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Reliability and Validity for Measuring Active Hip Rotation with the Clinometer Smartphone Application™

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ABSTRACT

Background: Accurate range of motion (ROM) assessment is an essential component of clinical practice to identify underlying deficits at the hip joint. Hip joint active ROM has been measured by goniometric methods in the clinical setting. More recently, the Clinometer Smartphone Application has gained attention for ROM measures. However, minimal research has been identified for the use of the Clinometer Smartphone Application™ for hip ROM. Therefore, the purpose of this study was to determine intrarater and interrater reliability of the Clinometer Smartphone Application™ as well as establishing its validity for active hip internal rotation (IR) and external rotation (ER).

Methods: A concurrent test-retest reliability study was conducted using a convenience sample at three different sites. This study included 46 males and 30 females (n=76) with an average age of 23.93 (5.37) years. Five clinicians measured each participant's active prone hip rotation at three different sites. Three trials were measured with the goniometer and with the Clinometer Smartphone Application™. Intrarater reliability was assessed within one week for the five clinicians. Interrater reliability was assessed between three clinicians located at the same site.

Results: The intrarater reliability of goniometer was moderate to excellent (ICC>0.73-0.96) for hip IR and moderate to good (ICC>0.76-0.89) for ER. Similarly, smartphone intrarater reliability was good to excellent for IR (ICC>0.81-0.96) and ER (ICC>0.77-0.90). The validity of the Clinometer Smartphone Application™ when compared to the goniometer and had a very strong relationship for IR (r=0.94-0.96) and ER (r=0.84-0.89).

Conclusion: The results of this study suggest this application may be a valid and reliable alternative to the goniometer for clinicians when measuring active hip rotation in clinical practice.

Introduction

It is essential for clinicians to assess hip rotational range of motion (ROM) in a reliable and valid manner for optimal patient care [1-15]. When a limitation in hip joint rotation occurs, the risk for injury and/or osteoarthritis increases if left untreated [1, 10, 11, 13, 14, 16-28]. When hip rotational deficits occur, increased stresses are placed on joints above or below the limitation [1, 3, 29]. Therefore, internal rotation (IR) and external rotation (ER) at the hip are important clinical measures for prevention and treatment of injuries.

Traditionally, clinicians have used the hand-held goniometer for ROM assessment [30-32]. Currently, the goniometer is the most common instrument

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used for measuring ROM within the clinical setting [31, 33, 34]. However, researchers have indicated limitations when using the hand-held goniometer [25, 33]. The goniometer must be held with two-hands, leaving neither hand free for stabilization. Researchers have cited challenges with appropriately stabilizing uninvolved body parts while applying the goniometer to the area of assessment [25, 33, 35]. Due to these limitations, clinicians have started to explore other devices to be able to measure ROM more effectively. More recently, the use of the smartphone for ROM assessments has gained popularity [30-32].

The use of smartphones by healthcare providers for medical purposes has increased dramatically within the last decade [30, 36, 37]. Smartphone applications can provide clinicians and researchers with another instrument for the assessment of ROM. Majority of smartphones have built-in sensors, such as accelerometers, gyroscopes or magnetometers that allow for the assessment of joint position and changes in joint ROM [37, 38]. However, there are limited studies using the same smartphone application for measuring hip joint ROM [31, 32].

Researchers have investigated reliability and validity in both shoulder and ankle joints using the Clinometer Smartphone Application™ [31, 32]. Previous reliability studies have used a variety of smartphone applications for the measurement of passive hip ROM [30, 39]. These studies report moderate to excellent intrarater reliability (0.63-0.94) and interrater reliability (0.89-0.99) for passive hip ROM [30, 39]. Although previous studies have examined intrarater and interrater reliability for passive hip joint ROM when using smartphone applications [30, 39], the reliability and validity of the Clinometer Smartphone Application™ for measuring active hip ROM remains to be explored.

The primary purpose of this study was to investigate multisite intrarater reliability of the goniometer and Clinometer Smartphone Application™. The secondary purpose of this study was to investigate interrater reliability of the goniometer and Clinometer Smartphone Application™ between a subgroup of the clinicians located at the same site. Lastly, the third purpose of this study was to determine the validity of the Clinometer Smartphone Application™ when compared to the hand-held goniometer in the measurement of hip rotation. We hypothesized that this study would have a good to excellent intraclass correlation (ICC) $\geq$0.75 for both intrarater and interrater reliability. Secondarily, we hypothesized that this study would have very strong validity (Pearson's $r \geq 0.80$) between the two instruments.

Methods

Participants

For this concurrent test-retest reliability study, a convenience sample (N=76) was used. The purpose of a multisite collection was to assess the ROM measures, allowing for a more diverse participant sample of asymptomatic participants. These sites included participants within the National Association of Intercollegiate Athletics, recreational sport clubs, and a general population of college students. Inclusion criteria for this study included asymptomatic males and females aged 18-34 from the three different Athletic Training clinics across the country. The participants were excluded from the study if they 1.) Reported any pain in the low back, pelvic girdle, or lower extremity; 2.) Were receiving medical treatment for pathologies limiting their movement patterns; 3.) had a musculoskeletal or neurological injury to the spine or lower extremity in the past six months prior to the time of data collection; and/or 4.) had surgery to the spine or lower extremity within the past year. All participants were informed of the purpose of the study and signed a consent form prior to data collection. Participants were able to opt-out of the study at any time. This study protocol was approved by the University's Institutional Review Board. All examiners had a similar educational background and between one and seven years of clinical experience as a certified Athletic Trainer.

Procedures

Over the course of the study, each participant's ROM was assessed twice, one-week apart. Participants did not perform a warm-up or stretching protocol prior to data collection and were advised to perform their normal daily activities. Intrarater reliability was collected with five clinicians at three different Athletic Training clinics. Three clinicians at the same clinic site collected data for interrater reliability and concurrent validity. For interrater reliability, clinician one identified and marked specific bony landmarks to assist with instrument placement for hip IR and ER [39]. Both the right and left limbs were assessed. Three active ROM trials were taken by each clinician for each movement pattern. First, the measurements were assessed with a hand-held goniometer for IR (Figure 1) and ER (Figure 2). Secondly, measurements were assessed with the Clinometer Smartphone Application™ for IR (Figure 3) and ER (Figure 4).

Hip IR and ER were both measured with the subject prone on an examination table with their hip in neutral position and knees flexed to 90°. As the clinicians wanted to mimic traditional clinical practice, no restraints were used during the assessment of hip ROM. The clinician centered the goniometer at the joint line, with the movement arm of the goniometer aligned along the midline of the tibia and the stationary arm aligned perpendicular to the floor [39]. The clinician asked the participant to move their hip into IR while keeping their hips stationary on the table. The clinician then asked the participant to move into ER while keeping their hips stationary on the table. These measures were then assessed on the contralateral limb. The clinician provided verbal cues to ensure that no compensation movements occurred during the motion [2]. Secondly, the Clinometer Smartphone Application™ was then utilized for measurement. The top of the smartphone was placed three centimeters below the tibial tuberosity

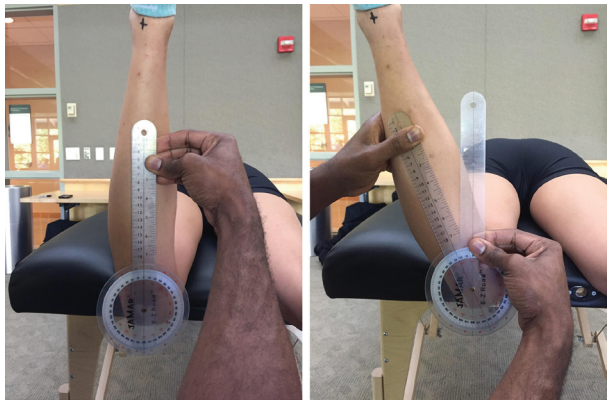

Figure 1: Hip IR ROM Technique with Goniometer

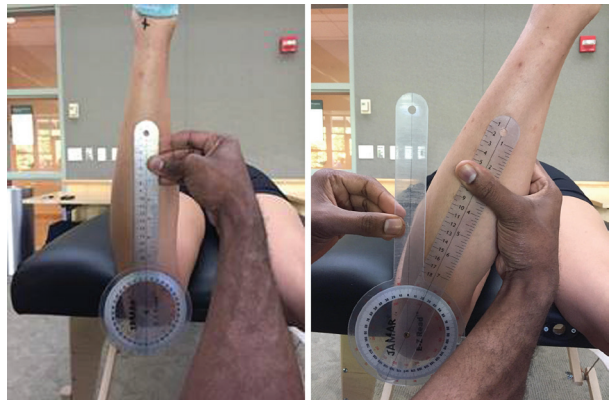

Figure 2: Hip ER ROM Technique with Goniometer

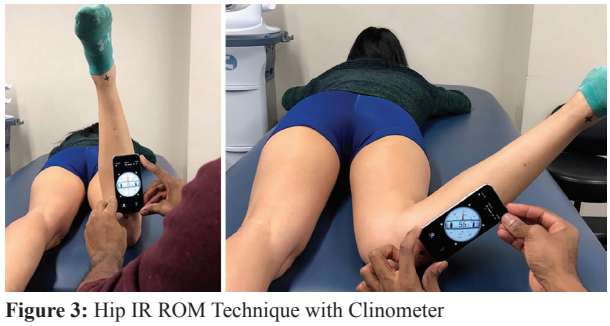

Figure 3: Hip IR ROM Technique with Clinometer

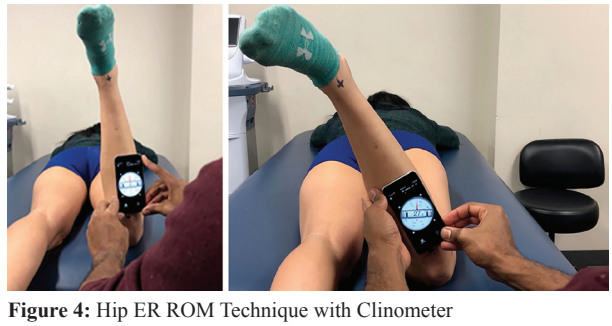

Figure 4: Hip ER ROM Technique with Clinometer

and the base of the smartphone was positioned towards the midline of the medial and lateral malleoli [39]. The clinician then asked the participant to move their hip into IR and then into ER and provided verbal cues to ensure that no compensation movements occurred during the motion [2]. These measures were then assessed on the contralateral limb.

Statistical Analysis

All data were analyzed using the SPSS Statistical Package Version 24 (IBM Corp. Armonk, NY, USA). The average of the three measurements was calculated and the left and right limbs were combined to give a total sample size (N=152) [32]. Intrarater and interrater reliability were evaluated using the ICC (3, *k*) set at a 95% confidence interval. Intrarater reliability was assessed between time-point one and time-point two measurements for the five clinicians. Interrater reliability was calculated with the three clinicians located at the same clinic at time-point two. The ICC values were interpreted as follows: values <0.50=poor, 0.50-0.75=moderate, 0.75-0.90=good, and values ≥0.90=excellent [40, 41]. An analysis of variance (ANOVA) was conducted to determine if there was any difference between the measurement devices. Statistical significance was set at P≤0.05 [40].

Standard error of measurement (SEM) values was calculated for the reliability study using the previously established formula: $SEM=SD\sqrt{(1-ICC)}$ [42]. The minimal detectable change (MDC) was calculated with the following formula: MDC=Standard Error of Measurement×1.96×√2 [43]. The MDC is the minimal amount of change that a measurement must show to be greater than the measurement error [43]. To determine the construct validity between the goniometer and the Clinometer Smartphone Application™, a Pearson's *r* correlation was analyzed through a bivariate correlation. Validity was analyzed with the time-point two data collected at the same time as interrater reliability. A Pearson's *r* value of .80 and above is considered a "very strong" correlation between measurement tools [40].

Results

This study consisted of 46 males and 30 females with an average age of 23.93 (5.37) years. The average weight for the participants was 73.01 (13.56) kg and an average height of 174.72 (8.90) cm. Descriptive measurements for each clinician are presented in Table 1.

Intrarater reliability was assessed within the five clinicians at three different clinics across the country (Table 2). The ICC values ranged from 0.73-0.96 for intrarater reliability using the goniometer to measure hip IR. The ICC values ranged from 0.76-0.89 for intrarater reliability using the goniometer to measure hip ER. Also, the ICC values ranged from 0.81-0.96 for intrarater reliability using the Smartphone Clinometer App to measure hip IR. In addition, a range of 0.77-0.90 was detected for the ICC values for intrarater reliability using the Smartphone Clinometer Application to measure hip ER. The SEM values were calculated from 2 and 6 degrees between the clinicians (Table 2). The MDC values were from 6-14 degrees (Table 2).

Interrater reliability was collected between clinicians 1-3, as they were located at the same clinic. The ICC values ranged from .83-.96 within the three raters when measuring with the goniometer (Table 3). Furthermore, we observed a range of 0.91-0.97 for the ICC values within the three raters when measuring with the Clinometer Smartphone Application™ (Table 3). The SEM values were calculated between 2 and 3 degrees

Table 1: Goniometer and smartphone app average hip ROM degrees (°) by each clinician.

	Clinician 1		Clinician 2		Clinician 3		Clinician 4		Clinician 5	
	Goniometer Mean (SD)	App Mean (SD)	Goniometer Mean (SD)	App Mean (SD)	Goniometer Mean (SD)	App Mean (SD)	Goniometer Mean (SD)	App Mean (SD)	Goniometer Mean (SD)	App Mean (SD)
IR	40.04 (9.86)	40.24 (10.12)	39.09 (10.60)	38.99 (11.70)	39.17 (11.50)	39.62 (11.66)	49.10 (8.14)	48.84 (8.92)	40.96 (7.09)	41.13 (6.83)
ER	36.36 (6.42)	38.20 (6.64)	39.40 (7.82)	39.09 (7.48)	39.30 (8.10)	39.27 (7.76)	53.10 (9.33)	54.88 (9.77)	42.80 (7.83)	43.65 (7.18)

IR: Internal Rotation; ER: External Rotation; SD: Standard Deviation

Table 2: Intrarater Reliability for Active Hip Range of Motion

	Clinician 1					
	Goniometer			Clinometer		
	ICC (95%CI)	MDC	SEM	ICC (95%CI)	MDC	SEM
IR	0.96 (0.92-0.97)	5.48	1.98	0.96 (0.93-0.98)	5.63	2.03
ER	0.76 (0.57-0.86)	8.76	3.16	0.86 (0.76-0.93)	6.92	2.50
	Clinician 2					
	Goniometer			Smartphone		
	ICC (95%CI)	MDC	SEM	ICC (95%CI)	MDC	SEM
IR	0.95 (0.91-0.97)	6.6	2.38	0.94 (0.81-0.93)	7.99	3.56
ER	0.85 (0.74-0.91)	8.42	3.04	0.77 (0.60-0.87)	9.87	5.63
	Clinician 3					
	Goniometer			Smartphone		
	ICC (95%CI)	MDC	SEM	ICC (95%CI)	MDC	SEM
IR	0.80 (0.66-0.89)	14.02	3.16	0.83 (0.71-0.90)	13.15	4.77
ER	0.89 (0.81-0.94)	8.73	5.63	0.87 (0.77-0.93)	7.68	2.79
	Clinician 4					
	Goniometer			Smartphone		
	ICC (95%CI)	MDC	SEM	ICC (95%CI)	MDC	SEM
IR	0.73 (0.52-0.85)	11.59	4.18	0.81 (0.68-0.89)	10.7	3.86
ER	0.83 (0.63-0.91)	10.41	3.76	0.90 (0.84-0.95)	8.32	5.63
	Clinician 5					
	Goniometer			Smartphone		
	ICC (95%CI)	MDC	SEM	ICC (95%CI)	MDC	SEM
IR	0.75 (0.51-0.87)	9.74	3.52	0.83 (0.69-0.84)	7.81	2.82
ER	0.88 (0.77-0.94)	7.54	2.72	0.88 (0.79-0.94)	6.92	2.50

IR: Internal Rotation; ER: External Rotation; ICC: Intraclass Correlation Coefficient; 95% CI: 95% Confidence Interval for ICC; MDC: Minimal Detectable Change; SEM: Standard Error of Measurement

Table 3: Interrater Reliability for Active Hip Range of Motion

	Goniometer			Clinometer		
	ICC	MDC	SEM	ICC	MDC	SEM
IR	0.96	6.81	2.23	0.97	5.96	2.15
ER	0.83	8.57	3.09	0.91	5.90	5.90

IR: Internal Rotation; ER: External Rotation; ICC: Intraclass Correlation Coefficient; 95% CI: 95% Confidence Interval for ICC; MDC: Minimal Detectable Change; SEM: Standard Error of Measurement

Table 4: Validity of the Smartphone App versus Goniometer

	N	Clinician 1		Clinician 2		Clinician 3	
		Pearson's *r* Correlation	Significance	Pearson's *r* Correlation	Significance	Pearson's *r* Correlation	Significance
IR	54	0.961	0.000	0.939	0.000	0.953	0.000
ER	54	0.850	0.000	0.854	0.000	0.889	0.000

IR: Internal Rotation; ER: External Rotation

(Table 3). The MDC values were 5 to 9 degrees within the clinicians.

Regarding validity, the measurements from the same three clinicians were assessed for interrater reliability were used. The Clinometer Smartphone Application and goniometer correlations ranged from .84-96 (Table 4). An ANOVA was conducted to determine if there were any differences between measurement devices. At time one, we observed P=0.762 for IR, and P=0.969 for ER. At time two, P=0.927 for IR, and P=0.555 for ER were found.

Discussion

To the best of our knowledge, this is the first study to assess the intrarater and interrater of the Clinometer Smartphone Application™ when compared to the goniometer for measuring active hip IR and ER ROM. Other studies have assessed smartphone applications

for the measurement of hip ROM; however, few articles used the same smartphone application [30]. So far, the Clinometer Smartphone Application™ has been found to be reliable and valid at the shoulder and ankle joints, but the use at the hip remains inconclusive [31, 32].

In this study, the intrarater reliability of the hand-held goniometer for the measurement of hip IR was moderate to excellent (ICC=0.73-0.96). For the measurement of hip ER, the results demonstrated good reliability (ICC=0.76-0.89). Similarly, for the Smartphone Clinometer Application™, intrarater reliability was identified to be good to excellent for IR (ICC=0.81-0.96) and ER (ICC=0.77-0.90) (Table 2). These findings are similar to the findings of Aefsky et al., reporting that prone active IR was good to excellent (ICC=0.87-0.95) and prone active ER was moderate to excellent (ICC=0.74-0.81) [44].

For interrater reliability, the results demonstrate good to excellent reliability for measuring hip IR with the goniometer (ICC=0.96) and for the Clinometer Smartphone Application™ (ICC=0.83). For the measurement of ER, the clinicians demonstrated excellent reliability for the goniometer (ICC=0.97) and the Clinometer Smartphone Application™ (ICC=0.91). In the studies by Norris et al., and Charlton et al., interrater reliability was reported to be moderate to excellent with the smartphone application (ICC=0.70-0.99) in the measurement of passive hip ROM [30, 39]. Therefore, the results of this study demonstrate similar results to other studies [30, 31, 39, 44].

During ROM assessments, clinicians wanted to replicate the measurement process similar to that of daily clinical practice. The clinicians used their judgment with verbal cues to inform the patient to stop prior to compensation patterns. This study is unique in the fact that the clinicians did not use restraints to limit compensatory movement during the measurement process. To the best of our knowledge, this is the first study to determine the validity of the Clinometer Smartphone Application™ for active hip ROM assessed outside a laboratory setting. Other studies that measured hip ROM used restraints or devices to minimize compensation [30, 39].

The results suggest a very strong correlation between the two instruments for IR (r=0.94-0.96) and for ER (r=0.84-0.89). These findings are comparable to the study by Norris et al. that used the Clinometer Smartphone Application™ versus the hand-held goniometer for the measurement of passive hip ROM when using a different smartphone application (3D Protractor, VBase2.1) [30]. Their findings suggest that there is excellent inter-instrument reliability for IR (ICC=0.93-0.97) and ER (ICC=0.91-0.94) between the two instruments [30]. In a second study by Cox et al. using the same Clinometer Smartphone Application™, the authors reported a very strong correlation (r=0.92) between the two instruments in the measurement of active ankle plantar flexion [32]. Similarly, from this study, we can determine that there is a very strong correlation between the hand-held goniometer and smartphone applications in the measurement of hip IR and ER in a prone position.

For the motions of hip IR and ER, values for the SEM were between 2°-6° for the goniometer and the Smartphone Clinometer Application™. These are slightly higher than the study by Norris et al. who reported SEM values to be between 1°-3° [30]. The MDC for the clinicians ranged from 5°-14° for the goniometer and 5°-13° for the smartphone application. However, this is the first known study to report the MCD values using the smartphone application in measuring hip ROM. These ranges suggest that the SEM and MDC are similar to that of the goniometer [30, 45]

The use of these reliable and valid measurements is crucial to actively measure hip rotation ROM to provide an intervention for future injury prevention. The hypothesis of the study was confirmed, as intrarater and interrater reliability of the clinicians was moderate to excellent using the goniometer and the Clinometer Smartphone Application™. Lastly, the hypothesis of validity was confirmed that there is a very strong relationship between the goniometer and the Clinometer Smartphone Application™ for the assessment of active hip IR and ER.

As a multisite project, participating clinicians collected data within their respective clinics. Further, as clinicians only assessed active IR and ER, these results cannot be considered when assessing passive ROM, hip flexion, and hip extension. This was a single-blinded study in which the participants remained unaware of their ROM measurements. The Clinometer Smartphone Application™ was limited to the use of the iPhone (Cupertino, CA) platform. The authors did not assess any of the limitations related to the use of the smartphone platform such as version updates, screen visibility or previous phone damage. Additionally, this study did not include imaging of the hip joints prior to the measurements. Therefore, the authors were unaware of any underlying pathologies that may have been asymptomatic. This study only assessed a healthy, nonpainful population.

As this current study focuses on active IR and ER, further investigations should assess passive ROM using the Clinometer Smartphone Application™. Also, studies assessing active flexion and extension ROM should be conducted. A double-blind study assessing the placement of the smartphone would allow the protocol of this study to be further investigated. A more diverse patient population who may be symptomatic could be further investigated as this study assessed asymptomatic population only. Further studies are necessary to determine if the Clinometer Smartphone Application™ could be used as a stand-alone instrument for measuring hip ROM.

Within this study, the clinicians wanted to mimic traditional clinical practice to allow for this research to be applicable in daily assessments. Therefore, no restraints were practiced in the subject's position in order to allow the clinicians to replicate their clinical measurements. The clinicians used a convenience sample participating in sports activity. The primary aim of using multiple clinics was to allow for a more diverse authentic sample population. The MDC values can be useful when providing

an intervention for restoring probable ROM deficits.

Conclusion

Clinicians located at different clinics have demonstrated moderate to excellent intrarater reliability for the measurement of active hip IR and ER when using the goniometer and the Clinometer Smartphone™. The clinicians also had good to excellent interrater reliability when measuring active hip IR and ER with both instruments, without restraining the participants. Therefore, clinicians are reliable when measuring hip ROM in a diverse patient population with the hand-held goniometer and the Clinometer Smartphone Application™. Additionally, the results of this study suggest that this smartphone application may be a valid alternative to the hand-held goniometer for clinicians when measuring active hip IR and ER in clinical practice.

Conflict of Interest: None declared.

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