Original Clinical Article

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Validity and reliability of smartphone inclinometer applications for measurement of elbow range of motion in paediatric patients

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Abstract

Purpose: Precise measurement of elbow range of motion (ROM) post-injury or surgery forms an important part of determining prognosis and the need for further intervention. Clinicians are increasingly incorporating smartphone use in our medical practice; we sought to determine if a smartphone goniometer application is a valid and reliable tool for assessment of elbow ROM in the paediatric patient, compared to visual and goniometer assessment.

Methods: In total, 20 paediatric patients (40 elbows) between six and 15 years of age with an elbow or forearm injury were included in this prospective series. Elbow flexion, extension, pronation and supination were measured independently by two orthopaedic clinicians. Measurements were taken from injured as well as unaffected side using a standardized technique, first with visual estimation and then using a universal goniometer (UG) and smartphone goniometer application Angle Meter via Google Play store (Smart Tool Factory, Istanbul, Turkey).

Results: There was excellent interobserver reliability for all three modalities, with average intraclass correlation coefficient (ICC) values greater than 0.90. Visual estimation had the lowest average ICC of 0.92, compared to 0.97 for UG and smartphone. Overall, there was excellent intraobserver reliability between the smartphone application and the gold standard UG for all elbow movements with ICCs ranging between 0.98 to 0.99 and mean absolute difference ranging from 1.1 ± 1.0° to 2.6 ± 1.9°. The smartphone application showed superior agreement over visual estimation when compared to the gold standard UG with lower mean differences and 95% limits of agreement (LOA) falling within 10°.

Conclusions: Our study demonstrates that a smartphone application is a valid and reliable assessment tool for measurement of elbow ROM in paediatric patients, and better than visualization alone.

Level of evidence: III

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Keywords: elbow; range of motion; goniometer; smartphone; paediatric

Introduction

Elbow injuries occur frequently and represent up to 15% of all paediatric fractures, second only to distal radius fractures.[1] The measurement of elbow joint range of motion (ROM) post-injury or surgical intervention in the outpatient clinic is a critical part of patient follow-up and determines prognosis or possible need for further intervention. Furthermore, accurate assessment of ROM is important for validating outcomes in clinical research.

Although the universal goniometer (UG) has been validated for measuring joint ROM and is the current gold standard tool, it is rarely used in practice due to its inconvenience. On the other hand, visual estimation is often inaccurate and varies amongst different clinicians. In recent times, smartphones equipped with advanced technologies have been increasingly incorporated in orthopaedic practice as a versatile, cheap and readily available alternative.[2,3] Several smartphone applications exist, including those with built-in cameras that infer joint angle measurements via trigonometry or 3D sensors with digital inclinometers that allow real-time ROM measurements. These have been studied and validated for knee, elbow and shoulder ROM evaluation in adult patients but not in the paediatric population.[4–8]

Therefore, we sought to determine if a smartphone goniometer application is a valid and reliable tool

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specifically for assessment of elbow ROM in paediatric patients, compared to visual estimation and the UG.

Methods

Subjects

In total, 20 consecutive paediatric patients (40 elbows) between six and 15 years of age presenting to the outpatient clinic were prospectively recruited to participate in the study. Subjects were included if they had elbow or forearm injuries that had previous treatment with above elbow immobilization and/or surgery and were able to follow simple instructions. Patients with neuromuscular conditions or those with concurrent ipsilateral shoulder injury were excluded. Subjects were assessed by two orthopaedic clinicians: a junior registrar and post-graduate fellow.

A mean difference between measurements on the same elbow of 10 degrees or higher was considered clinically important. Our sample of 40 elbows will have 80% power at $\alpha = 0.05$ to detect a difference between visual estimation, smartphone application and UG measurements. The study was approved by the local human research ethics committee and informed consent was gained from all participants prior to study inclusion.

Instruments

Elbow ROM was measured for each subject using three methods: visual estimation, UG and a smartphone inclinometer, Angle Meter (Smart Tool Factory, Istanbul, Turkey). The smartphone application is free to download from the Google Play store and is simple and easy to use (Fig. 1). Both assessors performed practice measurements on ten sample patients prior to starting the study to ensure that a standardized technique was used.

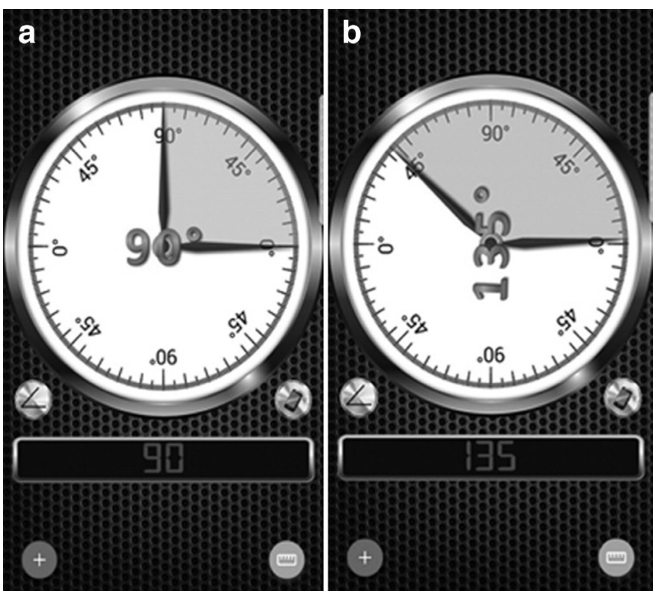

Fig. 1 Smartphone inclinometer application 'Angle Meter' example measurements at **(a)** 90 degrees and **(b)** 135 degrees from horizontal.

Measurement protocol

Measurements at maximal elbow flexion, extension, supination and pronation were taken independently by both clinicians for each study subject. Measurements were taken from the injured as well as contralateral unaffected side using a standardized protocol; first with visual estimation, then following with the UG and smartphone application. Furthermore, to control for patient fatigue, the assessor to take the first set of measurements was randomized for each consecutive patient. Each assessor was blinded to the other's measurement results.

Our standardized technique involved having the patient standing upright with their entire upper limb exposed from shoulder to wrist (Fig. 2 and Fig. 3). For the measurement of flexion and extension, the arm was extended with

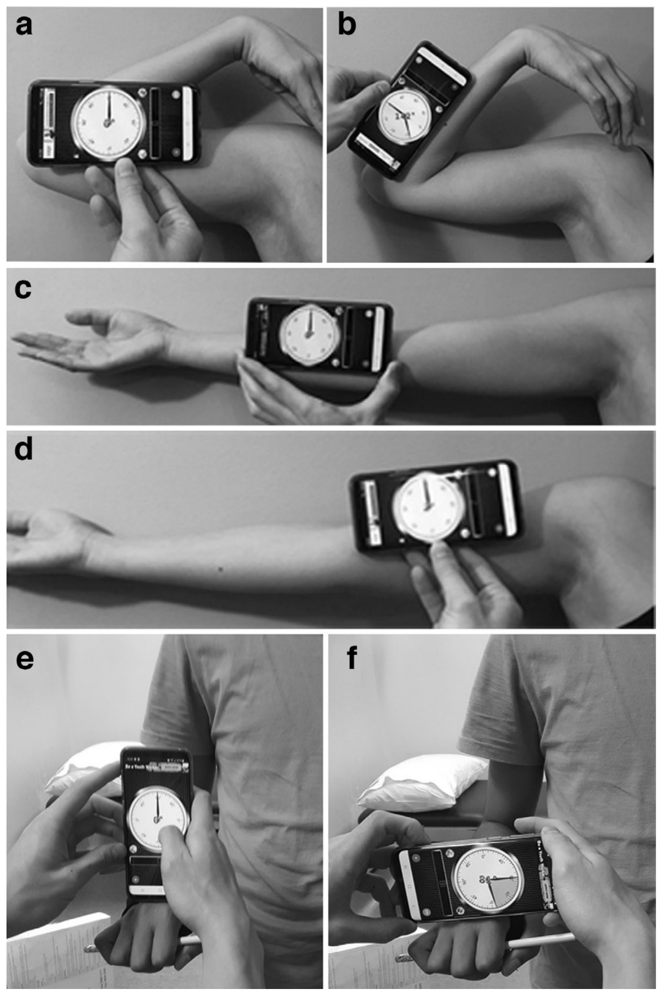

Fig. 2 Clinical photos of measurements using smartphone inclinometer application in flexion **(a and b)**, extension (**c and d)** and pronation **(e and f)**.

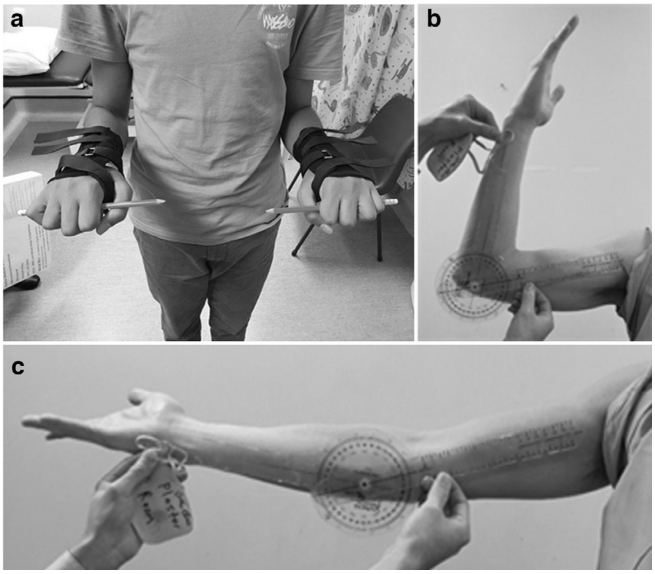

Fig. 3 Clinical photos of patient wearing wrist splints and holding pencils for pronation and supination measurements. Example of pronation in wrist splints **(a)**, flexion **(b)** and extension **(c)** measurements using universal goniometer.

shoulders at 90° of abduction and palms fully supinated and facing upwards. Our reference points were the medial epicondyle of the humerus, tip of acromion and midline of wrist. The UG was placed directly on the medial epicondyle and the stable arm was placed towards the acromial process. The smartphone was centred on the arm/forearm and zeroed along the horizontal axis. Upon flexion or extension of the elbow, the angle was assessed by moving the arm of the UG or placing the smartphone along the horizontal axis between the two anatomical landmarks.

For supination and pronation evaluations, the subject's elbows were tucked by their side and a wrist splint with a pen gripped in the hand was used to prevent wrist flexion/extension. The smartphone was zeroed at the vertical axis and the subject was instructed to fully supinate or pronate their forearm and the angle recorded. For the UG, the fixed arm was similarly located on the vertical axis.

Statistical analysis

Interobserver reliability was calculated for each measurement modality (visual estimation, standard goniometer and smartphone application) via the intraclass correlation coefficient (ICC) and two-way mixed effects model. ICCs were expressed with 95% confidence intervals (CI) and the degree of correlation interpreted according to definitions by Landis and Koch:[9] slight (0.00 to 0.20); fair (0.21 to 0.40); moderate (0.41 to 0.60); strong (0.61 to 0.80) and excellent (0.81 to 1.00). The average ICC for each measurement modality was compared via one-way analysis of variance (ANOVA) to assess for statistical significance with $\alpha = 0.05$.

Evaluation of the accuracy and validity between smartphone and visual estimation with the gold standard UG was performed using the ICC. Paired t-test were used for comparison of mean absolute differences with significance set at $\alpha = 0.05$. Bland–Altman plots with 95% limits of agreement (LOAs) were used to examine the level of agreement between modalities.[10] An upper limit of agreement of > 10° ([average] + 1.96 x sd) was considered clinically important based off previous studies[9,11] and used as reference value to accept or reject the smartphone application as a reliable tool to assess elbow ROM. Statistical analysis was performed on IBM SPSS Statistics (Version 24.0. IBM Corp., Armonk, New York, USA).

Results

Out of the 20 patients (40 elbows) included in the study, there were 15 male and five female patients with a mean age of 10.5 years (range 6 years to 15 years). Three patients were managed operatively, while the remainder were managed non-operatively with cast immobilization. Descriptive statistics for each measurement are summarized in Table 1.

Table 1 Descriptive statistics for each elbow movement and measurement modality in degrees

	Visual estimation (°)	Goniometer (°)	Smartphone (°)
Flexion			
Range	70–160	75–163	73–159
Median	142.5	145.0	145.0
Extension			
Range	–5–80	–7–80	–7–81
Median	0.0	–2.0	–1.5
Supination			
Range	10–90	20–94	20–94
Median	90.0	87.5	87.5
Pronation			
Range	30–90	20–89	23–91
Median	80.0	81.5	82.0

Table 2 Intraclass correlation coefficient between observers for each elbow movement (interobserver reliability)

Measurement	ICC	95% CI
Visual estimation		
Flexion	0.89	0.69–0.96
Extension	0.97	0.96–0.98
Supination	0.96	0.90–0.98
Pronation	0.89	0.70–0.95
Goniometer		
Flexion	0.96	0.82–0.98
Extension	0.99	0.99–0.99
Supination	0.99	0.97–0.99
Pronation	0.94	0.86–0.98
Smartphone application		
Flexion	0.97	0.92–0.98
Extension	0.99	0.99–0.99
Supination	0.99	0.98–0.99
Pronation	0.95	0.91–0.98

CI, confidence interval; ICC, intraclass correlation coefficient

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Table 3 Comparison of reliability and validity of smartphone and visual estimation measurements against universal goniometer measurements within observers (intraobserver reliability)

Movement / method	ICC (95% CI)	Mean absolute difference ± SD (°)	Bland–Altman mean difference (95% CI) (°)	± 95% LOA (°)	P value*
Flexion					
Visual estimation	0.92 (0.77–0.96)	7.7 ± 5.9	4.5 (3.0–5.9) 3.04–5.89	± 12.5	< 0.001
Smartphone	0.98 (0.97–0.99)	2.6 ± 1.9	0.3 –(–0.4–0.9) -0.43–0.95	± 6.1	0.450
Extension					
Visual estimation	0.98 (0.97–0.99)	2.9 ± 3.3	0.7 (–0.1–1.4) -0.13–1.43	± 3.5	0.102
Smartphone	0.99 (0.98–0.99)	1.1 ± 1.0	–0.2 (–0.3–0.3) -0.32–0.27	± 2.6	0.867
Supination					
Visual estimation	0.97 (0.96–0.98)	3.9 ± 3.3	0.5 (–0.4–1.4) -0.44–1.44	± 8.3	0.295
Smartphone	0.99 (0.98–0.99)	2.2 ± 1.5	0.7 (0.2–1.2) 0.19–1.21	± 4.5	0.108
Pronation					
Visual estimation	0.91 (0.86–0.94)	4.8 ± 3.5	0.4 (–0.9–1.7) -0.95–1.67	± 11.5	0.008
Smartphone	0.98 (0.97–0.99)	1.9 ± 1.1	–0.1 (–0.6–0.4) -0.64–0.37	± 4.4	0.589

CI, confidence interval; ICC, intraclass correlation coefficient; LOA, limits of agreement
*P values calculated via paired-T test for mean absolute differences. Significance set at α = 0.05

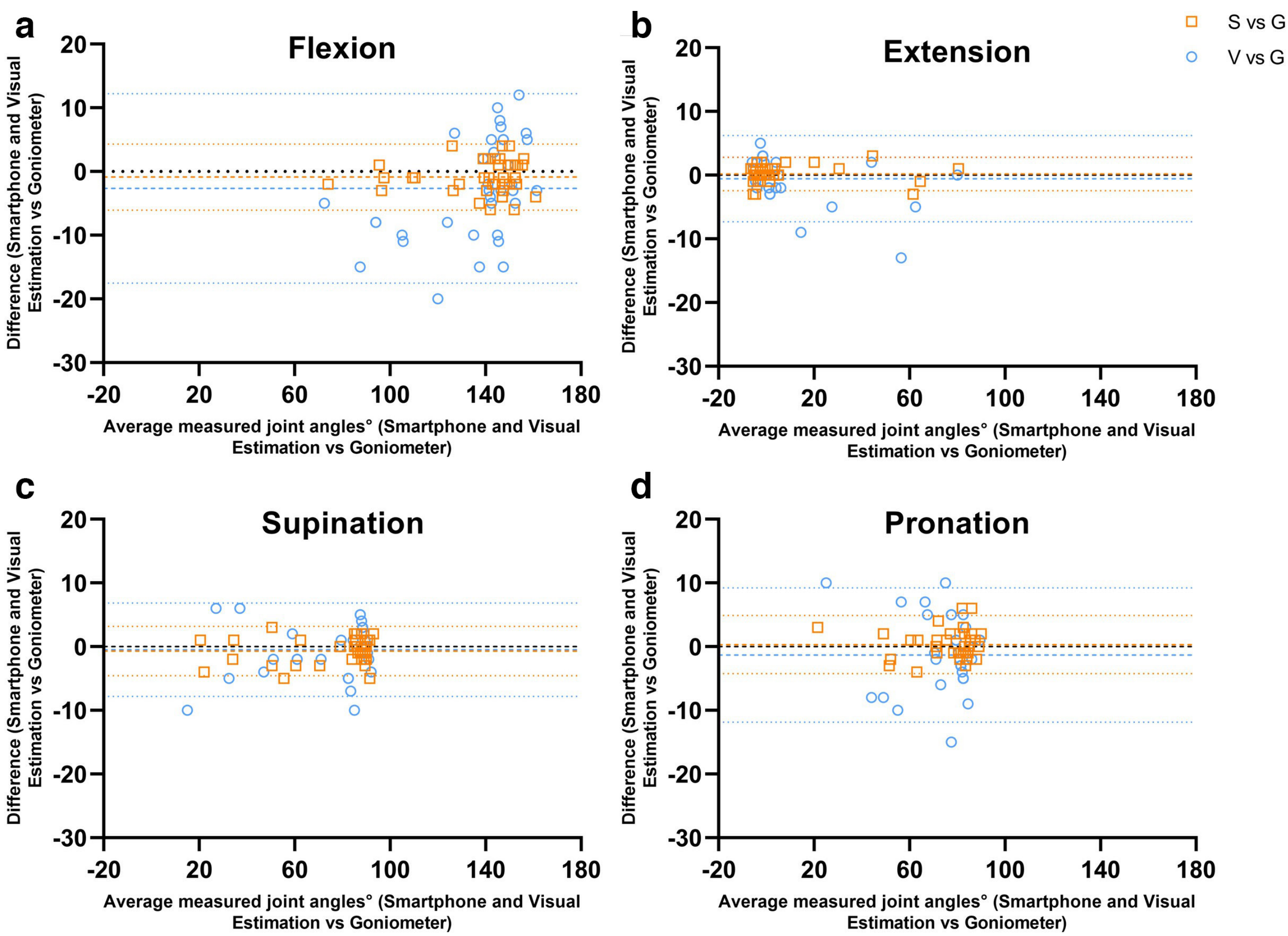

Fig. 4 Superimposed Bland–Altman plots of differences between smartphone application and visual estimation versus gold standard goniometer in elbow flexion, extension, supination and pronation. The mean difference (or systemic error) and 95% limits of agreement (LOA) are presented for the smartphone application (orange lines) and visual estimation (blue lines).

The interobserver reliability for all three measurement modalities between the two observers is reported in Table 2. There was excellent correlation of measurements for all three modalities, with average ICC values greater than 0.90. Between the two observers, visual estimation had the lowest average ICC of 0.92, while the average ICC for both UG and smartphone application was 0.97. In general, across all three measurement modalities, extension and supination had the highest ICC values with pronation having the lowest ICC values. One-way ANOVA testing showed no statistically significant difference in interobserver reliability between the three groups (F = 2.860, P = 0.109).

To assess intraobserver reliability and accuracy, the smartphone clinometer application and clinician visual estimation measurements were compared with the gold standard UG measurements (Table 3). Both visual estimation and smartphone inclinometer had excellent correlation with the gold standard UG, with ICC values ranging between 0.91 and 0.98 and 0.98 and 0.99 respectively. There was no significant difference between the injured side and non-injured side, although the study was underpowered for this comparison.

The mean absolute difference in measured ROM between smartphone application and UG ranged from 1.1° ± 1.0 to 2.6° ± 1.9, compared to visual estimation and UG; 2.9° ± 3.3 to 7.7° ± 5.9 (Table 3). There was no statistical difference between the smartphone application and UG for all elbow measurements. Between visual estimation and UG measurements, there was a significant difference; P = < 0.001 for flexion and P = 0.008 for pronation.

Bland–Altman plots with mean differences ± 95% LOA are presented in Figure 4. There was excellent agreement between the smartphone application and the gold standard UG for all elbow movements with the upper LOA falling within 10°. Overall, the smartphone inclinometer showed superior agreement over visual estimation when compared to the gold standard UG. In particular, visual estimation had poorer agreement to the UG, with the upper limit of agreement exceeding 10° for flexion (+12.5°) and pronation (+11.5°). Mean differences and 95% LOA were, in general, highest for the flexion measurements and lowest in extension for both methods.

Discussion

Accurate and consistent measurement of elbow ROM post-injury or surgical intervention is a daily and integral component in the clinical assessment of paediatric patients and also important for validating outcomes in clinical research. Modern smartphone applications are being increasingly integrated into orthopaedic practice as they are widely available, easy to use and offer potentially greater digital precision. When coupled with the advancement of modern video and mobile technology this has the potential to reduce costs of healthcare through virtual and remote patient assessment and management.

Although they present multiple advantages for measuring elbow ROM over alternative methods such as visual estimation or standard goniometers, there are few studies in the literature that systematically assess the validity and reliability of these technologies for clinical use.[3,12–15] This study demonstrated that a simple and inexpensive smartphone inclinometer application was a valid and reliable tool when compared to the standard UG for measurement of elbow ROM. To the best of our knowledge, this is the first such validation study performed in a paediatric cohort.

Overall, there was excellent interobserver reliability for all measurements and modalities with average ICC values greater than 0.90. Consistently lower ICC scores were seen for flexion (range 0.89 to 0.97) and pronation (range 0.89 to 0.95) measurements between assessors compared to supination and extension. This could be explained by the increased effect of patient fatigue and greater variability in determining anatomical reference points for these particular elbow motions. A study in 60 adult patients by Behnoush et al also reported good-to-excellent interobserver reliability for UG and smartphone inclinometer measurements, with the lowest ICC values also occurring in elbow flexion and pronation.[14]

In our series, the smartphone inclinometer demonstrated excellent reliability and proved to be comparable to the gold standard UG with all intraobserver ICC values > 0.95.

The smartphone application showed high agreement with the UG for all elbow measurements. Although the clinically important difference was set at 10 degrees for this study, we found that the mean absolute difference for all elbow movements measured by the smartphone was < 5°, with 95% LOA also within ± 10°; the upper threshold for clinical significance.[10] The greatest variability in measurements with the smartphone application was seen with elbow flexion (mean difference 2.6°; 95% LOA ± 6.1°), consistent with similar studies reporting the lowest agreements for elbow flexion between smartphones and goniometers.[14,15] Additionally, the smartphone inclinometer application showed superior agreement with the gold standard UG when compared to clinician visual estimation for all elbow measurements. In particular, visual estimation had significantly poorer agreement in flexion and pronation with upper 95% LOA exceeding 10° and mean difference close to or above 5°. This is in contrast to a previous study by Blonna et al, which concluded that visual estimation is as accurate as clinical goniometry for all elbow movements, although the authors note that this is highly dependent on the experience and training of the assessors.[12]

The aim of this study was to determine the feasibility of smartphone technology to measure ROM in paediatric elbows. However, measurement of elbow carrying angles could not be assessed due to inaccuracy related to flexion deformity in some patients. Furthermore, individual measurements for between each modality was not blinded, which may be a potential source of bias. Patient fatigue between each measurement was a confounding factor which we attempted to minimize by alternating assessors and limiting to a single measurement per movement. Repeated measurements on participants were not possible during the single clinic session due to logistical impracticalities, while delayed measurements at a later clinic may have introduced the confounding effects of improving ROM over time in the injured extremity.

Although there was high interobserver reliability, our assessors were both trained orthopaedic clinicians with experience measuring elbow ROM. As such, universal application of smartphone technology as a valid and reliable tool for untrained staff and patients cannot be assumed. Furthermore, our study was performed in a controlled clinical setting, but, measurement accuracy in paediatric patients may be negatively impacted in potentially stressful clinical environments. However, multiple clinical studies on goniometer-based elbow measurement have shown that, with a standardized technique and clear instructions, the reliability of ROM measurements can be improved in untrained examiners.[16] In conjunction with the convenience, accessibility and ease of handling offered by smartphones, incorporation of this technology facilitates the rapid trend towards remote patient self-monitoring in order to decrease costs and the burden of regular follow-up appointments to modern healthcare systems.[2]

Although, precise measurement of elbow ROM post-injury or surgical intervention is often critical in the clinical care, there a few clinical studies evaluating smartphone applications as an alternative method to visual estimation or gold standard goniometers in measuring elbow ROM. Specifically, there have been no studies in the paediatric population. Despite some limitations, our study demonstrates that a smartphone inclinometer application is a valid and reliable alternative for measurement of elbow ROM in paediatric patients.

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COMPLIANCE WITH ETHICAL STANDARDS

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OA LICENCE TEXT

ETHICAL STATEMENT

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

ICMJE CONFLICT OF INTEREST STATEMENT

DLG reports he is a member of the editorial board of the *Journal of Clinical Investigation* (unpaid position), outside the submitted work.

The other authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

DPK: Design, Recruitment and data collection, Analysis and interpretation of data, Drafting and critical revision of the manuscript.

JL: Design, Recruitment and data collection, Drafting and critical revision of the manuscript.

TLC: Analysis and interpretation of data, Drafting and critical revision of the manuscript.

DGL: Design, Analysis and interpretation of data, Drafting and critical revision of the manuscript.

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