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Knee Flexion Angle Measurement Using Virtual Assessment Tools: Correct Procedure and Potential Pitfalls

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ABSTRACT

Virtual patient assessment will inevitably require smartphone technology to remotely measure knee range of motion. We conducted an experiment to analyze the impact of observer position relative to the flexed knee on the perceived angle measured using an electronic application (Dr. Goniometer) for iPhone. Two observers measured the apparent knee flexion angle from 7 different positions at 3 different heights relative to the center of the knee joint. Intraclass correlations were calculated to evaluate the intra-observer and interobserver variability using two-way mixed-effects models. The intraclass correlation for interobserver variability was excellent at 0.804 (95% confidence interval 0.663–0.889). When the observer was greater than 15° from the knee perpendicular, the true angle of knee flexion (90°) was not observed in any of the measurements. This was the case when observed from both proximal (range 95°–121°) and distal (range 92°–108°) directions. Ideally the camera lens should be perpendicular to the long axis of the lower limb in the proximal-distal direction and at the same height. However, if the camera lens is within 15° of the perpendicular, then at 90° of true flexion, the perceived angle will not be greater than 95° in 94% of cases.

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Introduction

Virtual rehabilitation is now playing a more important role than ever in the context of total knee arthroplasty [1]. There are many reasons for the rising importance of this modality of rehabilitation. Since the onset of the COVID-19 pandemic, the utility of home-based procedures has allowed patients to engage in the rehabilitation process while reducing their exposure to potentially lethal pathogens [2]. The need for virtual platforms, however, has always been evident for patients that have particular difficulty with travel because of living in extremely remote areas [3]. Also, many patients depend on a relative for transport, with that person potentially having to take time off work. The benefits of virtual clinical reviews in relation to reduced work absenteeism have been described in many studies [4]. There are also often challenges with hospital car parking, waiting times, and overcrowding in clinic suites. For these reasons, increasing face to face hospital consultations will have to be justified.

Safe virtual examination of the extremity in Orthopedic practice has been demonstrated with the use of a smart phone device in prior studies [5]. With the rise in virtual patient assessment, there will also be a rise in the need to accurately measure the patient knee flexion angle with the use of smartphone applications. We conducted an experiment to analyze the impact of observer position relative to the flexed knee on the perceived angle measured using an electronic application (DrGoniometer, CDM S.r.l., Milano, Italy) for the iPhone [6].

Material and methods

Using a long-arm goniometer, we positioned an anatomically accurate synthetic knee prosthesis in a flexion angle of 90°. We chose this angle of 90° as it is considered an acceptable outcome after total knee arthroplasty.

Two observers measured the apparent knee flexion angle from 7 different positions at 3 different heights relative to the center of the knee joint. Observer 1 was a specialist musculoskeletal physiotherapist. Observer 2 was a clinical fellow in total knee arthroplasty. The perceived knee flexion angle was measured at the perpendicular position (0°) and also at 45°,

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30°, and 15° proximal to and distal to the joint, giving 7 measurements at this particular height (Fig. 1). The angles proximal to and distal to the joint line were confirmed using a long-arm goniometer.

These 7 measurements were repeated at both 15° above and 15° below the center of the knee joint. We did not measure the perceived knee flexion angle at 30° above or 30° below the joint line because in this position, the observer would be in an extremely uncomfortable position that is not likely to be replicated by any observer taking a photograph for a patient. To ensure accurate heights above and below the knee joint of 15°, an inclinometer was used to ensure that this angle was accurate. Specifically, we passed a rigid rod from the center of the knee joint to the camera lens and sat the inclinometer on this rod to ensure that we were either horizontally relative to the joint, at 15° above or 15° below the joint line.

Each observer, therefore, measured 21 perceived angles on 2 occasions to allow for calculation of both intraobserver and interobserver reliability. Line graphs were used to illustrate the interobserver and intraobserver variation in measurements for all values recorded.

In order to identify the most accurate positions of observation, mean angles were calculated for the accumulation of all values at each of the 3 heights. Mean angle values were also calculated for each of the 7 different angles of measurement (at all heights) relative to the knee joint for each observer. Box plots were used to illustrate the varying perceived angle as measured at each of the 7 positions for the 3 heights.

Intraclass correlations (ICCs) were calculated to evaluate the intraobserver and interobserver variability using two-way mixed-effects models. The ICC value was interpreted as either poor, fair, good, or excellent based on the definitions provided by Cicchetti [7]. Values less than 0.4 were defined as poor. A value in the range of 0.4 to 0.59 was defined as moderate. Values between 0.6 and 0.75 were deemed to be good, and a value of 0.76 or above was defined as an excellent ICC. The statistical software program Stata/IC 13.1 for Mac (64-bit Intel) was used.

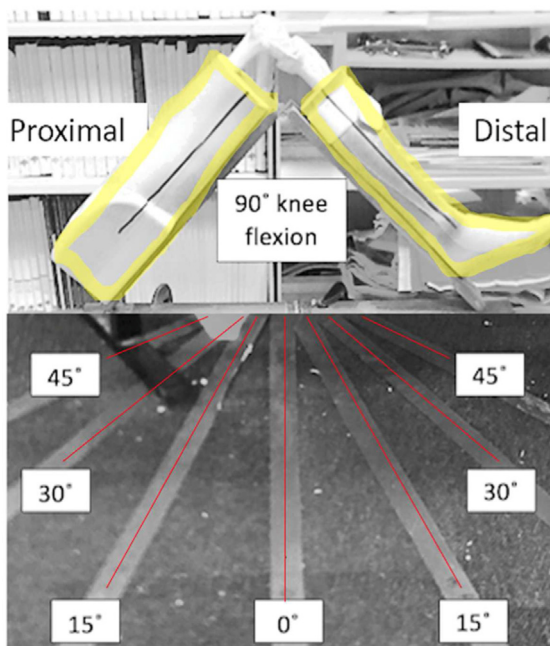


Figure 1. The 7 positions of observation along the proximal-distal axis.

A patient-friendly document, which is included as an appendix (Appendix 1), was developed to clearly explain the optimal position to record knee flexion angles when using electronic devices remotely. This has been designed to be adopted easily by any institution using remote measurement of patient knee range of motion in the outpatient setting.

Results

Observer variability

The ICC for interobserver variability was 0.804 (95% CI 0.663–0.889). Observer 1 had an intraobserver ICC of 0.898 (95% CI 0.766–0.957), and observer 2 had an intraobserver ICC of 0.945 (95% CI 0.870–0.977).

Variation due to height of observation

There were 28 values measured in total at a height of 15° above the knee joint. The mean angle value was 97.3° ($\sigma = 7.2^\circ$, range 86.4°–114.5°) (Fig. 2).

There were 28 values measured at the same height as the knee joint. The mean angle of measurement in this case was 99.6° ($\sigma = 8.08^\circ$, range 89.0°–121.5°) (Fig. 3).

There were 28 values measured at 15° below the knee joint. The mean angle of measurement in this case was 97.5° ($\sigma = 8.33^\circ$, range 86.1°–118.4°) (Fig. 4).

Variation due to the proximal-distal position of observation

45° Proximal to knee joint

The mean angle of measurement in this position (for all 3 heights of observation) was 110° ($\sigma = 6.60^\circ$, range 101.1°–121.5°).

30° Proximal to knee joint

The mean angle of measurement in this position (for all 3 heights of observation) was 100.3° ($\sigma = 4.33^\circ$, range 95.6°–107.9°).

15° Proximal to knee joint

The mean angle of measurement in this position (for all 3 heights of observation) was 93.51° ($\sigma = 2.96^\circ$, range 89.3°–98.2°).

Perpendicular to knee joint

The mean angle of measurement in this position (for all 3 heights of observation) was 89.9° ($\sigma = 2.83^\circ$, range 86.1°–95.2°).

15° Distal to knee joint

The mean angle of measurement in this position (for all 3 heights of observation) was 91.4° ($\sigma = 2.82^\circ$, range 87.3°–95.6°).

30° Distal to knee joint

The mean angle of measurement in this position (for all 3 heights of observation) was 96.7° ($\sigma = 3.41^\circ$, range 92°–105.6°).

45° Distal to knee joint

The mean angle of measurement in this position (for all 3 heights of observation) was 104.6° ($\sigma = 2.21^\circ$, range 101.2°–108°).

The boxplot in Figure 5 demonstrates the variation in perceived angle measurement at each of the 7 positions on the proximal-distal spectrum in relation to the knee joint.

Discussion

Our results demonstrate that during a virtual review of knee flexion, if the camera lens is within 15° of the knee perpendicular, then at 90° of true flexion, the perceived angle, although always greater than 90°, will not be greater than 98°. The advantages of virtual platforms include convenience for the patient, efficiency of care with the reduction of waiting times in hospital,

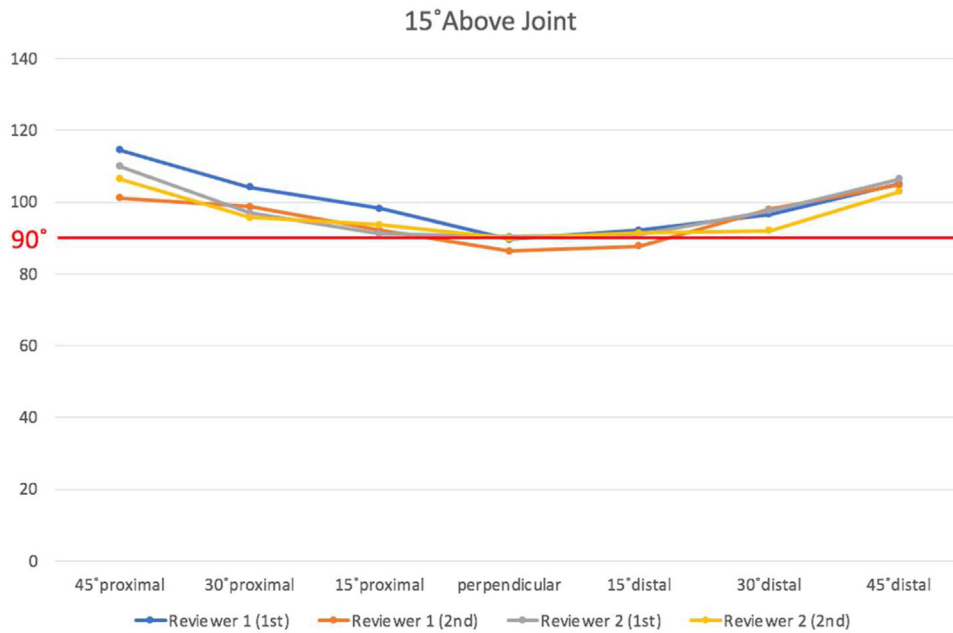


Figure 2. Angles measured at 15° above the knee joint.

and significant cost-reduction implications for the institution involved [1]. With the establishment of virtual joint replacement clinics, it has been demonstrated that patient satisfaction rates are extremely high with this mode of treatment [8]. In a study performed by El Ashmawy et al., it was found that less than 10% of patients needed an in-person appointment after their total joint arthroplasty [8]. In recent years, a standardized approach has been developed by numerous specialists involved in total joint arthroplasty patient care, which allows for the safe implementation of virtual arthroplasty clinics across the United Kingdom [9].

In the virtual setting, objective measurement of knee range of motion can be challenging. This difficulty can be overcome with the use of mobile applications that use the technology to allow patients to send images of their knee at the extremes of extension and flexion and then for these to be accurately measured. This can allow a patient's progress to be tracked postoperatively and identifies those that may require manipulation under anesthesia (MUS). There are many mobile applications that have been validated for this purpose [10,11]. Indeed, there are numerous studies confirming the superiority of these mobile phone applications compared with traditional universal goniometers [12].

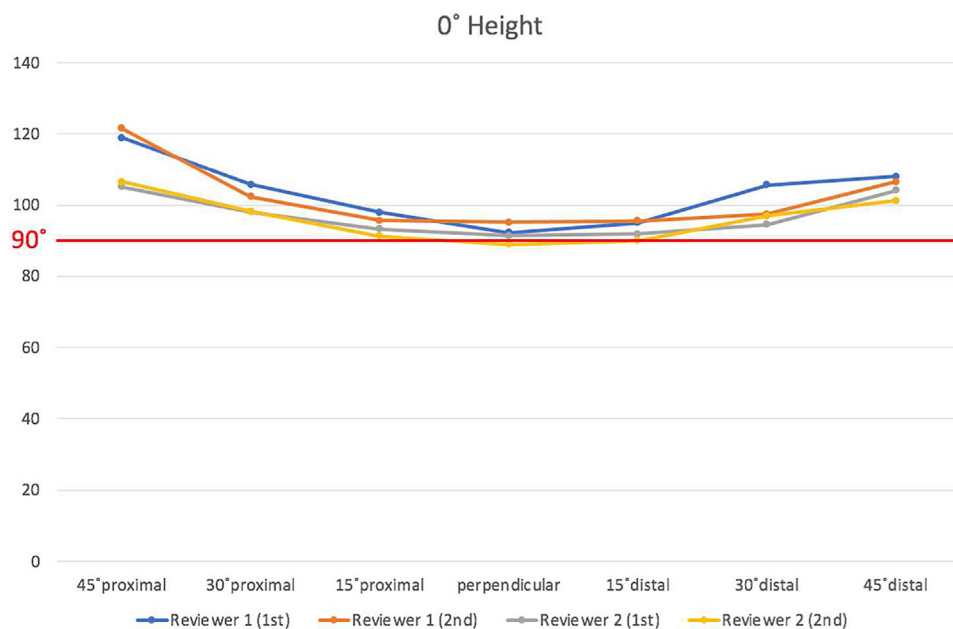


Figure 3. Angles measured at the level of the knee joint.

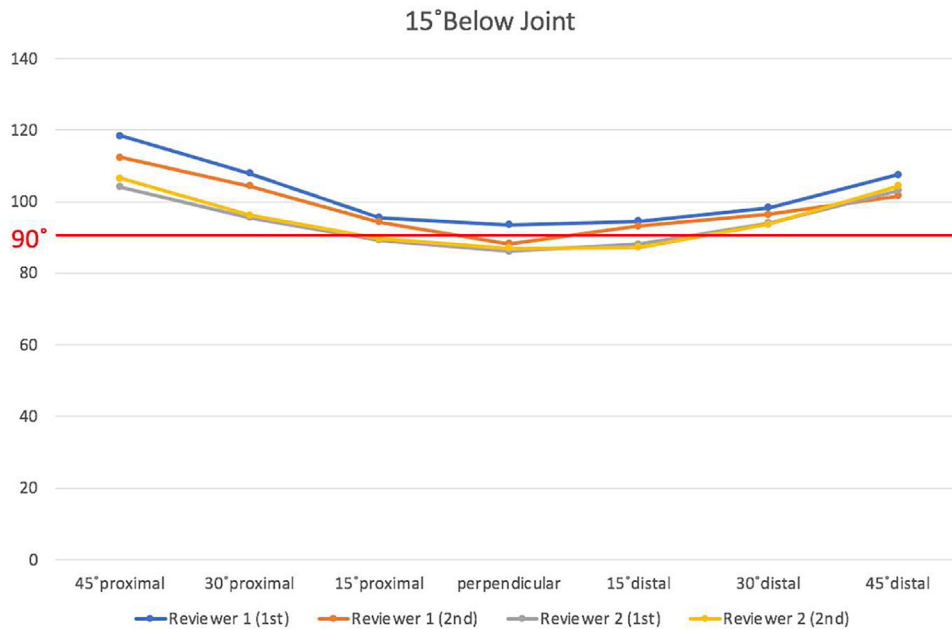


Figure 4. Angles measured at 15° below the knee joint.

Given the utility of these mobile applications for the measurement of knee flexion angles as the field of knee arthroplasty pushes forward, we set out to describe the optimal position that the person taking the photograph should be in to ensure acceptable accuracy. We found that when the observer was greater than 15° from the knee perpendicular, in either the proximal or distal direction, the true angle of knee flexion was not observed in any of the measurements using this digital software. For this reason, we recommend that all observers be perfectly perpendicular to the long axis of the lower limb and centered on the knee joint to accurately measure the angle (see images in Appendix 1). We also note that if the observer is positioned within 15° perpendicular to the knee, the perceived knee flexion angle will be within 5° of the true flexion angle in excess of 94% of cases.

Overestimating knee flexion in this setting risks missing a patient who could benefit from a MUA. Given good

instruction, it is unlikely that the observer will be greater than 15° off the perpendicular. Thus, if a clinical threshold for MUA was 80° as in our institution, then consideration of a face-to-face consultation should be considered if the angle is less than 90° [13].

Interestingly, the height of the observer relative to the knee joint seems to be less consequential for knee flexion angle measurement accuracy. Whether the observer was 15° above, 15° below, or on the same level as the knee joint, the range of measurements included the truly accurate reading of 90° in all cases. We conclude, therefore, that the most important factor when considering observer positioning for photographing is the angle relative to the perpendicular along the long axis of the lower limb in the proximal-distal direction. We, therefore, recommend that observers taking photographs of patient knees aim to be perfectly perpendicular to the long axis of the lower limb centered on the knee and at the same height as the knee joint.

To assist in the simple dissemination of this important patient information, we have designed an illustrated patient information leaflet, which may be used for institutions involved in the management of musculoskeletal pathologies of the knee where knee range of motion monitoring in the virtual setting is a useful aide (see Appendix 1).

Limitations

We used an anatomically correct synthetic knee flexed to 90°. The reason for this choice was to allow us to be sure that the knee was being kept at exactly 90° of flexion without any risk of patient fatigue adding to inaccuracy. The use of long-arm goniometers and inclinometers to determine the positions may also have its flaws. However, we have shown excellent rates of interobserver and intraobserver reliability, and so we believe that the readings of knee flexion measurements are likely to be reproducible based on our study design.

With this technique, the error always overestimates rather than underestimates, which risks missing patients suitable for an MUA, and if the observer is 15° from the perpendicular, then that error

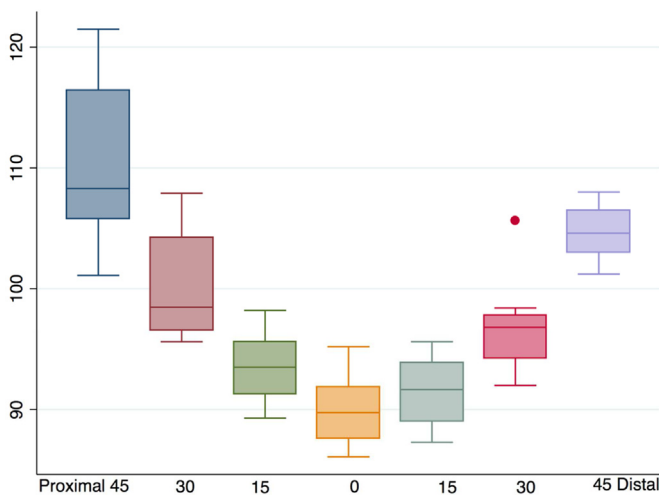


Figure 5. Variation in perceived angle measurement at each of the 7 positions on the proximal-distal spectrum. The red dot denotes an upper outlier (ie a value that lies outside of the upper adjacent values of the whisker plot).

can be up to 8° at 90° flexion. This must be taken account of it using this technique.

Conclusions

Virtual knee angle measurement using electronic mobile phone applications is likely to continually increase in the future for orthopedic services dealing with knee pathology. Ideally the camera lens should be perpendicular along the long axis of the lower limb in the proximal-distal direction and at the same height. However, if the camera lens is within 15° of the perpendicular, then at 90° of true flexion, the perceived angle, although always greater than 90°, will not be greater than 98°.

Conflicts of interest

The authors declare that there are no conflicts of interest.

For full disclosure statements refer to <https://doi.org/10.1016/j.1016/j.artd.2021.11.012>.

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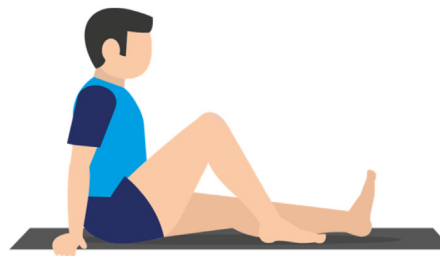
Appendix 1. Patient Information Leaflet

Instructions for you as the patient

- We would like your helper/relative to take 3 different photographs of your knee using a smart phone
- This is to see how well your knee is moving
- The best place to take the photographs is with you lying on a firm bed or a firm couch
- Make sure the room is bright either using natural light or an electric light but close the curtains if there is direct sunlight
- Please wear a pair of shorts
- Lie or sit in whatever way is most comfortable for you
- Your friend or relative will take a photograph of your knee in the following 3 positions:



Position 1 - Try and make both knees as flat or as straight as you can



Position 2 - Try and bend your knee as much as you can without touching your knee



Position 3 - Now lean forward as shown and using both hands clasped just above your ankle try to make your knee bend as much as possible

Instructions for the person taking the photographs

- Please use a smart phone to take the photographs so that they can be sent to us by email
- Make sure the patient is wearing shorts
- Make sure the patient is sitting or lying on a firm surface
- Take the photographs from the same side as the knee replacement – so if the patient had their left knee replaced take the photographs from their left and from the right if it was their right knee

Make sure that for each of the 3 photographs

1. The knee is in the center of each of the 3 photographs
2. You keep the face of phone vertical as shown in the image below – this is easier to do if you are sitting
3. The camera is held at the same height as the knee for each photograph as shown in the images below (Please note this height will change depending on whether the knee is straight or bent)
4. The camera is directly opposite the knee for each photograph as shown in the images below
5. Each photograph should include the very top of the thigh and the ankle of the knee you are photographing

