

# The Validity and Reliability of a Smartphone Application for Measuring Wrist and Metacarpophalangeal Joint Motion

Review began 03/31/2024  
Review ended 04/07/2024  
Published 04/11/2024

© Copyright 2024  
Özçelep et al. This is an open access article distributed under the terms of the Creative Commons Attribution License CC-BY 4.0., which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Ömer Faruk Özçelep<sup>1</sup>, Melek Güneş Yavuzer<sup>2</sup>, Ayşe Nur Tunali<sup>3</sup>

1. School of Physical Therapy and Rehabilitation, Ahi Evran University, Kırşehir, TUR 2. Department of Health Sciences, Haliç University, Istanbul, TUR 3. Department of Physiotherapy and Rehabilitation, Istanbul Medipol University, Istanbul, TUR

Corresponding author: Ömer Faruk Özçelep, omerfarukozcelep@gmail.com

---

---

## Abstract

### Background

Accurate measurement of the range of motion (ROM) is crucial for guiding upper extremity rehabilitation. Inaccurate measurements can mislead clinicians and harm patient compliance. This study aimed to evaluate the validity and reliability of a smartphone application (Angulus) for measuring wrist and metacarpophalangeal (MCP) joint ROM.

### Methodology

This study included 64 volunteers with no prior wrist injuries. The wrist flexion/extension, radial/ulnar deviation, and MCP joint flexion/extension ROM were assessed by an experienced physiotherapist (Assessor 1) using the Angulus and a standard two-arm goniometer. The validity of Angulus was evaluated by correlating it with the goniometer measurements using the Pearson correlation coefficient. For the reliability analysis, an inexperienced biomedical engineer (Assessor 2) performed the same measurements using Angulus twice in different sessions, in addition to Assessor 1. The intra-rater and inter-rater reliability were tested using the intraclass correlation coefficient.

### Results

The mean age of the participants was  $29.5 \pm 8.2$  years, with 62% being female. The validity of the Angulus app measurements was indicated by the adequate to excellent correlation between the Angulus and goniometer measurements (ranging from 0.44 to 0.81). The intra-rater reliability of the Angulus app was excellent for Assessor 1 (ranging from 0.76 to 0.90) and adequate to excellent for Assessor 2 (ranging from 0.71 to 0.88). The inter-rater reliability of Angulus was excellent (ranging from 0.91 to 0.96).

### Conclusions

Angulus is a valid and reliable method to measure the wrist and MCP joint ROM.

---

**Categories:** Physical Medicine & Rehabilitation, Healthcare Technology

**Keywords:** range of motion (rom), wrist evaluation, metacarpophalangeal joint, mobile phone application, reliability and validity

## Introduction

The hand and wrist are the most active parts of the upper extremity and are more susceptible to damage that can cause dysfunction [1]. Muscle weakness, deformity, edema, and pain can lead to a loss of range of motion (ROM), resulting in reduced fine manipulation, grasping ability, and grip strength [2]. Wrist and hand examinations require careful investigation to avoid incorrect diagnosis, which can lead to ineffective treatment [3]. It may lead to delayed return to work, reduced performance and function, pain, degenerative joint disease, and increased medical costs [4]. Wrist ROM is a critical measure in the clinical setting, essential for diagnosis, treatment evaluation, and quantification of potential changes [5]. In clinical practice, goniometers are presently the gold standard [6,7]. Wrist ROM measurements are obtained using a manual goniometer, a non-invasive and low-cost instrument [8]. However, ROM measurements require an experienced clinician for reliable results, which increases the costs for both patients and clinicians [9].

Smartphones with high-resolution photos are a potential platform for patient ROM assessment [9,10]. Recently, several smartphone applications have become available that provide an alternative method of monitoring joint angles [11]. Wassmuth et al. found the Goniometer PRO to be an effective tool for evaluating wrist ROM [12]. Similar results were found in forearm supination using the DrGoniometer, which is a valid and alternative tool for measuring ROM [13]. It is quick and easy to take a picture, which is an advantage for irritable patients [14]. The digital record created is useful for comparison during follow-up

#### How to cite this article

Özçelep Ö, Yavuzer M, Tunali A (April 11, 2024) The Validity and Reliability of a Smartphone Application for Measuring Wrist and Metacarpophalangeal Joint Motion. Cureus 16(4): e58047. DOI 10.7759/cureus.58047

treatments, telerehabilitation, and medical purposes [15]. According to Alford, a person's ability to self-monitor ROM gains at home can lead to increased motivation and compliance with home exercise programs [7]. This study aimed to determine if the Angulus application is a valid and reliable method for measuring wrist and metacarpophalangeal (MCP) joint ROM without the need for clinical experience.

This article was previously presented as a meeting abstract at the 2023 Federation of European Societies for Surgery of the Hand Congress on May 10-13, 2023.

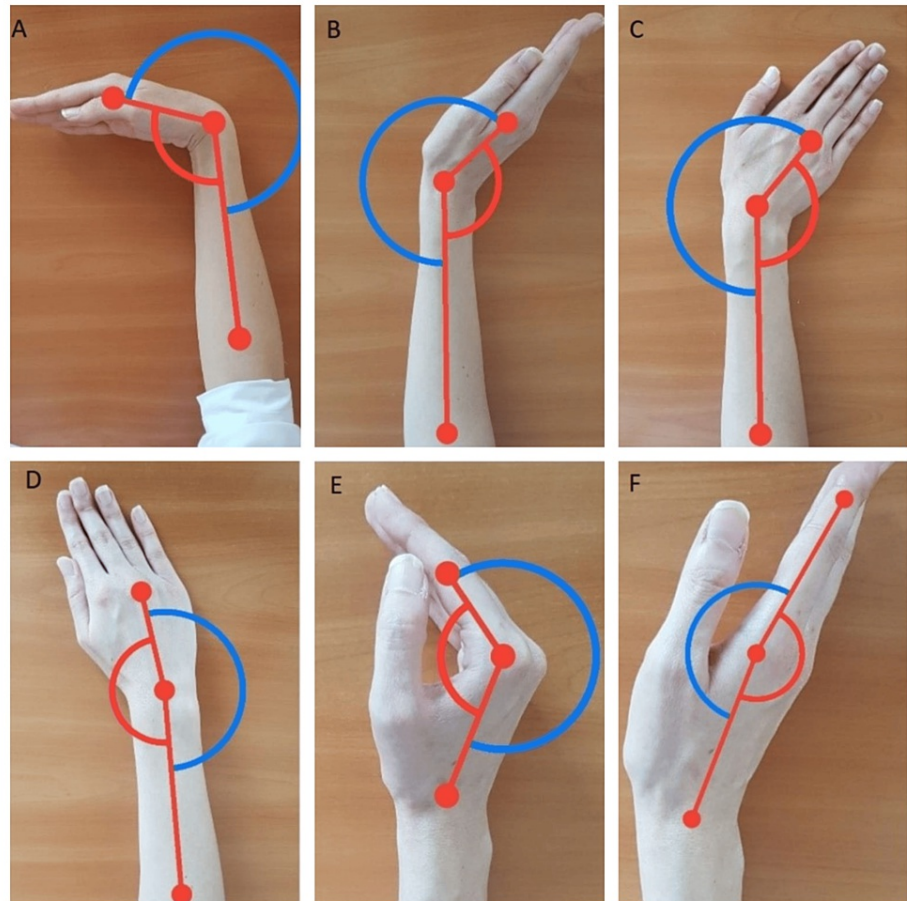
## Materials And Methods

### Participants

A total of 64 volunteers between the ages of 18-50 years who signed an informed consent form were enrolled in the study at Istanbul Medipol University Çamlica Hospital. Exclusion criteria were the presence of pain in the hand and wrist and the diagnosis of orthopedic, neurologic, and rheumatologic diseases. The study protocols were approved by the Haliç University Non-interventional Clinical Research Ethics Committee (approval number: 27.05.2021/110).

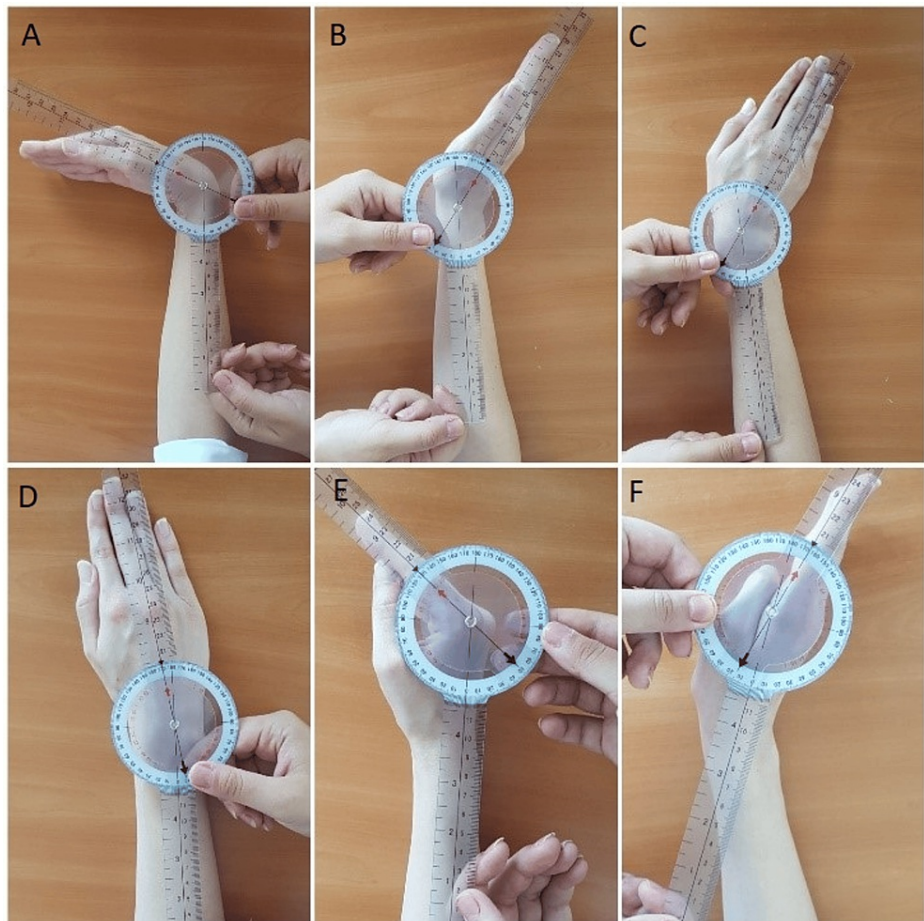
### Evaluating procedures

Angulus (DPP, USA) is an application for mobile phones that measures joint angles from photographs or videos captured by the phone's built-in camera. The software allows the user to measure the joint angle by drawing lines and points over the image. Basic photography skills are required to use the application, and the instructions for the user of the various wrist and MCP joint movements are straightforward. Therefore, the application is suitable for clinicians and researchers studying wrist pathology. Two assessors, a physical therapist (Assessor 1) and a biomedical engineer (Assessor 2), performed the measurements on the subject's dominant side. The goniometer measurements were followed by Angulus measurements, and this order was maintained for measurements performed at different times. Assessor 1 has worked in the field for six years and specializes in hand rehabilitation, while Assessor 2 was unfamiliar with ROM measurements. The assessors performed the measurements individually. Subjects were comfortably seated in a chair with their hands on the table, shoulders slightly abducted, and elbows at 90 degrees. Wrist flexion/extension and MCP joint flexion/extension ROMs were measured in the neutral position, while ulnar/radial deviation was measured in the pronated position. To assess validity, Assessor 1 used the Angulus application (Figure 1) and a standard two-arm goniometer (Figure 2) to measure the patients' wrist flexion/extension, radial/ulnar deviation, and MCP flexion/extension ROMs.



**FIGURE 1: Angulus measurements.**

(A) Wrist flexion. (B) Wrist extension. (C) Ulnar deviation. (D) Radial deviation. (E) Metacarpophalangeal flexion. (F) Metacarpophalangeal extension.



**FIGURE 2: Goniometric measurements.**

(A) Wrist flexion. (B) Wrist extension. (C) Ulnar deviation. (D) Radial deviation. (E) Metacarpophalangeal flexion. (F) Metacarpophalangeal extension.

Goniometric measurements were performed three times and the higher value was recorded. After the goniometric assessments, a 10-minute break was taken to prepare for the Angulus app measurements. Photographs of the same hand positions were taken at a distance of 60 cm, perpendicular to the MCP joint, with smartphone cameras (Samsung S8 and J7-Core), separately by two assessors, twice, with a five-minute break in between. At the end of the day, Assessor 1 and Assessor 2 separately performed the Angulus app measurements using photographs and entered the measurement data into their participant evaluation forms. The entire measurement process took approximately 45 minutes for each participant.

Statistical analyses were performed using SPSS version 24 (IBM Corp., Armonk, NY, USA). Mean values and standard deviations (SDs) were used for descriptive purposes [16]. Shapiro-Wilk test was used to establish the normality of the data, and the statistically significant level was determined as  $p$ -values  $<0.05$ . Due to the normal distribution of the data, the validity of the Angulus app measurements was assessed by Pearson correlation coefficient ( $r$ ). The Pearson correlation coefficient values were classified as  $<0.30$ ,  $0.30$ - $0.60$ , and  $>0.60$  being poor, adequate, and excellent, respectively. Intraclass correlations (ICC 2.1, two-way random effects absolute agreement) with 95% confidence intervals (CIs) were used to measure the inter- and intra-rater reliability for the joint ROM [17]. ICC values were classified as poor ( $<0.40$ ), adequate ( $0.40$ - $0.75$ ), and excellent ( $>0.75$ ) [18].

## Results

All 64 volunteers (40 females, 59 right-handed) completed the study without adverse events. The mean age was  $29.5 \pm 8.2$  years. The demographic characteristics of the participants are shown in Table 1.

|                                      | Min–Max   | Mean ± SD   |
|--------------------------------------|-----------|-------------|
| Age                                  | 20–48     | 29.5 ± 8.21 |
| Height                               | 1.55–1.88 | 1.68 ± 0.08 |
| Weight                               | 43–102    | 71 ± 15.8   |
| Body mass index (kg/m <sup>2</sup> ) | 17–39     | 25 ± 4.45   |

**TABLE 1: Demographic characteristics of the participants.**

Min = minimum; Max = maximum; SD = standard deviation

The measurements of Assessor 1 using the Angulus app and a standard goniometer for validity assessment are shown in Table 2.

| Assessor 1                 | Min–Max | X ± SD       | r     |
|----------------------------|---------|--------------|-------|
| Wrist flexion (G)          | 50–94   | 69.3 ± 9.58  | 0.791 |
| Wrist flexion (A)          | 40–93   | 64.9 ± 9.95  |       |
| Wrist extension (G)        | 36–80   | 61.7 ± 8.09  | 0.537 |
| Wrist extension (A)        | 28–77   | 58.4 ± 9.54  |       |
| Wrist ulnar deviation (G)  | 27–72   | 51 ± 8.65    | 0.675 |
| Wrist ulnar deviation (A)  | 26–61   | 43.3 ± 7.77  |       |
| Wrist radial deviation (G) | 0–40    | 23.7 ± 7.49  | 0.716 |
| Wrist radial deviation (A) | 0–46    | 19.4 ± 8.15  |       |
| MCP joint flexion (G)      | 65–109  | 81.3 ± 9.44  | 0.434 |
| MCP joint flexion (A)      | 44–86   | 68.9 ± 9.17  |       |
| MCP joint extension (G)    | 0–50    | 24.4 ± 11.46 | 0.814 |
| MCP joint extension (A)    | 0–47    | 27.8 ± 12.17 |       |

**TABLE 2: Measurements of Assessor 1 performed by the Angulus app and standard goniometer for validity assessment.**

r = Pearson correlation coefficient; Min = minimum; Max = maximum; SD = standard deviation; G = goniometer; A = Angulus; MCP = metacarpophalangeal

The correlation between the two methods was excellent for wrist flexion ( $r = 0.80$ ), radial deviation ( $r = 0.71$ ), ulnar deviation ( $r = 0.68$ ), and MCP joint extension ( $r = 0.81$ ) and adequate for wrist extension ( $r = 0.54$ ) and MCP joint flexion ( $r = 0.44$ ). The first and second measurements of Assessor 1 and Assessor 2 for intra-rater reliability of the Angulus application are shown in Table 3.

|            | Angulus app                | Min–Max | Mean ± SD    | ICC   |
|------------|----------------------------|---------|--------------|-------|
| Assessor 1 | Wrist flexion 1st          | 40–93   | 64.9 ± 9.95  | 0.801 |
|            | Wrist flexion 2nd          | 40–88   | 64.7 ± 9.28  |       |
|            | Wrist extension 1st        | 28–77   | 58.4 ± 9.54  | 0.797 |
|            | Wrist extension 2nd        | 35–77   | 57.6 ± 9.90  |       |
|            | Wrist ulnar deviation 1st  | 26–61   | 43.3 ± 7.77  | 0.795 |
|            | Wrist ulnar deviation 2nd  | 26–64   | 43.4 ± 7.90  |       |
|            | Wrist radial deviation 1st | 0–46    | 19.4 ± 8.15  | 0.820 |
|            | Wrist radial deviation 2nd | 0–47    | 19.5 ± 8.82  |       |
|            | MCP joint flexion 1st      | 44–86   | 68.9 ± 9.17  | 0.764 |
|            | MCP joint flexion 2nd      | 53–85   | 68.3 ± 7.76  |       |
|            | MCP joint extension 1st    | 0–47    | 27.8 ± 12.17 | 0.901 |
|            | MCP joint extension 2nd    | 0–46    | 28.4 ± 12.30 |       |
| Assessor 2 | Wrist flexion 1st          | 41–88   | 66.5 ± 11.25 | 0.873 |
|            | Wrist flexion 2nd          | 42–87   | 65.1 ± 11.63 |       |
|            | Wrist extension 1st        | 33–69   | 53.3 ± 8.13  | 0.882 |
|            | Wrist extension 2nd        | 35–70   | 53 ± 8.50    |       |
|            | Wrist ulnar deviation 1st  | 24–62   | 41.9 ± 7.47  | 0.714 |
|            | Wrist ulnar deviation 2nd  | 16–57   | 41.5 ± 8.25  |       |
|            | Wrist radial deviation 1st | 0–51    | 18.5 ± 8.46  | 0.877 |
|            | Wrist radial deviation 2nd | 0–45    | 18.2 ± 7.71  |       |
|            | MCP joint flexion 1st      | 56–95   | 78 ± 7.26    | 0.811 |
|            | MCP joint flexion 2nd      | 54–96   | 77 ± 8.27    |       |
|            | MCP joint extension 1st    | 0–47    | 23.8 ± 10.98 | 0.827 |
|            | MCP joint extension 2nd    | 0–76    | 24.8 ± 12.80 |       |

**TABLE 3: First and second measurements of Assessor 1 and Assessor 2 for intra-rater reliability of the Angulus app.**

Min = minimum; Max = maximum; SD = standard deviation; MCP = metacarpophalangeal; ICC = intraclass correlation

The ICCs for intra-rater reliability of the Angulus app were excellent (ranging from 0.76 to 0.90) for all measurements for both assessors, except for the wrist ulnar deviation of Assessor 2 (0.71), which was adequate. ICCs for inter-rater reliability of the Angulus app were excellent (ranging from 0.91 to 0.96) (Table 4).

| Angulus app                         | Min–Max | Mean ± SD    | ICC   |
|-------------------------------------|---------|--------------|-------|
| Wrist flexion (Assessor 1)          | 40–93   | 64.9 ± 9.95  | 0.933 |
| Wrist flexion (Assessor 2)          | 41–88   | 66.5 ± 11.25 |       |
| Wrist extension (Assessor 1)        | 28–77   | 58.4 ± 9.54  | 0.944 |
| Wrist extension (Assessor 2)        | 33–69   | 53.3 ± 8.13  |       |
| Wrist ulnar deviation (Assessor 1)  | 26–61   | 43.3 ± 7.77  | 0.910 |
| Wrist ulnar deviation (Assessor 2)  | 24–62   | 41.9 ± 7.47  |       |
| Wrist radial deviation (Assessor 1) | 0–46    | 19.4 ± 8.15  | 0.950 |
| Wrist radial deviation (Assessor 2) | 0–51    | 18.5 ± 8.46  |       |
| MCP joint flexion (Assessor 1)      | 44–86   | 68.9 ± 9.17  | 0.908 |
| MCP joint flexion (Assessor 2)      | 56–95   | 78 ± 7.26    |       |
| MCP joint extension (Assessor 1)    | 0–47    | 27.8 ± 12.17 | 0.960 |
| MCP joint extension (Assessor 2)    | 0–47    | 23.8 ± 10.98 |       |

**TABLE 4: Measurements of Assessor 1 and Assessor 2 for inter-rater reliability of the Angulus app.**

Min = minimum; Max = maximum; SD = standard deviation; MCP = metacarpophalangeal; ICC = intraclass correlation

## Discussion

Recent studies have reported the validity and reliability of various smartphone applications for measuring hand wrist ROM. Two types of apps can be distinguished, i.e., apps that use the smartphone’s built-in accelerometer and apps that work with images, called photogoniometers. No significant differences in reliability and validity were found between these two groups [19]. According to Valdes et al., mobile device applications can be a valuable intervention and impact performance in individuals with impaired hand function. Applications provide a client-centered and potentially motivating activity option that can be used to assist the hand therapist [20]. In addition, Mitchell et al. assessed the reliability and validity of accelerometer-based and photo-based goniometric applications and suggested that photo-based applications may offer a more appropriate measurement method by providing a permanent, printable protocol [21]. The application used in our study offers the possibility of evaluation through photography. This feature distinguishes it from accelerometer-based applications. According to Ferriero et al. [15], photo-based applications have several advantages: clinicians can measure the photo at any time; they can be used in telemedicine to monitor patients at home; and they can help improve patient compliance by showing the patient consecutive images that reveal the change. Because it does not require contact with the skin, photo-based measurement can be used in the operating room without special preparation. Cunha et al. reported that video-based goniometry could be used as a new standard goniometric technique because it is clinically validated and performed with greater consistency and excellent inter-rater reliability compared to goniometry. It also allows for better documentation of measurements and potential direct incorporation into medical records [22]. Ge et al. found smartphone photographs to be a valid and reliable method of measuring wrist ROM and an alternative to manual measurements using goniometers to assess functional outcomes of the wrist. According to Reid et al., DrGoniometer is an equivalent tool for measuring forearm supination compared to universal goniometer in healthy populations and populations with known forearm fractures [9,13]. In this study, we found similar results to the above-mentioned studies because the inter-rater and intra-rater validity and reliability were considerably higher in our study compared to the manual goniometer.

In all of the above-mentioned studies, assessors were selected from clinicians experienced in hand evaluation. Hand surgeons performed the assessments, or they were performed by researchers or raters whose expertise we could not obtain. Contrary to these studies, one of the evaluators in our study was an expert physiotherapist, while the other was a biomedical engineer with no experience in hand assessment. In our study, regardless of experience, inter-rater reliability was above 0.90, similar to the study of Mitchell et al. in shoulder external rotation. In the above-mentioned studies, except for Trehan et al., the photographs were assessed with computer programs such as Image J and Adome CS5. Trehan et al. evaluated photographs by placing a goniometer. In our study, the angle between the lines that appear when the evaluator determines the points on the photograph was calculated automatically. We believe this was the

main difference that made the assessment faster than the computer [21,23].

DrGoniometer showed excellent intra-rater reliability and good validity. However, inter-rater reliability was good to excellent in the fractured forearm group but poor to fair in the normal population. In our study, the correlation between goniometric ROM measurements and Angulus app was above 0.70, except for wrist extension (0.54) and MCP flexion (0.44), indicating adequate to excellent validity. In addition, ICCs were above 0.75, except for wrist ulnar deviation of Assessor 2 (0.71), indicating adequate and excellent reliability.

To minimize errors, it is necessary to strictly follow the correct procedures described in the validation studies for all measurement methods. In particular, the photo-based applications are subject to the same limitations as standard digital photographic goniometric measurements and have two main potential sources of error: (i) unstable handling of the smartphone when taking the picture, and (ii) imprecision in positioning the virtual goniometer on the mobile screen. The app is also convenient for use in clinical trials, as the photograph and data generated can be consulted if a measurement error is suspected, as was found in our study. Another advantage of the Angulus app is that once the app's dots are placed on the photograph, the app automatically calculates and displays the angle to reduce calculation errors that can occur when reading the measurement from a universal goniometer. The entire measurement process is slower when using the Angulus app to measure joint angles than when using a universal goniometer. Although the snapshot can be taken quickly to reduce the time the patient must remain in an uncomfortable position, the user must then save the image and apply the app's measurement points. Aligning the arms and reading the measurement directly from the universal goniometer can take longer. As a result, the use of the Angulus app may be impractical in some time-constrained situations, which may discourage clinicians from using the app. Future studies in this area may be qualitative to determine the challenges of using the Angulus app.

## Limitations

The robust study design according to the guidelines for reporting reliability and concordance studies and the sufficient number of subjects to assess the correlation between intra- and inter-rater reliability with statistically significant results are the main strengths of our study. The first of the main limitations was that as ROM was measured by two evaluators at different settings, the wrist had to be perfectly positioned to have comparable angles during manual measurements and photographic measurements. We placed the smartphone's camera at a certain distance from the exact line of the evaluated joint. However, this placement varies according to the person's photographing skills and the patient's compliance. Another major limitation was the lack of population diversity. Because this study was designed for healthy participants, the results will not be accurate for any disease population. In addition, it is one of the disadvantages of this application that the points in the photographs are difficult to match with the anatomical signs. Experienced clinicians will place the points in the anatomically correct places on the application, while inexperienced clinicians will have a hard time placing the points. Therefore, for a reliable assessment, a guide should show users how to take pictures.

## Conclusions

This study was designed to determine if the Angulus application is a valid and reliable method of measuring wrist and MCP ROM without the need for clinical experience. This study demonstrated that the Angulus application is a reliable and valid alternative to wrist and MCP goniometry. It was also concluded that lack of clinical experience was not a barrier to using the app and therefore could be incorporated into telerehabilitation practices. Further research may show that these tools can be effective as an adjunct to clinical practice or as part of a home program for therapists or patients who prefer to measure wrist and hand ROM using a smartphone-based app.

## Additional Information

### Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

**Concept and design:** Ömer Faruk Özçelep, Melek Güneş Yavuzer, Ayşe Nur Tunali

**Acquisition, analysis, or interpretation of data:** Ömer Faruk Özçelep

**Drafting of the manuscript:** Ömer Faruk Özçelep

**Critical review of the manuscript for important intellectual content:** Ömer Faruk Özçelep, Melek Güneş Yavuzer, Ayşe Nur Tunali

**Supervision:** Melek Güneş Yavuzer, Ayşe Nur Tunali

## Disclosures

**Human subjects:** Consent was obtained or waived by all participants in this study. Haliç University Non-interventional Clinical Research Ethics Committee issued approval 27.05.2021/110. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

## References

- Magee D: Orthopedic Physical Assessment. Saunders, New York; 2013.
- Bashardoust Tajali S, MacDermid JC, Grewal R, Young C: Reliability and validity of electro-goniometric range of motion measurements in patients with hand and wrist limitations. *Open Orthop J*. 2016, 10:190-205. [10.2174/1874325001610010190](https://doi.org/10.2174/1874325001610010190)
- Lendner N, Wells E, Lavi I, Kwok YY, Ho PC, Wollstein R: Utility of the iPhone 4 gyroscope application in the measurement of wrist motion. *Hand (N Y)*. 2019, 14:352-6. [10.1177/1558944717730604](https://doi.org/10.1177/1558944717730604)
- de Putter CE, Selles RW, Polinder S, Panneman MJ, Hovius SE, van Beeck EF: Economic impact of hand and wrist injuries: health-care costs and productivity costs in a population-based study. *J Bone Joint Surg Am*. 2012, 94:e56. [10.2106/JBJS.K.00561](https://doi.org/10.2106/JBJS.K.00561)
- Carter TI, Pansy B, Wolff AL, Hillstrom HJ, Backus SI, Lenhoff M, Wolfe SW: Accuracy and reliability of three different techniques for manual goniometry for wrist motion: a cadaveric study. *J Hand Surg Am*. 2009, 34:1422-8. [10.1016/j.jhsa.2009.06.002](https://doi.org/10.1016/j.jhsa.2009.06.002)
- Ellis B, Bruton A, Goddard JR: Joint angle measurement: a comparative study of the reliability of goniometry and wire tracing for the hand. *Clin Rehabil*. 1997, 11:314-20. [10.1177/026921559701100408](https://doi.org/10.1177/026921559701100408)
- Alford SL: Remote self-measurement of wrist range of motion performed on normal wrists by a minimally trained individual using the iPhone level application only demonstrated good reliability in measuring wrist flexion and extension. *J Hand Ther*. 2021, 34:549-54. [10.1016/j.jht.2020.05.001](https://doi.org/10.1016/j.jht.2020.05.001)
- Lefevre-Colau MM, Poiraudreau S, Oberlin C, Demaille S, Fermanian J, Rannou F, Revel M: Reliability, validity, and responsiveness of the modified Kapandji index for assessment of functional mobility of the rheumatoid hand. *Arch Phys Med Rehabil*. 2003, 84:1032-8. [10.1016/s0003-9995\(03\)00128-x](https://doi.org/10.1016/s0003-9995(03)00128-x)
- Ge M, Chen J, Zhu ZJ, Shi P, Yin LR, Xia L: Wrist ROM measurements using smartphone photography: reliability and validity. *Hand Surg Rehabil*. 2020, 39:261-4. [10.1016/j.hansur.2020.02.004](https://doi.org/10.1016/j.hansur.2020.02.004)
- Wagner ER, Conti Mica M, Shin AY: Smartphone photography utilized to measure wrist range of motion. *J Hand Surg Eur Vol*. 2018, 43:187-92. [10.1177/1753193417729140](https://doi.org/10.1177/1753193417729140)
- Keogh JW, Cox A, Anderson S, Liew B, Olsen A, Schram B, Furness J: Reliability and validity of clinically accessible smartphone applications to measure joint range of motion: a systematic review. *PLoS One*. 2019, 14:e0215806. [10.1371/journal.pone.0215806](https://doi.org/10.1371/journal.pone.0215806)
- Wassmuth T, Sakata MSB, Paula AM de, Pereira WM, Ferreira LAB, Rossi LP: Intra-examiner and inter-examiner reliability in the determination of angular measurements of the wrist using a smartphone application. *Man Ther Posturology Rehabil*. 2020, 18:1-6. [10.17784/mtprehabjournal.2020.18.811](https://doi.org/10.17784/mtprehabjournal.2020.18.811)
- Reid S, Egan B: The validity and reliability of DrGoniometer, a smartphone application, for measuring forearm supination. *J Hand Ther*. 2019, 32:110-7. [10.1016/j.jht.2018.03.003](https://doi.org/10.1016/j.jht.2018.03.003)
- Cuesta-Vargas AI, Roldán-Jiménez C: Validity and reliability of arm abduction angle measured on smartphone: a cross-sectional study. *BMC Musculoskelet Disord*. 2016, 17:93. [10.1186/s12891-016-0957-3](https://doi.org/10.1186/s12891-016-0957-3)
- Ferriero G, Vercelli S, Sartorio F, Foti C: Accelerometer- and photographic-based smartphone applications for measuring joint angle: are they reliable?. *J Arthroplasty*. 2014, 29:448-9. [10.1016/j.arth.2013.06.014](https://doi.org/10.1016/j.arth.2013.06.014)
- Rosvall F, Jedeskog U, Andersson JK, Söderberg T, Hagert E: Intrarater reliability test of the ISOmetric power device-a new instrument for assessment of isometric force in six directions of wrist motion. *J Hand Ther*. 2021, 34:100-8. [10.1016/j.jht.2019.12.013](https://doi.org/10.1016/j.jht.2019.12.013)
- Shrout PE, Fleiss JL: Intraclass correlations: uses in assessing rater reliability. *Psychol Bull*. 1979, 86:420-8. [10.1037//0033-2909.86.2.420](https://doi.org/10.1037//0033-2909.86.2.420)
- Andresen EM: Criteria for assessing the tools of disability outcomes research. *Arch Phys Med Rehabil*. 2000, 81:S15-20. [10.1053/apmr.2000.20619](https://doi.org/10.1053/apmr.2000.20619)
- Longoni L, Brunati R, Sale P, Casale R, Ronconi G, Ferriero G: Smartphone applications validated for joint angle measurement: a systematic review. *Int J Rehabil Res*. 2019, 42:11-9. [10.1097/MRR.0000000000000332](https://doi.org/10.1097/MRR.0000000000000332)
- Valdes K, Gendernalik E, Hauser J, Tipton M: Use of mobile applications in hand therapy. *J Hand Ther*. 2020, 33:229-34. [10.1016/j.jht.2019.10.003](https://doi.org/10.1016/j.jht.2019.10.003)
- Mitchell K, Gutierrez SB, Sutton S, Morton S, Morgenthaler A: Reliability and validity of goniometric iPhone applications for the assessment of active shoulder external rotation. *Physiother Theory Pract*. 2014, 30:521-5. [10.3109/09593985.2014.900593](https://doi.org/10.3109/09593985.2014.900593)
- Cunha AB, Babik I, Harbourne R, Cochran NJ, Stankus J, Szucs K, Lobo MA: Assessing the validity and reliability of a new video goniometer app for measuring joint angles in adults and children. *Arch Phys Med Rehabil*. 2020, 101:275-82. [10.1016/j.apmr.2019.07.008](https://doi.org/10.1016/j.apmr.2019.07.008)
- Trehan SK, Rancy SK, Johnsen PH, Hillstrom HJ, Lee SK, Wolfe SW: At home photography-based method for measuring wrist range of motion. *J Wrist Surg*. 2017, 6:280-4. [10.1055/s-0037-1599830](https://doi.org/10.1055/s-0037-1599830)