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ORIGINAL ARTICLE

The Intrarater and Interrater Reliability and Validity of Universal Goniometer, Digital Inclinometer, and Smartphone Application Measuring Range of Motion in Patients with Total Knee Arthroplasty

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Abstract

Objectives The aim of this study was to investigate the intrarater and interrater reliability and validity of range of motion measurements obtained with a universal goniometer, digital inclinometer, and smartphone application in patients with total knee arthroplasty.

Methods Range of motion of the knee joint was measured by two examiners with a universal goniometer, digital inclinometer, and a smartphone application. Data were obtained from 51 knees of 27 patients at postoperative 6 months. Two measurements made by the first examiner were compared to assess interrater reliability, and measurements from both examiners were compared to assess intrarater reliability. Statistical analysis was performed using intraclass correlation coefficient (ICC) and Spearman's rho values.

Results With all three methods, active and passive knee flexion range of motion measurements showed high intrarater and interrater reliability (ICC = 0.749–0.949). Concurrent validity analysis also demonstrated statistically significant, moderate to strong correlation among the three methods (r = 0.775–0.941).

Conclusion The universal goniometer, digital inclinometer, and smartphone application were all found to be reliable and valid assessment tools in clinical practice for patients with total knee arthroplasty.

Keywords Total knee arthroplasty · Range of motion · Goniometric measurement

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Background

Disability assessment in patients with knee osteoarthritis includes evaluation of pain, joint stiffness, altered range of motion (ROM), muscle weakness, instability, and radiographic changes. Activity limitations can be assessed according to self-report or measured by objective methods such as accelerometer and the up-and-go test. Methods for measuring ROM, such as the American Knee Association Score, are also used to assess disability. However, the relationship between ROM and function is controversial, as some authors report the importance of ROM in determining function, while others report they are poorly correlated. For this reason, it is important to determine joint ROM when evaluating disability in people who undergo joint replacement [1–3].

Joint replacement is the only surgical intervention that is performed for advanced knee osteoarthritis and is supported by high-level evidence. It has proven effectiveness based on the evaluation of postoperative outcomes, but many different measurement methods are used in this evaluation, and many have no theoretical basis. The International Classification of Functioning, Disability, and Health (ICF) developed by the World Health Organization (WHO) proposes a theoretical framework for defining and evaluating disability. Disability is conceptualized as encompassing impairments, activity limitations, and participation restrictions, and the ICF is also applicable to joint replacement [4].

Various instruments and techniques to measure ROM have been developed, each with advantages and limitations. Universal goniometers are used most commonly in clinics because they are easily accessible, inexpensive, portable, and easy to use [4]. However, stabilizing the joint can be difficult because the examiner must use both hands during the measurement, which increases the margin of error in measurements [2]. The majority of the previous studies about universal goniometers; it has better reliability for knee flexion than knee extension and even if the universal goniometer shows good intrarater and interrater reliability, it has a measurement error of 5° for measurement of the lower extremity. [5] Another tool recently used to measure knee joint ROM is the smartphone. Mobile applications offer a simple and fast method for measuring joint position in clinical settings. Besides, the use of smartphones were developed to maximize the practically and accessibility of goniometric resources on a smartphone and are based on the use of an accelerometer to analyze human movements and ROM of different body parts [6]. Some studies have reported that the reliability of these measurements is comparable or superior to traditional goniometer measurements [4, 7, 8]. In addition to universal goniometers and smartphones, digital inclinometers are another light and portable tool used to measure ROM in clinics [9]. Recently, digital inclinometer was used the purpose to digitize angle measurements to optimize the reliability. This may be held by one hand during measurements, leaving one hand free to stabilize a body part during measurements [5].

Determining the reliability and validity of repeated measures made by one or more practitioners with one or more instruments is important in clinical decision-making. The literature includes studies comparing the universal goniometer and smartphone applications in the evaluation of knee joint ROM, and studies investigating universal goniometer versus digital inclinometer measurements in several joints [4, 9]. However, we found no study comparing the use of a universal goniometer, smartphone application, and digital inclinometer in determining knee joint mobility. The aim of this study was to investigate the reliability and validity of a digital inclinometer, universal goniometer, and smartphone goniometer application for active and passive ROM measurements in patients with total knee prosthesis.

Methods

Participants and Design

This descriptive, cross-sectional, single-blind study was designed to investigate the interrater and intrarater reliability and validity of knee ROM measurements made using a digital inclinometer, universal goniometer, and smartphone application (Goniometer Pro, 5fuf5 co, NJ, United States) in patients with total knee prosthesis. A total of 51 knee joints of 27 participants were assessed for the study, which was conducted in the Department of Orthopedics and Traumatology of the University Faculty of Medicine, Department of Orthopedics. Participants who met the inclusion criteria and provided written informed consent were assessed at postoperative 6 months. Inclusion criteria were undergoing primary total knee replacement surgery for osteoarthritis, and age 18–75 years. Exclusion criteria were as follows: body mass index (BMI) of 40 kg/m^2 or higher, undergoing revision total knee replacement, and the presence of infection or any lower extremity deformity.

For calculation of the minimum necessary sample size, we determined from similar studies that the minimum intraclass correlation (ICC) value for intrarater reliability of angle measurement methods was 0.80. Using G*Power version 3.1.9.2, we calculated, based on an alpha value of 0.05, 80% power, and ICC of 0.80, that the sample should include a minimum of 51 knees.

Measurement Protocols

Patients who were attending postoperative outpatient follow-up and met the study inclusion criteria were identified by an orthopedics and traumatology physician. Those who volunteered to participate in this study were examined by the same physician and referred to the physiotherapist responsible for this study. Each patient was evaluated by two different physiotherapists. The patients were assessed in random order.

Sociodemographic information such as age, gender, height, weight, and BMI were recorded. Active and passive flexion ROM of the knee joint were measured using a universal goniometer, a digital inclinometer, and the Goniometer Pro smartphone application. Knee flexion ROM was measured after the patient rested for 5–10 min. For interrater analyses, the patient was evaluated by the first examiner, rested for 5–10 min, and was evaluated by the second examiner. After an additional hour of rest, the measurements were repeated by the first examiner for intrarater analyses. Each evaluation was recorded on a separate form and both examiners were blinded to the other's

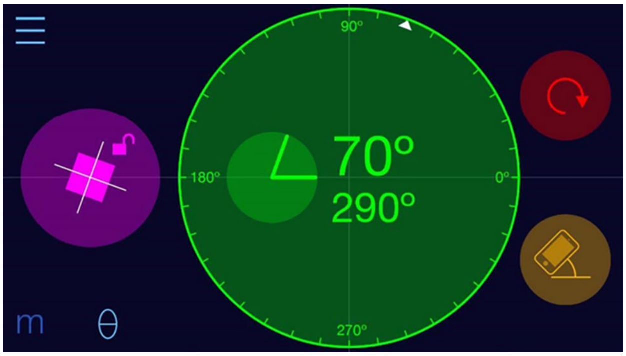

Fig. 1 Output of the Goniometer Pro smartphone application

Fig. 2 Knee joint range of motion measurement with the smartphone

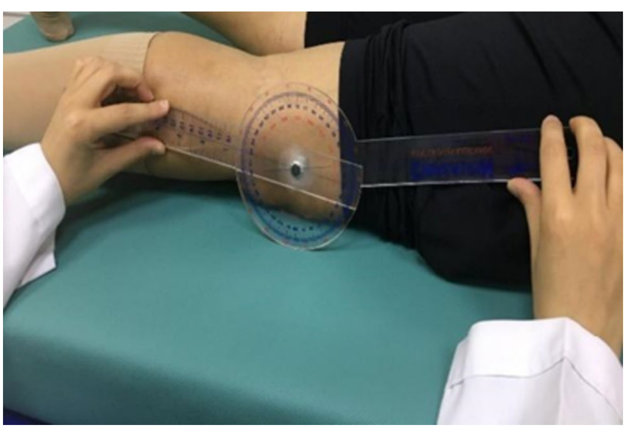

Fig. 3 Knee joint range of motion measurement with the universal goniometer

measurements. In order to ensure standardization of the evaluations, the examiners practiced measuring active and passive knee flexion ROM twice on two volunteers before performing measurements of the participants included in this study. Anatomical landmarks were located by visual estimation and palpation. For all evaluations, ROM measurements were performed in the same order: smartphone (Figs. 1, 2), universal goniometer (Fig. 3), and inclinometer (Fig. 4).

Fig. 4 Knee joint range of motion measurement with the digital inclinometer

Smartphone Measurement

Patients were placed in prone position. Knee joint extension was determined by placing the smartphone over the lateral midline of the tibia. For active flexion, the patient was asked to bend their knee from full extension (0°) to full flexion and the angle displayed by the app was recorded. The process was repeated with the examiner performing passive knee flexion (Figs. 1, 2).

Universal Goniometer Measurement

With the patient still in prone position, the goniometer was positioned with the pivot point at the femoral lateral condyle, the stationary arm at the greater trochanter, and the moving arm aligned with the fibular shaft and lateral malleolus. Active and passive knee flexion ROM measurements were performed as described above (Fig. 3).

Inclinometer Measurement

With the patient in prone position and knee in full extension, the inclinometer was placed on the lateral midline of the tibia and held in this position to obtain active and passive knee flexion ROM measurements as described above (Fig. 4).

Statistical Analysis

Data analysis was performed using IBM SPSS version 22.0 for Windows statistical package program. Normality of the data distributions was evaluated using Kolmogorov–Smirnov test. Continuous variables showing normal distribution are expressed as mean ± standard deviation or standard error; categorical data are expressed as frequency and percentage. The Wilcoxon signed-rank test was used to analyze the difference between the test and retest values obtained by the first examiner. Intrarater test–retest agreement is an indicator of variability in repeated measures. Independent-samples t-test was used for interrater comparisons of the values obtained by the first and second examiners. Friedman analysis of variance was also performed to evaluate differences among the three measurements obtained by the first and second examiners. Intrarater and interrater reliability were evaluated by ICC, with reliability considered excellent at ICC values > 0.75, moderate to high at 0.4–0.75, and low at < 0.4. Spearman correlation analysis was used to evaluate the concurrent validity of the measurement methods. The significance level was set at $p < 0.05$ [10].

Results

Demographic Characteristics

The demographic characteristics of the subjects included in this study were evaluated as mean and standard deviation. The patients' mean age was 66.44 ± 7.22 years, mean height was 159.92 ± 1.26 cm, mean weight was 79.22 ± 2.36 kg, and mean BMI was 32.29 ± 1.05 kg/m^2 (Table 1).

Table 1 Descriptive characteristics of the study participants

Variables	Mean ± SD	Min–max
Age (years)	66.44 ± 7.22	54.0–81.0
Height (cm)	156.92 ± 1.26	150.0–178.0
Weight (kg)	79.22 ± 2.36	50.0–105.0
Body mass index (kg/m^2)	32.29 ± 1.05	20.81–46.05
Duration of illness (months)	22.35 ± 8.14	6.00–48.00

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

Reliability Analysis

The results of intra- and interrater reliability analyses are shown in Table 2. In interrater comparisons, a statistically significant difference was observed only in measurements obtained with the universal goniometer ($p < 0.05$). When the interrater reliability of the measurement methods was examined within 95% confidence intervals, it was found that active and passive knee flexion measurements with the inclinometer had the highest ICC values (0.940 and 0.944, respectively), followed by the universal goniometer (0.889 and 0.883, respectively) and smartphone (0.852 and 0.856, respectively) (Table 2).

In the analysis of intrarater reliability, we detected no significant differences between test and retest measurements ($p > 0.05$). ICC values for active and passive knee flexion measurements were 0.910 and 0.901 for the smartphone, 0.949 and 0.749 for the inclinometer, and 0.915 and 0.926 for the universal goniometer, respectively (Table 2).

When all three measurements were compared, the only statistically significant differences were intrarater variation in smartphone measurements of passive knee flexion ROM and interrater variation in universal goniometer measurements of active knee flexion ROM ($p < 0.05$) (Table 3).

Validity Analysis

In validity analysis, criterion validity examines the extent to which a measure correlates with and predicts changes in the results of other methods aiming to measure the target construct. In our analysis of the concurrent validity of active

Table 2 Reliability measures for the smartphone, inclinometer, and universal goniometer

Assessment methods (degrees)	R1a (Mean ± SE)	R1b (Mean ± SD)	R2 (Mean ± SE)	Interrater reliability (R1 vs. R2)			Intrarater reliability (R1a vs. R1b)		
				ICC	95% CI	*p*	ICC	95% CI	*p*
Smartphone active ROM	91.74 ± 2.31	93.68 ± 15.66	91.34 ± 2.40	0.852	0.740 – 0.916	0.790	0.910	0.841 – 0.949	0.123
Smartphone passive ROM	103.78 ± 2.36	105.3 ± 16.36	103.42 ± 2.62	0.856	0.746 – 0.918	0.825	0.901	0.826 – 0.944	0.103
Inclinometer active ROM	91.66 ± 2.38	93.74 ± 16.07	91.18 ± 2.46	0.940	0.894 – 0.966	0.680	0.949	0.911 – 0.971	0.087
Inclinometer passive ROM	103.36 ± 2.61	103.56 ± 21.72	103.46 ± 2.78	0.944	0.901 – 0.968	0.936	0.749	0.557 – 0.857	0.087
Universal goniometer active ROM	87.56 ± 2.17	89.44 ± 15.40	92.26 ± 2.84	0.889	0.805 – 0.937	**0.013***	0.915	0.740 – 0.908	0.086
Universal goniometer passive ROM	101.10 ± 2.48	102.22 ± 15.94	102.34 ± 3.03	0.883	0.793 – 0.933	0.532	0.926	0.869 – 0.958	0.396

ROM, range of motion; SD, standard deviation; SE, standard error; ICC, intraclass correlation coefficient; CI, confidence interval. Rater 1a = Rater 1, first measurement; Rater 1b = Rater 1, second measurement; Rater 2 = Rater 2, *$p < 0.05$

Table 3 Friedman analysis of variance for smartphone, inclinometer, and universal goniometer measurements

Measurement methods (degrees)	Rater 1a (Mean ± SD)	Rater 1b (Mean ± SD)	*p* 1	Rater 2 (Mean ± SD)	*p* 2
Smartphone active ROM	91.74 ± 16.35	93.68 ± 15.66	0.132	91.34 ± 17.04	0.564
Smartphone passive ROM	103.78 ± 16.75	105.30 ± 16.36	**0.015***	103.42 ± 18.53	0.773
Inclinometer active ROM	91.66 ± 16.83	93.74 ± 16.07	0.180	91.66 ± 16. 83	0.199
Inclinometer passive ROM	103.36 ± 18. 48	103.56 ± 21.72	0.077	103.46 ± 19.69	1.00
Universal goniometer active ROM	87.56 ± 15.39	89.44 ± 15.40	0.64	92.26 ± 20.14	**0.043***
Universal goniometer passive ROM	101.10 ± 17.57	102.22 ± 15.94	0.768	102.34 ± 21.44	0.317

ROM: range of motion, SD: standard deviation. Rater 1a = Rater 1, first measurement; Rater 1b = Rater 1, second measurement; Rater 2 = Rater 2, $*p < 0.05$

The symbol which are bold reflected the significance results

and passive knee flexion ROM measurements made with the three methods used in our study, the strongest correlations were between the smartphone and inclinometer (0.891 and 0.941, respectively), followed by smartphone and universal goniometer (0.882 and 0.834, respectively) and inclinometer and universal goniometer (0.855 and 0.775, respectively). All correlations were highly significant ($p < 0.001$) (Table 4).

Discussion

In our study, patients who underwent total knee replacement for osteoarthritis were predominantly older, overweight women (96.3% female, mean age 66.44 ± 7.22 years, mean BMI 32.29 ± 1.05 kg/m^2), consistent with the literature describing age and gender-related linear regression models [11, 12]. Joint mobility is one of the most important endpoints in the evaluation of treatment outcomes in musculoskeletal care [13]. Knee flexion ROM is frequently a primary outcome measure. Postoperative rehabilitation following total knee arthroplasty typically involves functional evaluation of knee joint ROM. In the literature it has been hypothesized that the knee flexion angle might be assessed by comparing the self-reported questionnaires and visual estimates, universal goniometer, X-ray radiography, digital gravity goniometers, and smartphone applications. Obtaining the same results from different examiners is an important part of a method's reliability and validity [13, 14]. Therefore, in our study we assessed the validity and reliability of different goniometric measurements for both passive and active ROM between the different examiners.

In the literature, knee flexion ROM angles after total knee replacement have been reported as 90.4° for active knee flexion at postoperative 1–2 weeks and 105° for knee flexion at postoperative 8 weeks. In our study, the average measurements for the three tools used at postoperative 6 months ranged between 87.56° and 93.74° for active knee flexion, and between 101.10° and 105.30° for passive knee flexion. There is a reciprocal relationship between activities of daily living and common movement patterns, because in order to have a functional knee, patients must be able to climb and descend stairs and rise from a chair, and the knee bend must have 110° of flexion to achieve these activities [14, 15]. It is accepted that total knee arthroplasty patients should achieve 65° to 70° of active flexion before being discharged from the hospital [15], and a knee flexion ROM of less than 95° after total knee arthroplasty has been defined as knee stiffness [16]. It was reported that the knee joint should be able to perform full extension and 117° of flexion for normal performance of activities of daily living (e.g., 93° flexion while sitting, 83° flexion while climbing stairs, and 106° flexion when tying shoes in sitting position). In another study, patients with knee arthroplasty were reported to use 80.8–91.4° of knee flexion to complete activities [17]. According to data from the American Orthopedic Society, Kathryn et al. reported knee flexion of 135°-150° degrees. Although classical anatomy books usually state this range as 120°–140°, it is emphasized that 120° occurs from active movement and 140° is achieved with additional external

Table 4 Concurrent validity analysis of the smartphone, inclinometer, and universal goniometer

Measurements	Smartphone vs. inclinometer	Inclinometer vs. universal goniometer	Smartphone vs. universal goniometer
Active knee flexion ROM	$r = 0.891, p = 0.001$	$r = 0.855, p = 0.001$	$r = 0.882, p = 0.001$
Passive knee flexion ROM	$r = 0.941, p = 0.001$	$r = 0.775, p = 0.001$	$r = 0.834, p = 0.001$

ROM, range of motion; r = Spearman correlation coefficient force applied after active movement [18, 19]. In another study after the total knee arthroplasty the rehabilitation goal should be a 110-degree flexion angle. They also denoted most of the daily activities required > 120 degrees of flexion angle [20]. Active and passive knee flexion ROM is an indicator of the patient's functional status, and knee ROM is widely used to evaluate the outcomes of total knee arthroplasty surgery and rehabilitation programs [21]. In another article, it was reported that using stairs or chairs (90°–120°), kneeling or squatting (110°–165°), using a bathtub (135°), and gardening (> 150°) require a greater ROM than walking [16]. Therefore, there is a high correlation between the maximum flexion angle measured during daily activity and ROM measured during clinical examination.

There are numerous ways of measuring knee joint ROM. In rehabilitation studies, digital photography (multi-camera) and visual estimation can be used for the evaluation of knee ROM, and digital photography was found to have higher sensitivity for only two joint movements [22]. X-ray, considered the gold standard, also plays an important role in the evaluation of active and passive movements of the knee joint. This method can provide greater transparency among evaluators than other methods and simplify visualization of the knee center in a two-dimensional plane [23]. Studies have also shown that visual observation and clinical goniometer measurements can be used for evaluation of submaximal knee joint flexion [24], and passive joint movement can be measured using a manual goniometer. Universal goniometers are the most commonly used form of goniometers in clinical practice [4, 25]. Measurement of joint ROM using digital inclinometers has been reported only in studies evaluating the ROM of the hip joint. As smartphones become more technologically advanced and widespread, new applications are being developed for use in clinical settings, and the use of special sensors to monitor knee ROM [26].

On the other hand, knee angles are commonly reported as an outcome measures in the assessment of biomechanical function of population both for clinical and research purposes [27]. The knee ROM is not only a key parameter for evaluating the progress of knee function recovery but also an important measure of patient satisfaction with surgery [28].

Sensing technology is widely used in orthopedics nowadays. Since wearable technology nowadays possesses the capacity for monitoring and diagnostic functionality, this technology might help solve some of the challenges in the health care sector faces. To date, the topic of sensor technology in the medical field have investigated the issue from a broader view [29].

Additionally, many studies have developed their analysis methods using different combinations of wearable sensors to monitor and estimate knee ROM. During dynamic motion single inertial measurement units were established [28]. Feldhege et al. developed a novel inertial sensor system for walking behavior and joint motion measurement in daily environments. The results proved that the wearable sensor system showed high effectiveness for behavior classification and knee angle measurement in a laboratory environment [30].

Besides, smartwatches have come out to be one of the most pervasive commercial wearable devices bringing in factors of both utility and style. Smartwatches ensure their high acceptance owing to the convenience, practically and ubiquity offered by these devices [31].

Measurements obtained by all these methods are reported to have high reliability and validity. However, there is no study in the literature evaluating the reliability and validity of the digital inclinometer, universal goniometer, and smartphone application in patients with total knee arthroplasty. In the intrarater test–retest evaluation of our study, measurements of active knee joint ROM with a goniometer, inclinometer, and smartphone ranged from 87.56° to 91.74° and those for passive ROM ranged from 101.10° to 103.78° in the first measurement. In the second measurement (retest), these ranges were 89.44° to 93.68° and 102.22° to 105.30°, respectively. Consistent with the literature, we observed no statistically significant difference in test–retest reliability.

In interrater comparisons, active knee flexion ROM was measured as 87.56° to 91.74° by the first examiner and 91.34° to 92.29° by the second examiner, while the measured ranges for passive knee flexion ROM were 101.10° to 103.78° for the first examiner and 102.34° to 103.42° for the second examiner. Only universal goniometer measurements of active knee flexion ROM were found to differ significantly between the first and second examiners. There was no more than 5° of deviation between the universal goniometer, inclinometer, and smartphone ROM measurements made by the two examiners, indicating that the measurements are accurate and can be compared between clinicians. When we compared all three measurements made by both examiners, only passive knee flexion ROM measurements obtained with a smartphone showed significant intrarater variation.

In a previous study, the ICC coefficient of the universal goniometer for both intrarater and interrater reliability was found to be 0.90 [13], and a smartphone application was found to have excellent reliability (ICC 0.94–0.97) compared to the simple goniometer. In our intrarater analysis, active knee flexion ROM measurements had very high ICC values for the universal goniometer, inclinometer, and smartphone (0.915, 0.949, and 0.910, respectively), while ICC values for passive knee flexion ROM were very high for the goniometer (0.926) and smartphone (0.901) and high for the inclinometer (0.749). In interrater analysis, the inclinometer was found to have very high ICC for both active and passive knee flexion (0.940 and 0.944, respectively), with slightly lower ICC values for the smartphone, and universal goniometer (0.852 and 0.856, 0.889 and 0.883, respectively).

A previous study showed that compared to gold-standard radiographic measurements, universal goniometer measurements were strongly correlated at high degrees of knee flexion ($r = 0.73$–0.77) but weakly correlated at low degrees of knee flexion ($r = 0.33$–0.41). In our study, postoperative 6-month knee flexion ROM measurements showed moderate to strong correlation between inclinometer and universal goniometer (active $r = 0.855$, passive $r = 0.775$), strong correlation between smartphone and universal goniometer (active $r = 0.882$, passive $r = 0.834$), and very strong correlation between smartphone and inclinometer (active $r = 0.891$, passive $r = 0.941$). Thus, our results demonstrated statistically significant, strong correlation among universal goniometer, inclinometer, and smartphone measurements, consistent with the literature. Although previous studies have compared different combinations of inclinometer, universal goniometer, and smartphone, this is the first study to examine all three of these methods together.

Conclusions

1. Intrarater analysis revealed no significant differences in test–retest results, indicating that all three measurement methods have good repeatability by a single evaluator.
2. Interrater analysis showed a statistically significant difference between the evaluators in active knee flexion ROM measurements obtained with the universal goniometer ($p < 0.05$), while there was no statistical difference between the evaluators in the other measurements ($p > 0.05$). This suggests that these methods have good reproducibility overall, but universal goniometer measurements may vary between evaluators. This may be related to the evaluators' experience.
3. High intraclass correlation coefficients in interrater reliability analysis demonstrated that these methods are reliable.
4. The strong correlations among active and passive knee flexion ROM values obtained by the three methods in our analysis of concurrent validity indicated that these methods are valid.
5. This study is superior to others in the literature because we compared three instead of two methodologies. Moreover, all patients in the study had the same preoperative diagnosis, underwent knee replacement performed by the same surgeon (primary only, no revisions), and had the same rehabilitation program, resulting in a homogeneous sample. Future directions should involve the laboratory measurements for ROM related to the gait analysis, sitting and standing knee ROM. Our future hypothesis consist of dynamic motion single inertial movement unit assessments for knee ROM evaluation.

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Data availability The data sets used and analyzed during thecurrent study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study informed consent is not required.

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