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TECHNICAL REPORT

Validity and Intrarater Reliability Using a Smartphone Clinometer Application to Measure Active Cervical Range of Motion Including Rotation Measurements in Supine

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Context: Technological advances have given smartphones the capabilities of sensitive clinical measurement equipment at lesser cost and higher availability. The Clinometer is a smartphone application that can be used to measure the joint range of motion in a clinical setting, but psychometric properties of the tool's use measuring cervical range of motion (CROM) are not established. ***Objectives:*** The purpose of this study was to examine the validity and intrarater reliability of the Clinometer application for the measurement of CROM (ie, flexion, extension, rotation, lateral flexion) and to determine the minimal detectable change and SEM. ***Design:*** A blinded, repeated-measures correlational design was employed. ***Setting:*** The study was conducted collaboratively between 2 athletic training clinics. ***Participants:*** A convenience sample of healthy adults ages 18–30 years were recruited. Participants with any history in the last 3 months of cervical or thoracic pathology, pain, or any musculoskeletal injury were excluded. ***Main Outcome Measures:*** Three repetitions of each motion were measured by a primary researcher with a goniometer. The same researcher then conducted 3 blinded measurements with the Clinometer application following the same procedure. A second researcher, blinded to the goniometer measurements, recorded the results. Thirty minutes later, testing was repeated with the application. The Pearson correlation was calculated to determine validity of the application compared with goniometry. ***Results:*** The measurements between devices had moderate to excellent concurrent validity, with the coefficients ranging between 0.544 and 0.888, $P < .01$. Test–retest reliability of the CROM measurement using the application was moderate to excellent, with intraclass correlation coefficients ranging between .774 and .928. Across all movements, the SEM ranged from 1.17° to 2.01°, and the minimal detectable change ranged from 1.18° to 2.02°. ***Conclusion:*** The Clinometer application is a valid and reliable instrument for measuring active CROM. Level of evidence: clinical measurement, level 1b.

Keywords: clinical measurement, neck, psychometrics, body region(s), neck/cervical spine

Goniometer, inclinometer, or cervical range of motion (CROM) measurement devices are commonly used to measure CROM. CROM is an outcome measure often used in health care to help determine the presence and/or magnitude of cervical dysfunction, in addition to being used as a predictive tool for acute or chronic neck pain–related conditions.[1] These instruments can sometimes be cumbersome and expensive. Interestingly, clinicians are now using smartphone applications, colloquially known as "apps," as measurement tools in the clinical setting.[2] Smartphones are often equipped with an accelerometer (gravity sensor) and magnetometer (digital compass), which through software applications can perform various inclinometric functions. Smartphone apps are being used in the clinical setting to measure the range of motion of many joints, such as the cervical spine, ankle, and knee.[1–7]

Validity and intrarater reliability studies of various smartphone apps and devices for the measurement of joint range of motion have been conducted, 2 in particular for CROM. Tousignant-Laflamme et al[7] examined the psychometric properties of an iPhone app, the Clinometer (Clin-app), compared with a CROM device. Quek et al[1] built upon Tousignant-Laflamme's methods, investigating concurrent validity and test–retest reliability, but using an Android smartphone version of the Clin-app (PlainCode, Stephanskirchen, Germany) compared with 3-dimensional motion analysis (3DMA). When comparing the Clin-app to the CROM device, Tousignant-Laflamme et al[7] reported good validity for the movements of flexion and left lateral flexion, moderate validity for the movement of extension and left rotation, but poor validity for right rotation. Tousignant-Laflamme et al[7] also reported that all movements measured with the Clin-app had good to excellent reliability, with intraclass correlation coefficients (ICCs) ranging between .41 and .89, except for rotation (left rotation ICC = −.54 to .83 and right rotation = −.21 to .87). Although this study reported some interesting findings, limitations include the following: (1) no effort being made to control extra body movement and (2) the examiner(s) were not blinded to the measurements. These limitations could have led to reporting bias, potentially overestimating the validity results.[1]

Using similar methods, Quek et al[1] investigated concurrent validity and test–retest reliability assessing CROM. To verify the validity of the Clin-app, Quek et al[1] (1) concurrently assessed with a 3DMA system, (2) added a spirit-level type indicator to ensure a pure axis of movement, and (3) blinded the examiner to the results. All measures were performed in a seated position with shoulders securely strapped across the chair to ensure minimal contribution from the thoracic spine.[1] The phone was mounted on a helmet and then securely fastened to the participant's head while measurements were obtained.[1] The results demonstrated excellent concurrent validity for flexion, extension, and lateral flexion, but moderate validity for rotation. The intrarater reliability was excellent for both the Clin-app and 3DMA measurements in cervical flexion,

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extension, and lateral flexion, but poor for the Clin-app and moderate for the 3DMA in rotation. Although these researchers demonstrated that a smartphone application can be valid and reliable, achieving accurate rotation measures seemed to be problematic.

Both Tousignant-Laflamme et al[7] and Quek et al[1] used the Clin-app to measure cervical rotation with the participant in a seated position, meaning the app utilized the phone's magnetometer instead of the accelerometer to measure the motion.[8] The magnetometer functions as a compass in the horizontal plane, using the earth's magnetic field to determine the directions of north and south,[9] whereas the accelerometer is a measurement of inclination, calculating angles in an upright position.[2] By placing the participant in a supine position, similar to the position of measurement for a single inclinometer,[8] and placing the phone on the top of the head, similar to the measurement using a goniometer,[8] the phone's plane is changed into a vertical plane. Having the phone in the vertical plane utilizes the accelerometer sensors in the phone to measure angles.[2]

The purpose of this study was to investigate the validity and intrarater reliability of measuring cervical flexion, extension, and lateral flexion, as well as a new patient positioning for rotation, when using the Clin-app compared with a universal goniometer. Researchers of this study hypothesize that the changing of the patient's positioning during rotation measurement will change the phone's orientation and will improve the accuracy of the Clin-app's measurement of cervical rotation. By presenting an alternative procedure for measuring rotation (ie, supine position with phone in vertical plane), researchers anticipate that all directions of measurement when using the Clin-app will produce high validity and intrarater reliability.

Methods

Design

A blinded, repeated-measures correlational design was used to determine the validity of the Clin-app developed by Plaincode App Development by comparison to a baseline goniometer, plastic 360° international standards of measurement for measurement of active CROM in flexion, extension, left and right rotation, and left and right lateral flexion. In addition, researchers determined the intrarater reliability, SEM, and minimal detectable change (MDC) for the same ranges of motion when using the Clin-app.

Participants

Institutional review board approval was granted by Midwestern State University and the University of Idaho. A convenience sample of healthy adults aged 18–30 years was recruited by word of mouth from the community of Midwestern State University. Participants with a history in the last 3 months of cervical or thoracic pathology, pain, or any musculoskeletal injury were excluded from the study. After written consent was obtained, the participants were given verbal instructions regarding the purpose and procedure of the study. The volunteers did not receive a reward or compensation for participating.

Procedures

All measurements were taken by the same examiner with 7 years of athletic training clinical experience. The clinician had minimal experience using the Clin-app, but experience with goniometry and inclinometry expected of an athletic trainer with the same level of professional experience. Goniometric measurements were conducted first, and the Clin-app measurement was conducted second. Thirty minutes after the initial Clin-app measurements were collected, the procedures were repeated by the same researcher. Standardized positions and landmarks were used to measure each movement.[8]

Cervical flexion, extension, and lateral flexion measurements were performed with the participants seated. The participants were instructed to sit with their feet flat on the floor, back straight against the chair, eyes looking straight ahead, and arms at their side. Modifications were made for the participants who were unable to keep their feet flat on the floor due to the height of the chair (ie, book placed beneath their feet), as illustrated in Figure 1. A strap was placed around the participant's chest and arms to prevent compensatory movements during measurement, as illustrated in Figure 1. Once the participant was set up in the chair, the primary researcher demonstrated the movements to be measured. Then, the participants were instructed to attempt 3 movements in each direction, looking straight ahead upon completion of the full warm-up, to demonstrate an understanding of the procedures. Prior to measurement, a dot was drawn over the spinous process of the C7 vertebrae as a landmark indicator, to enhance the proper placement of the goniometer while measuring lateral flexion.

The participants were instructed to move at their own pace, without compensation or extreme effort to extend their end range motion. Goniometric measurements were taken first. The goniometer was aligned according to contemporary procedures.[8] Three repetitions of each range of motion were measured and recorded by the primary researcher.

The Clin-app measurements were taken second, using the same participant instructions. Flexion and extension measurements were taken with the smartphone on the left side of the participant's head while seated (Figure 2), aligned with external auditory meatus. Lateral flexion was measured with the smartphone on the contralateral side of the head (see Figure 2), with the display level aligned with the participant's eyes. All measurements were taken with the researcher's hands in contact with the phone and the participant's head to ensure the phone moved with the participant.

Figure 1 — Participant positioning and chest strap placement in the seated (left) and supine (right) positions.

Placement of the phone during use of the Clin-app is illustrated in Figure 2.

Cervical rotation was measured with the participants in the supine position on a treatment plinth after motions in the seated position were completed (Figure 2). A strap was utilized in the same manner to minimize compensatory and accessory trunk motion (Figure 1). Goniometric measurements were again conducted first, with Clin-app measurements second. Clin-app measurements were taken by placing the smartphone on the participant's head with the display arrow aligning with the nose and the display interface bar parallel to an imaginary line between the acromial processes (Figure 2). All measurements were taken with the researcher's hands in contact with the phone and the participant's head to ensure the phone moved with the participant. Each participant was again instructed to perform movements at their own pace. The motions were measured 3 times and silently recorded by a research assistant, who did not have knowledge of the goniometric results, while the primary researcher looked away from the display screen.

Statistical Analysis

Pearson correlation was used to evaluate the association between the measurements obtained by the Clin-app and the universal goniometer. Intrarater reliability of the Clin-app was assessed using a 2-way, absolute agreement, single measures ($ICC_{3,1}$). The mean scores and SD were computed to assess the SEM and MDC across all 6 movements.

Results

A total of 50 participants (15 male and 35 female), with a mean age of 21 years (21.46 [2.78] y), met the inclusion criteria for the study and were invited to participate. All participants meeting the inclusion criteria completed the study. The data analysis was conducted using IBM SPSS Statistics Processor (version 24; IBM, Armonk, NY).

The measurement devices yielded Pearson correlation coefficients ranging between .774 and .928 (Table 1). The Clin-app demonstrated good to excellent concurrent validity (ICC = .87 to .96), a measure of how well a particular test correlates to a previously validated measure, when compared with the goniometric measurement for ROM measurements in cervical flexion, extension, lateral flexion, and rotation.[11]

Intrarater reliability of the Clin-app was assessed using a 2-way, absolute agreement, single measures ICC ($ICC_{3,1}$) and Pearson *r* correlation (Table 1). Excellent intrarater reliability

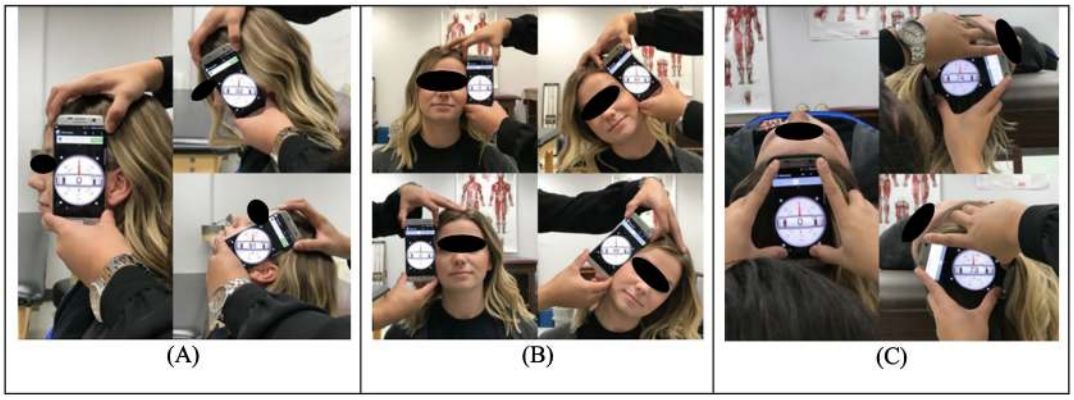

Figure 2 — (A) Position of android for the measurement of flexion and extension. (Left) Starting position. (Top right) Position at end range of flexion. (Bottom right) Position at end range of extension. (B) Position of android for the measurement of lateral flexion. (Left) Starting position level, aligned with eyes. (Right) Position at end range of lateral flexion. (C) Position of android for the measurement of cervical rotation. (Left) Starting position level, aligned parallel to imaginary line between acromial processes. (Right) Position at end range of rotation.

Table 1 Mean (SD), Pearson Correlation, and Cronbach α ($ICC_{3,1}$) of the Raters' Initial Measurements With the Clin-App Compared With the Repeat Measurements of the Clin-App

Motion	Mean normative data[3]	Clin-app measurement 1	Clin-app measurement 2	Pearson *r* intratester (ICC)	$ICC_{3,1}$	Cronbach α	Cronbach α based on standardized items
Cervical flexion	40 (12)	48.51 (11.44)	45.62 (12.42)	.743	.725	.851	.853
Cervical extension	50 (14)	68.86 (13.08)	64.34 (14.48)	.842	.799	.912	.914
Left lateral flexion	22 (7)	64.33 (14.98)	63.47 (14.64)	.930	.930	.964	.964
Right lateral flexion	22 (7)	65.06 (14.85)	62.79 (15.05)	.932	.923	.965	.965
Left rotation	49 (9)	52.12 (9.50)	51.11 (9.44)	.890	.888	.942	.942
Right rotation	51 (11)	55.67 (8.63)	52.79 (8.64)	.916	.868	.955	.955

Abbreviations: ICC, intraclass correlation coefficient; ROM, range of motion. Note: Cronbach α 2-way, absolute agreement, single measures ICC ($ICC_{3,1}$), as well as mean normative data for cervical ROM were taken from Norkin et al.[8]

Table 2 Mean (SD), SEM, and MDC of Initial Measurements of the Universal Goniometer Compared With the Initial Measurements of the Clin-App, and Repeated Measurements of the Clin-App

	Initial measurements				Repeat measurements	
Motion	**Universal goniometer**	**MDC**	**Clin-app measurement 1**	**MDC**	**Clin-app measurement 2**	**MDC**
Flexion	45.47 (11.26) SEM 1.85	1.86	48.51 (11.44) SEM 1.88	1.89	45.62 (12.42) SEM 2.04	2.05
Extension	51.93 (12.88) SEM 2.12	2.13	68.86 (13.08) SEM 2.15	2.16	64.34 (14.48) SEM 2.38	2.39
Left lateral flexion	58.07 (14.06) SEM 2.31	2.32	64.33 (14.98) SEM 2.46	2.47	63.47 (14.64) SEM 2.41	2.42
Right lateral flexion	54.82 (12.70) SEM 2.09	2.10	65.06 (14.85) SEM 2.44	2.45	62.79 (15.05) SEM 2.47	2.48
Left rotation	44.21 (13.03) SEM 2.14	2.15	52.12 (9.50) SEM 1.56	1.57	51.11 (9.44) SEM 1.55	1.56
Right rotation	43.97 (12.54) SEM 2.06	2.07	55.67 (8.63) SEM 1.42	1.43	52.79 (8.64) SEM 1.42	1.43

Abbreviation: MDC, minimal detectable change.

was demonstrated for cervical flexion, extension, lateral flexion, and rotation (ICC = .77–.93; Table 1).[11,12] Test–retest reliability using the Clin-app across all measurements was moderate to excellent, with ICCs ranging between .873 and .964. Across the 6 measurements, the SEM ranged from 1.17 to 2.01, and the MDC ranged from 1.18° to 2.02° (Table 2).[11,12]

Discussion

The aim of our study was to determine concurrent validity against the universal goniometer measurement tool and establish intrarater reproducibility of the Clin-app. The measures taken by the Clin-app for all cervical motions in the present study were very similar to the findings of Tousignant-Laflamme et al[7] and Quek et al.[1] Tousignant-Laflamme et al[7] and Quek et al[1] observed all cervical measurements from a seated position, resulting in a moderate to excellent validity for the movements of flexion (ICC = .76–.98), extension (ICC = .58–92), and lateral flexion (ICC = .70–.96), but poor validity for the movements of rotation (ICC = .53–.55), when compared with the CROM device and 3DMA device. In the seated position, the smartphone utilized the magnetometer to measure the movements of rotation[8] instead of the accelerometer, which is a measurement of inclination,[2] possibly leading to the inaccurate measurements of cervical rotation in the previous studies. By changing the patient's positioning during rotation measurements to a supine position and placing the phone on the top of the head, changing the phone's position into a vertical plane improved the accuracy of the Clin-app's measurement of cervical rotation. The results from the current study demonstrate moderate to excellent (ICC = .87–.96) concurrent validity in all 6 cervical movements, when compared with the universal goniometric measurements. The SEMs ranged from 1.17 to 2.01, representing an absolute estimate of the reliability of the goniometric and clinometric measurements. SEMs allow clinicians to estimate boundaries of an individual's true score.[10] The MDCs ranged between 1.08° and 2.02° in all 6 cervical movements. These MDCs are useful to clinicians to estimate the minimal difference in performance when measuring improvements of CROM after intervention (eg, therapeutic treatments or exercise program).[10] Measuring rotation on a plinth without comparing to a seated position may affect whether a patient can functionally move in a loaded position compared with an unloaded position. Clinicians could not prevent patients from using the plinth to roll into rotation compared with definite active ROM.

Conclusion

Assuming the clinician has access to a smartphone, a chair, a plinth, and an understanding of the proper procedures, the Clin-app can become a practical tool when measuring CROM. The results of this study demonstrate that the Clin-app is a valid and reliable device for measuring active ROM of the cervical spine in flexion, extension, lateral flexion, and rotation. The advantages of the Clin-app are as follows: (1) the tool does not have to be fitted to the patient, (2) the tool is easily portable, and (3) it is a convenient way for clinicians to quickly assess ROM. Previous findings have indicated the Clin-app is a reliable and valid device for assessing cervical flexion, extension, lateral flexion, and now, rotation. Further research is required to validate the use of the Clin-app across other joints and to compare to other methods of ROM assessment. Though other methods and instrumentation would need to be validated in future studies, the availability and utility of the Clin-app may become a valuable tool for clinicians and researchers as new technologies continue to develop.

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