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The validity and reliability of DrGoniometer, a smartphone application, for measuring forearm supination

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ABSTRACT

Study Design: Clinical measurement (reliability and validity) study.
Introduction: Forearm supination is important in many daily activities and is thus measured by therapists and researchers usually with a universal goniometer. DrGoniometer, a SmartPhone application, has been validated for other joint angles in the body.
Purpose of the Study: To establish the reliability and validity of DrGoniometer (CDM S.r.L, Cagliari, Italy) for measuring forearm supination in healthy populations and those with forearm fractures.
Methods: Participants had sustained a distal radius fracture that was treated non-surgically. Forearm supination of the participant's fractured ($n = 30$) and healthy forearm ($n = 30$) was measured using DrGoniometer and the universal goniometer by two assessors. The assessors were blinded to each other's measurements and their own previous measurements. Reliability was established by calculating Intraclass Correlation Coefficients, standard error of measurement and minimal detectable change. The validity of DrGoniometer was established against the universal goniometer using Pearson's correlation coefficient.
Results: Intra-rater reliability of both DrGoniometer and the universal goniometer was high for both fractured and healthy forearms (ICCs ranged from 0.74-0.88). Inter-rater reliability of both DrGoniometer and the universal goniometer was also high in the fractured forearm group (0.76 and 0.72 respectively), but low in the healthy forearm group (0.34 and 0.42 respectively). Correlation between the tools was excellent across the fractured and healthy forearm groups (0.94 and 0.93 respectively).
Discussion: Both goniometers demonstrated good-to-excellent intrarater and iner-rater reliability except in the healthy forearm group where both goniometers demonstrated poor inter-rater reliability which could be due to assessor instructions. The speed the photo can be taken and the digital record obtained are valuable aspects of DrGoniometer.
Conclusion: DrGoniometer is a valid, alternate tool for measuring forearm supination.

Introduction

Forearm supination is an essential component of many activities of daily living, including eating, dressing, and driving. Impaired forearm supination can occur due to trauma, surgery, and immobilization and can result in marked disability due to the importance of supination in everyday living.[1]

During rehabilitation of wrist and forearm range of motion (ROM) impairments, therapists measure supination ROM to monitor patient progress and response to treatment.[2] Forearm supination ROM is also used frequently as an outcome measure in clinical trials assessing the efficacy of surgical and conservative interventions aimed at restoring wrist and forearm movement.[3-7]

Currently, the American Society of Hand Therapists prescribes that the gold standard for measuring forearm supination is the universal goniometer.[8] The reliability and validity of this tool are well documented and have been demonstrated on a multitude of joints.[9] Previous studies have demonstrated excellent intrarater reliability (intraclass correlation coefficient [ICC] >0.75) of the universal goniometer when measuring supination.[10-13] Excellent inter-rater reliability for measuring supination has similarly been demonstrated across the literature.[10,11] Reliability has been established with both healthy populations and populations with known pathologies[10-12] and has also been established for both within-

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session and between-session variability.[13] The universal goniometer has therefore been widely adopted across clinical settings and practice guidelines.[8]

Recently however, a range of smartphone applications (apps) that offer an alternative means for measuring joint angles have become available. DrGoniometer is one such app that measures joint angles from photographs taken using the phone's inbuilt camera. The app allows the user to place a virtual goniometer over the photograph to measure the joint angle.[14] This app offers several advantages over the universal goniometer as it allows for fast recording and retrieval of patient information. In the case of a highly irritable patient, the photograph can be quickly recorded, and the virtual goniometer can be positioned at a later time so that the patient does not need to sustain the irritable position. The data obtained can be included in the patient's digital medical record and can be used by the therapist for comparison during follow-up treatments or for medicolegal purposes.[15] The app is also advantageous as it can improve communication between the therapist, the client, and other health care professionals. Data can be sent via the Internet, between the therapist and patient to facilitate telerehabilitation,[16] and between professionals to support opinions and provide evidence of the patient's progress and function.

To date, there is limited research studying the use of DrGoniometer. The validity and reliability of DrGoniometer have only been established for measuring elbow flexion,[17] shoulder external rotation,[18] knee flexion,[15] tibial external rotation,[19] and extension of the first metatarsophalangeal joint.[11] These joints are all classified as either hinge joints or ball and socket joints.[1] Joints with more complex movements that are difficult to measure, such as forearm supination, are yet to be studied. There is limited generalizability of existing DrGoniometer studies as they have only used healthy subjects. Participants have been excluded in previous DrGoniometer studies due to pain, edema, neurologic disorders, inflammatory or degenerative diseases, decreased ROM, and prior surgeries or procedures at the joint to be tested.[18,20] A study of a similar smartphone app found that inclusion of subjects with pathologies could significantly influence validity and reliability results.[16]

When any new clinical measurement tool is developed, it is important to establish its clinimetric properties (such as reliability and minimal detectable change [MDC]) so that researchers and clinicians can know whether to have confidence in the data it generates. Furthermore, where multiple tools are available to measure the same construct, the clinimetric properties of each tool can be compared so that the tool with the best combination of practicality and validity can be used. This will also help to reduce the redundancy in instruments measuring clinical variables.[21]

The purpose of this study was therefore to establish whether DrGoniometer is a reliable and valid tool for measuring forearm supination ROM, in both healthy subjects and subjects with known forearm fractures.

Methods

This was a study of clinical measurement (reliability and validity).

Subjects

The data for this reliability study were collected from participants of a randomized controlled trial (RCT), conducted at an Australian university, assessing the effectiveness of physiotherapy after distal radius fracture. Participants were included if they were older than 18 years, had sustained a distal radius fracture in the past 6 months, and had been treated nonsurgically (ie, in a cast). Participants were measured after cast removal. Potential participants were excluded from the study if they had a concurrent fracture of the ipsilateral upper limb or a diagnosis of complex regional pain syndrome. On the advice of a biostatistician, a total of 30 fractured and 30 healthy forearms were measured.

Participants had both their fractured forearm and healthy forearm measured. In the instance of the participant having sustained a fracture of both forearms, an aged matched asymptomatic participant was recruited to provide the healthy forearm measures.

The participants of the study received both verbal and written explanations of the study's purpose and procedures. All participants provided written informed consent before engaging in the study. Ethics approval was gained from the university's Human Ethics Committee.

Measurement techniques

Active forearm supination was measured using both the universal goniometer and DrGoniometer (CDM, S.r.L, Cagliari, Italy). Two assessors independently collected the measurements from each participant to establish the inter-rater reliability of both measurement tools. The first assessor collected a second set of measurements from each participant, 30 minutes after their first measurements, so that the intrarater reliability of the tools could also be established.

The 2 assessors were selected from a small pool of assessors who had been trained in the measurement methods and were selected based on availability. The assessors were blinded to each other and their own previous measurements.

Participants received standardized instructions and were asked to maintain the joint position until both the DrGoniometer and universal goniometer measurements had been performed.

Participant positioning

Participants were positioned as per the handheld pencil method for measuring forearm supination.[13] The participant stood with their humerus by their side and their elbow flexed to 90°. The participant held a pencil in their closed fist. A small "x" was drawn

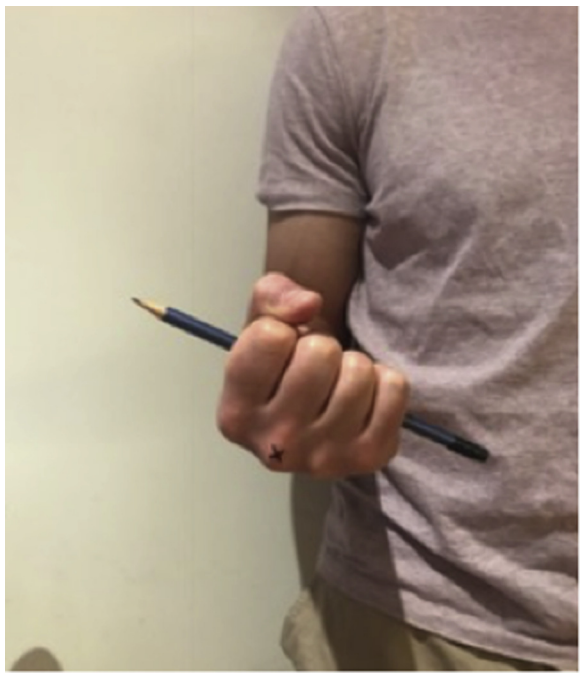


Fig. 1. Participant positioning for measurement of supination range of motion.

on the third metacarpal head (Fig. 1). The participant was asked to supinate their forearm as far as possible.

Universal goniometer placement

The universal goniometer axis was placed over the "x" drawn on the head of the third metacarpal. The stationary arm was placed parallel to the line of the humerus, and the moveable arm was placed parallel to the line of the pencil held in the participant's hand (Fig. 2).

DrGoniometer placement

The iPhone was held perpendicular to the floor with the third metacarpal positioned in the middle of the screen and the participant's humerus visible. The photograph was taken, and the app's 3 measurement points were placed as shown in Figure 3.

Analysis

Statistical analysis was performed using SPSS, version 22.0 (IBM Corp, Armonk, NY).

Reliability

One-way mixed-effect model ICCs were calculated to determine the intrarater and inter-rater reliability of both DrGoniometer and the universal goniometer. Cicchetti[22] gives the following often-quoted guidelines for interpretation for kappa or ICC inter-rater agreement measures: less than 0.40—poor, between 0.40 and 0.59—fair, between 0.60 and 0.74—good, and between 0.75 and 1.00—excellent.

Standard error of measurement (SEM) and MDC within a 90% confidence interval (MDC90) were also calculated to determine the minimal change that can be detected by the measurement techniques, which ensure that the change is not a result of measurement error.[23] The following equation was used to calculate the MDC90: MDC90 = 1.65 × SEM × square root of 2.

Fig. 2. Placement of the universal goniometer.

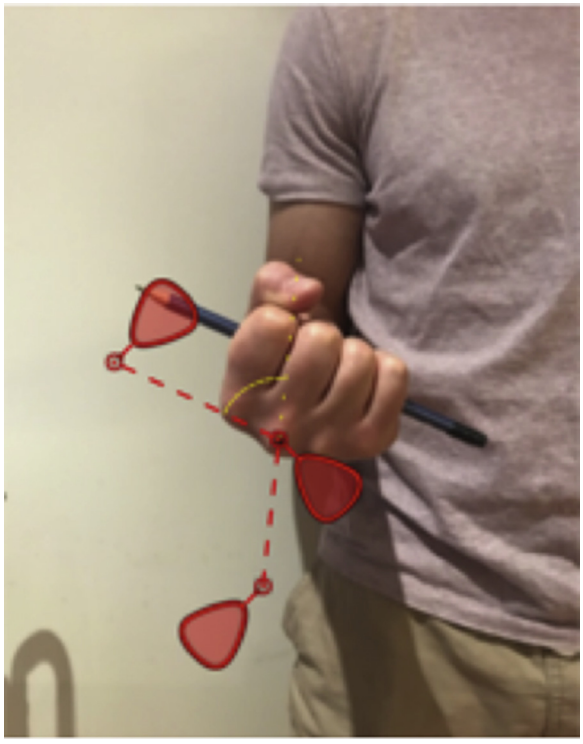


Fig. 3. Positioning of the 3 measurement points of the DrGoniometer application.

Bland-Altman plots were used to visually assess the intrarater and inter-rater agreement of each measurement method for any systematic bias.[24] The mean of the 2 measurements was used as the dependent variable, and the difference between the 2 measurements was used as the independent variable.[25]

Validity

Construct validity was estimated using Pearson correlation coefficient, *r*, between the 2 methods of goniometry. The thresholds for interpretation of the *r* were as follows: <0.30 = poor, 0.30-0.60 = moderate, and >0.60 = good.[26] For this analysis, we used the measurements taken by assessor 1.

Results

Data were collected during a 1-year period from September 2016 to September 2017.

Demographics

A total of 30 fractured forearms and 30 healthy forearms were measured. Demographic data for each of these groups can be found in Table 1. Participant age ranged from 22 to 73 with an average of 55 years in the fractured forearm group and 21-73 with an average of 53 years in the healthy forearm group. Seventy percent of the forearms measured in the fractured forearm group were left sided, whereas 73% of the forearms measured in the healthy forearm group were right sided. Seventy-seven percent of the fractured forearm group and 80% of the healthy forearm group were females.

Intrarater reliability

Intrarater reliability results, including ICCs (and 95% confidence intervals), SEMs, and MDCs, are displayed in Table 2.

Table 1
Group demographics

Characteristic	Fractured forearm group	Healthy forearm group
Sample size	30	30
Mean age (range)	55 (22-73)	53 (21-73)
Left-hand:right-hand ratio	21:9	8:22
Male:female ratio	7:23	6:24

Intrarater reliability of both DrGoniometer and the universal goniometer was excellent across both groups. The universal goniometer demonstrated slightly higher point estimates than DrGoniometer in both the fractured forearm group (0.88 vs 0.87) and the healthy forearm group (0.79 vs 0.74).

The SEM in the fractured forearm group was 6.4 for DrGoniometer and 6.3 for the universal goniometer, converting to an MDC90 of 15° for both measurement tools. The SEM in the healthy forearm group was 5.4 for DrGoniometer and 4.5 for the universal goniometer, converting to an MDC90 of 12° and 10°, respectively.

Inter-rater reliability

Inter-rater reliability results, including ICCs (and 95% confidence intervals), SEMs, and MDCs, are displayed in Table 3.

Inter-rater reliability of both DrGoniometer and the universal goniometer was good to excellent in the fractured forearm group (0.76 and 0.72, respectively) and poor to fair in the healthy forearm group (0.34 and 0.42, respectively). In the fractured forearm group, DrGoniometer demonstrated a higher point estimate compared with the universal goniometer (0.76 vs 0.72). In the healthy forearm group, DrGoniometer demonstrated a lower point estimate compared with the universal goniometer (0.34 vs 0.42).

The SEM in the fractured forearm group was 8.7 for DrGoniometer and 9.7 for the universal goniometer, converting to an MDC90 of 20° and 23°, respectively. The SEM in the healthy forearm group was 8.6 for DrGoniometer and 7.5 for the universal goniometer, converting to an MDC90 of 20° and 18°, respectively.

Bland-Altman analysis

Bland-Altman plots assessing the intrarater and inter-rater agreement of both tools can be found in Figure 4. The mean of the 2 measurements is plotted against the x-axis, and the difference between the 2 measurements is plotted against the y-axis. Visual assessment of the plots revealed no systematic bias across the methods. An exception existed for the inter-rater reliability of both DrGoniometer (Fig. 4G) and the universal goniometer (Fig. 4H) in the healthy forearm group. Figures 4G and 4H demonstrate an increase in the difference between the assessors' measures as the mean of the scores increases.

Table 2
Intrarater reliability of DrGoniometer and the universal goniometer

Groups	Method	ICC (95% confidence interval)	SEM	MDC90 (°)
Fractured forearm	DrGoniometer	0.87 (0.75-0.94)	6.4	15
	Universal goniometer	0.88 (0.77-0.94)	6.3	15
Healthy forearm	DrGoniometer	0.74 (0.53-0.87)	5.4	12
	Universal goniometer	0.79 (0.61-0.90)	4.5	10

ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC90 = minimal detectable change within a 90% confidence interval.

Table 3
Inter-rater reliability of DrGoniometer and the universal goniometer

Groups	Method	ICC (95% confidence interval)	SEM	MDC90 (°)
Fractured forearm	DrGoniometer	0.76 (0.56-0.88)	8.7	20
	Universal goniometer	0.72 (0.49-0.85)	9.7	23
Healthy forearm	DrGoniometer	0.34 (−0.01 to 0.62)	8.6	20
	Universal goniometer	0.42 (0.09-0.68)	7.5	18

ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC90 = minimal detectable change within a 90% confidence interval.

Validity

The Pearson correlation coefficient calculated between the tools in both the fractured forearm and healthy forearm groups is displayed in Table 4. Correlation between the tools was good across both groups (0.94 and 0.93, respectively).

Discussion

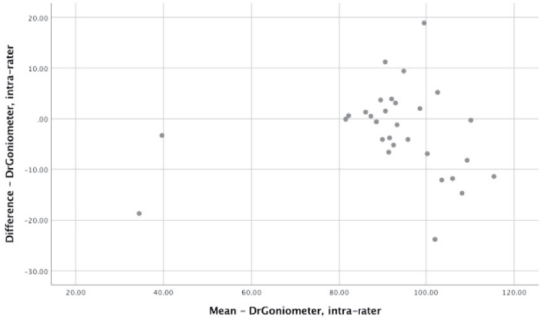
DrGoniometer and the universal goniometer demonstrated good-to-excellent intrarater and inter-rater reliability in both the fractured forearm and healthy forearm groups. An exception existed in the healthy forearm group, where both DrGoniometer and the universal goniometer demonstrated poor inter-rater reliability (ICC, 0.34 and 0.42, respectively). On review of the DrGoniometer photographs, it was found that in the healthy forearm group, a difference in the participant's end-range supination could be visually discerned between assessors. It is hypothesized that although the assessors were given a standardized set of instructions, some assessors may not have relayed these instructions to the participant. This may have influenced the participant's end position. If the assessor requested the participant to turn their forearm over as far as possible, per the standardized instructions, this may have elicited a measurement of greater than 90° in the healthy forearm group who had no supination restriction. Alternatively, had the assessor only asked the participant to turn their forearm to the ceiling, this may have limited the movement to approximately 90°. Any variation of instruction would have less influence on the end-range supination position of the fractured forearm group because many of these participants were restricted in their ROM and would not have been able to achieve greater range even with encouragement. This may explain why the inter-rater reliability of the tools was poor only in the healthy forearm group and not the fractured forearm group. Similarly, the intrarater reliability of both tools was good to excellent regardless of group because the same instructor repeated the instructions to each participant, thereby decreasing the chance of instruction variation between measurements.

The MDC90s calculated in this study are higher than those previously stated in the literature.[11,27] In this study, the MDC90s ranged from 10° to 15° for intrarater reliability and 18° to 23° for inter-rater reliability. The MDC90 for measuring forearm supination using the universal goniometer in populations with known forearm pathologies has been demonstrated to be as low as 3°.[27] The higher MDCs in our study may be attributed to the smaller sample size and larger standard deviations within the groups.

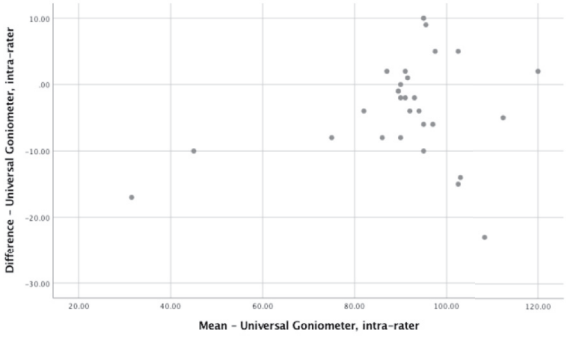
The higher MDC90s may also be attributed to the measurement approach. For both measurement tools used in this study, the participants were required to hold a pencil in their fist as a measurement reference point. Alternate studies have chosen to measure forearm rotation by aligning the goniometer arm with the volar aspect of the wrist.[10,11,27] There is debate in the literature as to

Intra-rater Reliability

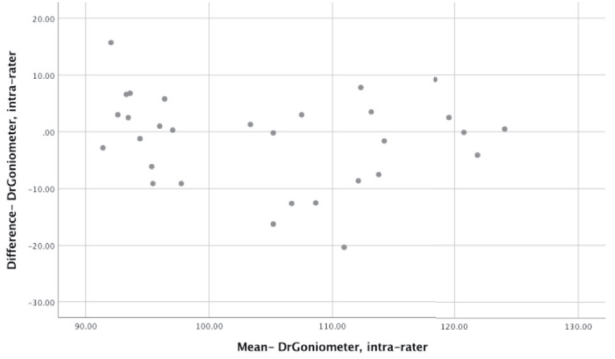
A - DrGoniometer, 'fractured forearm' group



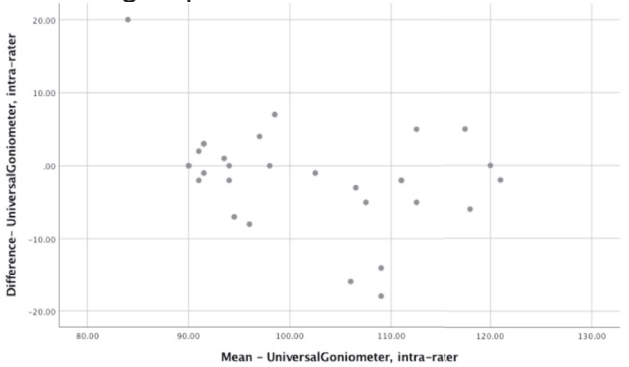
B - Universal Goniometer, 'fractured forearm' group



C - DrGoniometer, 'healthy forearm' group

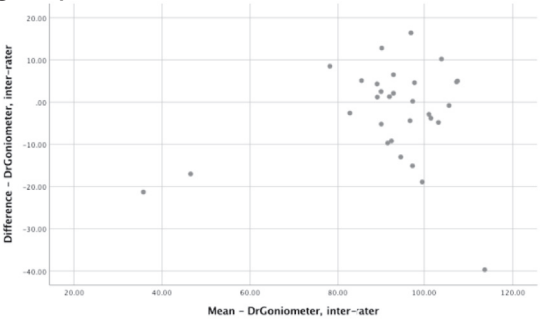


D - Universal Goniometer, 'healthy forearm' group

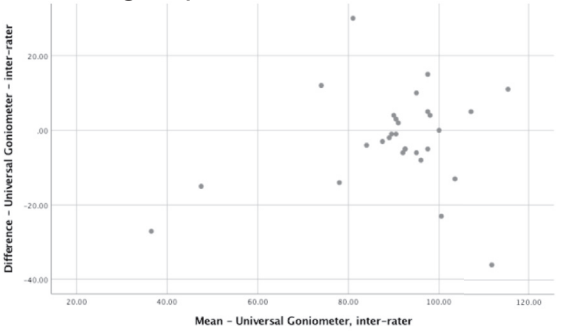


Inter-rater Reliability

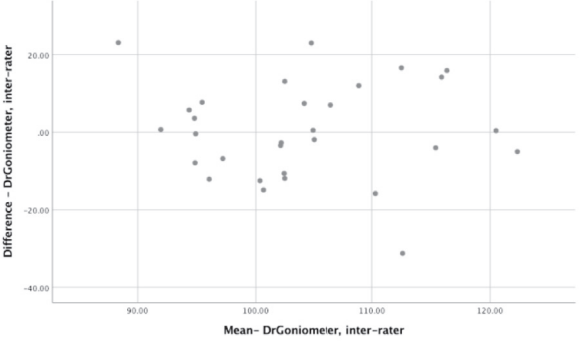
E - DrGoniometer, 'fractured forearm' group



F - Universal Goniometer, 'fractured forearm' group



G - DrGoniometer, 'healthy forearm' group



H -Universal Goniometer, 'healthy forearm' group

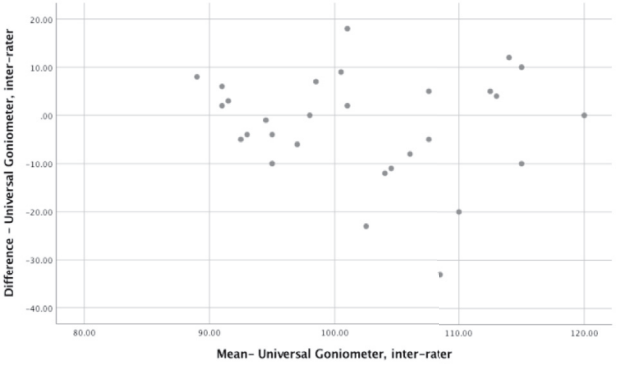


Fig. 4. Bland-Altman plots of DrGoniometer and universal goniometer (**A**-**D**) intrarater and (**E**-**H**) inter-rater reliability.

Table 4
Validity of DrGoniometer when compared with the universal goniometer

Group	Pearson correlation coefficient
Fractured forearm group	0.94[a]
Healthy forearm group	0.93[a]

[a] Significant at the .01 level.

the accuracy of the handheld pencil method, as used in our study, because it allows for movement at the wrist and carpal joints to increase the perceived supination ROM at the forearm.[13] However, the handheld pencil method was chosen for this study as it allows for the total functional movement produced by the forearm-wrist-carpal complex to be measured, and it may therefore be a useful technique for measuring functional capability.[12]

Despite the larger MDC90s found in this study, the MDC90s of DrGoniometer and the universal goniometer were found to be comparable, indicating similar accuracy between the tools for detecting changes in supination ROM.

Strengths of this study included the comparison of DrGoniometer to the current gold standard, blinding of the assessors, and the inclusion of participants with pathologies. As mentioned, another strength of this study was the use of the handheld pencil method as it allowed for the functional capability of the forearm to be measured.[12] This study was also designed such that it reflected the full clinical use of the app by requiring the assessor to both photograph the joint and align the app's measurement points. This overcame the limitations of a previous DrGoniometer study that did not require the assessors to take the photographs and only required the assessors to measure a set of 28 preprepared images.[17]

One weakness of this study is that although assessors were blinded to their previous measurements, assessor 1 only waited 30 minutes between measurement sets. Hence, there was the potential that assessor 1 may have remembered their first set of measurements, which would serve to bias their second set of measurements. Another weakness is that some participants were measured on more than one occasion, as they attended multiple measurement points of the larger RCT, effectively reducing the sample size of this study. However, the participants were concurrently undergoing physiotherapy to regain forearm ROM after distal radius fracture, and it was therefore expected that their ROM would vary between measurement points of the larger RCT (baseline, at 4 weeks, and 12 weeks after the start of the intervention). The participants who were measured on more than one occasion were therefore considered as a new data set at each point. A final weakness of this study is that there was no standardization of the distance between the smartphone's camera and the forearm to be measured. This may have introduced varying degrees of parallax error.

Overall, DrGoniometer was shown to be a valid alternate tool for measuring forearm supination when compared with the universal goniometer. As previously mentioned, the speed in which the photograph can be obtained is advantageous in the case of the irritable patient, and the digital record produced is useful for comparison during follow-up treatments, telerehabilitation,[16] and medicolegal purposes.[15] As was realized in our study, the app is also advantageous for use in clinical studies as the photograph and data produced can be consulted if a measurement error is suspected. A further advantage of DrGoniometer is that once the app's measurement points have been placed on the photograph, the app automatically calculates and displays the angle to avoid calculation errors that may occur when reading the measurement off a universal goniometer.

A disadvantage of using DrGoniometer to measure joint angles is that the overall measurement process is slower than with the universal goniometer. Although the photograph can be quickly taken to decrease the amount of time that the patient must sustain an irritable position, the user must then save the photograph and apply the app's measurement points. This can be more time consuming than aligning the arms and reading the measurement directly off the universal goniometer. Consequently, the use of DrGoniometer may not be practical in some time-limited settings, and this may discourage clinicians from using the app. Future research in this area may therefore be of a qualitative nature to establish the barriers to use of DrGoniometer. If these barriers can be overcome, clinicians may be encouraged to adopt the use of DrGoniometer such that the advantages of the app can be realized.

In conclusion, DrGoniometer is an equivalent tool for measuring forearm supination when compared with the universal goniometer in healthy populations and populations with known forearm fractures. DrGoniometer demonstrated excellent intrarater reliability and good validity. However, although the inter-rater reliability was good to excellent in the fractured forearm group, it was poor to fair in normals. Furthermore, it displayed good agreement measures in those with fractures.

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JHT Read for Credit
Quiz: # 597

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1. The article refers to the "pencil in the palm" and a traditional plastic goniometer method as
   a. unreliable for clinical use
   b. the gold standard for measuring forearm supination
   c. being attributable to LaStayo et al
   d. frought with inconsistencies
2. To use the DrGoniometer method, the examiner must have access to
   a. statistical software to analyze results
   b. a computer
   c. surface EMG equipment
   d. a smart phone
3. How many points are needed to determine the degrees of supination
   a. 1
   b. 2
   c. 3
   d. 4
4. The technique calls for
   a. the patient to have full digital ROM in order to grasp the pencil tightly
   b. aligning the head of the 3rd metacarpal with the center of the phone screen
   c. aligning the plane of the phone screen parallel with the long axis of the humerus
   d. making a vector analysis of the phone screen to determine its exact center point
5. One may infer that a SEM and MDC would be high, suggesting significant limitations to its clinical accuracy
   a. true
   b. false

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