JHT READ FOR CREDIT ARTICLE #644.
Scientific/Clinical Article

# Self-measured wrist range of motion by wrist-injured and wrist-healthy study participants using a built-in iPhone feature as compared with a universal goniometer

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## ABSTRACT

*Study Design:* Cross-sectional cohort.
*Introduction:* Smartphone gyroscope and goniometer applications have been shown to be a reliable way to measure wrist ROM when used by researchers or trained staff. If wrist-injured patients could reliably measure their own ROM, rehabilitation efforts could be more effectively tailored.
*Purpose of the Study:* To assess agreement of self-measured ROM by wrist-injured and wrist-healthy study participants using a built-in iPhone 5 level feature as compared to researcher-measured ROM using a universal goniometer (UG).
*Methods:* Thirty wrist-healthy and 30 wrist-injured subjects self-measured wrist flexion, extension, supination, and pronation ROM using the built-in preinstalled digital level feature on an iPhone 5. Simultaneously a researcher measured ROM with a UG.
*Results:* Average absolute deviation between the self-measured iPhone 5 level feature and researcher-measured UG ROM was less than 2° for all 4 movements individually and combined was found to be 1.6° for both populations. Intraclass correlation coefficient showed high correlation with values over 0.94 and Bland-Altman plots showed very strong agreement. There was no statistical difference in the ability of wrist-injured and healthy patients to self-measure wrist ROM.
*Discussion:* Both populations showed very high agreement between their self-measured ROM using the built-in level feature on an iPhone 5 and the researcher-measured ROM using the UG. Both populations were able to use the iPhone self-measurement equally well and the injury status of the subject did not affect the agreement results.
*Conclusion:* Wrist-healthy and wrist-injured subjects were able to reliably and independently measure ROM using a smartphone level feature.

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## Introduction

Measurement of range of motion (ROM) is a fundamental assessment tool used by hand therapists to determine the progression of recovery and the effectiveness of exercises in rehabilitation. A handheld universal goniometer (UG; Elite Medical Instruments, Fullerton, CA) is currently the clinically used gold standard for measurement of wrist ROM, but it requires a trained examiner.[1]

The use of smartphone goniometer technology to measure wrist ROM is of growing interest because of potential ease of use of this technology and the wide availability of smartphones that could allow patients to take their own measurements at home. The Pew Research Center reports that as of June 2017, 77% of American adults own a smartphone[2] and 62% of American adults reported using their smartphones to access information about a health condition, including 77% of those less than 30.[3] If smartphone goniometry technology is shown to be an accurate and reliable measure of wrist ROM compared with standard UG, and if wrist-injured patients could reliably use smartphone goniometry technology themselves, this technology has the potential to allow providers to track home progress and thereby modify treatment plans and follow-up. In addition, the immediate and direct feedback could incentivize patients to be more actively involved in their own care and recovery.

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Previous work evaluating smartphone technology to measure wrist ROM has been promising, with demonstration of high measurement agreement between smartphone goniometer technology with a UG when all measurements were performed by a research evaluator or a physiotherapist. Kim et al[4] showed that there were no statistically significant differences in average measurement values when using a UG compared with an iPhone 4 (Apple, Cupertino, CA) gyroscope application in wrist-healthy participants when measured by research evaluators. Pourahamadi et al[5] found the iPhone Goniometer Pro application to have good intrarater and inter-rater reliability compared with UG when measuring wrist ROM in a wrist-healthy participant by research examiners. Santos et al[6] built on this work using both wrist-healthy and wrist-injured subjects and showed that there was a high intraobserver consistency and interobserver reliability when using either an iPhone 5 gyroscope application or a UG to measure wrist supination and pronation by qualified physiotherapists.

Although previous studies relied on researchers using the iPhone for measurements, the primary purpose of this study was to expand on the use of smartphone technology in wrist rehabilitation, and specifically determine if *wrist-injured* subjects could *self-measure* wrist ROM using the iPhone 5 as a goniometer, and if these measurements agreed with the standard clinical measurements obtained by a trained researcher using a UG. To answer this question, both wrist-injured and wrist-healthy subjects were recruited, and the agreement was calculated between the iPhone measurements obtained by the subject and the standard UG measurements obtained by a researcher. As a secondary outcome, these results from both wrist-injured and wrist-healthy subject populations were compared to examine if wrist-injured subjects could use the iPhone with the same accuracy and agreement as wrist-healthy subjects.

## Materials and methods

### Study design

This study was a cross-sectional cohort design involving 2 populations: 30 wrist-injured subjects and 30 wrist-healthy subjects. We estimated the sample size with a 2-sided 95% confidence interval for intraclass correlation coefficient (ICC) with a total interval width of 0.20 (ie, ICC, ±0.10) to be 60 subjects with 8 observations per subject using the procedure for confidence interval for intraclass correlation in Power Analysis and Sample Size Software 2017 (NCSS, LLC. Kaysville, Utah, USA). The inclusion criterion for the healthy population was any adult volunteer with no history of injury affecting wrist ROM. The inclusion criterion for the injured population was any adult volunteer who had any wrist injury that required current hand therapy. The wrist-healthy population had a mean age of 38 (standard deviation [SD], 15; range, 20-65). The wrist-injured population had a mean age of 47 (SD, 19; range, 18-92). The study subjects were voluntary and kept anonymous, with the only subject-specific data being their age, hand dominance, and what injury they had, if any. The study was conducted after institutional review board approval.

### Measurement technique

The smartphone (iPhone 5; Apple, Cupertino, CA) built-in digital level feature was used as a goniometer for this study. The feature was accessed through the compass application, which is located in the utilities folder; this application is preloaded on the iPhone 5 and iPod Touch devices. Swiping left on the compass screen accesses a horizontal and vertical level. Before each measurement, the phone was zeroed on a flat table surface by placing the phone upright on a flat surface and tapping the screen to read 0°.

Each study subject was instructed on how to measure flexion, extension, pronation, and supination using the iPhone 5 level feature (Video Attachment 1). Each subject self-measured all 4 motions, twice on each wrist for a total of 16 readings by the iPhone 5 level feature. Although the study subject self-measured their ROM with the iPhone 5 level appropriately placed on the hand, a researcher simultaneously measured the same 16 measurements using a UG. Simultaneous measurement by the iPhone 5 and the UG for the same subject movement was conducted to allow for direct comparison of ROM measurements and to control for inherent variability in repeated ROM measurements. During the study, the iPhone 5 screen faced the subject the researcher was blinded to the subject's self-measured results. Note, in Figures 1A-4B, the iPhone 5 faces the camera solely to demonstrate readings.

For measurement of wrist flexion and extension, the subject sat upright and put his and/or her elbow on the table, forearm vertical, and fingers extended in a neutral position. For flexion, the subject held the zeroed iPhone 5 with their contralateral hand against the dorsal side between the second and third metacarpal bones (Fig. 1A). The wrist to be measured was then palmar flexed, and the iPhone 5 level reading was recorded (Fig. 1B). While maintaining this position, the researcher then placed the UG adjacent to the iPhone 5 on the dorsum of the hand between the second and third metacarpals. The other arm of the goniometer was aligned with the dorsal aspect of the forearm.

For wrist extension, the zeroed iPhone 5 was placed along the palmar surface of the hand and held by the subject's contralateral hand (Fig. 2A). The wrist to be measured was then dorsiflexed, and the reading was recorded (Fig. 2B). As mentioned previously, the researcher recorded the measurement with a UG by placing one arm of the goniometer next to the iPhone 5 on the palm. The other arm of the UG was aligned with the palmar aspect of the forearm, and the reading was recorded.

Pronation and supination were measured with the subjects seated or standing. The subject adducted their arm against their trunk to avoid shoulder motion and ensure measurement of only forearm supination and pronation. Their elbow was flexed to 90°, and the forearm was held in neutral rotation. For supination, the iPhone 5 was held by the subject's contralateral hand against the wrist to be measured at the level of the wrist crease (Fig. 3A). The measured wrist was then supinated, and the reading was recorded (Fig. 3B). The researcher measured the ROM by placing one arm of the UG across the wrist in a similar position, and the other arm dropped vertically toward the floor.

For pronation, the forearm was positioned in neutral position as in supination measurements mentioned previously. The iPhone 5 was held on the dorsal side of the wrist by the subject's contralateral hand (Fig. 4A). The wrist was then pronated, and the reading was recorded (Fig. 4B). The researcher measured the ROM with the UG by placing one arm of the goniometer along the dorsal aspect of the wrist, next to the iPhone 5, and dropping the other arm vertically toward the floor.

### Statistical analysis

To compare the 30 wrist-healthy and 30 wrist-injured population's percent deviation and absolute difference, a 2-sample Student *t* test was used. Two statistical parameters were examined for analysis of the data:
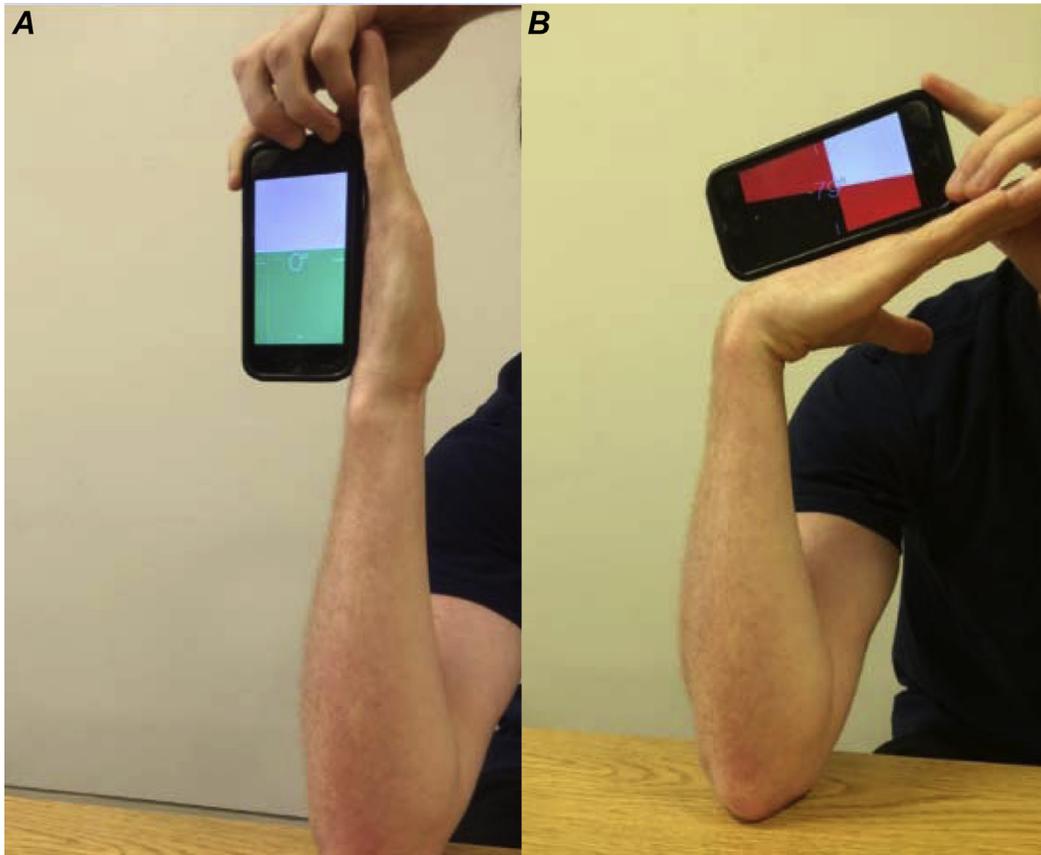
**Fig. 1.** Technique for measurement of wrist flexion. (**A**) Phone zeroed, neutral position. (**B**) Wrist flexed at 79°.
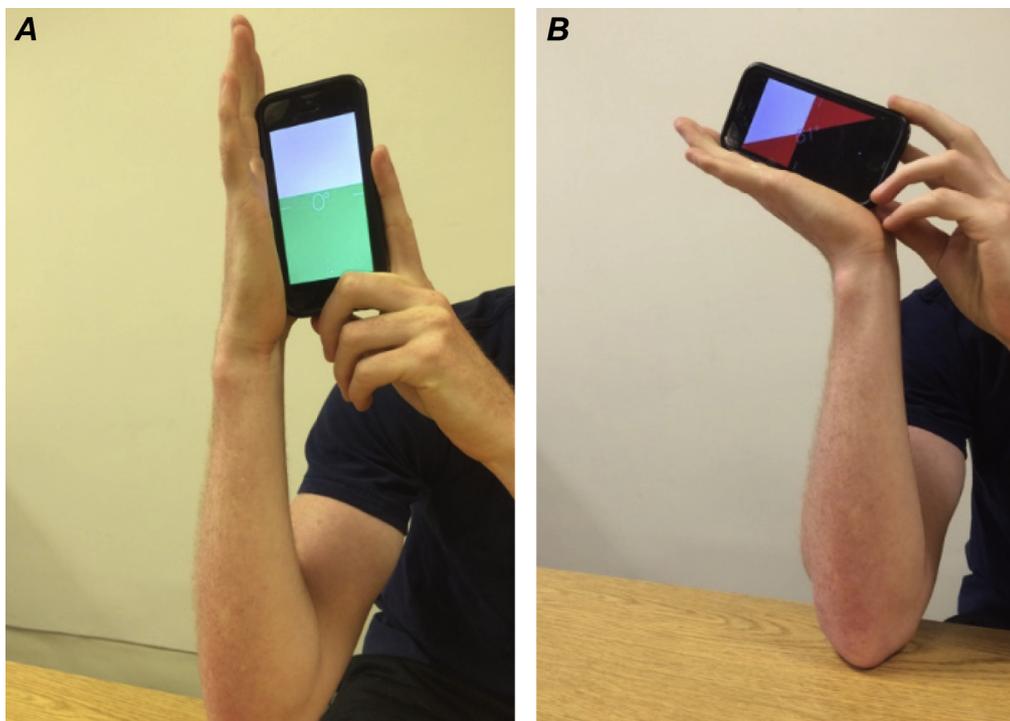


**Fig. 2.** Technique for measurement of wrist extension. (**A**) Phone zeroed, neutral position. (**B**) Extended wrist at 61°.
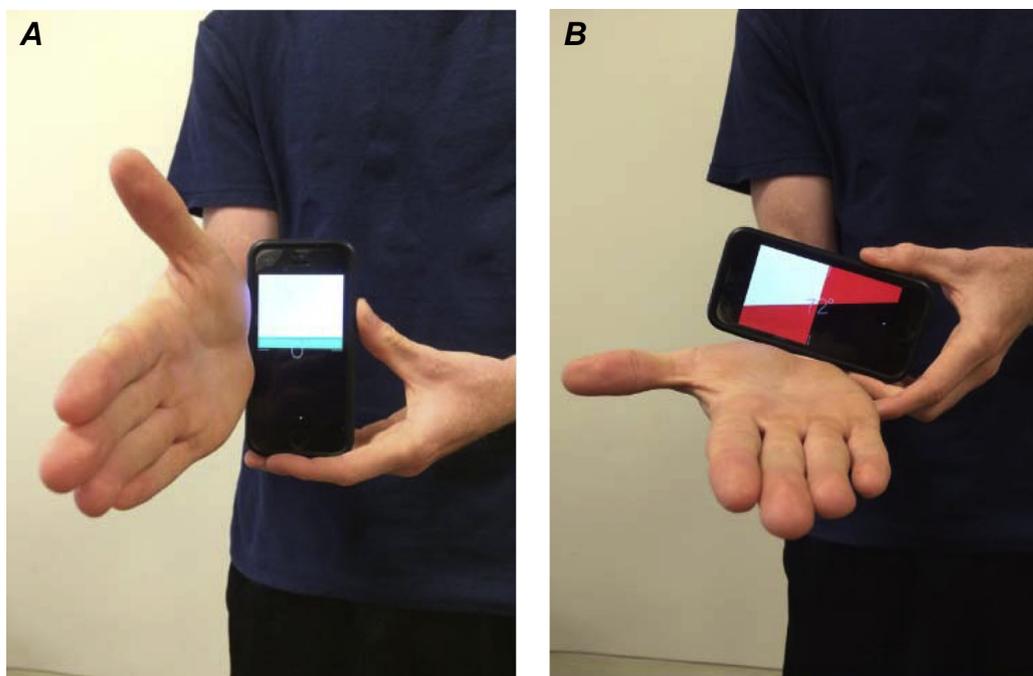
**Fig. 3.** Technique for measurement of supination. (**A**) Phone zeroed, neutral position. (**B**) Supination at 72°.

$$\text{Percent deviation} = \text{Absolute value}\left(\frac{\text{iPhone 5 measurement} - \text{UG measurement}}{\text{UG measurement}}\right) \tag{1}$$

$$\text{Absolute difference} = \text{Absolute value}(\text{ iPhone 5 measurement} - \text{UG measurement}) \tag{2}$$

The null hypothesis was that the 2 populations had the same percent deviation and absolute difference in comparing ROM measurements obtained via the iPhone 5 level feature vs the UG. The alternative hypothesis was that the 2 populations had
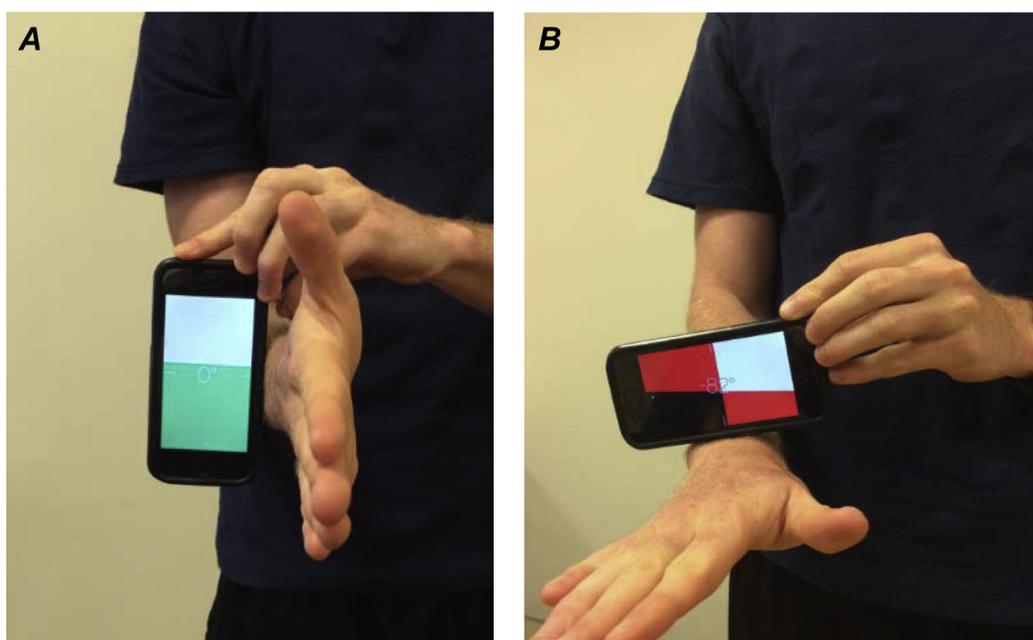


**Fig. 4.** Technique for measurement of pronation. (**A**) Phone zeroed, neutral position. (**B**) Pronation wrist at 87°.

statistically significant differences in the agreement of the iPhone with the UG at the alpha level of 0.05.

ICCs were also calculated to examine correlation between measurement modalities. The ICCs for flexion, extension, supination, and pronation were calculated for both study populations, with 120 paired data points per calculation.

Bland-Altman plots were used to illustrate the agreement between the iPhone 5 level feature as a goniometer and the UG measurement techniques. Bland-Altman plots show instrument bias by depicting the average absolute difference between the 2 measurement techniques on the y-axis as a function of the average ROM measurement, the best estimate of the real value, on the x-axis. For example, for flexion, the average absolute deviation was calculated by averaging the absolute deviation between the 2 measurement techniques for all 4 of the study subject's flexion movements, 2 from the right hand and 2 from the left hand. The best estimate of the real value of the ROM was found by averaging all 8 flexion measurements, 4 from the iPhone 5 and 4 from the UG.

## Results

For the wrist-healthy population, the mean percent deviation of the iPhone 5 level feature from the UG was 2.1% (SD, 3.0%), and the mean absolute deviation was 1.6° (SD, 2.4°). For the wrist-injured population, the mean percent deviation of the iPhone 5 level feature from the UG was 2.9% (SD, 4.7%), and the mean absolute deviation was 1.6° (SD, 2.4°). The ICC for the wrist-healthy population with 95% confidence intervals was as follows: flexion 0.969 (0.956-0.979), extension 0.959 (0.934-0.972), supination 0.945 (0.921-0.962), and pronation 0.955 (0.935-0.969). The ICC for the wrist-injured population with 95% confidence intervals was as follows: flexion 0.990 (0.985-0.994), extension 0.989 (0.984-0.992), supination 0.990 (0.985-0.993), and pronation 0.987 (0.982-0.991).

For the secondary outcome comparing the wrist-injured vs the wrist-healthy subject populations, the Student 2-sample *t* test was found to be 0.44 in comparing the mean percent deviation and 0.95 in comparing the mean absolute degree difference.

The Bland-Altman difference plots for flexion (Fig. 5), extension (Fig. 6), supination (Fig. 7), and pronation (Fig. 8) depict the agreement between the iPhone 5 level feature and the UG methods of measuring ROM. The wrist-injured subjects are shown as red dots, whereas the wrist-healthy subjects are shown as blue dots. In each plot, each point is a single subject's average absolute deviation for that movement plotted against the subject's average ROM for

that movement. The red lines through each graph show the average absolute deviation, and the flanking green lines show 2 SDs in either direction.

In all 4 Bland-Altman plots (Figs. 5-8), the average absolute deviation of the iPhone 5 from the UG was less than 2°. Each graph shows a few outliers but generally depicts a central cluster ranging from 0° to 2° of absolute deviation. Table 1 shows the absolute measurement error when broken down by the wrist-healthy vs wrist-injured population.

## Discussion

For its primary outcome, this study found that both healthy and wrist-injured subject, self-measured ROM using the iPhone 5 level feature had a high agreement with the ROM measurements obtained by researchers using the UG, with an overall mean absolute deviation of less than 2° and a mean percent deviation of less than 3% between the 2 methods. Table 1 shows the breakdown of all 4 wrist ROM plots individually, with each movement having just 1°-2° of absolute deviation between the UG and the iPhone measurements. In addition, the ICCs showed very high consistency between both measurement modalities with values more than

**Fig. 6.** Bland-Altman plot for wrist extension. UG = universal goniometer; ROM = range of motion.
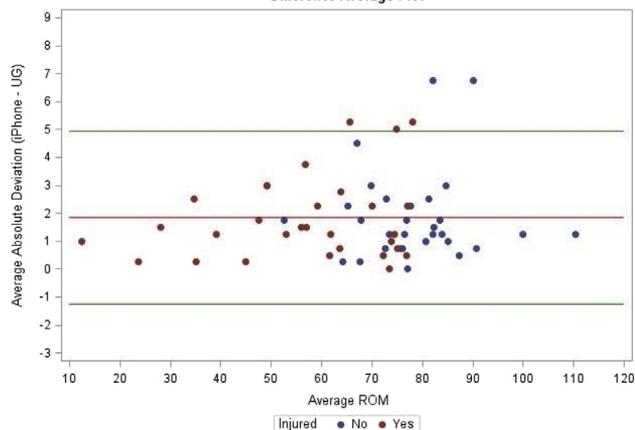
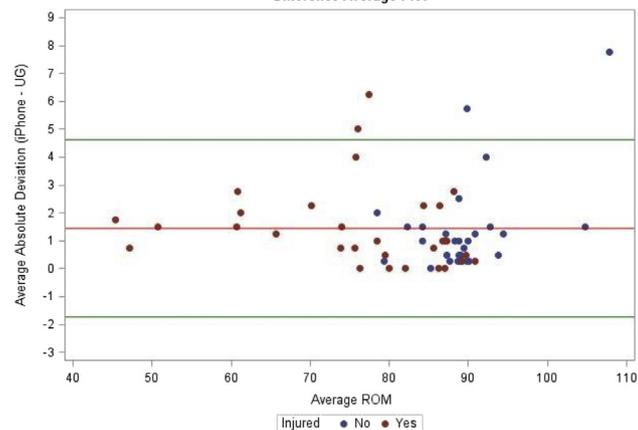**Fig. 5.** Bland-Altman plot for wrist flexion. UG = universal goniometer; ROM = range of motion.

**Fig. 7.** Bland-Altman plot for wrist supination. UG = universal goniometer; ROM = range of motion.
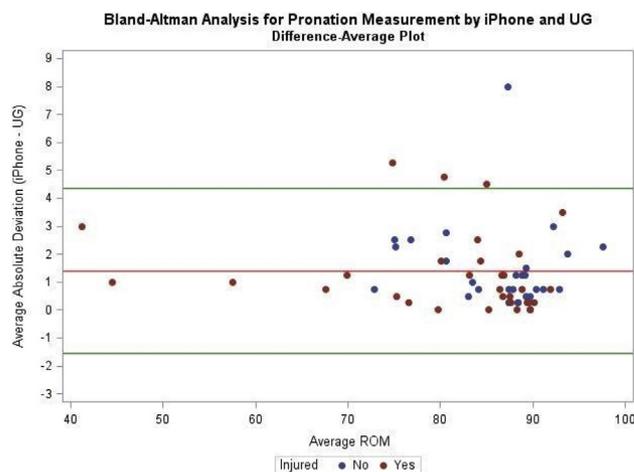
**Fig. 8.** Bland-Altman plot for wrist pronation. UG = universal goniometer; ROM = range of motion.

0.94. Due to the 120 paired, or 240 total, data points for each ICC calculation, the 95% confidence intervals were narrow for each ICC.

For its secondary outcome, this study showed that the iPhone was as accurate for the wrist-injured subjects as for the healthy subjects. Both wrist-healthy and wrist-injured populations had equally robust results with a strong agreement of self-measurement using the iPhone 5 level feature as compared with a researcher measurement using the UG. Statistical comparison between the 2 study populations found no significant difference in each groups' overall mean absolute difference and mean percent deviation of the iPhone self-measurement ROM from the researcher measurements using UG, with *P*-values of >.05. Table 1 further confirms there was no difference between wrist-injured and healthy subject self-measurement for any of the 4 movements individually with *P*-values of >.05.

The Bland-Altman plots show very strong agreement between iPhone 5 level feature and the UG methods of measuring ROM. Each wrist ROM plot shows a leftward deviation toward lower overall average ROM in the wrist-injured population. This is expected for 2 reasons: first, by population definition, these subjects were injured and were undergoing hand therapy, therefore having lower ROM is expected; and second, as the population demographics show, the injured population had a higher average age (47 vs 38), and ROM is typically inversely proportional to age. Another finding on the Bland-Altman plots is that outliers with higher absolute measurement differences occur at the higher range of ROM measurements. It is possible that this is because the iPhone has a stable percentage deviation difference, in our study of about 3%, which leads to higher absolute differences as ROM increases; that is, a 3% error of a 70° ROM being 2.1° off vs a 3% error of a 100° ROM being 3° off. A larger sample size is required to determine if there is a trend due to random sampling or due to increasing absolute deviation at higher

ROM values. However, although outlying data points were noted, this finding did not greatly affect our results because overall both the 2° mean absolute difference and 3% mean percent difference show the iPhone to have high agreement with the UG despite this potential trend.

It is worth noting the potential for selection bias, as the 2 populations had demographically different ages; the wrist-healthy population had a mean age of 38 (SD, 15), and the wrist-injured population had a mean age of 47 (SD, 19). However, both injury and relatively older age in the wrist-injured population could affect the ability to use the iPhone 5 level feature, whereas the results showed that there was in fact no statistical difference in the accuracy of the iPhone 5 measurements in these 2 groups. There is also a potential for measurement bias as the researcher was not blinded to injury status of the subject. However, the researcher was blinded to the subject's self-measured ROM and because the purpose of the study was to examine the agreement between the measurement modalities, and not track quantitative ROM, this effect of this potential bias is minimal.

An important aspect of this work is that 2 previous studies focused on wrist-healthy participants,[4,5] whereas 1 had both wrist-healthy and wrist-injured participants[6] using smartphone technology; all these studies used research evaluators or physiotherapists to measure wrist ROM. Our study's purpose was to evaluate and specifically determine if *wrist-injured subjects* could *self-measure* all 4 wrist ROMs using the built-in level feature on an iPhone 5 as a goniometer, and if these measurements agreed with the measurements obtained by a trained researcher using a UG. Our results show the agreement of the *self-measured smartphone ROM* compared with a trained researcher's UG measurements and brings the smartphone ROM field closer to achieving at-home patient data measurement.

Another important aspect of this study is that others evaluating smartphone goniometer technology used various goniometer applications requiring a download,[4-6] whereas the in-built smartphone level feature on the compass utility used in our study does not require downloading or additional payment. This free and readily available, easy to use, and simple feature does not rely on the use of English, making it available for use in non−English-reading populations without modifications. In addition, security risks are minimized as patients are not required to download third-party applications, and there is no storage of personal medical information.

This study demonstrated that subjects are reliably and independently able to measure wrist ROM using the iPhone 5 level feature. Data generated in this manner have the potential to provide more data points in real time. Such information could be accessed by health providers to aid in providing a more targeted approach based on the specific progress of each individual. This may allow patients who are progressing well at home to see the therapist less frequently, saving time and money, whereas those not progressing well can have their recovery plans modified and be followed more closely. In addition, such immediate feedback could further motivate patients and increase adherence to prescribed exercises or treatment therapies.

## Conclusion

This study showed very strong agreement of the iPhone 5 digital level feature used as a goniometer by study participants to self-measure wrist ROM as compared with researcher-measured ROM using the gold standard UG. The average absolute deviation between the 2 measurement modalities was less than 2° each for flexion, extension, supination, and pronation measurements. Wrist-injured populations performed equally well as wrist-healthy

**Table 1**
Population comparison by movement

| Movement | Healthy: mean absolute deviation (iPhone 5-UG) | SD | Injured: mean absolute deviation (iPhone 5-UG) | SD | Healthy vs injured: 2-sample t test; P |
|---|---|---|---|---|---|
| Flexion | 1.9° | 1.6° | 1.8° | 1.5° | .80 |
| Extension | 2.0° | 2.2° | 1.4° | 1.7° | .24 |
| Supination | 1.5° | 1.5° | 1.7° | 1.4° | .60 |
| Pronation | 1.4° | 1.5° | 1.4° | 1.5° | .98 |

UG = universal goniometer; SD = standard deviation.

participants in self-measurement. Overall, we validated that the in-built level feature of smartphone used as a goniometer has a high agreement with UG, the current gold standard. This supports the findings of others who compared similar technology to UG but who used researcher or physiotherapist measurements.[4-6] In addition, our findings further show that this technology can be used by wrist-injured patients to self-measure wrist ROM and that the measurements are comparable to standard UG ROM assessments by health providers. This additional finding has significant implications for use of such devices by patients themselves in wrist rehabilitation.

Further evaluation is needed using smartphone goniometry technology for wrist rehabilitation to confirm these findings and assess smartphone goniometry technology's potential impact on altering treatment plans, adherence, and provider follow-up frequency, recovery time, and functional outcomes.

## Acknowledgments

## Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jht.2018.03.004.

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# JHT Read for Credit
## Quiz: # 644

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# 1. The purpose of the study was to
    a. encourage patients to purchase iPhones
    b. perfect the use of the iPhone level feature for research purposes
    c. compare wrist ROM readings using an iPhone level feature vs. traditional goniometry
    d. educate hand therapists in the proper use of the iPhone level feature for measuring wrist ROM

# 2. Pronation and supination measures were
    a. all AROM
    b. all PROM
    c. active-assistive ROM
    d. unreliable

# 3. There was an approximate _____ degrees difference in measures between groups
    a. 20
    b. 10
    c. 5
    d. 2

# 4. Reliability was calculated using
    a. the Pearson Correlation Coefficient
    b. an ANOVA
    c. an ICC
    d. a weighted Kappa

# 5. The iPhone technique is too technically difficult to expect patients to perform it accurately
    a. true
    b. false

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