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original research

Validity of the Digital Inclinometer and iPhone When Measuring Thoracic Spine Rotation

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Context: Spinal axial rotation is required for many functional and sporting activities. Eighty percent of axial rotation occurs in the thoracic spine. Existing measures of thoracic spine rotation commonly involve laboratory equipment, use a seated position, and include lumbar motion. A simple performance-based outcome measure would allow clinicians to evaluate isolated thoracic spine rotation. Currently, no valid measure exists.

Objective: To explore the criterion and concurrent validity of a digital inclinometer (DI) and iPhone Clinometer app (iPhone) for measuring thoracic spine rotation using the heel-sit position.

Design: Controlled laboratory study.

Setting: University laboratory.

Patients or Other Participants: A total of 23 asymptomatic healthy participants (14 men, 9 women; age = 25.82 ± 4.28 years, height = 170.26 ± 8.01 cm, mass = 67.50 ± 9.46 kg, body mass index = 23.26 ± 2.79) were recruited from a student population.

Main Outcome Measure(s): We took DI and iPhone measurements of thoracic spine rotation in the heel-sit position concurrently with dual-motion analysis (laboratory measure) and ultrasound imaging of the underlying bony tissue motion (reference standard). To determine the criterion and concurrent validity, we used the Pearson product moment correlation coefficient (r, 2 tailed) and Bland-Altman plots.

Results: The DI ($r = 0.88$, $P < .001$) and iPhone ($r = 0.88$, $P < .001$) demonstrated strong criterion validity. Both also had strong concurrent validity ($r = 0.98$, $P < .001$). Bland-Altman plots illustrated mean differences of 5.82° (95% confidence interval [CI] = 20.37°, –8.73°) and 4.94° (95% CI = 19.23°, –9.35°) between the DI and iPhone, respectively, and the reference standard and 0.87° (95% CI = 6.79°, –5.05°) between the DI and iPhone.

Conclusions: The DI and iPhone provided valid measures of thoracic spine rotation in the heel-sit position. Both can be used in clinical practice to assess thoracic spine rotation, which may be valuable when evaluating thoracic dysfunction.

Key Words: thoracic spine mobility, criterion validity, reference standard

Key Points

- The digital inclinometer (DI) and iPhone Clinometer app (iPhone) had strong criterion validity when compared with motion analysis using ultrasound imaging of underlying bony tissue motion.
- The DI and iPhone had strong concurrent validity and therefore can be used interchangeably with confidence for measuring thoracic spine rotation in the heel-sit position.
- The DI and iPhone may be used with confidence to evaluate asymptomatic thoracic spine mobility restriction and evaluate the effect of therapeutic interventions on thoracic mobility, leading to improved athlete performance.

Axial rotation is an important physiological movement of the spine and vitally important in many functional and sporting activities such as gymnastics, boxing, and rowing.[1] Approximately 80% of axial rotation originates in the thoracic spine.[2] Limited thoracic mobility may impair functional performance or predispose individuals to injury in anatomically related regions such as the low back, neck, or shoulder.[3,4]

Researchers[5,6] have demonstrated this relationship, with mechanically restricted thoracic spine mobility resulting in reduced shoulder elevation, decreased shoulder function, and pain. Functional movement occurs in more than 1 anatomic region, with tissue stress and movement demands possibly increasing in associated regions when thoracic spine mobility is restricted. Tsang et al[7] reported that motion at spinal levels T1, T6, and T12 occurs during all neck movements, likely due to these spinal regions being linked both anatomically and in joint interplay.

Accurately quantifying thoracic spine rotation in athletes may be vitally important to determine sporting limitations, effectiveness of therapeutic interventions, and predisposition to injury.[1] A simple performance-based outcome measure would allow clinicians to measure isolated (without lumbar movement) thoracic spine rotation in a clinical setting. Whereas a number of measurement approaches for the thoracic spine have been documented,[1] they have involved the use of skin sensors, with soft tissue artefact threatening validity[8]; costly laboratory technical equipment[9]; or a nonfunctional seated position[1,9] and have included lumbar spine motion.[1,9] These approaches contrast with those used to assess the cervical and lumbar spine: the prevalence of whiplash-associated disorders and nonspe-

Figure 1. Heel-sit starting position.

cific low back pain, respectively, likely have driven the development of readily available, noninvasive tools.[10–13]

The 4-point lumbar-locked rotation position localizes assessment of axial rotation to the thoracic spine.[1] The participant is in a quadruped position, sitting back on his or her heels (Figure 1). Placing the lumbar spine and hips in maximal flexion minimizes lumbar motion during axial rotation, localizing motion to the thoracic region.[1] This allows clinicians to evaluate restricted thoracic spine mobility and understand "silent" contributors to the primary source of pain.[1,4] However, given that the lumbar spine is not "locked," a more appropriate name is the *heel-sit position* (Figure 1). Measurements of thoracic rotation in this position have been found to be reliable,[1] but their validity has not been established. Therefore, the purpose of our study was to determine both the criterion and concurrent validity of a digital inclinometer (DI) and iPhone (version 5C; Apple Inc, Cupertino, CA) programmed with the Clinometer app (version 4.4; Peter Breitling, Apple Inc) when measuring thoracic spine rotation in the heel-sit position in a healthy population.

METHODS

Design

A prospective validity study was conducted within a university laboratory setting.

Participants

A convenience sample of healthy participants aged 19 to 34 years was recruited from a student population for pragmatic purposes. The 23 participants included 14 men and 9 women (age = 25.82 $\pm$ 4.28 years, height = 170.26 $\pm$ 8.01 cm, mass = 67.50 $\pm$ 9.46 kg, body mass index [BMI] = 23.26 $\pm$ 2.79).

The results of an a priori power analysis indicated a need for 13 or more participants to detect a correlation of 0.7, with an α level of .05 and power of 80%.[14] Participants were excluded if they had a neuromusculoskeletal spine problem within the 12 months before the study, rheumatologic condition, or current or chronic respiratory condition; were pregnant; or were unable to adopt the heel-sit position. All participants provided written informed consent, and the study was approved by the School of Sport, Exercise and Rehabilitation Sciences Ethics Committee, University of Birmingham.

Instrumentation

We used 3 devices to measure thoracic spine rotation in the heel-sit position: (1) reference standard, for which we acquired ultrasound images of participants' spinal laminae using a Philips Sonos 5500 device (Guildford, Surrey, United Kingdom) in conjunction with the Liberty (Polhemus, Colchester, VT) motion-analysis system[9]; (2) Acumar DI (model ACU 360; Lafayette Instrument Company, Lafayette, IN); and (3) iPhone programmed with the Clinometer app (plaincode, Stephanskirchen, Germany). Measurements of thoracic rotation in this position were reliable in an athletic population (C. Steggles and L. Herrington, written communication, July 2015) using a DI (intraclass correlation coefficient [ICC] = 0.89; 95% confidence interval [CI] = 0.81, 0.94) and iPhone (ICC = 0.94; 95% CI = 0.82, 0.98) and in a nonathletic population[1] using a bubble inclinometer (ICC = 0.90; 95% CI = 0.81, 0.94). We piloted the procedures and training before the main study to ensure familiarization with the instruments and to refine the procedure.

Procedures

Testing was undertaken in a laboratory setting. The DI and iPhone measurements were completed by rater 1 (J.B.), an experienced musculoskeletal physiotherapist. The real-time ultrasound imaging with the Liberty motion-analysis system was carried out by rater 2 (N.R.H.), an experienced musculoskeletal physiotherapist with training in sonography.

Participants familiarized themselves with the movement of thoracic rotation in the heel-sit position before data collection but completed no formal warm-up to reflect clinical practice (C. Steggles and L. Herrington, written communication, July 2015). The DI and iPhone were calibrated before data collection according to the manufacturers' guidelines. Participants adopted the heel-sit start position on a plinth (Figure 1). To obtain the DI and iPhone measurements, we placed the devices over the C7–T1 interspinous space perpendicular to the spine, which we located by palpating the participant's cervical spine while he or she was in the heel-sit position. To minimize the sustained time in 1 position, we used a hypoallergenic skin marker to draw a 5-cm horizontal line at 90° to and passing straight through the C7–T1 interspinous space. The C7–T1 interspinous space was rechecked by palpation before each measurement to account for soft tissue artefact.[8]

Reference standard measurements were obtained according to a previously described protocol.[9] This protocol has demonstrated validity, given that it allows measurement of dynamic movement and visualization of the underlying bony tissue to negate the influence of soft tissue artefact.[8] Measures of segmental laminar rotation obtained through ultrasound have been correlated with vertebral rotation as assessed using radiographs.[15] Ultrasound images of the T1 spinal laminae were obtained using reference lines on the monitor. The coordinate position of the transducer was then recorded using the motion-analysis system.

Figure 2. Heel-sit left-rotation end-of-range position.

We instructed participants to place their ipsilateral upper extremity at the side of the body in full elbow flexion, keep the head aligned with the thoracic spine in the horizontal plane, and maintain the kneeling position. Oral feedback was provided to ensure compliance with the procedure. We instructed them to maintain this position while we observed for compensatory patterns of movement. Three measurements were taken with each device in the starting position: participants' perceived midrange left- and right-rotation positions and end-range left- and right-rotation positions (Figure 2). These positions allowed us to determine the validity of the devices throughout the range of thoracic spine rotation. The mean of the 3 measurements for each device was calculated for each position and subsequently used for data analysis because this provided the greatest measurement stability (C. Steggles and L. Herrington, written communication, July 2015).[9] The order of testing, both movement positions, and devices were block randomized to minimize potential effects from tissue stress relaxation and hysteresis.[9]

Common compensatory patterns of movement that would result in a failed test, as determined by rater 1, and repeating the movement because rotation was not isolated to the thoracic spine were extension of the trunk; scapular retraction; loss of upper extremity position unilaterally or bilaterally; loss of lumbar spine position; or loss of pelvis, hip, or knee position.[1,16]

The devices were removed during movement repetitions to ensure their contact did not influence participants' movement.[9] Participants were blinded to all measurements, and raters were blinded to each other's measurements. Raters took their own measurements in situ, saved them to the devices, and transferred them to records after testing to minimize review bias. Data analysis occurred after all data had been collected.

Data Analysis

Data were analyzed for normality using the Shapiro-Wilk test. We analyzed participant demographic data using the mean ± standard deviation for age, height, mass, and BMI. Descriptive data for measurement angles (mean ± standard deviation) were determined for each device in each position to obtain an initial impression of the data.

The criterion validity of the DI and iPhone compared with the reference standard was calculated using the Pearson product moment correlation coefficient (r, 2 tailed). The concurrent validity of the DI and iPhone was also calculated using the Pearson product moment correlation coefficient (r, 2 tailed). Correlations were interpreted as *weak* (0.1–0.39), *moderate* (0.4–0.69), or *strong* (0.7–0.99).[17] Bland-Altman plots were used to visually assess the mean differences and 95% limits of agreement between the DI and reference standard, the iPhone and reference standard, and the DI and iPhone.[18] We set the α level a priori at .05. All data analysis was performed using SPSS (version 22; IBM Corp, Armonk, NY).

RESULTS

All data were normally distributed according to the Shapiro-Wilk test ($P > .05$).

Descriptive Data

Thoracic spine rotation mean (± standard deviation) measurements from the DI and iPhone were similar to those obtained with the reference standard (Table). The starting and midrange right-rotation positions showed the greatest similarity in measurements.

Digital Inclinometer. The DI demonstrated strong criterion validity when compared with the reference standard ($r = 0.88$, $P < .001$). The Bland-Altman plot illustrated the agreement between the DI and reference standard, with most values falling within the 95% limits of agreement (Figure 3). The mean difference between the DI and reference standard measurement angle was 5.82° (95% CI = –8.73°, 20.37°).

iPhone. The iPhone demonstrated strong criterion validity compared with the reference standard ($r = 0.88$, $P < .001$). The Bland-Altman plot illustrated the agreement between the iPhone and reference standard, with most values falling within the 95% limits of agreement (Figure 4). The mean difference between the iPhone and reference standard measurement angle was 4.94° (95% CI = –9.35°, 19.23°).

The DI and iPhone had strong concurrent validity ($r = 0.98$, $P < .001$). The Bland-Altman plot illustrated the

Table. Measurements of Thoracic Spine Rotation for Each Device in Each Position, ° (Mean ± SD)

Position	Reference Standard, °	Digital Inclinometer	iPhone With Clinometer App[a,b]
Starting	3.57 ± 4.26	2.49 ± 1.49	2.31 ± 1.28
Midrange left rotation	22.38 ± 7.90	30.03 ± 9.32	29.37 ± 8.83
End-of-range left rotation	29.36 ± 9.81	39.82 ± 7.24	38.28 ± 8.64
Midrange right rotation	21.26 ± 8.39	26.61 ± 7.21	25.29 ± 6.33
End-of-range right rotation	30.25 ± 8.63	38.14 ± 7.30	36.29 ± 8.58

[a] iPhone version 5c; Apple Inc, Cupertino, CA.
[b] Clinometer app version 4.4; Peter Breitling, Apple, Inc.

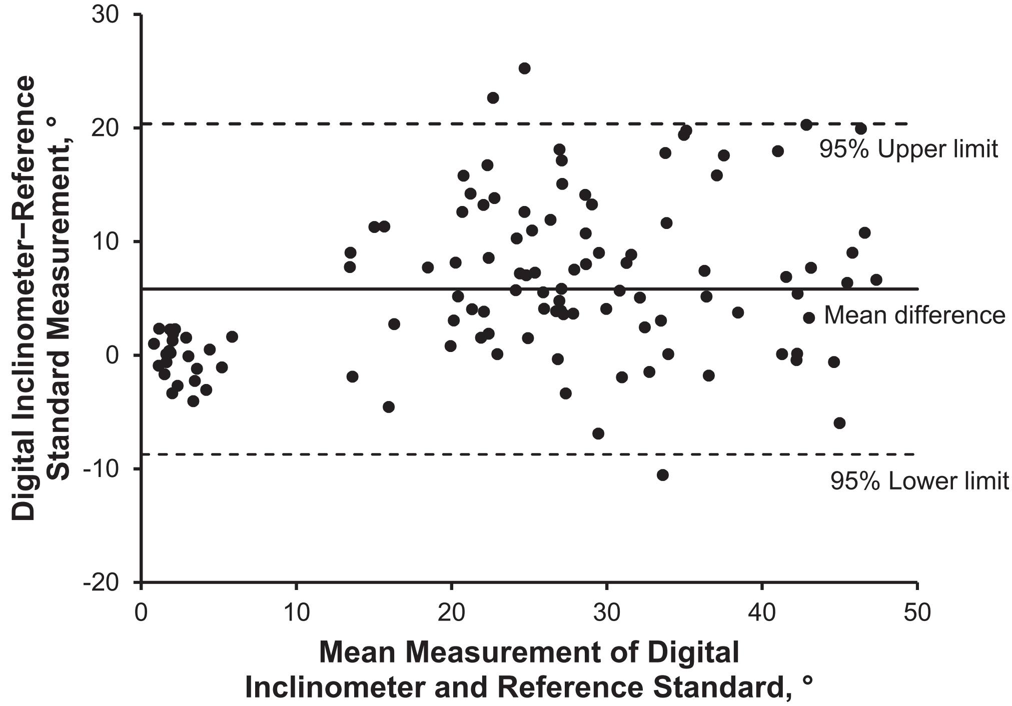

Figure 3. Bland-Altman plot for the digital inclinometer and reference standard.

agreement between the DI and iPhone (Figure 5). The mean difference between the DI and iPhone measurement angle was 0.87° (95% CI = −5.05°, 6.79°).

DISCUSSION

We are the first to investigate the validity of the DI and iPhone when measuring thoracic spine rotation in the heel-sit position. Based on our findings, we recommend using the heel-sit position in clinical practice. The DI and iPhone had strong criterion validities and offer clinicians inexpensive, clinically appropriate techniques for measuring thoracic spine rotation. In addition, these devices possessed strong concurrent validity, suggesting they can be used interchangeably.

Given that the reliability of these devices for measuring thoracic spine rotation in the heel-sit position has been

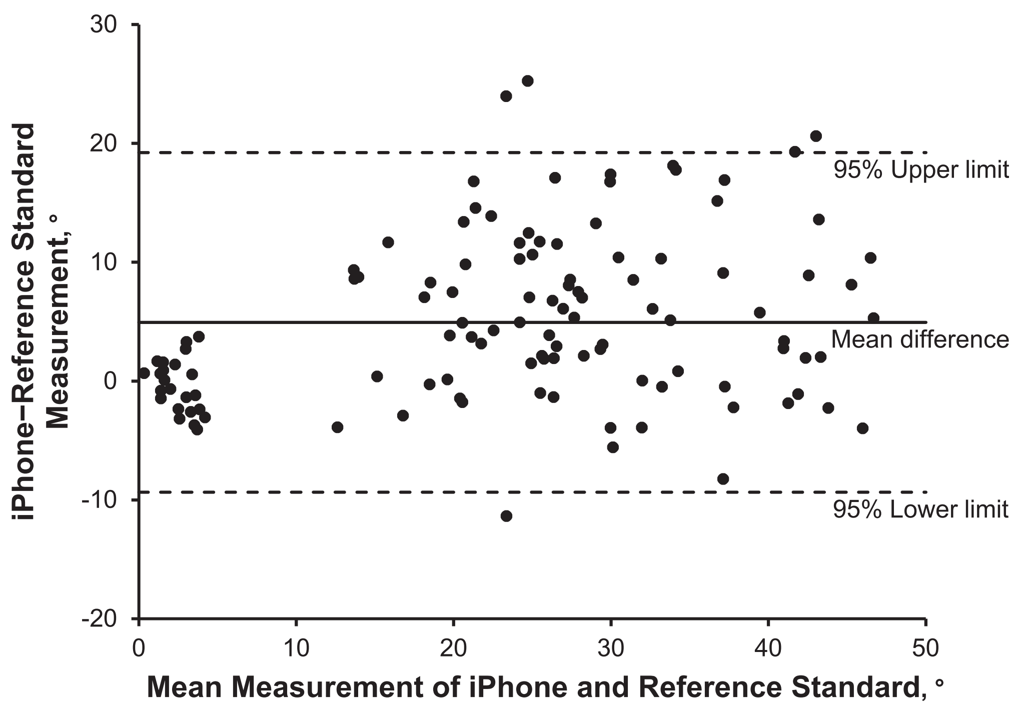

Figure 4. Bland-Altman plot for the iPhone (version 5C; Apple Inc, Cupertino, CA) with Clinometer app (version 4.4; Peter Breitling, Apple Inc) and reference standard.

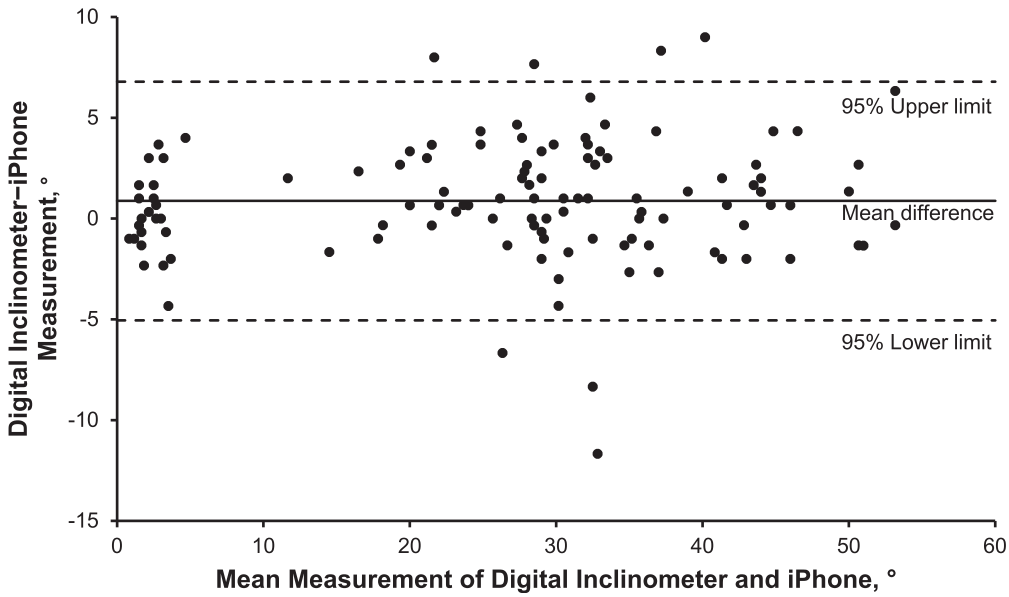

Figure 5. Bland-Altman plot for the digital inclinometer and iPhone (version 5C; Apple Inc, Cupertino, CA) with Clinometer app (version 4.4; Peter Breitling, Apple Inc).

established and reported, they may now be used with confidence in clinical practice (C. Steggles and L. Herrington, written communication, July 2015).[1] The DI and iPhone are readily available, easy to use, and portable, allowing results to be obtained instantaneously in a sport setting by clinicians and away from the laboratory setting by researchers.

The need to accurately quantify thoracic spine mobility is supported by our understanding of regional interdependence: functional movement (eg, throwing) requires orchestrated movement from more than 1 anatomic region (eg, shoulder and spine). Whereas symptoms may be reported clinically in 1 area, the restriction or dysfunction in a clinically silent area must also be managed to optimize function.[3,4] Given that present tools involve technical equipment and include lumbar spine motion,[1,9] the DI and iPhone offer an opportunity to measure thoracic spine mobility without the current limitations. Anecdotally, the cut-out shape of the DI allowed for easier positioning because it sat in the interspinous space more snugly than did the flat-edged iPhone.

A strength of this study was the reference standard: dual Liberty motion analysis and ultrasound imaging of underlying bony tissue motion. Whereas radiography is widely considered the criterion standard for motion-analysis testing,[8] the technique we used overcomes the limitations of soft tissue artefact while not exposing individuals to ionizing radiation.[8] A further strength of the study was the heel-sit position because it allows inclinometers to be used as body position changes relative to the horizontal plane. This may minimize measurement errors that occur in other positions when universal goniometers are required.[1,19] Furthermore, it will help to identify asymptomatic thoracic spine mobility restriction, which may contribute to symptoms in an associated anatomic region, and it may be useful for evaluating the effect of therapeutic interventions on thoracic mobility.

Despite strong validity values, we observed differences among the DI, iPhone, and reference standard (Figures 3 and 4). These differences may be partly attributable to instrument variability, with the standard error of measurement in the heel-sit position nearing 3° (C. Steggles and L. Herrington, written communication, July 2015).[1] In addition, participants were required to hold a fixed position while measurements were taken with each device. Despite making every effort to maintain this position, some participants may have moved while measurements were being taken with each device. Nonetheless, any changes in thoracic spine rotation would have been minimal and, therefore, unlikely to affect the results of the study. In clinical practice, this error would be minimized further because only 1 device would be used for measurements. Another possible source of measurement error may have resulted from increased tissue adiposity among certain participants. Volunteers were healthy and of an athletic age, but, for pragmatic purposes, they were not excluded on the basis of tissue adiposity or BMI. From visual analysis of the data, the 3 greatest measurement errors (Figures 3 and 4) were in participants with the highest BMIs (BMI = 30.1, 27.5, and 27.4). This may have been due to increased soft tissue artefact, errors in palpation, or difficulty positioning the devices.

Our study had limitations. Raters were not blinded to their own measurements during testing; however, measurements were taken, saved to the device, and viewed by the rater only on completion of all measurements. Future research involving individuals with symptoms, restricted thoracic spine mobility, and a greater age range would improve the generalizability of these findings. In addition, investigators should aim to identify whether asymptomatic thoracic spine mobility restriction contributes to symptoms in associated anatomic regions and assess the responsiveness of the DI and iPhone to changes in thoracic range of motion after targeted interventions.

CONCLUSIONS

We provided clinicians with a valid, readily available, easy-to-use performance-based outcome measure to quantify thoracic spine rotation mobility. The DI and iPhone Clinometer app can be used interchangeably with confidence, as they possess strong concurrent validity. Either tool may be useful for identifying asymptomatic thoracic spine mobility restriction, which may contribute to symptoms in an associated anatomic region. This performance-based outcome measure may also be useful in evaluating the effect of therapeutic interventions on thoracic mobility and lead to improved athletic performance. Future researchers should attempt to answer these questions.

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