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Reliability and validity of lower limb joint range of motion measurements using a smartphone

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ABSTRACT

This study aimed to examine the reliability and validity of using a smartphone to measure the multi-joint range of motion of the lower limbs. We measured the straight leg raise angle, ankle dorsiflexion angle, and hip internal rotation angle in each of the 40 lower extremities of 20 healthy adults. Measurements were compared between a conventional method using a goniometer and a smartphone application method. The intraclass correlation coefficient (ICC) was used to evaluate the reliability of each smartphone measurement, and Bland–Altman analysis was used to examine measurement errors. The criterion-related validity of the two methods was also examined. Intra-rater reliability (ICC 0.668–0.939) was substantial to almost perfect, with no systematic errors found for all items, and the standard errors of measurement were acceptable. Inter-rater reliability (ICC 0.701–0.936) was also substantial to almost perfect, but the straight leg raise angle and hip internal rotation angle showed fixation errors. For these two measurements, with more than one examiner, the limit of agreement of error needs to be considered. No systematic errors were found in the ankle dorsiflexion angle, and the standard error of measurement was within the acceptable range. A moderate to strong correlation (r = 0.626–0.915) was found between the conventional and smartphone methods, demonstrating good criterion-related validity. However, in the ankle dorsiflexion angle measurements, the reliability and validity were shown to be lower than the other two items. This suggested the necessity of changing the measurement conditions in order to use the ankle dorsiflexion angle in clinical practice.

Keywords: reliability, validity, smartphone, range of motion, measurement

Abbreviations:
ROM: range of motion
ICC: intraclass correlation coefficient
MDC: minimal detective change
SEm: standard error of measurement
LOA: limit of agreement
ICT: information and communications technology
3D: three-dimensional

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INTRODUCTION

Measuring joint range of motion (ROM) is important for rehabilitation, as it allows the function of a joint and the cause of joint dysfunction to be investigated. In clinical practice, ROM is commonly quantified using a goniometer, which is considered the most objective and reliable method[1,2,3] and is the gold standard.[4,5,6]

The measurement of ROM using a goniometer is conducted by applying one arm of the goniometer to the proximal side of the extremity adjoining the joint of interest (basic axis) and the other arm to the distal side (moving axis). When measuring, it is necessary to palpate the anatomical landmarks, to fix the basic axis, and to appropriately apply the goniometer arm to the moving axis. Therefore, the accuracy of a measurement is dependent on the experience, knowledge, and technique of the examiner.

In addition to their use in rehabilitation, ROM measurements also form part of the medical assessments conducted in athletes for the prevention of sports injuries. Indeed, reduced ROM is associated with the development of sports injuries. Verrall et al[7] have suggested that hip stiffness is associated with the after-effects of chronic groin injuries. Changes in ankle dorsiflexion ROM have been associated with foot pain and ankle injuries,[8] neuritis, and lower extremity disorders.[9] Thus, there are many reports showing an association between ROM and sports injuries. However, the relationship between ROM and sports injuries remains unclear. Some reports have found causal relationship between throwing disorders[10,11] and internal rotation ROM of the shoulder, whereas another found a lower risk of injury in individuals with 20° or more of internal rotation ROM restriction compared to those with no internal rotation ROM restriction.[12] Moreover, as medical assessments such as ROM are held before and after competition seasons, it is difficult to determine if ROM is directly related to injury within the sporting season.

Reduced ROM can also occur with delayed onset muscle soreness and increased stiffness after an eccentric contraction load on the muscle. Furthermore, reduced ROM has been reported to lead to poor physical performance. Nosaka et al[13] reported that eccentric contraction exercises resulted in an approximately 15% reduction in joint ROM immediately after exercise, followed by a further reduction for up to 3 days. Thus, the timing of measurement, time of injury onset, and variations with the exercise load must be considered in the measurement of ROM. Longitudinal studies on ROM once or twice a year make it difficult to prevent sports injuries and to predict a causal relationship with an injury. As an athlete's physical condition is constantly changing during exercise, it is important to routinely and regularly check and manage ROM on the sports field.[14] However, this is not practical because the gold standard for the measurement of ROM is based on the medical knowledge of professionals, such as physicians and physical therapists, using specialized tools. In order to use the measurement of ROM in daily life, it is essential to establish methods that can be easily performed by the general public without specialized equipment.

Smartphones have become our most familiar sources of information and communications technology (ICT), and their penetration rate has surpassed 70% in Japan within only a few years. Smartphones are highly valuable in a variety of fields, not only because they are easy to use by the general public but also because they are convenient for sending, receiving, and managing data. With the development of hardware technology such as gyro sensors, and software technology centered on applications, the use of smartphones or tablets to evaluate patients has become well established in the field of rehabilitation. Cerrito et al[15] developed an application to quantify the standing-up movement of healthy older adults and reported high reliability and correlation between the floor reaction force measured using conventional methods and that measured using the smartphone application. Finkbiner et al[16] conducted a study to compare walking movement analysis between smartphone and three-dimensional (3D) motion capture and reported that although there was no significant agreement with the 3D motion capture, a clinical application is feasible if the protocol is properly defined. Some smartphones are also equipped with powerful built-in sensors, such as accelerometers, magnetometers, and gyro sensors, thereby giving them the capacity to measure ROM.[17]

In recent years, a number of studies have evaluated the reliability and validity of smartphone applications for the measurement of ROM.[18,19] In general, good to excellent intra-rater and inter-rater reliabilities have been reported.[20-22] Regarding ROM of the lower limb joints, several studies have reported the usefulness of the measurement of ROM using smartphones.[23-26] Charlton et al[27] have shown the validity of ROM of the hip joint using a 3D motion analysis system. Dos Santos et al[28] reported comparable reliability of the smartphone method to conventional methods using a goniometer for measuring ROM of the knee joint. The high reliability of the measurement of ROM of the ankle joint using a smartphone has also been reported.[29,30] However, these studies are single-joint ROM survey reports, and, to the best of our knowledge, no study has investigated the reliability and validity of multi-joint ROM comprehensively using a smartphone application and goniometer. Therefore, to fill this gap in the literature, this study aimed to examine the reliability and validity of the measurement of ROM of the lower limb joints using a smartphone in comparison with the conventional method using a goniometer.

MATERIALS AND METHODS

Study design, population, and ethical standards

This cross-sectional study included 40 lower limbs of 20 healthy adults at a single center. Prior to the study, we fully explained the objectives and methods of the study to the participants and obtained informed consent. Exclusion criteria were severe pain in the lower limbs, any disease affecting lower limb function, and apparent limitation in ROM distal to the lumbar spine. This study was approved by the Chubu University Ethics Committee (approval number: 20190042). Two examiners, both of whom with 5 years of experience as physical therapists, performed each measurement separately.

Instrumentation

The iPhone® model 6 (Apple Inc., Cupertino, CA, USA) and Compass application (Apple Pty Limited, Cupertino, CA, USA) were used in this study. The Compass application comes pre-installed on all iPhones; this application allows angle measurement using the built-in gyro sensor.

Measurement procedure

The straight leg raise angle, ankle dorsiflexion angle, and hip internal rotation angle in the hip flexion position (measured in the upright sitting position) were recorded for each lower extremity (Figure 1). The measurements were taken using both the conventional method (using a goniometer) and the smartphone application method. The side (right or left), angle, and measurement method were randomized using a random number table to determine which one to use first. First, two examiners measured all of the angles once using the smartphone measurement method on the first day (test measurements). One week later, examiner 1 took all of the measurements using the smartphone measurement method (retest measurements). Examiner 1 also took measurements using the conventional measurement method once. All measurements were taken during active motion.

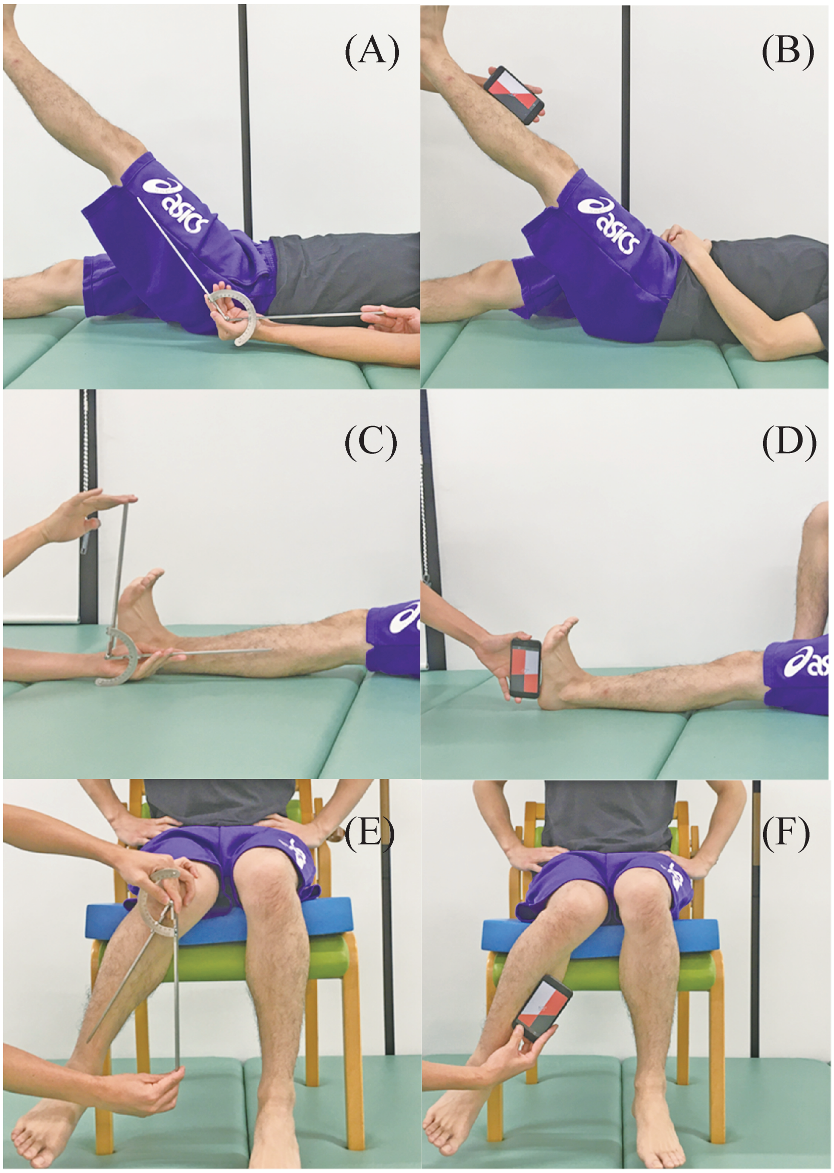

Fig. 1 Participant setup and measurement techniques
Participant setup and measurement techniques using either conventional measurement methods (left column) or a smartphone measurement method (right column). (A, B) Straight leg raise angle: (A) The angle between the floor and the long axis of the femur. (B) The smartphone was applied horizontally at a point 15 cm distal to the tibial tuberosity on the anterior border of the tibia. (C, D) Ankle dorsiflexion angle: (C) The angle between the fibula and the fifth metatarsal bone. (D) The smartphone was applied horizontally to the bottom surface of the center of the fifth metatarsal bone. (E, F) Hip internal rotation angle: (E) The angle between the vertical line from the patella to the floor and the midline of the lower leg. (F) The smartphone was applied in the same location as in panel B to the medial edge of the tibia.

Straight leg raise angle measurements

The straight leg angle was measured with the participant in the supine position and with the leg raised to the maximum straight leg angle (the knee joint should be in full extension). In the conventional method of measurement, the angle between the floor and the long axis of the femur was measured. In the smartphone measurement method (Figure 1-A), the smartphone was applied horizontally at a point 15 cm distal to the tibial tuberosity on the anterior border of the tibia, and the angle between the long axis of the smartphone to the floor was measured, following the procedure of Vohralik et al (Figure 1-B).[19]

Ankle dorsiflexion angle measurements

We measured the maximum dorsiflexion of the ankle with the participant in the supine position, with the knee extended. In the conventional method, the angle between the fibula and the fifth metatarsal bone was measured using a goniometer (Figure 1-C). For the smartphone method, which was based on a method devised by Cox et al,[31] the smartphone was applied horizontally to the bottom surface of the center of the fifth metatarsal bone, and the angle between the long axis of the smartphone to the floor was measured (Figure 1-D).

Hip internal rotation angle measurements

The hip internal rotation angle is defined as the angle measured when the hip is maximally internally rotated in an upright sitting position. In the conventional measurement method, the angle between the vertical line from the patella to the floor and the midline of the lower leg (the line connecting the center of the patella to the center of the medial and lateral malleolus) was measured using a goniometer (Figure 1-E). In the smartphone method, the smartphone was applied in the same location as in Figure 1B to the medial edge of the tibia, and the angle between the long axis of the smartphone and a vertical line to the floor surface was measured (Figure 1-F).

Reliability

We used the reliability coefficients presented by Shrout et al[32] to investigate the intra-rater and inter-rater reliability of each measurement of the smartphone method obtained from the tests and retests of examiners 1 and 2. For examiner 1, the intraclass correlation coefficient (ICC) (1.1) and 95% confidence intervals were calculated for the intra-rater reliability of each measurement item. Inter-rater reliability of examiners 1 and 2 was calculated using day 1 results obtained by both examiners to calculate the ICC (2.1) and 95% confidence intervals. The strength of the correlation was judged using Landis et al[33] criteria (slight: 0.00–0.20, fair: 0.21–0.40, moderate: 0.41–0.60, substantial: 0.61–0.80, almost perfect: 0.81–1.00).

Measurement errors

The errors involved in the measured values were roughly divided into random and systematic errors. The Bland–Altman analysis was performed to calculate the systematic errors (fixed error and proportional bias) and the limit of agreement (LOA).[25] The fixed error was judged not to be a fixed error if it included 0 at the upper and lower limits of the LOA of the difference between the two measurements. Proportional bias was determined not to exist if there was no significant correlation between the difference in the two measurements and the average of the two measurements. In the absence of systematic errors, the possible errors that reduce the reliability of the measurements were random errors. Random errors can be divided into two categories: biological individual differences and measurement errors that occur during measurement. The standard error of measurement (SEm) and minimal detective change (MDC) were calculated to investigate the measurement error during measurements. The MDC shows the limit range in which the amount of change in the two measured values obtained by repeated measurements, such as retesting, is due to measurement error. Changes larger than the MDC are judged to be "true changes" with a 5% significance level. The SEm and MDC were calculated using the following formula: $SEm=sx\sqrt{(1-rxx)}$ (sx: standard deviation, rxx: correlation coefficient). The MDC was calculated using the following formula: $MDC=1.96\sqrt{2}SEm$.

Criterion-related validity

Pearson's rank correlation coefficients was calculated to assess the validity of the two measurement methods, using the measurements taken by examiner 1 on the second day. The significance level was set at $p < 0.05$. A correlation coefficient > 0.90 indicated excellent correlation, 0.75–0.90 indicated good correlation, and < 0.75 indicated poor to moderate correlation.[34]

Analysis method

Based on the guidelines provided by the Consensus-based Standards for the Selection of Health Measurement Instruments,[35] the absolute reliability using the MDC and the criterion-related validity (concurrent validity) were determined. All statistical analyses were performed using R2.8.1 (CRAN, freeware), and statistical significance was set at $p < 0.05$.

RESULTS

Participant attributes

Eleven of the included participants were male, and nine were female. Participants' mean age was 28.5 ± 5.5 years, mean height was 166.3 ± 8.5 cm, and mean weight was 57.8 ± 5.5 kg. No participant met the exclusion criteria, based on interviews and confirmation of comorbidities.

Intra-rater reliability

Table 1 shows the results of intra-rater reliability. ICCs of the straight leg raise angle and hip internal rotation angle were 0.939 (95%CI 0.89–0.97) and 0.901 (95%CI 0.821–0.946), respectively, indicating "almost perfect" intra-rater reliability, and that of the ankle dorsiflexion angle was 0.668 (95%CI 0.455–0.809), indicating "substantial" intra-rater reliability. The Bland–Altman analysis showed neither fixed nor proportional errors, and the MDCs were 9.10°–13.50° and SEms were 3.28°–4.87º.

Inter-rater reliability

Table 2 shows the results of inter-rater reliability. The ICCs of the straight leg raise angle and hip internal rotation angle were 0.936 (95%CI 0.853–0.969) and 0.878 (95%CI 0.765–0.936), respectively, indicating "almost perfect" inter-rater reliability, and that of the ankle dorsiflexion angle was 0.701 (95%CI 0.502–0.830), indicating "substantial" inter-rater reliability. The Bland–Altman analysis of the ankle dorsiflexion angles showed neither fixed nor proportional errors, and the MDC was 8.39°. Fixed errors were seen in the measurements for the straight leg raise angle and hip internal rotation angle. The LOA of the measurements of the straight leg raise angle had upper and lower limits of 12.70° and –6°, respectively; and that of the measurements of the hip internal rotation angles had upper and lower limits of 10.01° and –5.61°, respectively. The SEms were 3.03°–4.70°.

Table 1 Intra-rater reliability (ICC 1.1) for ROM measurements

	Test mean ±SD (°)	Retest mean ±SD (°)	ICC 1.1 (95% CI)	SEm (°)	LOA (°)	Fixed error		Proportional bias		MDC (°)
						95% CI	Result	Regression coefficient	Result	
Straight leg raise angle	67.3 ±19.6	66.6 ±19.6	0.939 (0.89, 0.97)	4.87	–8.99 ~ 10.39	–1.50 ~ 2.90	No	p=0.998	No	13.50
Ankle dorsiflexion angle	11.2 ±5.7	10.8 ±5.6	0.668 (0.455, 0.809)	3.28	–6.13 ~ 6.93	–1.09 ~ 1.89	No	p=0.97	No	9.10
Hip internal rotation angle	40.4 ±12.0	40.4 ±11.6	0.901 (0.821, 0.946)	3.76	–7.50 ~ 7.45	–1.72 ~ 1.67	No	p=0.59	No	10.41

SD: standard deviation
95% CI: 95% confidence interval
SEm: standard error of the measurement
LOA: limit of agreement
MDC: minimal detectable change
ICC: intraclass correlation coefficient
ROM: range of motion

Table 2 Inter-rater reliability (ICC 2.1) for ROM measurements

	Examiner 1 mean ±SD (°)	Examiner 2 mean ±SD (°)	ICC 2.1 (95% CI)	SEm (°)	LOA (°)	Fixed error		Proportional bias		MDC (°)
						95% CI	Result	Regression coefficient	Result	
Straight leg raise angle	67.3 ±19.6	64.0 ±21.3	0.936 (0.853, 0.969)	4.70	–6.00 ~ 12.70	1.22 ~ 5.48	Yes	p=0.09	No	—
Ankle dorsiflexion angle	11.2 ±5.7	11.6 ±5.3	0.701 (0.502, 0.830)	3.03	–6.49 ~ 5.54	–1.84 ~ 0.89	No	p=0.61	No	8.39
Hip internal rotation angle	40.4 ±12.0	38.2 ±11.8	0.878 (0.765, 0.936)	3.93	–5.6 ~ 10.01	0.42 ~ 3.98	Yes	p=0.77	No	—

SD: standard deviation
95% CI: 95% confidence interval
SEm: standard error of the measurement
LOA: limit of agreement
MDC: minimal detectable change
ICC: intraclass correlation coefficient
ROM: range of motion

Criterion-related validity

Table 3 shows the results of criterion-related validity. The correlation coefficients of the measurements of the straight leg raise angle was 0.915, indicating "excellent" positive correlations and that of the measurements of the hip internal rotation angle was 0.884, indicating "good" positive correlations respectively, and that of the measurements of the ankle dorsiflexion angle was 0.626, indicating "poor to moderate" positive correlations, between the two measurement methods for these ROM parameters.

Table 3 Criterion-related validity of ROM measurements

	Conventional method mean±SD	Smartphone measurement method mean±SD	Correlation coefficient
Straight leg raise angle (°)	70.1±19.5	66.6±19.6	0.915
Ankle dorsiflexion angle (°)	17.6±5.3	10.8±5.6	0.626
Hip internal rotation angle (°)	40.6±11.7	40.4±11.6	0.884

SD: standard deviation
ROM: range of motion

DISCUSSION

For each of the three ROM measures included in the study, intra-rater reliability of "substantial" or better was found (ICC of ≥ 0.6). The criteria for ICC are generally based on the Kappa coefficient by Landis et al. Even when other criteria are included, a value of approximately 0.7 or higher is said to be highly reliable. The lower limits of the 95% confidence intervals for the straight leg raise angle and hip internal rotation angle were also above 0.81, indicating "almost perfect" and high intra-rater reliability. However, unlike the other two items, the ankle dorsiflexion angle is not highly reliable. Previous studies of the ankle dorsiflexion angle measurement using a smartphone have shown high validity with correlation coefficients of 0.9 or higher. In this previous study, the dorsiflexion ROM was measured using the weight-bearing measures, and the location of the smartphone was different from that of this study.[19] It has been reported that measuring the ankle dorsiflexion angle with weight-bearing measures is more reliable than non-weight-bearing measures,[36] and the measurement method should be re-examined in this study to increase the reliability of the ankle dorsiflexion angle. Bland–Altman analyses did not show systematic errors. Therefore, accidental errors, represented by SEm and MDC, may be the cause of any inaccurate measurements. SEm calculations revealed that each measurement value includes measurement errors of 3.3°–4.9°, and the calculated MDC was high at 9.1°–13.5°. According to a systematic review by Keogh et al,[37] the reliability and validity of a smartphone application for ROM measurement are considered good if both the SEm and MDC are ≤ 5°. In this study, all SEm values were ≤ 5°; thus, the errors are within the allowable range. Vohralik et al[19] previously reported greater SEm values that ours for ankle dorsiflexion (3.4° vs 3.28°, respectively). However, each measured value in our study had an MDC > 5°, which is considered poor. However, the MDC varies depending on the characteristics of the target population and the type of measurement; therefore, the values obtained by dividing MDC by each measured value (%MDC) are often used to assess the measurement errors. According to Hamersma et al,[38] a %MDC of 20% can be considered good in the measurement of trunk ROM in patients with lumbar pain. In our study, the %MDC in all measured values, except for ankle dorsiflexion, was between 20.3% and 25.8%. Therefore, the conventional and smartphone measurement methods can be considered acceptable. In addition, in the actual measurement of the straight leg raise angle and hip internal rotation angle, when the measured value changes by 20% or more, it can be considered as a change greater than the measurement error. Conversely, the %MDC of the ankle dorsiflexion angle was ≥ 80% in our study. Ankle dorsiflexion had a lower total ROM than the other measurements, which may have heightened the percentage of error and resulted in a high %MDC. Another factor in the measurement of the dorsiflexion angle of the ankle is that the smartphone is placed on a soft and unstable surface rather than a hard, bony surface for other measurements. In the measurement of the ankle dorsiflexion angle, it was suggested that in order to capture the changes in measurements before and after the intervention, it is necessary to take multiple measurements, and using the average to reduce errors and approach the true value.

In this study, the ICC was ≥ 0.7 for all measured values, indicating that inter-rater reliability was high. The lower limits of the 95% confidence intervals for the straight leg raise angle and hip internal rotation angle were also higher than 0.85, respectively, indicating high reliability as well as the results of intra-rater reliability. However, the lower limit of the 95% confidence interval for the ankle dorsiflexion angle was as low as 0.50, and further studies are needed to improve the reliability. Bland–Altman analyses showed no systematic error in the ankle dorsiflexion angles. However, fixed errors were seen in the straight leg raise angle, hip internal rotation angle. The LOA was calculated to determine the allowable range of the fixed errors of the straight leg raise angle and hip internal rotation angle. The LOAs calculated in our study were –6.00°–12.70° for the straight leg raise angle and –5.6°–10.0° for the hip internal rotation angle. In cases where there is more than one examiner, these two measurement items need to be considered for the LOA. However, the measurements of the ankle dorsiflexion angles had no systematic errors. Therefore, determining how much error is included in the measurement values is based on the SEm and MDC, which revealed an error of approximately 3°. Nevertheless, both the MDC and %MDC were high at 8.4° and 72.3%–74.9%, respectively, indicating that it is necessary to improve accuracy and inter-rater reliability before applying the smartphone method in a clinical setting.

We used Pearson's rank correlation coefficients to determine the criterion-related validity of the conventional method using a goniometer versus the smartphone method. A positive correlation was seen in all measured values, indicating the validity of the two methods. The correlation coefficients of the straight leg raise angle was indicating "excellent" positive correlations and that of the hip internal rotation angle was indicating "good" positive correlations respectively, and that of the ankle dorsiflexion angle was indicating "poor to moderate" positive correlations. All three items demonstrated a correlation of "moderate" or higher, but the ankle dorsiflexion angle was not sufficiently valid compared to the other two items. There was a high positive correlation between the straight leg raise angle and the hip internal rotation angle. The measurement of these two items using the smartphone method is a clinically applicable and valid alternative to the conventional method, which is the gold standard for the measurement of ROM. On the other hand, the ankle dorsiflexion angle showed lower inter- and intra-rater reliability than the other two items, as well as lower criterion related validity. For the clinical application of the ankle dorsiflexion angle measurement used in this study, as mentioned earlier, it is essential to reconsider the measurement method, the number of measurements, and the location of the smartphone.

The smartphone method used in this study provides a simple means to measure ROM. It is a very convenient method that can be used not only in clinical or research settings, but also by the general public as it does not require specialized knowledge in anatomy or kinesiology, palpation techniques for identifying landmarks, or specialized tools.

The straight leg raise angle is typically used to assess hamstring muscle tightness during the straight leg raise test in clinical settings. The hip internal rotation angle is used to measure the muscle tightness of the external rotators of the hip. Thus, our smartphone method can be used to measure the tightness of the muscles around the hip joint that are often closely related to sports injuries.[39,7,40] In addition, anyone, including athletes, managers, coaches, and parents, can easily measure the ROM because smartphones are common, easy to use, and relatively inexpensive.

Our study is not without limitations. First, the accuracy of the gyro sensor of the smartphone was not assessed. However, there have been no negative reports about the accuracy of the gyro sensor built into iPhone6. Second, because the population of this study was limited to healthy men and women aged 20–30 years, it is necessary to widen the range of subjects in terms of age, body shape, and activity level. Third, active movement was used for the measurement, which is not appropriate for individuals who cannot move their lower limbs sufficiently by themselves, such as elderly individuals and those with diseases. Fourth, in this study, values obtained from a single measurement by two examiners with the same number of years of experience working in the same hospital were analyzed. In order to obtain higher reliability, we believe it is necessary to investigate various groups of examiners, including those with different years of experience and proficiency in measurement techniques, as well as to determine the optimal number of measurements. Fifth, this study did not compare the accuracy of the smartphone and conventional methods. Lastly, in an effort to generalize the smartphone method presented in this study, we did not compare and verify the accuracy of the measurement using the optical motion capture system, which is the standard method used for the measurement of joint motion in the biomechanics and ergonomics fields.

Despite various research limitations, the procedures presented in this study provide a simple method with which to measure the ROM of the lower limb joints using familiar objects if an appropriate protocol is implemented. From this aspect, we recommend that this method should be used for the general public who do not have any diseases and are forced to engage in high physical activities, such as work and sports/exercise, rather than for clinical use in individuals with diseases. By using the measurement of ROM as part of a daily condition checklist, we expect it to play an important role as a healthcare tool for many people. To this end, we believe it is necessary to work on developing applications and systems for the visualization and analysis of data obtained using smartphones. By investigating the relationship between this daily ROM and exercise intensity, subjective fatigue, and skeletal muscle hardness using ultrasound shear wave elastography, further development of the tool to prevent sports injuries and promote health improvement can be expected in the future.

CONCLUSIONS

Our method of lower limb Joint ROM measurements using a Smartphone had high intra- and inter-rater reliability in the straight leg raise angle and the hip internal rotation angle, and had a strong correlation with the conventional measurement method, which is the gold standard for measuring joint ROM using a goniometer. Intra-rater reliability showed no systematic errors for all items, and the SEm were within acceptable limits. Fixed errors were observed in the inter-rater reliability of two items except for the ankle dorsiflexion angle, and it was necessary to consider the LOA when there were multiple examiners. Ankle dorsiflexion angle was found to have lower reliability and validity than the other two items. This suggests the necessity of changing the measurement conditions when using the ankle dorsiflexion angle for judging clinical effects.

CONFLICTING INTERESTS

The authors have no conflicts of interest to declare.

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