Validity and Reliability of Rebee Wearable Sensor in Measurement of Knee Joint Range of Motion: Cross-Sectional Study

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Abstract:

Purpose: This study was conducted to test the criterion related validity and the intra-rater reliability of rebee wearable sensor in measuring Active Range of Motion (AROM) of knee joint flexion and extension compared with the valid digital goniometer in measurement of the AROM of the knee joint.

Methods: Forty normal participant's age ranged from 30 to 45 years and their Body Mass Index (BMI) from 19 to 25 kg/m2 involved in one group. The Digital Goniometer and rebee wearable sensor were utilized to measure AROM of knee joint flexion and extension.

Results: showed that measurement of AROM of the knee joint flexion with rebee sensor was significantly correlated with the measurement of digital goniometer for AROM of knee joint Flexion (p-value=0.001). The correlation between the two measurements for AROM of knee joint flexion was very good. The intra-rater reliability using the Intra-class Correlation Coefficient (ICC) showed that there was a high reliability of rebee wearable sensor in measurement the AROM of knee joint Flexion with ICC=0.816 and p-value=0.0001, but there was a low reliability of rebee wearable sensor in measurement the AROM of knee joint Extension with ICC=0.409 and p-value=0.004 when compared with measurements for AROM of knee joint using digital goniometer.

Conclusion Rebee wearable sensor is a valid instrument for measurement of AROM of knee joint flexion, but not valid for measurement of AROM of knee joint extension. Regarding reliability rebee wearable sensor has high reliability of measurement of AROM of knee joint flexion, but low reliability for measurement of AROM of knee joint extension.

Keywords Digital Goniometer, Rebee wearable sensor, Reliability, Validity, Active range of motion of knee joint.

1. Introduction:

Range of Motion of the joint is one of the aspects that define how well the musculoskeletal system functions. The measurement of AROM needs a valid and reliable measurement device (1). Lower limb AROM examination is very important in physical therapy assessment, which may be used with a variety

of devices such as goniometers and inclinometers (2). One of the most important factors determining the outcome following a knee injury is the AROM of the knee joint. Many knee scoring systems also require it as a measurement to determine preoperative status and postoperative outcome (3).

Physical therapists using measurements of knee joint AROM to quantify limitations of motion, to decide an appropriate therapeutic approaches and to document the outcomes of these therapies. The optimal measurement equipment should provide valid and reliable data (1).

The two-arm digital goniometer is one of the most commonly used clinical device for measuring joint AROM and still frequently used to assess uniaxial AROM of extremity joints. It has a high validity, intra-rater and inter-rater reliability that simplify physical therapists' work (4). Sensor technology and applications (Apps) development has made them simple to use, inexpensive, and widely available (5).

Rebee wearable sensor is a wearable motion sensor with its own android mobile application. Which measures AROM in different planes easily. The patient able to wear the rebee wearable sensor and move easily to measure AROM. The examiner able to record the AROM measurement at the application software. It facilitates the tele-measurement which the patients are supposed to put on the sensors and perform the actions themselves, or with assistance from physical therapist.

There is a lack in the literature about rebee wearable sensor in measuring the AROM of knee joint. This study was conducted to test the criterion related validity and intra-rater reliability of rebee wearable sensor in measuring of AROM of knee joint compared with measurement for AROM of knee joint using the valid and reliable digital goniometer.

2. Materials and Methods:

The study is Cross Section Study (Observational study). The Institutional Review Board, Faculty of Physical Therapy, Cairo University, Egypt. Approved this study (No: P.T. REC/012/002999). The study was conducted from June 2021 to September 2021. Forty normal participants (27 males and 13 females) were selected and involved in one group. They were recruited from Faculty of Physical Therapy, staff, and students of Pharos University, Alexandria, Egypt. Their mean age was 35.32±4.35 years, and BMI was 23.67±2.05 kg/m2. Sample size calculation was conducted by using G*Power (version 3.1.9.2) (Franz Faul, Uni Kiel, Germany). It was based on t-test, the type I error significance rate set at 5% (alpha-level 0.05). The expecting r=0.5 and type II error rate was at 80% power. The estimated number was 26 subjects, but due to the probability of drop out, forty subjects

were included. All Statistical analyses were carried out using SPSS version 23.00 software (IBM Corporation. Illinois. USA).

2.1. Instrumentations:

2.1.1. Digital Goniometer: The most often used clinical instrument for assessing joint AROM is the digital goniometer. It is used as a valid and reliable AROM measurement device with a high validity, intra- rater and inter-rater reliability (4). The type of digital goniometer used in this study called digital absolute axis goniometer with accuracy about 0.99 (6).

2.1.2. Rebee Wearable Sensor: It is a package of sensor and android mobile application that is used to measure, interpret and store participant measurements. It is used to test its criterion related validity and intra-rater reliability in measuring knee joint AROM in healthy subjects with no known significant health problems specially related to knee joint.

2.1.3. Digital health Weight and Height Scale :It is a digital scale that is used to measure height and weight to calculate BMI. BMI= weight (kg) / height (m) 2 (7). It has two advantages, first it provides high precise data, and then it reduces parallax errors (8).

2.2. Procedure:

Participants signed a consent form before starting the study, after explaining the study's nature, purpose, benefits, ability to decline or withdraw at any moment and the privacy of their own data. There were no dropouts in the participants throughout this study .

The digital goniometer was used as a valid and reliable AROM measurement device to compare its measurements of AROM of knee joint with rebee wearable sensor measurements of AROM of knee joint of knee joint in degrees to test its criterion validity in measurement of AROM of knee joint .

The measurements of AROM of knee joint flexion and extension using rebee wearable sensor were repeated two times with one week interval between measurements to investigate the intrarater reliability of a rebee sensor in measurement of AROM knee joint.

2.2.1. Procedures for testing Validity of Rebee Wearable Sensor to Measure AROM of Knee Joint: The digital goniometer was used as a valid and reliable AROM measurement device to compare its measurements of AROM of knee joint flexion and extension with rebee wearable sensor measurements of AROM of knee joint of knee joint flexion and extension in degrees to test its criterion validity in measurement of AROM of knee joint.

2.2.1.1. Measurement of Active Range of Motion of Knee Flexion with Digital Goniometer: Each participant was asked to assume supine position with the examined knee extended, which allows

measurements of the joint AROM without interference from tightness in the rectus femoris muscle. The axis was located at the lateral epicondyle of the femur. The stationary arm was located along the femur to the greater trochanter, and the moving arm was located along the fibula to the lateral malleolus. The participant was asked to flex his measured knee fully through available AROM and the therapist recorded the measurements in degrees to be compared with measurements of AROM of knee flexion using rebee wearable sensor.

2.2.1.2. Measurement of Active Range of Motion of Knee Extension with Digital Goniometer: Each participant was asked to assume supine position with the examined hip and knee flexed which allows assessment of the joint AROM without interference from tightness in the rectus femoris muscle. The axis was located at the lateral epicondyle of the femur. The stationary arm was located along the femur to the greater trochanter and the moving arm was located along the fibula to the lateral malleolus. The participants were asked to extent the measured knee fully through available AROM and the therapist recorded the measurement in degrees to be compared with measurements of AROM of knee extension using rebee wearable sensor.

2.2.2 Testing Reliability of Rebee Wearable Sensor:

Designed in accordance with the Reliability Reporting Guidelines. The current study investigating the intra-rater reliability of a rebee wearable sensor was conducted. The measurements using rebee wearable sensor were repeated two times with one week interval between measurements to investigate the intrarater reliability of rebee wearable sensor in measurement of AROM of knee joint.

2.2.2.1. Procedures for Using Rebee Sensor Package:

Take the charging end of the charging cable and looking for the charging port on the sensor, making sure that the cable aligns with the port then connects the charger, the USB end of the charging cable must be connected to a USB port (**Fig. 1**), check the sensor for a red LED light to know that it is successfully charging (**Fig. 2**). The red LED will turn off once the device is fully charged, participant asked to wear the device at the level of the Lateral malleolus with the sensor light facing upward, looking for "HC-06" (Default sensor name) under "Available devices" and tap on it and finally Identifying the Sensors to Software.

2.2.2.2. Measurement of Active Range of Motion of Knee Flexion with Rebee Wearable Sensor: Each participant was asked to assume standing in upright position. The sensor position at the level of the Lateral malleolus (**Fig. 3.A**). Participant was asked to flex the tested knee fully actively while standing supported in one leg (**Fig. 3.B**). The examiner read and reported the measurement of AROM of knee joint flexion in degree.

Fig. (1): Connect the charger

Fig. (2): Check the LED light of sensor

Fig. (3.A): Measurement of knee flexion AROM with rebee wearable sensor (Starting position)

Fig. (3.B): Measurement of knee flexion AROM with rebee wearable sensor (Ending position)

Fig. (4.B): Measurement of knee Extension AROM with rebee wearable sensor (Ending position)

2.2.2.3. Measurement of Active Range of Motion of Knee Extension with Rebee Wearable Sensor: Each participants was at sitting at the edge of plinth with knee flexed. The sensor position at the level of the Lateral malleolus (**Fig. 4.A**). Participant was asked to extent the tested knee through the full AROM (**Fig. 4.B**). The examiner read and reported the measurement of AROM of knee joint extension in degree.

Fig. (4.A): Measurement of knee Extension AROM with rebee wearable sensor (Starting position)

Statistical analysis:

All Statistical analyses were carried out using SPSS version 23.00 software (IBM Corporation. Illinois. USA). Alpha level is 0.05. The descriptive statistics as mean and standard deviation, also the Pearson product-moment correlation coefficient (r) were calculated for study group.

3. Results:
3.1. Subject characteristics:

Forty normal participants (27 males and 13 females) were selected and involved in one group. They were recruited from Faculty of Physical Therapy, staff, and students of Pharos University, Alexandria, Egypt. Their mean age was 35.32±4.35 years, and BMI was 23.67±2.05 kg/m2. (**Table 1-2**).

Table 1: Demographic data of the participants.

Study group	Mean	±SD	Minimum	Maximum
Age (years)	35.32	4.35	30	45
Body mass (Kg)	73	8.01	60	89
BMI (kg/m2)	23.67	2.05	18.5	29

±SD: standard deviation,　　BMI: Body mass index

Table 2: Sex distribution in the study group.

Group	Study group	
Sex	Male	Female
Frequency	27	13
Percentage	67.5%	32.5%

3.2. Intra rater Reliability of Rebee Wearable Sensor in Measurement of knee Flexion AROM:

The value of mean ±SD for measurements of AROM of knee flexion using rebee sensor was 127.67 ± 5.13 for the first reading of the participants and 127.42 ± 4.88 for the second reading for the same participants after 1 week. The intra-rater reliability

using the Intra-class Correlation Coefficient showed that there was a high reliability of rebee wearable sensor in measurement of AROM of knee joint flexion with ICC=0.816 and p-value=0.0001 as shown in **table 3.**

Table 3: Intra-class Correlation Coefficient for test-retest Intra rater reliability of rebee wearable sensor in measurement knee joint flexion AROM

	Rebee measurements for knee flexion AROM	
	1st reading	2nd reading
Mean	127.67	127.42
±SD	±5.13	±4.88
ICC	0.816	
p-value	0.0001	
S	S	

±SD: standard deviation, ICC: intra-class correlation coefficient, p-value: probability, S: Significance. S: Significant

3.3. Intra rater Reliability of Rebee Wearable Sensor in Measurement of knee Extension AROM:

The value of mean ±SD for measurements of AROM of knee extension using rebee sensor was 173.15±2.27 for the first reading of the participants and 172.27±2.98 for the second reading for the same examiner after 1 week. The intra-rater reliability using the Intra- second reading for the same participants after 1 week. The intra-rater reliability using the Intra-class Correlation Coefficient showed that there was a low reliability of rebee sensor in measurement of AROM of knee joint extension with ICC=0.409 and P-value=0.004 as shown in **table 4.**

Table 4: Intra-class Correlation Coefficient for test-retest Intra rater reliability of rebee wearable sensor in measurement knee joint extension AROM

	Rebee measurements for knee extension AROM	
	1st reading	2nd reading
Mean	173.15	172.27
±SD	±2.27	±2.98
ICC	0.409	
p-value	0.004	
S	S	

±SD: standard deviation, ICC: intra-class correlation coefficient, p-value: probability, S: Significance. S: Significant.

3.4. Validity of Rebee Wearable Sensor in Measurement Active Range of Motion of Knee joint Flexion and extension:

Pearson correlation coefficient (r) between mean value of measurement of AROM of knee flexion with rebee wearable sensor and digital goniometer measurement of knee joint Flexion was 0.509. The results indicated that Rebee measurements for knee flexion AROM was significantly correlated with digital goniometer measurements of AROM of knee joint flexion (p-value=0.001) (**Fig.5**). Correlation between the two measurements was very good. Pearson correlation coefficient (r) between mean value of measurement of AROM of knee extension with rebee sensor and digital goniometer measurement of knee joint extension was 0.067. The results indicated that rebee wearable sensor measurement of AROM for knee extension was not significantly correlated with digital goniometer measurement for knee extension (p-value=0.681) (**Fig.6**).
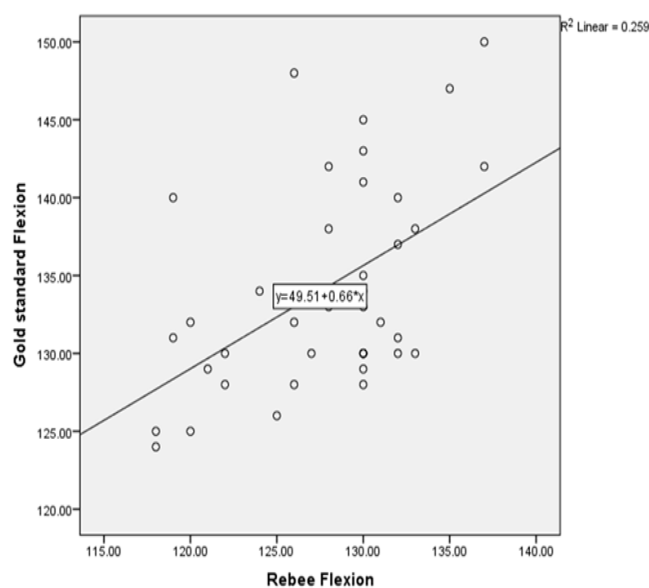
Fig. 5: Scatter plot to show correlation of the mean value between rebee measurement of AROM of knee Flexion and digital goniometer measurement.

4. Discussion:

Active range of motion clinical measurement in physical therapy was used to allow recording the state of the joint motion. It aids therapists in diagnosing patients and developing treatment plans. Information about joint mobility may indicate the severity of the disease and even provide a prognosis (9).
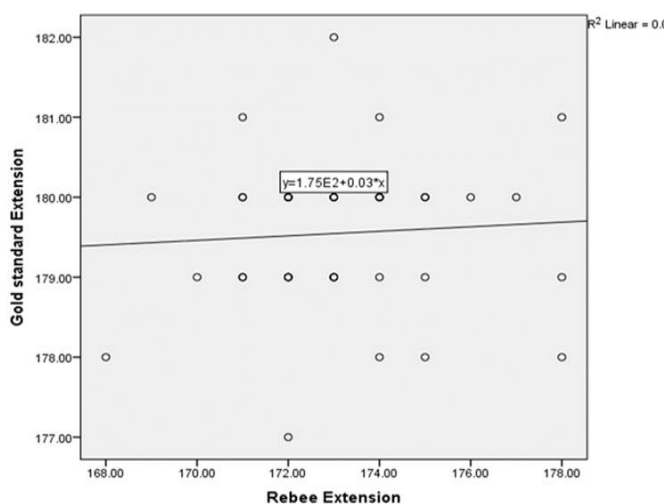
Fig. 6: Scatter plot to show correlation of the mean value between rebee measurement of knee extension AROM and digital goniometer measurement.

Active range of motion is an important for evaluating and monitoring different neurological and musculoskeletal disorders. Physiotherapist may use the **AROM** of the opposite healthy joint as a reference of normal value of the affected joint, or they may rely on readings from one of the various devices used to measure joint **AROM** (10). Active range of motion measurements are used to detect disability, provide a baseline, and document mobility impairments. The goal of **AROM** measurements is to restore joint motion and thus promoting functional activity rehabilitation (11).

Many devices have been developed and used to measure joint motion, such as two-dimensional range of motion measurement, which offers basic planar angular motion of the joint with regard to a single fixed axis of motion. Other devices as visual estimation, radiograph techniques, kinematics analysis systems, 3-D measurement of angular motion, still photo-camera, visible video recording and automated motion analysis are also used to measure **AROM** (9).

The universal goniometer is the simplest of all these instruments. It is widely used clinically, the most cost-effective, and the most portable device for **AROM** measurement. However, these devices have some limitations such as the beginning position must be assessed visually, and the standard goniometer must be held with two hands, leaving neither hand free for body stabilization on the proximal part of the joint (12).

Also, there is the digital inclinometer that used by some clinicians to measure **AROM**. It is one of the most commonly used clinical device for measuring joint **AROM**. Advancements in sensor technology and applications have made them simple to use, inexpensive, and widely available (5). Both the inclinometer and the goniometer are small and portable equipment. The inclinometer, on the other hand, has a substantially higher related cost and it has been demonstrated to have good to high reliability and concurrent validity with the universal goniometer (13).

Visual estimation is obviously the simplest strategy to employ because no equipment is required, and it is useful when no equipment is available. Many researchers hypothesized that measuring with tools yielded more reliable findings than visual judgement. Observing rapid motion at more than one joint details escape even the most expert observer (14).

Automated motion analysis is a modern way for measuring **AROM** that provides digital data that was introduced to the computer. There are two systems that have been utilized for automated motion analysis, and these systems used various types of markers, passive and active markers. These systems are limited by marker placement by one or more investigators, placement of markers on multiple days and skin movement over bony landmarks during movement. Rapid movement of an extremity obstruction of marker by another body part, one movement that makes two markers come close together or merge may cause the automated computer process to become confused (15).

One of the primary goals of employing a new tool for measuring **AROM** is to assess dysfunction, determine rehabilitation progress and assess treatment effect (9). The use of a reliable instrument for measuring range of motion is critical for monitoring the progression of various diseases as well as determining and evaluating treatment (16). So, there is a need to new technology such as rebee wearable sensor.

This study was conducted to test the criterion related validity and intra-rater reliability of rebee wearable sensor in measuring Knee Joint **AROM** compared with digital goniometer measurement of **AROM** of knee joint in healthy subjects. Study group consisted of 40 Participants (27 males and 13 females). The measurements of **AROM** of knee joint flexion and extension were done by digital goniometer to be compared with the measurements of **AROM** of knee joint by rebee wearable sensor.

Regarding validity: the results of the present study in measuring knee flexion showed that measurement of **AROM** of knee joint flexion with rebee wearable sensor was significantly correlated with digital goniometer measurement of **AROM** of knee joint flexion (p-value=0.001). Correlation between the two measurements was very good.

The results of the current study came into agreement with the findings of a similar study done by **Keogh et al. (2019)** that provide relatively strong

evidence for the validity of smartphones and **apps** for assessing joint **AROM**. These findings is consistent across multiple joints, populations, smartphones, and apps. Findings imply that clinicians may be able to quantify joint **AROM** using a relatively wide variety of smartphones and **apps**.

Measuring the **AROM** of knee extension in the present study showed that measurement of **AROM** of knee extension with rebee sensor was not significantly correlated with digital goniometer measurement of **AROM** of knee joint extension (p-value=0.681). Correlation between the two measurements was very poor. Which is suggested that is due to use of one sensor only at distal bony land mark which is recommended that the extension movement require more than one sensor and more adjustment at the application developed by the sensor's developer for more valid measurement of the **AROM** of knee Extension.

Regarding reliability: The intra-rater reliability using the Intra-class Correlation Coefficient showed that there was a high reliability of rebee wearable sensor in measurement of **AROM** of knee joint flexion with ICC=0.816 and P-value=0.0001. The intra-rater reliability using the Intra-class Correlation Coefficient showed that there was a low reliability of rebee sensor in measurement of **AROM** of knee joint extension with ICC=0.409 and P-value=0.004. So, rebee wearable sensor is a valid instrument for measuring **AROM** of knee flexion, but not valid in measuring **AROM** of knee extension. Also it has high reliability of measurement of **AROM** of knee flexion and low reliability for measurement of **AROM** of knee extension.

This study got several limitations:
1- The participants were only normal subjects and from the same university.
2- Measurement with rebee wearable sensor required a lot of time from the author to contact the developers of the sensor to adjust the application software with the desire movement intended to measure as it was the first time to measure AROM of knee joint with rebee wearable sensor.
3-Measurement with rebee wearable sensor was limited to the prescription of sensor developers as in measurement of **AROM** for knee flexion was from standing in upright position, while in measurement of **AROM** for knee extension was from sitting at the edge of plinth with knee flexed as it calibrated on software application.

5. Conclusion:

Within the limitation of this study, rebee wearable sensor is a valid instrument for measuring AROM of knee joint flexion, but not valid in measuring AROM of knee joint extension. Also, it has high reliability for measurement of AROM of knee joint Flexion, but low reliability for measurement of AROM of knee joint knee Extension.

6. Recommendations:

It is recommended that further studies should be conducted to:
1. Replicate the study with measuring joint AROM at functional daily living activities such as gait and up and down stairs in normal and pathological conditions.
2. Investigation using more than one sensor to place one sensor on bony land mark proximal to the joint and the other sensor on the distal bony land mark to knee joint.
3. Measure the other joints AROM in normal and pathological conditions.

Conflict of Interests:

The authors declare no conflict of interest.

Acknowledgements:

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