ORIGINAL ARTICLE

Nr 2024;14 (4):545-552

Reliability and Validity of Digital Inclinometer in Assessing Ankle Dorsiflexion: A Focus on First Detectable Resistance Position in Individuals With and Without Achilles Tendinopathy

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DOI:
10.32098/mltj.04.2024.04

LEVEL OF EVIDENCE: 3

SUMMARY

Introduction. The dorsiflexion range of motion in the ankle joint within an open kinetic chain can be measured by the First Detectable Resistance Position. Understanding such biomechanical alterations is crucial for intervening in the prevention and expediting the rehabilitation time of these injuries.

Objective. To determine the reliability and concurrent validity of the digital inclinometer as a tool for assessing the First Detectable Resistance Position and the maximum dorsiflexion range of motion in the ankle joint complex.

Methods. The sample comprised 50 healthy and symptomatic participants with Achilles tendinopathy of both genders. All participants had their ankle joint's First Detectable Resistance Position measured using both a manual goniometer and a digital inclinometer. Data analysis involved descriptive analysis, independent t-test, Intraclass Correlation Coefficient, and Pearson's Correlation.

Results. The majority of the sample was female (58%), with a mean age of 26.70 ± 10.26 years and BMI (kg/m^2) of 25.72 ± 4.52. Intraexaminer and interexaminer reliability Intraclass Correlation Coefficients (ICC) for the digital inclinometer were 0.96 (95%CI 0.94-0.98) and 0.94 (95%CI 0.87-0.97), respectively. The Standard Error of Measurement for digital inclinometer measurements in our study was 0.48° and 0.75° for intraexaminer and interexaminer, respectively. Pearson's Correlation Coefficient showed a strong direct correlation for Examiner A (r = 0.95; p = 0.001) and Examiner B (r = 0.93; p = 0.001) between the digital inclinometer and the manual goniometer. The Bland–Altman plot showed greater agreement in the digital goniometer when comparing measurements with the manual goniometer for evaluating the First Detectable Resistance Position of the ankle joint complex.

Conclusions. The study achieved excellent reliability and validity with a strong correlation between the manual goniometer and the digital inclinometer for evaluating the First Detectable Resistance Position of the ankle joint complex.

KEY WORDS

Ankle joint; tendinopathy; validation study; passive stiffness; clinical measurement.

INTRODUTION

Ankle complex injuries represent prevalent musculoskeletal conditions with a high incidence within both general and athletic populations (1). Notably, lateral ankle sprains affect 13.6 women per 1,000/year and 6.94 men per 1,000/year (2). Furthermore, they exhibit an incidence rate of 7 per 1,000 exposure hours in athletes engaged in indoor court sports (3). Adding to this, Achilles tendinopathy afflicts 9% of recreational runners (4) and is responsible for the premature retirement of 5% of athletes, regardless of the sport (5). Ankle complex injuries not only compromise physiological function but also curtail work-related activities and social participation, resulting in an aggregate economic burden (6). In the Netherlands, recent surveys indicate that the annual cost of exclusively physiotherapeutic treatment surpasses €320 euros per patient (7).

Ankle injuries may stem from or result in modifications to the structural and mechanical properties of the joint complex. Reduced passive stiffness of the ankle complex leads to increased muscle fatigue, while heightened stiffness hinders joint movement during gait, promoting the emergence of lower limb pathologies (8). Immobilization resulting from the post-surgical process of Achilles tendon rupture also alters its passive stiffness (8) and muscular performance (9). Lateral ankle sprains cause an increase in talus inversion and abnormal symptoms due to alterations in the mechanical stiffness of soft tissues (2). Conversely, chronic instability adversely affects central motor control mechanisms (3, 10), and the increased cross-sectional area in Achilles tendinopathy alters tendon stiffness through the modification of the normal organization of collagen structures, rendering the tissue less elastic and more brittle (11). Experimental studies examining the mechanical behavior of the Achilles tendon in diabetic individuals reveal a clear negative effect on tissue mechanical properties (12, 13).

The First Detectable Resistance Position serves as an alternative measurement method that can be utilized to assess passive stiffness and the maximum dorsiflexion amplitude of the ankle complex in open kinetic chain, facilitated by a manual goniometer (MG). This procedure offers a simple, cost-effective assessment validated concurrently with isokinetic dynamometry (14). Additionally, a quick and technically straightforward method involves utilizing the digital inclinometer for evaluation. Recent psychometric studies indicate that the digital inclinometer possesses higher inter-examiner reliability than the MG, possibly attributed to challenges in precisely positioning the goniometer axis (15). Consequently, although both methods are cost-effective, digital measuring instruments are favored by clinicians, provided they exhibit validity and reliability comparable to or better than the MG (16). Hence, it is imperative to conduct an inquiry into the intra- and inter-examiner validity and reliability of the digital inclinometer as an innovative tool for assessing the First Detectable Resistance Position and the maximum dorsiflexion amplitude of the ankle complex to ensure its practical applicability.

METHODS

This clinimetric study was conducted at the Federal University of Ceará. Data collection occurred from March 2020 to March 2021, and participants were recruited through social media platforms for the general community and campus-wide advertisements. The study protocol obtained approval from the University's Research Ethics Committee (36711220.5.0000.5054 – date of approval: October 22, 2020). All patients provided informed and voluntary consent before participating in the study.

Sample

The sample included participants of both sexes, aged between 18 and 55 years, capable of performing a minimum knee flexion of 90°. Participants were categorized into two groups outlined in the descriptive table: 1) Healthy Group (HG), consisting of individuals without functional clinical alterations in the ankle complex; 2) Tendinopathy Group (TG), comprising participants exhibiting clinical signs of Achilles Tendinopathy.

To characterize the TG, participants were required to self-report tenderness upon palpation in the medial or insertion portion of the Achilles tendon, experience morning stiffness, and test positively for the Royal London Hospital Test. In addition to these criteria, individuals in the TG were further required to have a VISA-A questionnaire score equal to or below 80. Exclusion criteria encompassed participants who (I) were unable to maintain relaxation of the plantar flexor muscles during the First Detectable Resistance Position test, (II) had amputation of toes or forefoot, and (III) declined participation in the research.

Data collection and instruments

Data collection occurred in a single face-to-face encounter following the reading and signing of the informed consent form. Anthropometric and sociodemographic information was initially obtained, followed by the completion of the VISA-A questionnaire (17). The measurements of the First Detectable Resistance Position (FDRP) of the ankle complex were subsequently collected separately using the manual goniometer (MG) (Manufactured by CARCI® – City of São Paulo – Brazil - Technical characteristics: Transfer system from 0° to 360°, made of acrylic material weighing 50 g) and the digital inclinometer (DI) (Manufactured by Sanhe Measuring Instrument CO., LTD. – Wenzhou city - China. Digital inclinometer model 5315-90C, made of plastic material with a magnetic base. Values can be easily read on the LCD display with an accuracy of ± 0.2° and a resolution of 0.05°. Measurement range 4 × 90°. It has an operating temperature of 0 °C to 50 °C/32 °F – 122 °F, dimensions of 57 × 55 × 26 mm/2.5 × 2.1 × 1 in, and weight of 80 g/0.17 lb). Examiner "A" conducted the initial collection, erasing markings before leaving the room to prevent any influence on the second evaluator. After walking for 1 minute, the participant was instructed to lie back on the examination table for Examiner "B" to collect the FDRP, followed by the process of erasing the template for a new assessment by Examiner "A". In the second assessment, Examiner "A" returned, repeating the initial procedure using a blank sheet of paper to avoid memory bias. Intra-examiner assessments took place on the same day with a 15-minute interval between them, a strategy adopted to avoid sample loss due to social isolation restrictions and the high number of COVID-19 cases during the data collection period. Examiners "A" and "B" remained consistent across all collections.

Measurement of first detectable resistance position (FDRP)

The FDRP was recorded through the passive measurement of ankle dorsiflexion angle in Open Kinetic Chain after applying a 2 kg load to each patient (8). The 90° angle between foot and leg was considered as the zero point, referenced to the horizon line. Negative values were assigned if the foot did not reach the zero mark (plantar flexion), while positive angular values were considered when the foot surpassed the zero mark (dorsiflexion).

The participant, lying in prone position, barefoot, with the knee flexed at 90°, was secured by a stainless steel "L"-shaped rigid device (**figure 1**). Demographic pencil markings were made at the fibular head, lateral malleolus, 1 cm below the sole of the foot in line with the lateral malleolus, and another at the 5th metatarsal region, where a 2 kg load was positioned. The MG was positioned 1 cm below the lateral edge of the foot, following the orientation of the fibula line. The DI was placed immediately after MG reading, over the 5th metatarsal, without applying downward vertical force. The ankle remained relaxed, and five uniform and passive repetitions of dorsiflexion movement were performed to allow for viscoelastic accommodation. If any visual or palpable signs of muscle contraction were observed, the test was repeated. These measurements were recorded in degrees, representing the average of three repetitions for both MG and DI, concluding the data collection (13).

Ankle dorsiflexion range of motion

Ankle dorsiflexion range of motion in a closed kinetic chain was assessed using the Weight Bearing Lunge Test (WBLT) following the method described by Ferreira *et al.* (18). Participants positioned their assessed foot over a tape on the ground, aligning the first toe to the center of the heel. While maintaining this position, they were instructed to lunge forward until their knee touched a second line drawn on the wall, with the heel remaining in contact with the floor. An examiner ensured that the calcaneus did not lift during the test and participants were permitted to use the wall for balance. Once the maximum lunge distance was achieved, an

Figure 1. Clinical measurement of the position of the first detectable resistance.
(A) Manual goniometer; **(B)** Digital inclinometer.

inclinometer was placed 15 cm below the tibial tuberosity to measure the ankle dorsiflexion angle. At least five repetitions were performed to determine the maximum lunge angle.

Data analysis

For the descriptive statistical analysis, an exhaustive examination of variables such as age, gender, weight, height, BMI, and foot length was undertaken, coupled with the rigorous assessment of the final dorsiflexion angle through the Pronator Quadratus Resisted Dorsiflexion (PPRD) technique and the Victorian Institute of Sport Assessment – Achilles (VISA-A). Concurrently, the Kolmogorov-Smirnov normality test was meticulously applied. The independent t-test, a stalwart in comparative mean analysis, was employed to discern subtle yet significant mean distinctions between cohorts manifesting health and those afflicted with tendinopathy.

In the realm of clinimetric scrutiny, the reliability of intraexaminer and interexaminer assessments assumed paramount importance. This was meticulously evaluated via the Intraclass Correlation Coefficient (ICC), utilizing a sophisticated random two-way model (ICC2,1) for both goniometric and inclinometric measurements. The stratification of reliability spanned from levels deemed suboptimal (ICC < 0.50) through moderate (0.50 ≤ ICC ≤ 0.75) and good (0.75 < ICC ≤ 0.90) to exemplary (ICC > 0.90), adhering to established benchmarks (16).

The quantification of measurement precision was achieved through the calculation of the Standard Error of Measurement (SEM). Employing the formula SEM = SD × √1 - ICC, where SD represents the standard deviation of baseline measurements, this metric offered insight into the inherent variability of intra- and interexaminer evaluations. Furthermore, the pivotal concept of the Smallest Detectable Change (SDC95) was derived as 1.96 × √2 × SEM, representing the smallest discernible alteration. In the domain of validity, the Pearson Correlation Coefficient was invoked to delineate the relationship between the Digital inclinometer and Manual Goniometer. Noteworthy was the categorization of correlation strength: null for values approximating zero, weak for those within the 0 to 0.5 range, moderate for 0.5 ≤ r < 0.7, and robust for r ≥ 0.7. The Bland-Altman plot was generated for the digital inclinometer contrasted with the manual goniometer to assess agreement between both instruments. Limits of agreement were calculated, as well as the linear regression coefficient (r2) and their respective bias in relation to the maximum agreement. Data analysis was conducted using SPSS (Statistical Package for Social Sciences) version 20.0, as well as Microsoft Excel 2017. A significance level of $p < 0.05$ was established.

RESULTS

Data from 50 participants were subjected to analysis, with no exclusions. Participant characteristics are detailed in **table I**. We observed excellent intraexaminer reliabilities (ICC2,1 0.97; 95%CI 0.96-0.98) and interexaminer reliabilities (ICC2,1 0.94; 95%CI 0.89-0.96) for goniometric measurements. The SEM was less than 1 degree for both intraexaminer and interexaminer measurements. However, the SDC was less than 1 degree for intraexaminer and slightly higher than 2 degrees for interexaminer measurements. The data are presented in **table II**.

For the clinical measurement of the maximum dorsiflexion range of motion of the ankle complex in the position of

Table I. Anthropometric and functional characterization.

Variable	Healthy Group (n = 26)	Tendinopathy Group (n = 24)	Overall
Sex (n, %)			
Male	12 (46.2%)	9 (37.5%)	21 (42%)
Female	14 (53.8%)	15 (62.5%)	29 (58%)
Age (years)	22.58 ± 3.37	31.17 ± 13.11	26.70 ± 10.26
Weight (kg)	69.86 ± 16.15	74.95 ± 16.79	72.31 ± 16.49
Height (m)	1.68 ± 0.09	1.65 ± 0.08	1.67 ± 0.08
BMI (kg/m^2)	24.39 ± 3.85	27.16 ± 4.82	25.72 ± 4.52
Foot length (cm)	24.57 ± 2.35	24.16 ± 1.61	24.38 ± 2.02
Manual goniometer (degrees)	5.70 ± 4.86	3.23 ± 7.77	4.51 ± 6.48
Digital inclinometer (degrees)	6.16 ± 6.08	4.08 ± 8.10	5.16 ± 7.12
VISA-A Score	90.54 ± 10.38	57.13 ± 20.87	74.50 ± 23.32
WBLT (degrees)	46.66 ± 4.08	43.09 ± 5.30	44.95 ± 4.99

n: represents the number of participants per group; continuous data are presented as means ± standard deviation (SD); WBLT: weight bearing lunge test.

Table II. Reliability and agreement for goniometer mean measurements.

Measurements (n = 50)	Mean ± SD	Mean difference ± SD	ICC2,1 (95%CI)	SEM	SDC
		Goniometer			
Examiner A					
Test 1	4.51 ± 6.48	-			
Test 2	4.93 ± 6.38	-			
Examiner B	4.86 ± 6.94	-			
Intraexaminer (A1 × A2)	-	-0.41 ± 1.89	0.97 (0.96 to 0.98)	0.32	0.90
Interexaminer (A1 × B)	-	-0.34 ± 3.13	0.94 (0.89 to 0.96)	0.76	2.12

n: represents the number of participants per group; continuous data are presented as means ± standard deviation (SD); ICC: intraclass correlation coefficient; SDC: smallest detectable change; the standard error of measurement (SEM).

the first detectable resistance, conducted using the Digital Inclinometer, intraexaminer reliabilities (ICC2,1 0.96; 95%CI 0.94-0.98) and interexaminer reliabilities (ICC2,1 0.94; 95%CI 0.87-0.97) were also excellent. The standard error of measurement (SEM) was less than 1 degree for both intraexaminer and interexaminer measurements. However, the smallest detectable change (SDC) was less than 2 degrees for intraexaminer and greater than 2 degrees for interexaminer measurements. The data are presented in **table III**.

Our study demonstrated excellent concurrent validity between the DI and MG for the clinical measurement of the maximum dorsiflexion range of motion of the ankle complex in the position of the first detectable resistance. We found a strong correlation between the instruments for Examiner A (r = 0.95; p = 0.001) and for Examiner B (r = 0.93; p = 0.001). The agreement between the digital inclinometer and manual goniometer is depicted in **figure 2**. The mean difference was -0.528, with a paired t-test indicating no significant difference between the two devices (p = 0.170). The 95% Limits of Agreement (LoA) for the

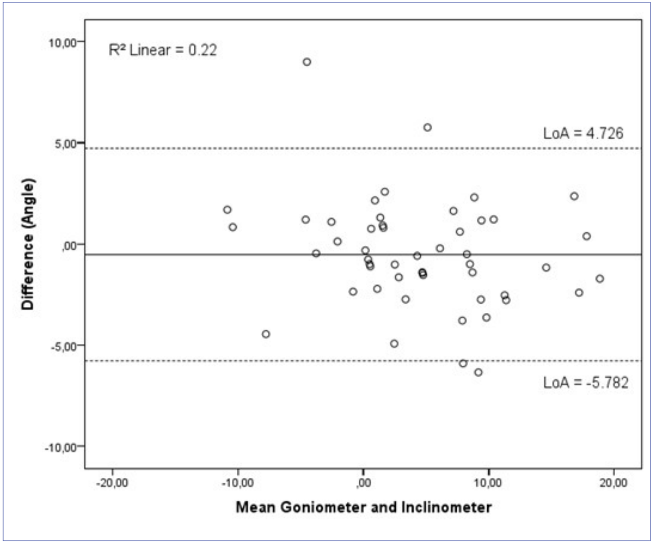

Figure 2. Bland-Altman plot showing agreement between the digital inclinometer and manual goniometer in the clinical measurement of the first detectable resistance position.
LoA: Limits of Agreement.

Table III. Reliability and agreement for digital inclinometer mean measurements.

Measurements (n = 50)	Mean ± SD	Mean difference ± SD	ICC2,1 (95%CI)	SEM	SDC
		Digital inclinometer			
Examiner A					
Test 1	5.16 ± 7.12	-			
Test 2	4.88 ± 6.64	-			
Examiner B	6.83 ± 8.02	-			
Intraexaminer (A1 × A2)	-	0.28 ± 2.42	0.96 (0.94 to 0.98)	0.48	1.34
Interexaminer (A1 × B)	-	-1.67 ± 3.08	0.94 (0.87 to 0.97)	0.75	2.09

n: represents the number of participants per group; continuous data are presented as means ± standard deviation (SD); ICC: intraclass correlation coefficient; SDC: smallest detectable change; SEM: the standard error of measurement.

two devices ranged from -5.782 to 4.726, as shown in the Bland-Altman plot.

DISCUSSION

In our study, we sought to investigate the reliability and validity of the Digital Inclinometer as an alternative tool for measuring ankle dorsiflexion range of motion in the position of the first detectable resistance. The primary outcome of our investigation revealed excellent intraexaminer and interexaminer reproducibility, coupled with a strong correlation between the DI and the previously validated Goniometer.

The advantageous practical features of the DI, including its ease of use without the need for markings and its clear digital display, make it a favorable choice for both novice and experienced professionals. The clinical utility of the DI, demonstrated through its reliability and validity, positions it as a valuable tool for practical applications in clinical settings and opens avenues for future research endeavors.

Our study, encompassing an adequate sample size within recommended guidelines (19), showcased intraexaminer and interexaminer ICC values considered excellent for the DI, surpassing the threshold of 0.9 (20). These reliability indices align favorably with previous investigations comparing the MG with isokinetic dynamometry in ankle dorsiflexion measurement (15, 22).

The Standard Error of Measurement (SEM) values close to zero in our study indicate high agreement between test and retest measurements for both intraexaminer and interexaminer assessments (20). Knowledge of the study's SEM is relevant, as values below those established as reference indicate a lack of meaningful change in ankle dorsiflexion amplitude (14). Our SEM values for digital inclinometer measurements were 0.48° and 0.75° for intraexaminer and interexaminer, respectively, surpassing the performance observed in a study assessing knee range of motion with digital inclinometers (22).

The Pearson Correlation Coefficient in our study revealed a strong positive correlation between the DI and MG for both examiners. This aligns with findings in the evaluation of PPRD between the MG and isokinetic dynamometry, where increased tissue resistance correlated with decreased ankle dorsiflexion displacement (14). Our study adds to the body of evidence by showcasing a strong correlation akin to another investigation comparing the DI with a smartphone application for ankle dorsiflexion angle measurement under joint load (23, 24). Furthermore, we observed a moderate correlation in a study utilizing the DI as a reference standard for validating the LegMotion device, which measures ankle dorsiflexion (25). These findings underscore the substantial similarity between the investigated instruments, contributing to the exploration of alternative measurement approaches.

The agreement verified with the Bland-Altman plot analysis was good, suggesting that the digital inclinometer could potentially replace manual goniometer measurements. This finding is significant in the context of clinical practice, as it indicates that the DI provides reliable measurements comparable to those of the manual goniometer. This not only streamlines the measurement process but also reduces potential human error associated with manual readings. Additionally, the DI's ease of use and quick, precise readings make it a valuable tool for clinicians, particularly in settings where efficiency and accuracy are crucial, such as in Telemedicine applications (26).

However, it is essential to acknowledge that the proposed clinical measurement may not be applicable in individuals with an ankle dorsiflexion range of motion less than 10°, as this restriction compromises the passive measurement of ankle joint motion. Additionally, attention to knee positioning is crucial when utilizing the DI for PPRD measurement, as its alignment at 90 degrees influences outcomes. Our study utilized a support structure to maintain knee positioning, mitigating potential deviations in tibial alignment and ensuring accurate DI measurements. Despite these considerations, the low cost, ease of handling, and measurement precision position the DI as an excellent tool for assessing ankle dorsiflexion through the PPRD method, offering valuable contributions for both clinical practice and future research endeavors.

CONCLUSIONS

Based on our results, we conclude that the Digital Inclinometer demonstrates excellent intraexaminer and interexaminer reliability for ankle dorsiflexion measurement in the position of the first detectable resistance. Furthermore, the validity of the DI is underscored by a robust correlation with the established Goniometer. Consequently, the Digital Inclinometer emerges as a viable instrument for both clinical and research applications in assessing ankle dorsiflexion.

Impact for clinicians

The Digital Inclinometer stands as a dependable and valid alternative to the manual goniometer for assessing ankle dorsiflexion angles, particularly when employing the First Detectable Resistance Position (FDRP) method. This validation underscores its reliability, emphasizing its potential as a valuable tool for accurate and efficient measurements in ankle joint complex evaluations.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

RRO, MAB: statistical data analysis, interim reviews, writing – original draft, final assessments, data analysis, writing – review & editing. DNBM, PAP: sample selection, evaluation, interim reviews, writing – original draft, statistical analysis.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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