterior line on the calf. This measures maximal plantarflexion.

Figure 9. Photograph of patient with fixed flexion deformity of the knee sitting down with their knee bent and the foot plantigrade. The chair is brought forward to achieve maximal dorsiflexion of the foot/ankle while the observer is careful to ensure the heel remains on the floor.

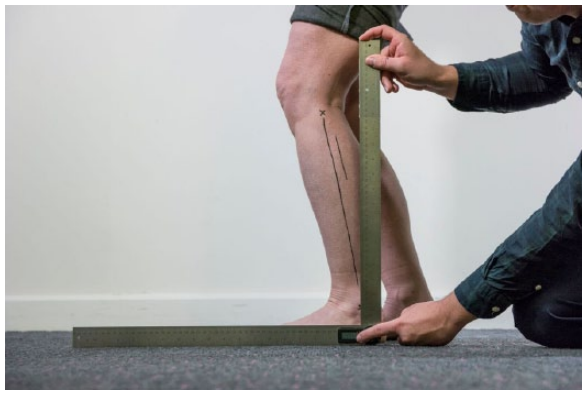

Figure 10. Photograph of patient with fixed flexion deformity of the knee standing. The vertical limb of the goniometer is zeroed at 90 degrees and then moved forwards to measure maximal dorsiflexion and plantar flexion are measured as normal.

between the 2 arms of the goniometer was the maximal tibia to floor plantarflexion.

Results

Control Group—No Ankle Pathology

In the control group without ankle pathology, 20 ankles were measured in 10 participants (4 male, 6 female). The median dorsiflexion was 29.6 (interquartile range [IQR] 24.5-37.9) degrees. The median plantarflexion was 51.2 (IQR 48.6-53.5) degrees. The median total range of motion from the floor to the tibia was 79.8 (IQR 74.9-90.5) degrees.

The median difference in measurements between observers for dorsiflexion was 0.8 (IQR 0.4-2.9) degrees and 1.9 (IQR 1.0-3.5) degrees for plantarflexion. The median difference in measurements within an observer was 1.4 (IQR 0.6-2.5) degrees for dorsiflexion and 1.6 (IQR 0.8-2.4) degrees for plantarflexion. The median difference for all measurements within an observer was 1.5 (IQR 0.7-2.5) degrees for observer 1 and 1.4 (IQR 0.7-2.2) degrees for observer 2. The intraclass coefficient (ICC) for interrater total ankle range of motion was excellent (0.95 [95% CI 0.91-0.97], $P < .001$). The ICC for intrarater total ankle range of motion was 0.942 (95% CI 0.859-0.977, $P < .001$) for observer 1 and 0.959 (95% CI 0.898-0.983, $P < .001$) for observer 2.

Ankle Arthritis Group

In the group with ankle arthritis, 26 ankles of 23 patients were measured. Fourteen patients had end-stage osteoarthritis and were measured preoperatively. Six patients were assessed following ankle fusion and 6 patients following ankle replacement at their 6-month follow-up appointment. For end-stage ankle arthritis patients, the median dorsiflexion was 12.6 (IQR 6.9-18.4) degrees. The median plantarflexion was 30.6 (IQR 21.8-40.3) degrees. The median total range of motion was 45.2 (IQR 26.8-58.6) degrees. For post–ankle fusion patients, the median dorsiflexion was 5.0 (IQR 3.3-5.1) degrees. The median plantarflexion was 14.7 (IQR 14.4-14.9) degrees. The median total range of motion was 17.7 (IQR 16.2-20.0) degrees. For post–total ankle replacement patients, the median dorsiflexion was 13.7 (IQR 11.3-17.3) degrees. The median plantarflexion was 32.9 (IQR 29.9-35.9). The median total range of motion was 46.6 (IQR 43.3-51.0) degrees.

The median difference for all dorsiflexion measurements between observers was 0.8 (IQR 0.3-1.5) degrees and 1.1 (IQR 0.4-2.3) degrees for all plantarflexion measurements. The median difference in measurements within an observer was 0.4 (IQR 0.2-0.8) degrees for dorsiflexion and 0.8 (IQR 0.5-1.5) degrees for plantarflexion. The median difference for all measurements within an observer was 0.6 (IQR 0.2-1.3) degrees. The intraclass coefficient (ICC) for interrater total ankle range of motion was excellent (0.99 [95% CI 0.97-1.0], $P < .001$). The ICC for intrarater total ankle range of motion was (0.99 [95% CI 0.96-1.0], $P < .001$).

Discussion

We have validated a standardized, cheap, and simple method for measuring total range of motion from the floor to the tibia that can be used to document outcomes in patients with ankle osteoarthritis. The technique was reproducible, with excellent inter- and intrarater reliability both in patients with and without ankle arthritis. This study formed part of the pilot work for the Total Ankle Replacement Versus Ankle Arthrodesis (TARVA) randomized controlled trial, and it was deemed that functional range of motion was an important variable for patients, and hence it was important to have a validated method to accurately measure range of motion in these patients pre- and postoperatively, especially as the study was being run across multiple sites. This technique had a number of benefits over the existing techniques, being simple, quick, and noninvasive, and we have shown the method to have a high degree of precision and reliability without the need for much training. Although the radiographic technique proposed by Coetzee and Castro in 2004 is useful in measuring tibiotalar motion, it is limited by being expensive and can be affected by parallax effects associated with plain radiographs.[3]

The aims of the study were to validate the technique and not to evaluate the actual differences in range of motion for the various cohorts so no inference from those findings will be discussed in this article. A further limitation of this study is that we have not assessed the accuracy of digital goniometers. However, the manufacturer (Trend Manufacturing and Cutting Tools Ltd, United Kingdom) claimed accuracy to within 0.5 degrees and in a clinical study where change

in total range of motion is important, the absolute numbers matter less. In the TARVA study, each participating site was using the same goniometer throughout its study assessments but we believe that the technique would work equally well using a traditional orthopedic goniometer. In this study, only 2 patients had deformity (1 severe varus and 1 valgus), and the technique worked as described on both.

The technique has been modified to enable measurement of patients with fixed equinus or fixed flexion of the knee. In patients with fixed equinus, the patients sit on a wheeled chair with the height adjusted so that their knee is bent and the measured foot is flat to the floor. The chair is then brought forward until the ankle reaches maximum dorsiflexion. The horizontal limb of the goniometer is placed flat on the floor and the vertical limb is moved backward so that the center of the goniometer corresponds with the fibula line, giving a negative value for maximum dorsiflexion (Figure 9). The patient is then asked to extend their knee maximally and the angle subtended between the limbs of the goniometer corresponds to maximal plantarflexion (Figure 8). In fixed flexion of the knee, the goniometer is zeroed when the vertical limb is at 90 degrees (Figure 10) and the maximal plantarflexion and dorsiflexion are measured as before.

Conclusion

This study established a cheap, reproducible, reliable, and standardized technique for the measurement of total range of motion of the tibia to the floor using a digital 2-limbed goniometer, with excellent inter- and intrarater reliability in both healthy volunteers and patients with ankle arthritis and can be used even after ankle arthrodesis to enable comparison of total range of functional motion for any operative ankle patients.

Declaration of Conflicting Interests

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