# The Reliability of a Smartphone Goniometer Application Compared With a Traditional Goniometer for Measuring Ankle Joint Range of Motion

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**Background:** Evaluation of range of motion (ROM) is integral to assessment of the musculoskeletal system, is required in health fitness and pathologic conditions, and is used as an objective outcome measure. Several methods are described to check ROM, each with advantages and disadvantages. Hence, this study introduces a new device using a smartphone goniometer to measure ankle joint ROM.

**Objective:** To test the reliability of smartphone goniometry in the ankle joint by comparing it with the universal goniometer (UG) and to assess interrater and intrarater reliability for the smartphone goniometer record (SGR) application.

**Methods:** Fifty-eight healthy volunteers (29 men and 29 women aged 18–30 years) underwent SGR and UG measurement of ankle joint dorsiflexion and plantarflexion. Two examiners measured ankle joint ROM. Descriptive statistics were calculated for descriptive and anthropometric variables, as were intraclass correlation coefficients (ICCs).

**Results:** There were 58 usable data sets. For measuring ankle dorsiflexion ROM, both instruments showed excellent interrater reliability: UG (ICC = 0.87) and SGR (ICC = 0.89). Intrarater reliability was excellent in both instruments in ankle dorsiflexion: UG and SGR (mean ICC = 0.91). For measuring ankle plantarflexion, both instruments showed excellent interrater reliability: UG (ICC = 0.76) and SGR (ICC = 0.82). Intrarater reliability was excellent in both instruments in ankle plantarflexion: UG (mean ICC = 0.85) and SGR (mean ICC = 0.82).

**Conclusions:** Smartphone-based goniometers can be used to assess active ROM of the ankle joint because they can achieve a high degree of intrarater and interrater reliability.
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Range of motion (ROM) is a key measurement to help in detecting and diagnosing musculoskeletal deficits, monitoring treatment progression, and guiding the treatment plan. Measurement of ROM is a relevant point and an important item of the joint evaluation process when using any ankle scoring system as part of the ankle and ankle joint evaluation.[1]

There are many tools that can be used to determine ankle joint mobility, such as universal goniometers (UGs), visual estimation, inclinometers, tape measures, digital gravity goniometers, or measurement of joint angles after radiographic visualization in maximum flexion or extension.[1]

The UG is inexpensive, is widely used, and requires the greatest degree of technical proficiency.[2,3] In previous studies, Munteanu et al[4] found that UG reliability (intraclass correlation coefficient [ICC] = 0. 65–0.89) was lower than digital inclinometer reliability (ICC = 0.88) and acrylic plate apparatus reliability (ICC = 0.89) when they measured ankle joint dorsiflexion in a weightbearing position with the knee extended on two occasions, 1 week apart. Also, Venturini et al[5] found that the UG had low-to-moderate intrarater reliability (ICC = 0–0.72) compared with the closed kinetic chain ROM measurement (ICC = 0.93–0.96) when

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two examiners measured ankle dorsiflexion in 22 healthy individuals on 2 test days.

The inclinometer has shown improved reliability (ICC = 0.84–0.95) for novice raters compared with the UG (ICC = 0.65–0.77) when ankle active dorsiflexion was tested in healthy individuals.[5-7] Also, the tape measure showed more sensitivity to changes than other tools in weightbearing dorsiflexion in individuals with recurrent lateral ankle sprain and deficits.[8-10]

Smartphone technology is one of the alternative ways that is being increasingly used. This technology does not require advanced palpation skills, training, or knowledge of surface anatomy; is readily available; incurs almost no additional cost; and is easier to use than specific digital techniques and so may improve the precision and accuracy of the measurement.[11,12] The validity and reliability of different smartphone ROM measurement applications have been tested in previous studies. These studies showed that smartphone ROM measurement applications have good validity and reliability in measuring ROM in different joints (elbow, knee, and fifth metatarsophalangeal joints).[11,13-19]

To our knowledge, there are no studies that test the reliability of smartphone ROM applications in ankle plantarflexion. We found just one study, by Vohralik et al,[20] of the reliability and validity of a free smartphone inclinometer application in ankle joint dorsiflexion. They found that the smartphone application was valid and had excellent interrater reliability (95% confidence interval [CI] = 0.92–0.99) and intrarater reliability (95% CI = 0.01–0.93).[20] The difference between the present study and the study by Vohralik et al[20] is that we tested active ROM and they tested passive ROM during the weightbearing lunge test, as smartphone technology is one of the alternative ways that is starting to be increasingly used in clinics.

Because the literature does not provide enough information about the reliability of smartphone ROM measurement applications in the ankle joint, there is a high need to establish enough information about its reliability and validity and the contributing errors in the different techniques, which may be helpful for the clinician while assessing ankle ROM.[14]

Because the reliability of smartphone goniometry had been tested in many other joints but has not been tested in ankle joint plantarflexion, the purpose of this study was to test the reliability of smartphone goniometry in ankle joint dorsiflexion and plantarflexion ROM measurement compared with UG ROM measurement by two raters and to assess the interrater and intrarater reliability of the smartphone goniometer records application (SGR).

## Methods

The SGR is based on accelerometer technology and is tested for accuracy by scientific methods with papers published in peer-reviewed journals.[20] It is simple to use and very accurate. It can be used for large joints and also small joints of the hand. The SGR is based on a simple patient record sheet and is useful in capturing and recording specific patient data, including demographic features, diagnosis, and treatment schedule. This will help in keeping watchful eyes on the patient's improvement and in comparing the ROM at sequential intervals. The application is obtained by putting the phone longitudinally on the stationary joint axes to establish the zero point; then the phone should be moved to the movable joint to determine the angle. This application has been tested previously by using the SGR in measuring lumbar flexion ROM and showed high intrarater reliability and moderate interrater reliability.[20] We used a Samsung Galaxy S3 model with the Android mobile operating system developed by Google, based on the Linux kernel and designed primarily for touch screen mobile devices such as smartphones and tablets.

### Participants

Before starting this study, a power analysis was performed to determine the number of participants needed. Fifty-eight healthy volunteers (29 men and 29 women aged 18–30 years) were recruited from the university population. Participant descriptive data are presented in Table 1. Participants were excluded if they reported 1) previous hip/pelvis, knee, ankle, or foot surgery in the past year; 2) lower-extremity amputation; 3) injury to the lower extremities in the previous 6 months; 4) known balance impairment due to a neurologic disorder, a vestibular disorder, medication use, or other; 5) pregnancy; 6) concussion within the previous 3 months, or 7) a contagious skin disease. Participants were asked to wash their foot with water and soap before starting the

**Table 1. Summary Statistics for the 58 Study Participants**

| Statistic | Minimum | Maximum | Mean | SD |
|---|---|---|---|---|
| Age (years) | 19 | 27 | 22.14 | 1.49 |
| Height (cm) | 148 | 195 | 172.21 | 9.46 |
| Weight (kg) | 47 | 110 | 67.76 | 14.57 |

procedures. Standard clinical stability testing of the ankle ligamentous structures was performed to rule out anterior and lateral talocrural joint instability and lower-extremity injuries during the previous 6 months. Each volunteer signed an informed consent form before participation. The study was approved by the ethics committee of Dokuz Eylul University (Izmir, Turkey).

Participants were asked to wear shorts to allow exposure of the area from the knee joint to the foot. Right ankle joint ROM was measured in all of the participants while in a supine position on a high bed; the testing session was completed at the faculty of medicine campus of Dokuz Eylul University.

Standard protocols for the use of UG[21] and SGR,[22] were provided to the examiners a week before the testing session. On the day of testing, all of the examiners were provided with a familiarization and training session for both the UG and the SGR, and when all examiners reported that they were confident with the protocol, the testing session began.

### Examiners

Goniometric measurement was performed by two physical therapy PhD candidates who had extensive experience with use of the UG during their clinical experience. Both of the examiners had some experience using the SGR. Each examiner performed four ROM measurements: ankle dorsiflexion and plantarflexion were each measured twice by each examiner using the UG and the SGR.

The measurements on the UG were blinded from the examiners at all times. When the examiner was satisfied that he or she had completed the measurement, the recorder documented the angle in whole degrees by examining the nonblinded side of the goniometer.

### Recorders

Documentation of all goniometric measurements was performed by two independent recorders. Recorders were trained in interpretation of the UG angle measuring scale before commencement of the data collection.

### UG Protocol

A UG with a plastic 360° goniometer face and 10-inch movable arms was used. Examiners were asked to position themselves lateral to the right ankle joint of each volunteer. The measurements on the UG were blinded from the examiners at all times. The UG was positioned so that the goniometer axis rested over the center of the lateral malleolus of the fibula. The stationary goniometer arm was aligned parallel to the longitudinal axis of the fibula, and the mobile arm was placed parallel to the longitudinal axis of the fifth metatarsal bone. When the examiner was satisfied that he or she had completed the measurement, the recorder documented the angle in whole degrees by examining the nonblinded side of the UG. The recorder ensured movement of the ankle joint, and no movement of the knee joint and UG arms occurred during recording. One measurement for ankle dorsiflexion and one measurement for ankle plantarflexion were performed by each examiner. Active dorsiflexion and plantarflexion ROM were measured as the participants were asked to perform ankle dorsiflexion and then plantarflexion actively as much as possible.[23]

### Ankle SGR

Examiners were asked to activate the SGR on the Samsung Galaxy smartphone. The phone was placed with the screen facing away against the distal part of the longitudinal axis of the fibula just above the lateral malleolus, ensuring that the longitudinal axis of the phone is parallel to the longitudinal axis of the fibula. The examiner then activated the "set" facility using the touch screen and pressing on the start button to determine the stationary axis in the smartphone goniometer. The participant was asked to do the movement actively as much as possible. Then the examiner positioned the smartphone parallel to the fifth metatarsal bone and pressed the stop button, storing the goniometric reading for recording purposes. The measurements on the UG were blinded from the examiners at all times, so when the examiner was satisfied that he or she had completed the measurement, the recorder documented the measured angle from the device screen before clearing the reading from the smartphone. One measurement for ankle dorsiflexion and one measurement for ankle plantarflexion were performed by each examiner.

### Statistical Analysis

A commercially available software program (SPSS for Windows, Version 14.0; SPSS Inc, Chicago, Illinois) was used for all of the statistical analyses.

Data were checked for accuracy and normal distribution. Descriptive data are available in (Table 2). Pearson correlation coefficients were used to identify significant associations between the two instruments when measuring ankle dorsiflexion and plantarflexion. Intraclass correlation coefficients, together with 95% CIs and the standard error of measurement (SEM), were used to report the best practice.[24] The ICC values were interpreted accordingly: greater than 0.75 indicates excellent reliability; 0.4 to 0.75 indicates moderate-to-good reliability; and less than 0.4 indicates poor reliability.[23] Bland-Altman plots were also produced.

Because the number of participants was greater than 50, we calculated the norm by using the Kolmogorov-Smirnov test on histograms. The ICC[2,k] type was used in this study. We used the following this formula to calculate the SEM: $SEM = s/\sqrt{N}$.

We used the following formula to calculate the minimal detectable change (MDC): $MDC = 1.96 \times SEM \times$ square root of 2.

## Results

For comparing the two devices, 58 usable data sets were available. The mean ± SD ROM of ankle joint dorsiflexion measured with the UG was 19.24° ± 3.87° and measured with the SGR was 20.34° ± 3.61°. For ankle plantarflexion, the mean ± SD ROM of ankle joint plantarflexion measured with the UG was 53.28° ± 10.4° and measured with the SGR was 51.23° ± 4.95°. The correlation between the UG and the SGR in assessing ankle dorsiflexion and plantarflexion was significant ($P < .001$).

For measuring ankle dorsiflexion ROM, both of the instruments showed excellent interrater reliability: UG (ICC = 0.87) and SGR (ICC = 0.89). Also, intrarater reliability was excellent in both instruments in ankle dorsiflexion: UG (mean ICC = 0.91) and SGR (mean ICC = 0.91) (Table 3). The Bland-Altman graph (Fig. 1) shows that measuring ankle dorsiflexion with the SGR is a little bit more consistent than measuring it with the UG as shown by the plot being near the zero line.

For measuring of ankle plantarflexion, both instruments showed excellent interrater reliability: UG (ICC = 0.76) and SGR (ICC = 0.82). Intrarater reliability was also excellent in both instruments in ankle plantarflexion: UG (mean ICC = 0.85) and SGR (mean ICC = 0.82) (Table 4). The Bland-Altman graph (Fig. 2) shows that measuring ankle plantarflexion with the SGR is a little bit more consistent than measuring it with the UG as indicated by the plots being near the zero line.

**Table 2. Summary Statistics for Ankle Joint ROM Measurements in the 58 Study Participants**

| ROM | Minimum | Maximum | Mean | SD |
|---|---|---|---|---|
| SGR dorsiflexion | 10 | 26 | 20.335 | 3.614 |
| SGR plantarflexion | 32 | 62 | 51.225 | 5.25 |
| UG dorsiflexion | 10.5 | 29.5 | 19.24 | 3.869 |
| UG plantarflexion | 44.5 | 67.5 | 53.275 | 5.202 |

Abbreviations: ROM, range of motion; SGR, smartphone goniometer record; UG, universal goniometer.

## Discussion

In the clinical measurements, interrater reliability is lower than intrarater reliability because of the technical differences.[25,26] In this study, the intrarater reliability of both instruments (UG and SGR)

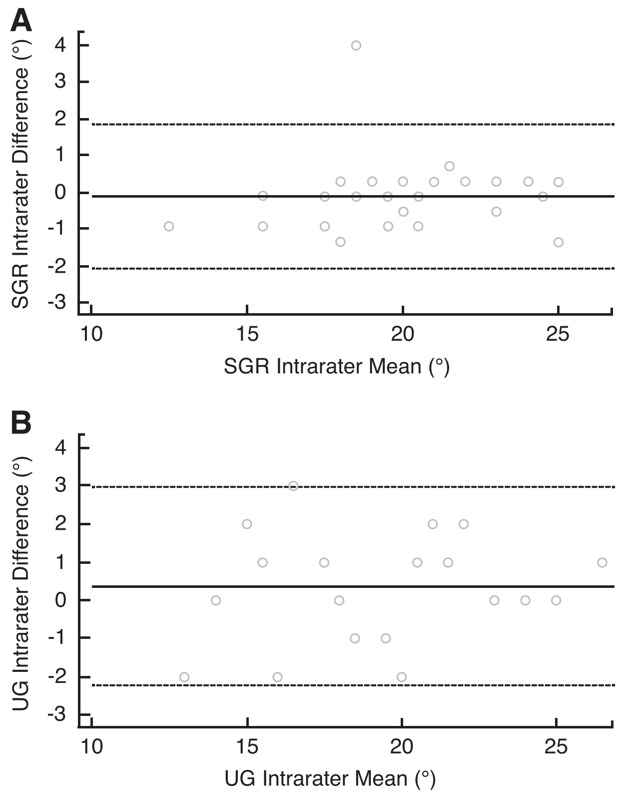


**Figure 1.** Bland-Altman plots of dorsiflexion intrarater reliability with mean (solid line) and 2 SDs (dashed lines) marked. A, Smartphone goniometer record (SGR). B, Universal goniometer (UG). In this figure, measuring ankle dorsiflexion with the SGR is a little bit more consistent than measuring it with the UG as the plot is near the zero line.

**Table 3. Intrarater and Interrater Reliability for Measuring Ankle Dorsiflexion**

| Variable | UG | SGR |
|---|---|---|
| Ankle joint dorsiflexion (mean ± SD [°]) | 19.24 ± 3.87 | 20.02 ± 3.61 |
| Rater 1 intrarater reliability ICC (95% CI) SEM; MDC | 0.96 (0.9–0.98) 0.36; 1 | 0.95 (0.96–0.99) 0.36; 1 |
| Rater 2 intrarater reliability ICC (95% CI) SEM; MDC | 0.85(0.91–0.97) 0.36; 1 | 0.87 (0–0.1) 0.36; 1 |
| Average interarater reliability (ICC [95% CI]) | 0.905 (0.91–0.97) | 0.91 (0.97–0.99) |
| Interrater reliability (ICC [95% CI]) | 0.870 (0.68–0.88) | 0.890 (0–0.88) |

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimum detectable change; SGR, smartphone goniometer record; UG, universal goniometer.

was excellent for assessing ankle dorsiflexion and plantarflexion. The SGR intrarater reliability was equal to the UG intrarater reliability during measurements in dorsiflexion, and the UG intrarater reliability was higher than the SGR intrarater reliability during measurements in plantarflexion. The ICC values were so close to each other, and the variation was so small between the instruments, that we concluded that these measurement tools can be used interchangeably.

The results reported by Otter et al[17] are close to the present study's results in that they found that the smartphone application intrarater reliability is higher than the UG intrarater reliability during fifth metatarsophalangeal joint position measurements, and the UG intrarater reliability is higher than the smartphone intrarater reliability during the measurement of passive ROM of the fifth metatarsophalangeal joint using the SGR compared with a traditional goniometer.[17] Also, the results obtained by Vohralik et al[20] were so close to those of the present study as they compared the medically rated inclinometer and the iHandy Level app on an iPhone to test ankle joint dorsiflexion ROM using the weightbearing lunge test.

The UG intrarater reliability in the present study was found to be higher than the results reported by Otter et al,[17] Konor et al,[27] and Meislin et al[15] when they tested ankle dorsiflexion ROM measures in a weightbearing lunge position using a standard goniometer, a digital inclinometer, and a tape measure using the distance-to-wall technique in healthy athletes; also, it was slightly higher than the results found by Venturini et al[5] when they tested ankle joint ROM using the UG and the measuring tape, and Shin et al[28] when they examined the within-day reliability of shoulder ROM measurement with a smartphone.

Besides that, we found in this study that during the measurement of dorsiflexion the UG intrarater reliability was near to the value found by Elveru et al[29] when they tested the measurements of the subtalar joint neutral position and passive ROM of the ankle joint and the subtalar joint, and it was the same as the result found by Youdas et al[30] when they examined ankle joint active dorsiflexion and plantarflexion.

The smartphone measurements of intrarater reliability in the present study were higher than those reported by Otter et al[17] but lower than the value reported by Ferriero et al[31] when they compared the smartphone-based application developed for photographic-based goniometry, DrGoniometer, and the UG on the elbow joint.

The variation between the results of the studies may be related to the fact that each study tested different joints, different movements, different ROM measurement applications, and different smartphone types. Because some joints' anatomical landmarks and movements are small and hard to detect, this will make the goniometer alignment on the joint axis hard. In addition, some smartphone goniometer applications are more complicated and need more accuracy to be used.

**Table 4. Intrarater and Interrater Reliability for Measuring Ankle Plantarflexion**

| Variable | UG | SGR |
|---|---|---|
| Ankle joint plantarflexion (mean ± SD [°]) | 53.43 ± 10.4 | 51.23 ± 4.95 |
| Rater 1 intrarater reliability ICC (95% CI) SEM; MDC | 0.88 (0.95–0.99) 0.36; 1 | 0.81 (0.98–0.91) 0.36; 1 |
| Rater 2 intrarater reliability ICC (95% CI) SEM; MDC | 0.82 (0.91–0.91) 0.36; 1 | 0.83 (0.99–0.91) 0.36; 1 |
| Average interrater reliability (ICC [95% CI]) | 0.85 (0.97–0.91) | 0.82 (0.99–0.91) |
| Interrater reliability (ICC [95% CI]) | 0.760 (0.59–0.86) | 0.821 (0.86–0.89) |

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimum detectable change; SGR, smartphone goniometer record; UG, universal goniometer.

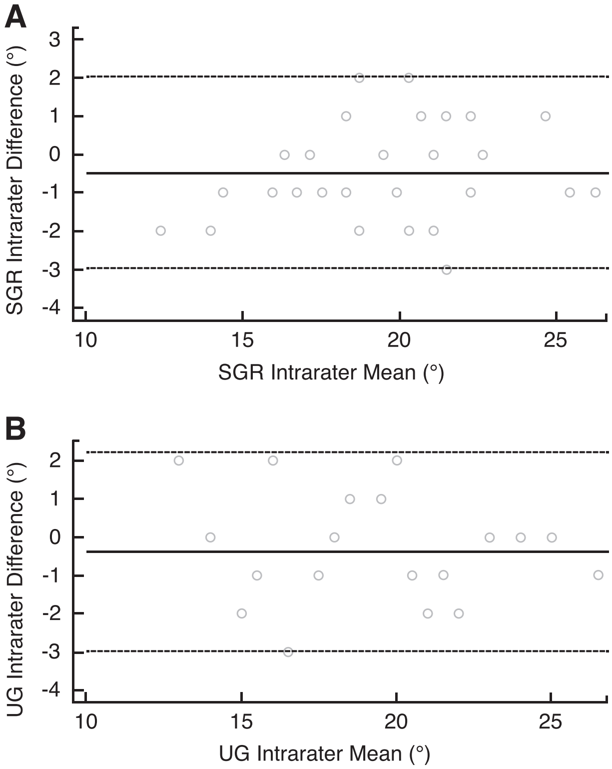


**Figure 2.** Bland-Altman plots of plantarflexion intrarater reliability with mean (solid line) and 2 SDs (dashed lines) marked. A, Smartphone goniometer record (SGR). B, Universal goniometer (UG). In this figure, measuring ankle plantarflexion with the SGR is a little bit more consistent than measuring it with the UG as the plot is near the zero line.

In comparing the interrater reliability of the two instruments, we found that the SGR interrater reliability was higher than the UG interrater reliability during the measurements of ankle joint dorsiflexion and plantarflexion; this may be because plantarflexion ROM is larger than dorsiflexion ROM and metatarsophalangeal joint movement may affect ankle plantarflexion ROM.

However, in this study, the UG interrater reliability during ankle joint dorsiflexion and plantarflexion ROM measurements was found to be higher than that reported by Otter et al[17] when they assessed passive ROM of the fifth metatarsophalangeal joint. Also, it was higher than the results reported by Cosby et al,[6] who examined the relationships among four dorsiflexion ROM measurements and talar glide as measured manually by the posterior talar glide test and posterior talar displacement as measured by an arthrometer. These results can be emphasized by the results reported by Gajdosik and Bohannon,[32] who found that the lower reliability scores for the UG while measuring the ROM of the lower limbs is due to the difficulty in locating landmarks of the lower limbs.

The SGR interrater reliability in dorsiflexion and plantarflexion in this study was higher than the smartphone interrater reliability for the fifth metatarsophalangeal joint, that reported by Otter et al,[17] and SGR interrater reliability in the present study was lower than that reported by Ferriero et al,[14] who tested the smartphone goniometry reliability in knee joint ROM measurement. It may be that in the ankle joint the anatomy is easier to visualize and positioning of goniometers is more straightforward. Other potential causes of reduced reliability unique to using this type of technology include the recommended use of the inbuilt smartphone inclinometer while photographing the joint. Although the feature aims to align the lens with the joint axis of motion, alignment of the first metatarsal and phalanx on the ground and subsequent dorsiflexion of the joint is challenging and may cause the patient to engage muscles that potentially restrict movement.

Using visual evaluation or mechanical goniometers to measure the ROM is inexpensive and easy and fast to perform but involves significant inaccuracy. The additional exposure of the radiographic evaluation prevents its widespread use, but it has been accepted to be the reference technique. The other ROM measurement techniques, such as digital goniometers, gait analysis, or digital imaging with computer image analysis, are considered to be too time-consuming and expensive to use routinely.[32] On the other hand, the smartphone application has advantages for novice practitioners and students and could potentially be used by patients to measure and monitor their own progress because it requires less knowledge of surface anatomy landmarks, less palpation skill, and less training. During the ankle joint injury rehabilitation process, home-based physiotherapy is one of the important items, and similar to the smartphone ROM measurement applications, give the patient the advantage of being able to monitor their ROM without buying the expensive devices; this motivates the patients for an enthusiastic self-rehabilitation during home-based physiotherapy for conservative or postoperative management, as they make immediate self-feedback possible.[16,17]

A limitation of this study was that the participants were healthy persons, which made it easy to find the anatomical landmarks, easy to position the goniometer in the proper location, and more accurate to measure the ROM than in patients with obesity, limb deformity, or orthosis. Another limitation of this study was that the ankle joint anatomical landmarks may be inherently variable, and the exclusion of structural deformities may not fully reflect clinical practice. In addition, the measurement procedures were not assessed as in the clinical condition. The lack of between-day reliability data is another limitation of this study. When studies that use repeated tests are performed at short intervals, as the present study was, this may lead to different results compared with studies that performed the repeated tests at longer intervals (ie, days or weeks).[32] However, ROM measurement following up within a short interval (ie, days) has substantial difficulty, and it is not absolutely necessary for the management of patients' problems. Meanwhile, the ROM longer follow-up interval (ie, weeks or months) may show greater ROM variations according to the patient's clinical course than according to the observational error, which will make use of a measuring device to detect the progression over time limited. For this reason, there is a high need for further study to assess between-day reliability of the smartphone to document the changes over time in the ROM.

## Conclusions

These results demonstrate that both UG and smartphone-based goniometers can be used to assess active ROM (dorsiflexion and plantarflexion) of the ankle joint as they can achieve a high degree of intrarater and interrater reliability and can be used interchangeably.

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