Reliability and concurrent validity of mobile health technology for patient self-monitoring in physical rehabilitation

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Background: Forearm pronation and supination are important for everyday functional tasks and some recreational activities. Healthcare providers use reliable and valid tools during the physical rehabilitation process to measure joint range of motion (ROM), assess functional mobility, guide decisions for skilled interventions, and progress a plan of care. Since the onset of the COVID-19 pandemic, both healthcare providers and patients benefited from mobile health technologies that have emerged, which can be used by patients in the home to monitor ROM and assist the healthcare provider in guiding the rehabilitation process when utilizing telehealth.
Purpose: The goal of this study was to investigate the reliability and concurrent validity of a smartphone application for obtaining goniometric measurements of forearm pronation and supination.
Methods: This study consisted of 83 participants that were recruited on a voluntary basis from an academic institution. An iPhone with the application Clinometer and a standard goniometer (SG) were utilized to obtain goniometric measurements of forearm pronation and supination. The intraclass correlation coefficient (ICC) was used to analyze intrarater reliability, and the Pearson correlation coefficient was used to analyze concurrent validity. Scatterplots with regression lines were created to visually display the results.
Results: The smartphone demonstrated strong correlations for both pronation and supination ($r = 0.71$, $P < .001$; $r = 0.73$, $P < .001$). This study demonstrated overall good-excellent intrarater reliability and good concurrent validity for the smartphone application with a higher test-retest reliability in the measurement of forearm pronation compared to supination.
Conclusions: This study concludes that the reliability and concurrent validity of the smartphone was consistent with the SG for assessing forearm pronation and supination. It may be of value to further investigate interrater reliability between patient and healthcare practitioner, and report on the ease of use to assess ROM with a smartphone.

The use of mobile health technologies in clinical practice has consistently increased over recent years.[23] The COVID-19 pandemic further increased usage as healthcare moved toward telehealth and patient instructed self-management. In recent years, mobile health devices such as smartphones have been introduced as an alternative to the standard goniometer (SG).[12] Smartphones have built-in sensors such as accelerometers, magnetometers, and gyroscopes that make them capable of detecting joint positions and measuring joint range of motion (ROM). These sensors, and specific goniometric applications, allow clinicians to take valid and quantifiable ROM measurements. In a telehealth environment, they offer the patient a free and easily accessible method of providing information to the healthcare provider. Having a way to assess ROM through telehealth allows healthcare providers to understand patient impairments, create objective goals, and assess progress in a virtual environment. Prior studies have reported good reliability of goniometric applications to assess sagittal plane ROM in various body regions.[2,5,6,9,10,13,14,28] However, there appears to be a lack of research to support reliability and validity for assessing ROM with a smartphone specifically for transverse plane/rotary motion such as forearm pronation and supination.[25] Therefore, the goal of this study was to investigate the intrarater reliability and concurrent validity of a smartphone application when used to assess joint ROM. This will hopefully serve as the first step to the future

Figure 1 (**A**) Clinometer application on the iPhone, (**B**) Standard half-circle goniometer used to measure forearm ROM.

establishment of reliability and validity of smartphones for patient self-monitoring of forearm ROM in a telehealth environment.

Adequate forearm ROM is fundamental to perform activities of daily living (ADLs) such as personal grooming, opening a door, and steering a car. For example, 50° of forearm pronation and 60° of forearm supination is needed to do activities involving lifting, grabbing, and placing items down.[11] Vocational activities that require the use of a keyboard need at least 65° of forearm pronation, opening a door requires at least 80° of forearm pronation available. Thus, it is important for healthcare providers to assess and reassess forearm ROM during the physical rehabilitation process to ensure sufficient progress toward return to function.

While the SG is a widely used tool for measuring joint ROM, other tools for this purpose are available to healthcare providers.[7] There are a few benefits when using smartphones for ROM assessment. First, many smartphone applications used to assess ROM are free of cost, providing a low-cost method for measuring ROM when compared to other tools such as an SG or digital inclinometer. Second, smartphone applications are easy to download and readily available, which makes it possible for healthcare providers to obtain ROM measurements in a time-effective manner. Third, most individuals own or have access to a smartphone, making them easily accessible to both healthcare providers and patients.

Smartphones have built-in sensors such as accelerometers, magnetometers, and gyroscopes that make them capable of detecting joint positions and measuring joint ROM.[4,16] By reporting on the reliability and validity of these mobile devices, healthcare providers and patients have an option to use these tools for simplified assessment and evaluation for rotary movements such as forearm pronation and supination, as well as monitoring patient progress toward functional goals during the rehabilitation process for impairments related to the upper extremity.

Materials and methods

Participants

Healthy individuals were recruited on a voluntary basis. The total sample size of participants meeting inclusion criteria was 83; 35 who identify as male and 48 who identify as female. The age span for all participants ranged from 22 to 65 years old, with nine left-hand dominant and seventy-four right-hand dominant. Exclusion criteria were any skin allergies or sensitivities, previous injury, current complaint of pain, numbness or tingling in the dominant upper extremity (UE), previous medical treatment to the UE, previous surgical intervention, and previous physical or occupational therapy to the UE.

Instruments

The instruments utilized for data collection are represented in Figure 1. They include (A) an iPhone with a gravity-based inclinometer application installed on the device: *Clinometer Version 4.9.2 by Plaincode*, and (B) one half-circle body SG. This application was selected as previous studies reported this application to be a reliable and valid option for measuring ROM in various joints.[3,16] Gravity-based applications use an accelerometer in the smartphone, but minimizes the effects of gravity rather than using acceleration forces to measure ROM. For data collection, two homogeneous iPhones were used. The application selected utilizes the smartphone's built-in accelerometer to measure joint angulation. The half-circle SG was used in this study to compare measurements between the smartphone and a gold-standard tool that is commonly utilized by healthcare professionals. It has been reported the Standard Error of Measurement (SEM) for the SG to be 3.5° while the Minimal Detectable Change (MDC) at a 95% confidence interval (CI) ranged from 4° to 21° with a mean of 9.6°.[1,20,21]

Ethical approval

Ethical approval to conduct this study was granted by Touro College School of Health Sciences Institutional Review Board. Prior to data collection, participants reviewed and signed an informed consent.

Tester selection and procedure

The testers for this study were two third-year Doctor of Physical Therapy (DPT) students who received training from the authors on handling the smartphone when assessing ROM. Accuracy for tester selection was determined by having five third-year DPT students perform the following procedure: landmarks were denoted with a charcoal pencil on the styloid process of the ulna and styloid process of the radius at the wrist. The Clinometer application was reset between each measurement to assure that each measurement began at the anticipated measure of zero degrees. The calibration and blinding procedure are shown in Figure 2. Each tester measured pronation and supination. Testers were blinded to the displayed readings by turning the display screen away from the tester, and one of the authors recorded the measurements. Each
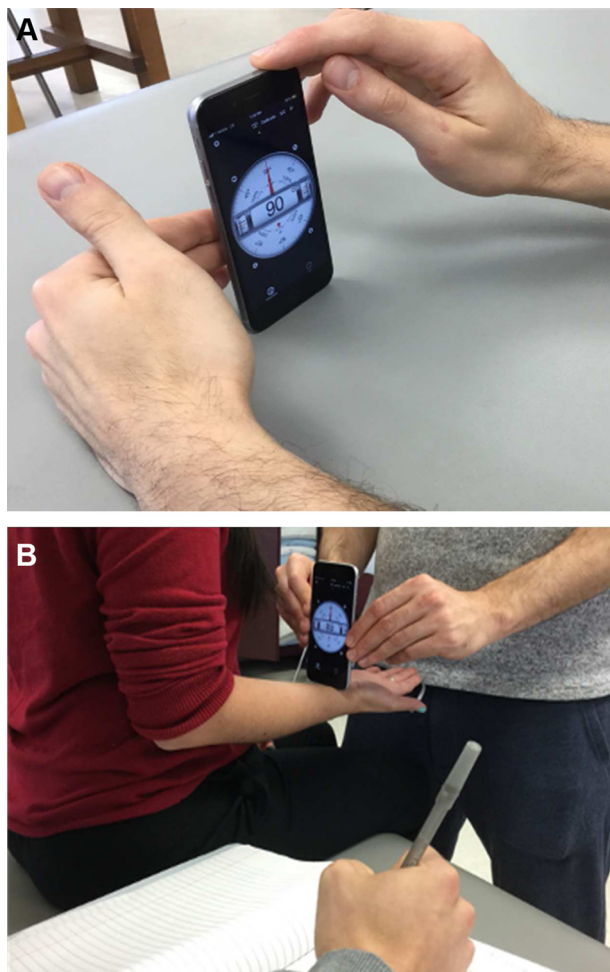
Figure 2 (**A**) Calibration procedure between subjects, (**B**) Blinding procedure for testers.

Table I
Comparison of smartphone and standard goniometer for pronation and supination with ICC at 95% and SEM.

	Standard goniometer (degrees)	iPhone (degrees)
Pronation (mean)	77.5 (5.5)	81.5 (6.5)
Supination (mean)	79.6 (5.3)	81.9 (6.9)

ICC, intraclass correlation coefficient; *SEM*, standard error of measurement.

tester performed three repeated measures, then the SEM was calculated for each tester. The two testers with the lowest SEM were selected to proceed as testers for the study.

For data collection, the procedure described above was followed, including randomization of measurement and device. In addition, participants were shown the proper arm and hand positioning for pronation and supination, followed by a demonstration of the movements. The starting position of the participant was with their dominant upper extremity at their side and with their elbow in 90° of flexion and the forearm in a neutral position. Three separate measurements were obtained for forearm pronation and supination using both an SG and the smartphone, and the averaged value was used for data analysis. Finally, another cycle of measurements was repeated to obtain corresponding measurements to evaluate intrarater reliability.

Data analysis

Data were analyzed using SPSS Statistics v25 (IBM, Armonk, NY, USA). Concurrent validity was determined using the Pearson Correlation Coefficient through a comparison of goniometric and iPhone measurements. Intrarater reliability was determined using the Intraclass Correlation Coefficient (model 3,1).

Results

Measured values

Average pronation and supination with standard deviation (SD) values are reported in Table I. Pronation in degrees was 77.3 (5.5) for the SG and 81.5 (6.5) for the smartphone, supination was 79.6 (5.3) for the SG and 81.9 (6.9) for the smartphone.

Concurrent validity

Figure 3 illustrates the relationship for pronation and supination respectively between the smartphone and standard goniometer. The smartphone and standard goniometer demonstrated strong correlations for both pronation and supination (r = 0.71, $P < .001$; r = 0.73, $P < .001$).
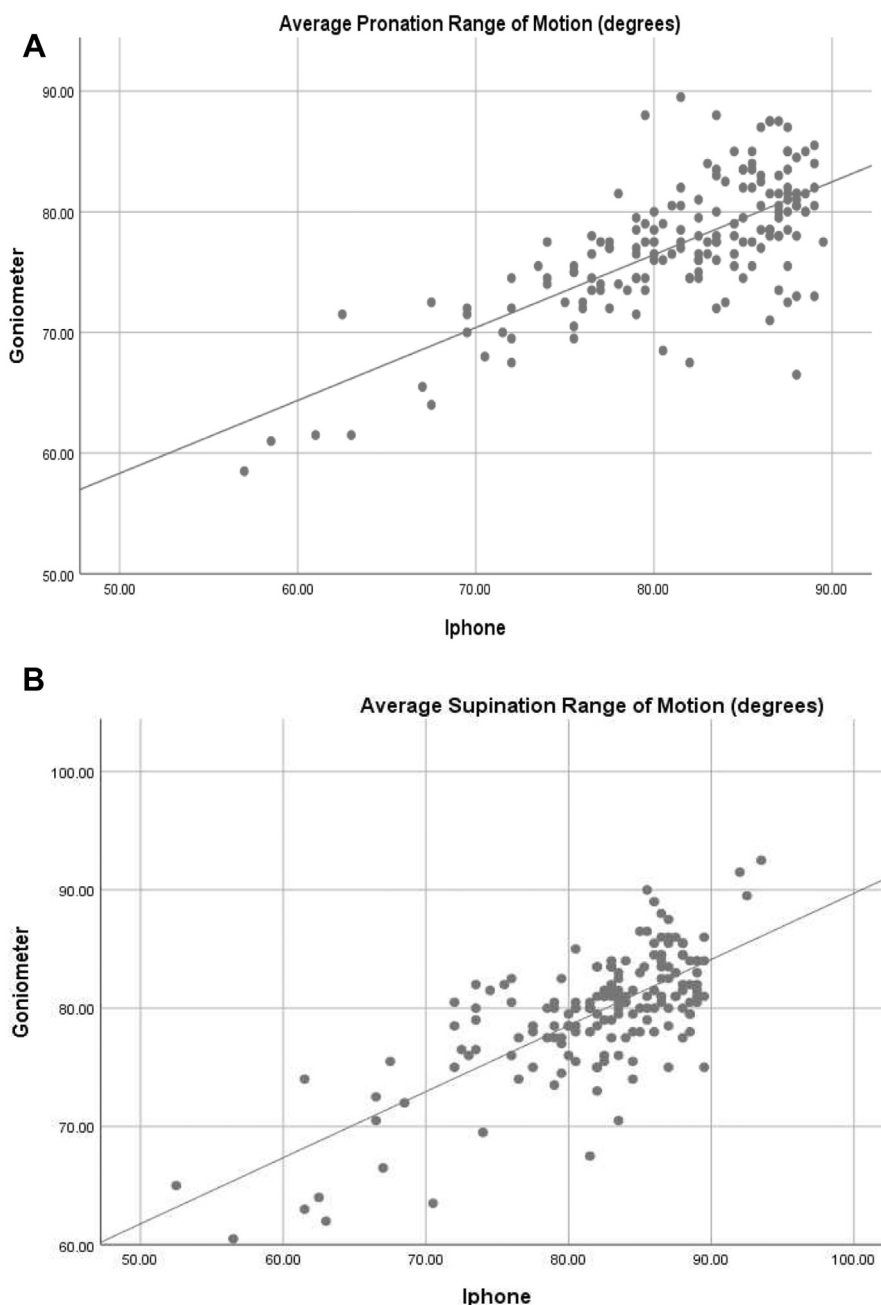
Intrarater reliability

The intrarater reliability between the smartphone and SG for pronation and supination is reported on Table II with ICC values and 95% CI. For both testers, pronation ICC values taken with a smartphone were greater than those taken with the SG, while supination ICC values taken with a smartphone were greater than those taken with the SG for tester one and less than those taken with the SG for tester two. Median values for supination were 80.25° for the SG, as compared to 83.50° for the smartphone. Pronation median values were 77.50° for the SG and 83.00° for the smartphone. These median values indicate that the smartphone provided a higher range of motion value when compared to the SG.

Discussion

In this study, reliability and validity were reported for assessing forearm ROM using a smartphone application entitled Clinometer. Results from this study are significant to healthcare providers such as orthopedic surgeons, medical doctors, physical therapists, occupational therapists, and other healthcare providers treating impairments of the UE. The use of mobile devices in healthcare has been increasing, and as technology advances, clinicians can utilize such tools to assist in the evaluation and guide clinical decision-making. Due to the COVID-19 pandemic, there has been a general movement for healthcare providers toward patient instructed self-management through telehealth, when possible. Mobile devices such as smartphones are easily accessible and simple to use for patients and healthcare providers in reporting ROM and enable healthcare providers to assess/re-assess progress during physical rehabilitation of the UE when a patient is managed via a virtual environment. Patients who are unable or prefer not to leave the home may benefit from these advances in technology.

The purpose of this study was to investigate the intrarater reliability and concurrent validity of a smartphone application when used to assess joint ROM on a transverse/rotary plane, as the first step to the future establishment of reliability and validity of smartphones for patient self-monitoring at home in a telehealth environment. Results from this study demonstrated overall good-excellent intrarater reliability and good concurrent validity for the

Figure 3 Relationship for (**A**) pronation on the smartphone and standard goniometer. (r = 0.71, P < .001) and (**B**) Supination on the smartphone and standard goniometer (r = 0.71, P < .001).

Table II
Intrarater reliability between the smartphone and standard goniometer for pronation and supination shown as ICC, 95% confidence interval.

	Goniometer ICC (95% CI)	iPhone ICC (95% CI)
Pronation		
Tester 1	ICC = 0.68 (0.50-0.81)	ICC = 0.76 (0.61-0.85)
Tester 2	ICC = 0.39 (0.06-0.64)	ICC = 0.66 (0.42-0.82)
Supination		
Tester 1	ICC = 0.64 (0.44-0.78)	ICC = 0.77 (0.63-0.86)
Tester 2	ICC = 0.80 (0.63-0.90)	ICC = 0.60 (0.33-0.78)

ICC, intraclass correlation coefficient; *CI*, confidence interval.

smartphone. These results are consistent with previous literature reporting similar correlation values when assessing joint ROM with a smartphone for supination and other joints in the body.[5,12,15,17,18,21] The smartphone application also demonstrated strong correlations to the SG for both pronation and supination, respectively r = 0.71, P < .001, r = 0.73, P < .001. There was one exception: pronation with a goniometer for one of the testers. This value may be due to human error in phone position, consistency between measurements, or not using the landmarks accurately. Additionally, previous studies have reported standard error for forearm pronation and supination measured with an SG: +/−7.7° for pronation and +/−14.3° for supination.[2,26] Therefore, larger standard error values can impact the ICC values but still be consistent with the standard tools used in clinical practice today. Median values for supination were 80.25° for the goniometer as compared to 83.50° for the smartphone.

Pronation median values were 77.50° for the goniometer and 83.00° for the Smartphone. These results indicate the smartphone is comparable to the gold-standard tool, SG, when used to assess forearm pronation and supination. These results are also consistent with previous studies that reported ICC values for various joints in the body.[17,20-22]

Few studies have investigated the reliability and validity of smartphone applications for forearm pronation and supination. This may be due to greater complexity in assessing transverse plane/rotary motion, such as with pronation and supination, rather than sagittal plane/straight plane motion such as knee flexion/extension. Other studies reported good to excellent reliability and validity in the measurement of forearm pronation and supination.[19] Results from the current study demonstrated overall good-excellent intrarater reliability and good criterion validity.

There are many foreseeable benefits of using the iPhone or other smartphones for joint ROM assessment. First, most people today own or have access to a smartphone. Recent studies reported that seven out of ten Americans carry a smartphone.[8] In a recent study, 46 out of 48 third-year student physical therapists reported owning a smartphone.[11] Second, the portability of a smartphone compared to an SG makes it an attractive prospective measurement device. Third, the small profile of many smartphone devices can also allow for one-handed use, then the clinician's free hand can then be used for patient positioning while working with patients who need that extra stabilization as for patients with neurological conditions. Last, smartphones may provide patients with an easy mechanism to measure their own ROM, which is helpful for healthcare providers utilizing telehealth. These conclusions are consistent with suggestions from other studies, which reported on the ease of use for patients using smartphones to take measurements on their own without having to wait to be measured by a licensed practitioner.[21]

Conclusions

This study provides evidence to support the reliability and validity of a smartphone when assessing joint ROM of forearm supination and pronation. This study also demonstrated comparable reliability and validity of a smartphone application to the SG when assessing forearm supination and pronation and was consistent with previous studies that reported on sagittal plane ROM.[5,12,15,24,27] This provides healthcare providers with another reliable and valid tool to assess forearm ROM. Most individuals own a smartphone, making this tool readily available. This tool does not require visual estimation for alignment as with the stationary arm; and thus, may be more time efficient and simplified. Recommendations for future studies are to include participants that have diagnosed impairments to the shoulder, elbow, wrist, or hand. It would also be beneficial for future studies to include a larger sample of participants to assess normal distributions and to repeat this study with more than two testers to report stronger conclusions on interrater reliability and validity values.

Disclaimers:

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