The Journal of Foot & Ankle Surgery xxx (2016) 1–5

Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Original Research

Validity and Reliability of the Achillometer®: An Ankle Dorsiflexion Measurement Device

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A R T I C L E I N F O

Level of Clinical Evidence: 2

Keywords:
ankle dorsiflexion
goniometer
reliability

A B S T R A C T

Limited ankle dorsiflexion is closely related to important foot and ankle pathologies. Various measurement devices and methods have been examined, but these have demonstrated limited validity and reliability. The purpose of the present study was to assess the validity and intra- and interobserver reliability of the Achillometer®. A total of 22 consecutive subjects with ankle or foot pathologies and 39 healthy participants were included. All participants were measured using the goniometer and the Achillometer®, a portable device used to assess ankle dorsiflexion in the weightbearing position with knee in extension. The intraclass correlation coefficient, standard error of the mean, and minimal detectable change were determined. The goniometer and Achillometer® revealed high intraobserver reliability coefficients with an intraclass correlation coefficient of 0.88 (standard error of the mean 1.49, minimal detectable change 4.12) and 0.85 (standard error of the mean 1.57, minimal detectable change 4.34), respectively. The interobserver reliability of both measurement techniques ranged from 0.63 to 0.67. The Achillometer® showed a strong correlation with the goniometer for both observers. In conclusion, the Achillometer® is a valid measurement device to assess ankle dorsiflexion range of motion in the weightbearing position with an extended knee in a heterogeneous population. The device has good intraobserver and moderate interobserver reliability and measurement properties comparable to those of the goniometer.

Limited ankle dorsiflexion is commonly caused by tightness of the soleus and gastrocnemius muscles (1). Clinically, it is closely related to important foot and ankle pathologies, such as metatarsalgia, pes planus, plantar fasciitis, and diabetic foot ulcers (1–4). Various treatment modalities have been reported to increase the dorsiflexion range of motion (ROM), including stretching exercises, casting, and surgical lengthening of the gastrocnemius–soleus complex (5–9).

Over the past years, several measurement devices and methods have been examined to assess ankle dorsiflexion ROM. In current clinical practice, the goniometer is used most. However, its application in the clinical and research context, similar to that for the inclinometer and instrumented techniques (e.g., Iowa ankle range of motion, leg motion system), has been questioned (10–14). The currently used systems have proved to be highly variable among observers concerning reliability; they are also laborious to use and time consuming (10,11,13,15). Furthermore, earlier studies used healthy individuals to prove the validity of the new device. Thus, these results cannot be extrapolated to patients with lower limb pathology.

Therefore, to assess the dorsiflexion ROM of the ankle, a new instrument is needed that will be easy to use and has high intra- and interobserver reliability. To overcome the previously mentioned shortcomings, we designed a new measurement device to assess ankle dorsiflexion ROM: the Achillometer® (Orthopaedic Instrument Manufacturer, Spaarne Gasthuis, Hoofddorp, The Netherlands). The Achillometer® is a stable metal construction and can be used with the patient in the weightbearing (WB) position with an extended knee. It is designed to observe relatively small changes and, ultimately, the effectiveness of treatment. The aim of the present study was to validate the Achillometer® and assess the intra- and interobserver reliability compared with the goniometer in the orthopedic outpatient clinic.

Patients and Methods

The local ethics committee of the Spaarne Gasthuis (Hoofddorp, The Netherlands) approved the present study.

Financial Disclosure: None reported.
Conflict of Interest: None reported.
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1067-2516/$ - see front matter
http://dx.doi.org/10.1053/j.jfas.2015.11.006

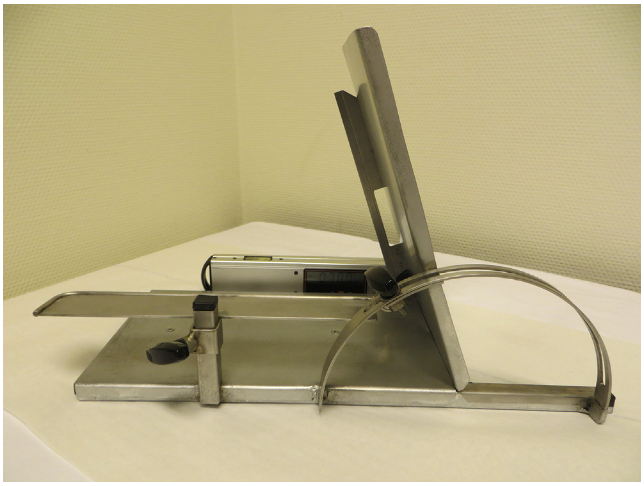

Fig. 1. Achillometer® with accompanying digital inclinometer.

Participants

The subjects eligible for the present study were consecutive patients presenting at the orthopedic outpatient clinic with foot and ankle complaints, such as metatarsalgia, Achilles tendinitis, or plantar fasciitis. Subsequently, patients without foot or ankle pathology were included to serve as the control group. The exclusion criteria were the existence of neuromuscular disorders (multiple sclerosis, Parkinson disease, cerebrovascular accident), connective tissue diseases (Marfan syndrome, Ehlers-Danlos disease), or foot and ankle surgery 6 months before testing. All participants provided written informed consent before data acquisition and were observed between May 2015 and August 2015.

Achillometer®

The Achillometer® was designed to improve the accuracy of ankle dorsiflexion measurement. The device consists of 2 metal plates connected by a hinge, which is the pivot point of the system. Emanating from this point, the angle of the rear (vertical) plate relative to the (horizontal) base plate is determined by a digital inclinometer, which is placed against the apparatus (Fig. 1). The dorsiflexion angle is defined as the difference between the vertical angle (90°) and the measured angle.

When standing on the base plate, the rear plate is placed against the posterior calf. To keep a stable position, the construction can be locked using an arc on the side of the device. Subsequently, the digital inclinometer is placed right next to the device and shows the angle of dorsiflexion accurate to a tenth of a degree (Fig. 1).

Goniometer

The reference standard was a flat, clear plastic goniometer with 2° increments (Protek AG, Bern, Switzerland).

Measurements

The angle of ankle dorsiflexion was measured with the patient in the WB position. The measurements were performed using the goniometer and the Achillometer®. The goniometric measurement was performed as follows: the participant was positioned in the stance phase with the knee in forced end-range extension (Fig. 2). The observer kept the hallux in dorsiflexion to correct any valgus hindfoot alignment (Fig. 3) (16,17). Subsequently, the subject was asked to stretch the calf to its maximum by leaning forward, keeping the heel in contact with the ground. The angle of dorsiflexion was then determined by a goniometer using the following reference points: the course of the fibula from the lateral malleolus to its proximal head for the vertical arm, and the radius of the fifth metatarsal bone for the horizontal arm (16,18).

Next, the measurement was performed with the Achillometer® with the participant in the same position (the stance phase and stretching the calf with an extended knee without lifting the heel). The apparatus was locked (Fig. 3), and the angle of dorsiflexion was determined with the digital inclinometer. The contralateral leg remained in a comfortable unrestricted position to help patients maintain their balance.

Procedure

The ankle dorsiflexion measurements were conducted using a standardized protocol. Each measurement was performed by 2 different observers, a 6-year medical student (L.J.K., observer 1) and an orthopedic surgeon (D.A.V., observer 2), both unaware of each other's results. The medical student was well trained after 6 hours of preparation before to the present study.

Observer 1 executed 2 WB measurements twice, with an interval of 15 minutes. Observer 2 measured the subject's ankle dorsiflexion ROM with both devices once. Subsequently, the circumference of the calf was determined in centimeters. All measurements were recorded using specific measurement forms, which were composed in advance of the present study in consultation with an independent epidemiologist (I.N.S.) and orthopedic surgeon.

Statistical Analysis

Statistical analysis was performed using SPSS, version 21.0 (SPSS, Inc., Chicago, IL). The continuous variables were checked for normal distribution using the Kolmogorov-Smirnov test and are presented as the mean ± standard deviation. Because of the ceiling effect of the Achillometer® at 27°, patients were excluded from the analysis when their measurement was equal to 27°. The statistical analysis was conducted by an independent epidemiologist (I.N.S.).

To assess the intra- and interobserver reliability for each measurement technique, 3 approaches were used:

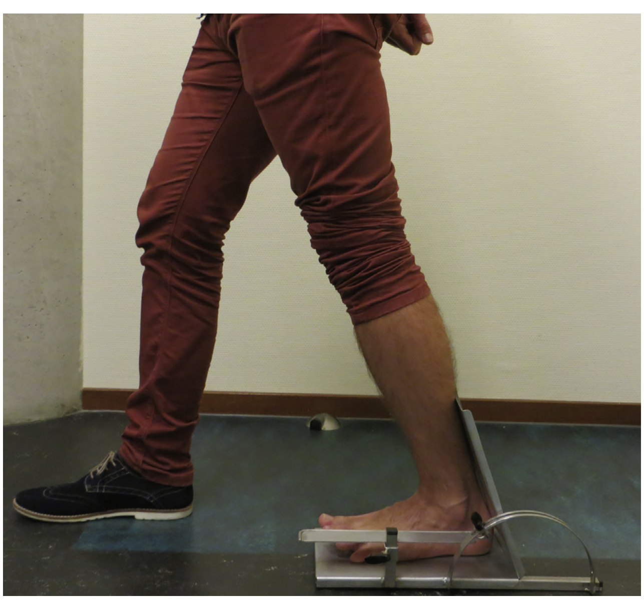

Fig. 2. Weightbearing position with the subject's knee in extension.

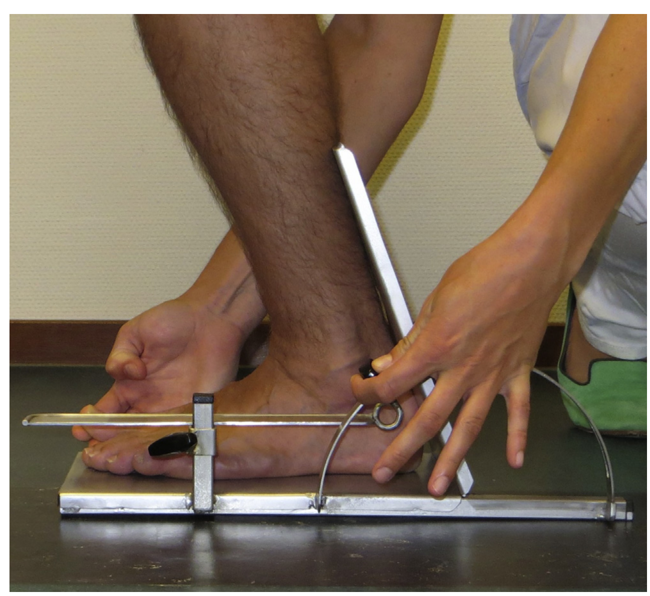

Fig. 3. Measurement of ankle dorsiflexion with the subject in weightbearing position with the knee in extension and hallux in dorsiflexion.

Table 1
Intra- and interobserver reliability of goniometer and Achillometer® measurements with subjects in weightbearing position

Variable	Mean ± SD	ICC (95% CI)	SEM	MDC
Intraobserver reliability				
Goniometer (WB)		0.80 (0.67 to 0.89)	1.56	4.31
Measurement 1	19.1° ± 3.3°			
Measurement 2	19.8° ± 3.7°			
Achillometer® (WB)		0.85 (0.75 to 0.91)	1.40	3.89
Measurement 1	19.4° ± 3.3°			
Measurement 2	19.8° ± 3.9°			
Interobserver reliability				
Goniometer (WB)		0.46 (0.19 to 0.66)	3.00	8.32
Observer 1	19.1° ± 3.3°			
Observer2	18.1° ± 4.8°			
Achillometer® (WB)		0.62 (0.41 to 0.77)	2.55	7.06
Observer 1	19.4° ± 3.3°			
Observer 2	18.3° ± 4.7°			

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimal detectable change; SD, standard deviation; SEM, standard error of the mean; WB, weightbearing.

1. Intraclass correlation coefficients (ICCs; 2-way random effects model)
2. Standard error of the mean (SEM)
3. Minimal detectable change (MDC) (19,20)

The SEM was calculated by taking the square root of the within-subject variance, obtained from analysis of variance (i.e., the sum of the between-measures variance and the residual variance). The MDC could then be easily computed (MDC = SEM $\times$ 1.96 $\times$ $\sqrt{2}$) (20,21). In brief, the SEM reflects the absolute measurement error, and the MDC provides an objective threshold to determine whether the values obtained are beyond measurement variability on an individual level (13,19). Moreover, paired *t* tests were performed to evaluate possible systematic differences between the 2 observers.

The validity of the Achillometer® was assessed by calculating the ICC as a measure of agreement between the 2 measurement methods, and the presence of systematic differences was evaluated using a paired *t* test. The variability in the differences in the 2 measurements was calculated using the SEM and MDC. To evaluate whether the error of measurement is dependent on the magnitude of the measurement, a scatter plot of the differences was constructed (22). For all statistical tests, the level of significance was set at $p \leq .05$.

Results

A total of 61 patients were eligible for the study. Nine patients were excluded from the analysis because of measurement values of the Achillometer® of 27°. Of the 52 patients, 22 with ankle or foot pathologies, such as metatarsalgia, pes planus, or plantar fasciitis, and 30 participants without complaints of the foot or ankle were included. Twenty-four patients were male (46%) and 26 were female (54%); their mean age was 53 ± 15.6 (range 21 to 80) years.

Reliability

The mean angle of dorsiflexion for the WB measurements with the knee in extension using the goniometer was 19.1° ± 3.3° for observer 1 and 18.1° ± 4.8° for observer 2. The Achillometer® showed mean values of 19.4° ± 3.3° and 18.3° ± 4.7° for observers 1 and 2, respectively. Both the goniometer and the Achillometer® revealed high intraobserver reliability coefficients with an ICC of 0.80 (95% confidence interval [CI] 0.67 to 0.89) and 0.85 (95% CI 0.75 to 0.91), respectively. The associated SEM and MDC were 1.6° and 4.3° for the goniometer and 1.4° and 3.9° for the Achillometer®, respectively. The interobserver reliability of both measurement techniques is displayed by ICCs with a range of 0.46 to 0.62 (Table 1). No significant systematic differences were observed between the 2 observers for the goniometer. The Achillometer® showed a significant difference of 1.1° (95% CI 0.1 to 2.1; $p = .03$).

Table 2
Validity of the Achillometer® measurement

Validity for Goniometer vs. Achillometer®	ICC (95% CI)	SEM	MDC
Observer 1	0.71 (0.54 to 0.82)	1.78	4.94
Observer 2	0.78 (0.63 to 0.88)	2.09	5.80

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimal detectable change; SD, standard deviation; SEM, standard error of the mean; WB, weightbearing.

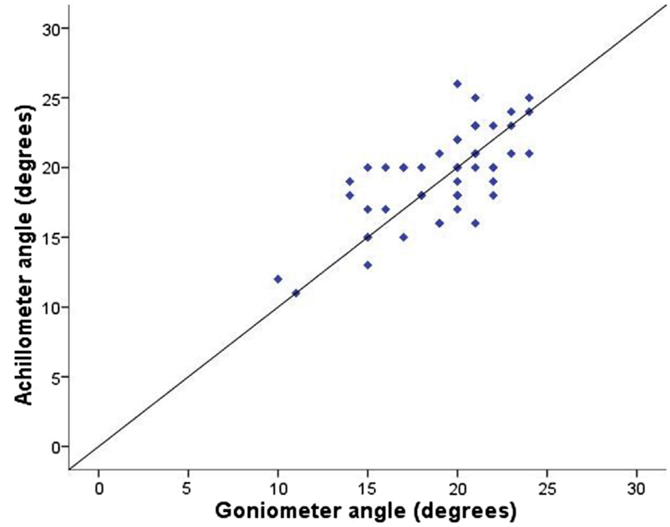

Fig. 4. Scatter plot for measurements by observer 1.

Validity

The Achillometer® showed a strong correlation with the goniometer for both observers. The correlation coefficients are listed in Table 2. For each observer, the differences between the measurement instruments were neither statistically significant ($p = .06$ and $p = .43$ for observers 1 and 2, respectively) nor associated with the calf size ($p = .20$ and $p = .22$ for observers 1 and 2, respectively). To compare both measurement techniques and the variability among measurements, 2 scatter plots were constructed (Figs. 4 and 5). They showed positive differences between the Achillometer® and goniometer with small values from the goniometer (<14°) and negative differences when the values from the goniometer were large (>27°).

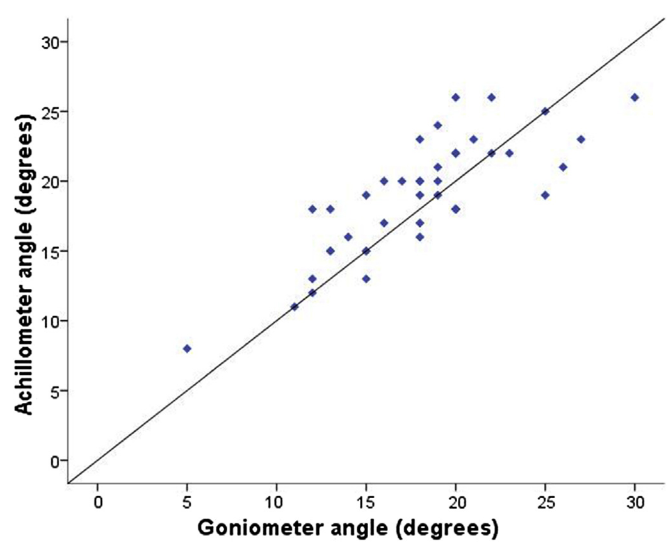

Fig. 5. Scatter plot for measurements by observer 2.

Discussion

In the present study, the validity and reliability of the dorsiflexion measurements using the Achillometer® were assessed. The results showed high intraobserver reliability, moderate interobserver reliability, and sufficient validity for this WB measurement device.

These findings are comparable to the results from studies by Calatayud et al (11), Konor et al (13), and Cejudo et al (23), with high ICCs (0.98, 0.85, and 0.95, respectively) reported. The results of the present study add to the results from those studies, which assessed the intraobserver reliability, because we also assessed the interobserver reliability of both measurement techniques.

Regarding the reliability analysis, the test–retest method was used to assess the intraobserver reliability. The Achillometer® and goniometer showed high intraobserver reliability with small SEM values. The intraobserver reliability could therefore be classified as good. The data showed large variability among the observers for the Achillometer® and goniometer, with decreasing interobserver reliability as a result. The interobserver reliability was therefore rated as moderate. The MDCs were determined to allow us to interpret the reliability of the findings in a clinical context (22). Values of 7° and 8° for the goniometer and Achillometer®, respectively, indicate that differences between the measurements can only be interpreted as real differences between observers when the measurements exceed these values. Daily activities (i.e., walking, kneeling, descending stairs) require an ankle dorsiflexion of $\geq$10°; therefore, differences of $<$7° or $<$8° could be considered clinically relevant (24). Our values were too large to monitor patients individually, suggesting the Achillometer® device is more suitable for evaluations at the group level.

The high ICC between the 2 measurement methods indicates good agreement. Together with the high correlation coefficients and the absence of a systematic difference, the validity of the Achillometer® can be considered good. Because the variability of the 2 measurement methods was comparable to the variability within each method, these 2 measurement techniques can be used interchangeably, preferably by the same observer.

The results of the present study need to be interpreted in the context of its limitations. First, the angle of ankle dorsiflexion is a combined result of movement at a number of joints, including the talocrural, subtalar, and midtarsal joints (14). Positioning the ankle and foot before testing is a key factor to achieving similar measurement conditions. To correct any supination or pronation of the foot, the subtalar joint was held in a neutral position for every measurement during data collection. Despite the strict protocol and the experience of both observers, patient positioning and foot posture could explain the moderate interobserver reliability and larger MDCs. Furthermore, the measurements are also dependent on the force applied by the patient. To reach maximal dorsiflexion, a participant should be fully motivated to stretch the calf muscle to its utmost. By forcing the knee into end-range extension, the maximum length of the gastrocnemius muscles will be reached.

Additionally, the variability among the measurements with the Achillometer® could be partially explained by a limitation of the device. The variability in the differences between the Achillometer® and goniometer were random when the measurement values of the reference standard (goniometer) varied from 14° to 27°. For measurements $<$14°, the Achillometer® measurements were greater than those of the goniometer. A possible explanation could be that, accounting for the calcaneus, the foot was positioned too far from the rear plate, resulting in a larger angle measured by the Achillometer®. The apparatus showed a ceiling effect at 27°, caused by a restriction of the arc. In particular, the high goniometric angles showed a large difference between the 2 measurement techniques, because the Achillometer® was restricted at 27°. Of the 61 patients, 9 were excluded because of this effect, which does not threaten the validity of our findings. Moreover, the calf size was considered, because the rear plate runs parallel with the posterior calf. However, the calf size was not associated with a systematic difference between the devices. Another validity issue with the use of the Achillometer® is whether a prominent calcaneus would be a confounder. The foot must be placed on the base plate as far as needed to fit the rear plate against the posterior calf. The angle of dorsiflexion will be larger with a more protruding calcaneus. We did not directly address this issue in our study. However, because no systematic differences were found between the 2 measurement techniques, the 2 devices provided the same information about ankle joint mobility.

The strengths of the present study resulted from the inclusion of both healthy subjects and patients with ankle or foot pathologies. In contrast to earlier studies, which mainly included healthy subjects (11–14), we were able to demonstrate the reliability and validity of the Achillometer® in a heterogeneous population. All participants were able to comply with the WB measurements; therefore, we have concluded that the Achillometer® is suitable for everyone.

Originally, ankle dorsiflexion was measured with the participant in a non-WB position (12). As shown in the review by Martin and McPoil (15), the reliability of this procedure is questionable, with an intra- and interobserver reliability ranging from 0.64 to 0.99 and 0.29 to 0.81, respectively. This variability in the ICCs has led to the development of alternative methods to objectify ankle dorsiflexion; for example, the WB lunge, which showed greater intra- and interobserver reliability ($>$0.85 and 0.77 to 0.88, respectively) (12–14,23,25,26). However, the WB lunge has 1 major limitation in that it mainly assesses the role of the soleus muscle, because it is performed with a flexed knee (27). Because it covers two thirds of the size of the posterior calf, the tightness of the gastrocnemius muscle could be a contributing factor to limited ankle dorsiflexion ROM (2). Baumbach et al (28) showed that the gastrocnemius was already eliminated by a 20° flexion angle of the knee. Therefore, measurements should be performed with the patient in an extended knee position to cover the whole gastrocnemius–soleus complex (12,29). Another advantage of WB measurements is that they are independent of the force applied to the forefoot by the examiner. In contrast, with the Achillometer®, the participant determines the force applied to the foot, which reflects the physiologic movement of the ankle during gait.

In conclusion, the Achillometer® is a valid measurement device to assess the ankle dorsiflexion ROM with the knee in extension in a heterogeneous population. The device has good intraobserver, moderate interobserver reliability, and measurement properties comparable to those of the goniometer. Furthermore, the results provide evidence to support WB measurements becoming the standard in the orthopedic outpatient clinic.

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