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# Reliability and concurrent validity of a Smartphone, bubble inclinometer and motion analysis system for measurement of hip joint range of motion

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ABSTRACT

*Objectives:* Traditional methods of assessing joint range of motion (ROM) involve specialized tools that may not be widely available to clinicians. This study assesses the reliability and validity of a custom Smartphone application for assessing hip joint range of motion.
*Design:* Intra-tester reliability with concurrent validity.
*Methods:* Passive hip joint range of motion was recorded for seven different movements in 20 males on two separate occasions. Data from a Smartphone, bubble inclinometer and a three dimensional motion analysis (3DMA) system were collected simultaneously. Intraclass correlation coefficients (ICCs), coefficients of variation (CV) and standard error of measurement (SEM) were used to assess reliability. To assess validity of the Smartphone application and the bubble inclinometer against the three dimensional motion analysis system, intraclass correlation coefficients and fixed and proportional biases were used.
*Results:* The Smartphone demonstrated good to excellent reliability (ICCs > 0.75) for four out of the seven movements, and moderate to good reliability for the remaining three movements (ICC = 0.63–0.68). Additionally, the Smartphone application displayed comparable reliability to the bubble inclinometer. The Smartphone application displayed excellent validity when compared to the three dimensional motion analysis system for all movements (ICCs > 0.88) except one, which displayed moderate to good validity (ICC = 0.71).
*Conclusions:* Smartphones are portable and widely available tools that are mostly reliable and valid for assessing passive hip range of motion, with potential for large-scale use when a bubble inclinometer is not available. However, caution must be taken in its implementation as some movement axes demonstrated only moderate reliability.



## 1. Introduction

The accurate evaluation of hip joint ROM is an important component in the overall clinical assessment of injuries of the lower limb, particularly those of the hip and groin, and may also play a role in screening for potential risk of injury.[1] Restricted hip joint ROM has been reported in athletes presenting with various groin and hip-related injuries including osteitis pubis,[2] pubic bone stress injury,[3] groin strain,[4] adductor-related groin pain[5] and femoroacetabular impingement.[6] Prospectively, reduced total end-range hip joint rotation has been associated with subsequent onset of chronic groin injury in elite Australian Rules Football players.[1]

A variety of measurement tools are available to clinicians to quantify joint ROM. These include manual goniometers, inclinometers and more recently Smartphone applications. Goniometer-based assessments of passive hip joint ROM have demonstrated good intra-tester reliability (ICCs > 0.82) in both healthy participants and patients with femoroacetabular impingement. However, the goniometric measurements were reported to greatly overestimate joint angles compared with those derived using an electromagnetic tracking system.[7] Potential causes of these overestimations were reported to be uncontrolled pelvic rotation in the measurements and difficulty aligning the goniometer and executing the anatomically correct motion simultaneously.[7] The bubble inclinometer is another popular, relatively inexpensive clinical tool

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that has demonstrated high inter and intra-tester reliability for the measurement of hip extension ROM.[8] However, its reliability for other directions of hip joint ROM and validity is yet to be established.

A Smartphone application may provide a simple and more accessible means of evaluating hip joint ROM, especially considering a recent survey of medical practitioners reported that the majority own a Smartphone.[9] To date, the reliability of Smartphone applications have been reported for the measurement of ROM in joints such as the spine, knee and ankle.[10–12] However, the reliability and validity of a Smartphone application to measure hip ROM is yet to be determined, and is of novel interest due to the degrees of freedom this joint possesses. This study therefore aims to evaluate the test–retest reliability and concurrent validity of a Smartphone application for the evaluation of hip joint flexion, rotation and adduction/abduction ROM, and to compare these results to a commonly implemented and inexpensive ROM assessment tool, a bubble inclinometer.

## 2. Methods

A sample of 20 young, healthy participants (mean ± SD age: 23.8 ± 4.6 years, height: 179.0 ± 7.4 cm, mass: 78.9 ± 11.4 kg) were recruited for this study. Participants were included if they were male, aged 18–35 years, and pain free at the time of testing with no significant lower limb injuries in the two months prior to study participation. All participants completed written informed consent prior to testing and the Faculty Human Research Ethics Committee approved all procedures.

This study used a concurrent validity, test–retest reliability design to determine if a Smartphone application could provide a reliable and valid assessment of passive hip ROM. Validity of the Smartphone was measured against a laboratory based reference, a nine camera marker-based 3DMA system (Vicon, Oxford, United Kingdom) sampling at 200 Hz. Additionally, the reliability and validity of a bubble inclinometer was concurrently assessed to provide a comparison with another clinically feasible system of measurement. All participants attended two identical testing sessions approximately three days apart, with comparisons between and within sessions used for reliability and validity assessment respectively.

All ROM tests were conducted by a single physiotherapist with nine years of clinical experience. The tests were performed on the right limb only, with the exception of hip adduction, which was performed on the left limb to avoid excessive position changes. Only passive range of movement was assessed. The end-range of passive motion for each movement direction was the point at which either the assessor determined a firm or stiff end feel, further movement was restricted by pain, and/or compensatory movement at the pelvis or trunk occurred.[13] Compensatory movement was defined as additional movement at joints adjacent to the hip mimicking an increase in hip joint ROM. Three trials for each movement direction were recorded and the median value was used for analysis. The results for the bubble inclinometer and Smartphone were manually recorded at the time of testing.

The custom Smartphone application used in this study was the "Hip ROM Tester", designed by a co-author (RC) of this study using MIT App Inventor. This application is freely available for download from Google Play (https://play.google.com/store/apps). The actual values derived from this program use the standard pitch angle data parsed from the inertial monitoring unit angle calculation performed within the Smartphone's Android operating system. Therefore our results are likely to be valid regardless of the software interface used to measure joint angle as long as it uses these standard data. The Smartphone used in this study was a Samsung Galaxy S2 running Android 4.0. To verify the inter-device validity of the angles recorded, we compared angle data using our application from this device to a Samsung Galaxy S3 and Sony Xperia SP and found little difference. Specifically, we attached the phones together on a rigid surface and rotated them to multiple positions along the axis of rotation to simulate the movements performed in this study. The angles recorded at each position were then observed, and the difference never exceeded two degrees.

Hip ROM tests were performed in the following order; flexion, abduction, adduction, supine internal and external rotation and sitting internal and external rotation. Hip flexion ROM was measured with participants in the supine position (Fig. 1A). A bubble inclinometer was firmly attached with adhesive tape to the anterior aspect of the thigh, two centimeters proximal to the superior pole of the patella. The 3DMA required multiple markers and post-processing. This consisted of modeling the marker sets as anatomical segments, with the only angle of interest being the longitudinal axis of the segment relative to the laboratory reference frame in the plane of movement. Specifically, the thigh segment during flexion and abduction/adduction was expressed relative to the ground and the shank segment during internal and external rotation was expressed relative to the vertical. The angles were expressed with respect to the laboratory reference frame to allow for direct comparison between the 3DMA data and the other two systems, which determine angles relative to the ground. This comparison of laboratory reference frame 3DMA data to inclinometer angle has been used previously to assess segment angles. Due to the inevitable marker occlusion that would occur during supine tests with an assessor holding the limbs, custom marker sets with multiple marker redundancies were required to derive angles. These marker sets were designed to create a longitudinal anatomical segment axis which reflected the measurement plane of both the Smartphone and bubble inclinometer, and to allow for recreation of segment definition markers using redundant markers in the event of occlusion.

For hip flexion, four reflective markers were adhered to the lateral aspect of the thigh using double-sided tape to create a thigh segment. The first marker was adhered to the greater trochanter, two markers were adhered each ten centimeters superior and inferior to the midpoint of the lateral thigh and a fourth marker was adhered to the lateral condyle of the femur. The longitudinal axis was deemed the vector between the greater trochanter and the lateral condyle of the femur.[14] Prior to commencing the three hip flexion trials, the Smartphone application was zeroed to the horizontal position. To establish a starting position for each trial both the reading on the bubble inclinometer and the reading on the Smartphone held against the skin laterally at the midpoint of the thigh (determined as midway between the lateral femoral condyle and greater trochanter) with the leg relaxed in neutral hip rotation, were recorded. Maximal passive hip flexion was then performed with the knee in flexion and recorded at the point at which a firm end-feel was experienced. This position was then maintained for three seconds to allow the Smartphone and bubble inclinometer to record the measurement.

Hip abduction ROM was measured in the sidelying position with the contralateral hip held by the participant in 90 degrees of hip flexion, with the testing leg resting on a box 30 cm high to establish a neutral abduction starting position for the bubble inclinometer and Smartphone. The Smartphone was zeroed to the horizontal and then strapped to the midpoint of the lateral thigh with the bubble inclinometer positioned beneath the strap on the uppermost aspect of the thigh (Fig. 1B). Reflective markers remained in the same position as for the hip flexion trials. With the leg in a neutral hip position and the knee extended, the starting position reading from the bubble inclinometer and Smartphone were recorded. The participant's limb was taken to maximal hip abduction by the assessor and held