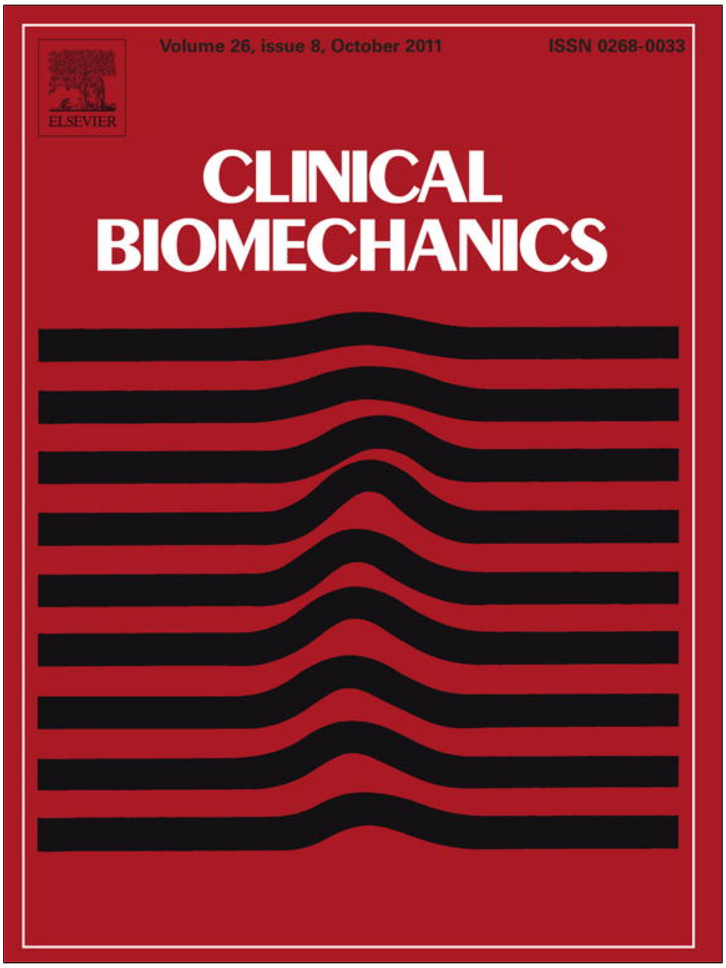
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Quantifying normal 3D hip ROM in healthy young adult males with clinical and laboratory tools: Hip mobility restrictions appear to be plane-specific

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ABSTRACT

Background: Hip mobility is known to affect lumbar spine motion, yet the literature is unclear as to what constitutes normal, limited or excessive motion, given differences in methods, postures, age, etc. The purpose of this study was to establish normative and percentile data for hip rotation and extension, in a young adult male population, using varying methods of quantification.

Methods: 77 males (age 18–35) were recruited. Position data was captured using the Vicon Motion capture system, as participants were passively positioned in hip extension (using the Modified Thomas test) and prone hip rotation. 22 of these participants also had measurements obtained with a goniometer. 3D hip extension angles were calculated using Euler angles, and compared to those calculated in 2D. Goniometric results were compared to 2D measurements.

Findings: Normal distribution of hip extension and rotation range of motion was established, as were average values for the 5th through 95th percentiles. No significant differences existed between hip extension angles measured with the 2D and 3D approaches. Goniometric measurements of hip extension averaged 3.9° less than 2D, less than 1° different for external rotation, and not different for internal rotation.

Interpretation: The normative and percentile data documented here for hip rotation and extension appear to be validly quantified with goniometric techniques when compared to more objective techniques. Further, hip restriction in one plane may not predict restrictions in other planes.

1. Introduction

Hip range of motion has been linked to low back pain and the mechanics of movements such as the squat. The question is: what constitutes normal range of motion (ROM)? However, arriving at an answer does not appear to be straightforward. Measurement outcomes are affected by the position of the participant (Simoneau et al., 1998) and whether the end ROM is obtained actively or passively (James and Parker, 1989). Hip extension range decreases with age (Kerrigan et al., 2001; Roach and Miles, 1991), both in typical clinical exam measures and during gait. Arthritic joints tend to lose ROM in a specific capsular pattern of restriction (Cyriax, 1975; Magee, 1987), but there is little evidence that this pattern applies to healthy joints which are lacking range. Even gender effects are confusing; with some authors reporting increased hip mobility in females (Bach et al., 1985; Roach and Miles, 1991; Simoneau et al., 1998), while others found more in males (Gombatto et al., 2006; Mellin, 1990). Test postures and methods also appear to obscure the building of a data base. Either goniometers or inclinometers have been used to measure hip rotation and extension, although inter-tester variability has been shown to be higher than intra-tester, thus limiting measuring to a single investigator is recommended (Boone et al., 1978; Bovens et al., 1990). New innovations in motion capture have resulted in joint angles being calculated from markers placed on the skin. This presents an additional source of error, as skin motion artifact is well documented in the literature (Benoit et al., 2006; Cappozzo et al., 1996; Leardini et al., 2005). Research which compares these two methods (motion capture vs. goniometer) appears to be lacking.

The purpose of this study was to collect normative data that would represent available passive hip internal rotation (IR), external rotation (ER) and extension in a young (18–35) male population. The intent was to both unify the previous literature and adapt methods to control some of the limitations. Thus, the measurements in this study were obtained using a 3D motion capture system, together with traditional clinical assessments.

2. Methods

2.1. Participants

In total, 77 men were recruited from the university setting and the local community, via posters and word of mouth (mean age (SD) = 22.8 (3.2) years; mean height (SD) = 179.7 (6.6) cm; mean mass (SD) = 78.9 (12.0) kg). Sixty-eight of the seventy-seven claimed that their right leg

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was dominant, defined as the preferred leg for ball contact when kicking a ball. All subjects were healthy, without current hip or back pain or past pathology in these regions. Participants completed a written informed consent document approved by the University Office for Research Ethics.

2.2. Quantitative and clinical range of motion measurements

Quantitative measures of motion used an infrared based 3D motion capture system (Vicon MX Motion System, Oxford, UK). Three non-colinear reflective markers were placed bilaterally on each thigh and 2 on each shin, using the following anatomical landmarks: proximal shin over the tibial tubercle (PS), anterior mid-shin at the level of the ankle (DS), greater trochanter of the thigh (PT), lateral femoral condyle (DT), as well as one technical marker on the anterior-lateral thigh, approximately 10 cm anterior-distal to the greater trochanter (Cappozzo et al., 1996). Placement of all reflective markers, as well as passive positioning of each participant, was performed by a single individual with over 30 years experience as a clinical physiotherapist (See Fig. 1). Data were collected in static positions, each lasting approximately 3 sec.

2.2.1. Hip extension

Initial supine quiet lying trials were captured with the participant in relaxed supine lying, and feet passively oriented in a vertical direction by the investigator, to standardize for neutral thigh/leg position. Supine hip extension was measured using the Modified Thomas test (Kendall and McCreary, 1983), whereby the leg of interest is cantilevered over the end of the examining table, with the investigator controlling for ab/adduction and rotation (Fig. 1). However, it was decided after the first 11 participants that the simple Modified Thomas test did not allow for enough objective control of the pelvis and lumbar spine. Subsequently, a blood pressure cuff was placed under the lumbar spine: the investigator would flex both hips/knees while maintaining her hand under the lumbar lordosis, until she and the participant both agreed that the lordosis had reduced to a neutral position, indicating posterior rotation of the pelvis in the sagittal plane. The hand was then removed from the low back, with minimal alteration to lumbar sagittal position. The blood pressure cuff was placed under the lumbar spine, and then inflated to 60 mmHg. This pressure was monitored as one of the participant's legs was lowered passively to a position of maximum hip extension without associated changes in pelvic position or pressure in the blood pressure cuff. The opposite leg was held passively in a position of hip/knee flexion by the investigator. Participants were encouraged to give feedback as to their perception of pelvis position, in an attempt to further minimize pelvic rotation during hip extension.

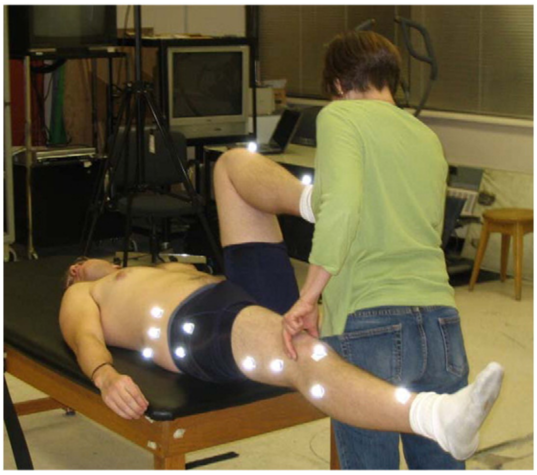

Fig. 1. Position adopted during the Modified Thomas Test, to measure hip extension. Here, the right thigh is being slowly lowered to full extension, while controlling for ab/adduction. The investigator maintains the right hip in passive flexion to minimize sagittal rotation of the pelvis.

2.2.2. Hip rotation

Measurements were obtained with participants in prone lying. An initial quiet lying position required both knees to be bent approximately 90°, with the shanks passively oriented vertically towards the ceiling by the investigator (Fig. 2a). These quiet lying trials represent a "bias" which was later subtracted from the rotation trials, to remove error induced by marker placement. Bilateral internal rotation measurements were done simultaneously, as participants were asked to let both lower legs fall out to the side, while maintaining the knees at 90° of bend (Fig. 2b). External rotation required the leg of interest to passively rotate across the midline (Fig. 2c). Pressure was applied on the ipsilateral pelvis by the investigator to ensure pelvis rotation did not occur. In those cases where large amounts of hip ER was present, the non-tested leg was abducted approximately 10° to allow free motion of the tested leg (Barbee Ellison et al., 1990).

2.2.3. Goniometer

A subgroup of twenty-two of the participants also had hip extension and prone rotation measured manually with a goniometer, together with simultaneous Vicon captures, by a visiting physiotherapist. The goniometer was modified with the addition of two spirit levels: one on each of the 25 cm long arms, to improve accuracy of determining horizontal and vertical positioning (Gabbe et al., 2004). For hip extension, measurements represent the line of the femoral shaft relative to a horizontal axis. In prone, the goniometer aligned with the shaft of the tibia, and rotation was measured relative to a vertical axis. All measurements were done by this one therapist, to reduce error associated with inter-tester reliability (Boone et al., 1978; Bovens et al., 1990; Ekstrand et al., 1982; Gabbe et al., 2004). The goniometer was subsequently passed to another person to read and record the angle (i.e. blinded measurement). Order of collection trials in each position was randomized, as was the variable of supine or prone, and right or left hip. Each measurement was repeated twice, as per previous literature recommendations regarding intra-tester reliability (Boone et al., 1978; Ekstrand et al., 1982; Gabbe et al., 2004). In that the measurements were calculated mathematically after the trials, there was no immediate feedback to indicate position at the time of capture.

2.3. Calculation of angles

An average of the marker position over each 3-second capture was calculated. Hip extension angles were calculated relative to the laboratory coordinate system, wherein the z axis was vertical, the y axis was oriented across the plinthe (treatment table), and the x axis was in line with the length of the plinth. Angle calculations were done twice: the first using simple 2D angles:

$$Angle = arctan[(DTz–PTz) / (DTx–PTx)]$$

(DT = distal thigh, PT = proximal thigh, x and y indicate the axis in a 3D coordinate system). 3D angles were also calculated using an Euler angle method utilizing Mathcad software (PTC, Needham, USA). Order of rotations was flexion/extension, ab/adduction, then rotation, as recommended by the International Society of Biomechanics (D'Lima et al., 2011).

Prone rotation angles were calculated relative to the vertical z-axis, using the following equation:

$$Angle = arctan[(DSy-PSy) / (DSz-PSz)]$$

Fig. 2. The three positions used for measuring prone hip rotations: neutral quiet lying (a), bilateral internal hip rotation (b) and internal rotation, here shown for the left hip (c).

(DS = distal shin, PS = proximal shin, y and z indicate the axis in a 3D coordinate system).

For each participant, bias angles resulting from the quiet lying trials were subtracted from each subsequent trial. Total hip rotation (TRot), was calculated as the sum of IR and ER.

2.4. Data analysis

All analyses utilized the SPSS (version 17) package with a significance level chosen at $P<0.05$. Pearson correlations were performed to compare hip extension measurements calculated in 2D and 3D. For each hip angle measurement type (Ext, IR, ER, TRot), paired t-tests with Bonferroni adjustments were calculated to compare right and left sides, resulting in a significance level of 0.0125 (0.05/4). If no significant differences were found, these right and left data were collapsed. Shapiro–Wilk tests were used to test normal distribution. From these, angles were determined that represented hip extension and rotation measurements at relevant percentiles. In a separate analysis, angles obtained from the goniometric measurements of 22 participants were compared to those calculated using the Vicon data. Again, paired t-tests were used to compare right and left sides, which were collapsed if not different. T-tests with Bonferroni adjustments were then used to compare goniometer to Vicon (Ext, IR, ER, and TRot). Pearson correlations were conducted comparing the ROM of total hip rotation with hip extension (right and left sides collapsed).

3. Results

3.1. Hip extension

Pearson correlations between 2D and 3D hip extension angles for both the right and left sides were 0.99 with r^2 values of 0.975 and 0.98, respectively. This high association indicates minimal difference between the two computational methods, thus 2D was chosen for subsequent analyses.

No difference was found between right and left hip extension ($P=0.213$) (Table 1), thus were collapsed for normative data analyses. The distribution was determined to be normal ($P=0.609$), thus percentiles were calculated representing the pertinent hip extension ROM representative of this data set, as shown in Table 3 (the 5th percentile represents the least amount of hip motion, the 95th the most). A negative number reflects a lack of extension in the Modified Thomas Test, thus the thigh lies above the horizontal. As is standard with the Modifed Thomas Test, 10° of hip extension has been added to the measured angles, to account for flexion of the pelvis (Kendall and McCreary, 1983). Despite the fact that these numbers may represent the true amount of hip extension relative to the pelvis, they can be confusing when trying to imagine the position of the thigh in space. Thus, the second row gives the same Vicon data percentiles in terms of what would be visualized (thus, +ve means the thigh is above the horizontal, −ve is below), with no accounting for pelvis flexion.

3.2. Hip rotation

There was a difference between right and left sides in TRot, with average left hip rotation being 56.6° compared to 61.4° on the right ($P=0.01$). Upon closer examination, there were 3 participants who demonstrated a greater than 17° difference between the right and left TRot, which, although interesting and clinically relevant, would be considered highly unusual. It was decided to remove the data from

Table 1
Results from paired t-tests comparing right vs. left of various hip motions and type of measurement.

Comparison	Mean diff (°)	95% CI	df	*P*-value
Hip ext: 2D	0.82	−0.45 to 2.08	59	0.21
Hip ext: gon	2.1	−0.85 to 5.1	18	1.52
Hip TRot	1.69	−0.015 to 3.39	63	0.05
Hip IR	0.03	−1.53 to 1.59	66	0.97
Hip ER	2.3	0.26 to 4.35	66	0.03
Hip IR gon	0.50	−2.94 to 5.94	19	0.67
Hip ER gon	0.85	−2.94 to 4.69	19	0.64

Table 2
Percentile data for passive supine hip extension and prone hip rotation. Goniometer data is based on 22 subjects only. Other calculations were made in 2D from data collected with the Vicon MX Motion System, collected on 77 subjects.

	Hip extension						
Percentile	5th	10th	25th	50th	75th	90th	95th
Modified Thomas Test	−18°	−16°	−12°	−8°	−5°	−2°	4°
Relative to horizontal, no correction for pelvis	+8°	+6°	+2°	−2°	−5°	−8°	−14°
Goniometer extension	+11°	+9°	+4°	−3°	−7°	−9°	−10°
	Hip rotation						
Total rotation	44°	46°	53°	59°	66°	75°	82°
Internal rotation	12°	15°	20°	26°	31°	37°	42°
External rotation	19°	23°	28°	34°	40°	46°	50°
Goniometer total rotation	51°	52°	58°	62°	67°	78°	89°
Goniometer IR	20°	23°	26°	27°	33°	39°	46°
Goniometer ER	25°	26°	29°	35°	38°	43°	44°

these 3 participants, resulting in a P-value of 0.052, allowing the right/left sides to be collapsed (Table 1). A normal distribution ($P = 0.377$) allowed for further analysis to determine TRot percentile data (Table 2).

There was no difference between right and left sides for hip IR and ER (Table 1) with the distribution being normal ($P = 0.125$, 0.101 for ER and IR, respectively). Subsequent percentile data are shown in Table 2.

3.3. Rotation and extension

Pearson correlations between the two sets of measurements resulted in a value of 0.331, or an r^2 value of 0.110, indicating a weak correlation between the hip extension and hip rotation measurements.

3.4. Goniometer

No differences were found between the right and left sides in hip extension or rotation measurements obtained with the goniometer (Table 1), thus sides were collapsed. There was a significant difference, however, between the goniometric measurements of hip extension and those calculated in 2D ($P < 0.001$), with the goniometer measurements being an average of 3.9° less (indicating greater amounts of extension) (95% CI: −5.1 to −2.8, df = 21). In spite of this, the Pearson correlation was high (0.940), with an RMS error of 2.52°, and r^2 value of 0.88, indicating high correlation between the two techniques (Fig. 3). Similarly, differences exist between the two measurement types for ER ($P = 0.046$). However, the goniometric measurements were less than one degree different than the Vicon measures, which would be considered within the margin of error for clinical measurement, and less than the RMS error of 1.89° (mean: −0.92°, 95% CI: −1.8 to −0.16, df = 19). No differences were demonstrated between the Vicon and goniometer measures for IR (mean 0.72°, 95% CI: −0.21 to 1.66, df = 19, $P = 0.122$). Table 2 includes percentile data from both the Vicon data collected over 77 participants, as well as the goniometric data collected on 22.

4. Discussion

The normative data presented here suggests the goniometer remains a viable clinical tool for measuring hip ROM, when compared to angles obtained using a motion capture system. Goniometric measurements of hip extension, however, should be done with the understanding that they tend to overstate extension by an average of 3.9°, when compared to the Vicon system, which may assist in interpreting available data sets. Both sets of data are thus presented in Table 2, allowing the researcher to choose the appropriate measurement set. Recall, however, that only 22 subjects were measured with the goniometer data set, thus this set is not necessarily representative of a normal distribution.

Not all participants fit into the same percentiles for both rotation and extension. For example, one participant demonstrated 75° of hip rotation bilaterally (90th percentile), yet placed near the 30th percentile for extension, with his thigh being 4° above the horizontal. Similarly, another showed the opposite trend: 46° of hip rotation, but 15° below the horizontal for extension (thus 10th and 95th percentiles, respectively). Although these measurements are indicative of extreme cases, they highlight the variability demonstrated in a group of healthy, pain-free young males. Based on the low correlation between extension and rotation ROM (0.331) clinicians are cautioned to not assume that healthy hip joints lacking range in one plane will also be restricted in other planes.

The main limitation of this study is the method used for positioning the participants to measure hip extension: the Modified Thomas Test. Over the course of many participants, it became obvious that stabilizing the pelvis to accurately measure hip extension ROM

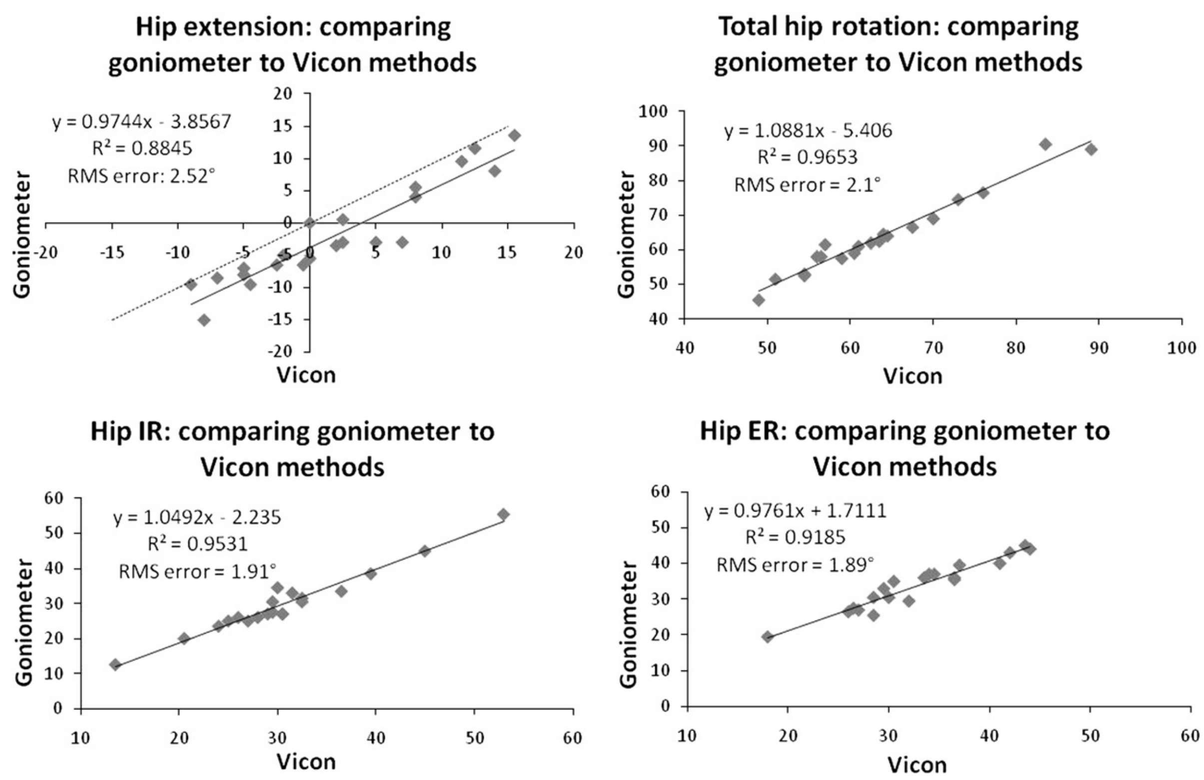

Fig. 3. Scatterplot of the hip extension measurements obtained with the goniometer compared to the Vicon system. The solid line are the results, the dotted line represents a hypothetical correlation of 1.0, thus demonstrating that the goniometric measurement was consistently less than the Vicon.

relies heavily on the investigator subjectively determining when the pelvis begins to rotate, and counteract that rotation with increased contra-lateral hip flexion force. Positioning of the blood pressure cuff was helpful to provide objective feedback, but it also required the participant to subjectively indicate if they felt the cuff was midline (as the investigator could not see its specific position). Blood pressure cuffs which were laterally displaced would not respond accurately to changes in the lumbar lordosis. Motion capture systems measuring pelvis positions are also problematic. Much of the previous literature measuring hip joint angles have recommended attaching markers to the bony landmarks of the pelvis: the anterior-superior and posterior-superior iliac crests (Cappozzo et al., 1995). In this experiment, the horizontal positioning of the participants complicated use of these marker positions. Attaching markers to the anterior-lateral pelvis may be acceptable with the hip in limited flexion, but preliminary collections indicated that full hip flexion, as was required in this study, resulted in a large amount of skin crimping over the anterior hip/pelvis, which tends to distort marker position (skin mounted or on a fin). Thus, the blood pressure cuff seemed to be the best option, and is easily reproducible in most research or clinical environments. This research is further limited by the specific population that was studied: healthy young males. Future investigations should broaden the participant base to include different age groups, both genders, and variance in weight and body fat.

The values of hip motion reported here are less than those previously described in the literature, for this population base (Table 3). The amount of end range pressure applied to obtain full passive ROM likely differs between investigators. Simoneau et al. (1998) and Roach and Miles (1991) both measured active ROM, with participants being asked to use maximum effort. This would tend to encourage stretching of the soft tissues, possibly resulting in a greater ROM than the technique used in this investigation, where ROM was calculated at the time pelvis motion began, without additional over-pressure. Roach and Miles (1991) chose to position their participants in sitting, which would alter not only joint mechanics, but soft tissue tensions in the surrounding structures. Malliaras et al. (2009) examined mobility in a younger population: (15–21 yrs), which could explain some of the increased range. They used a supine position for hip ER, with the knee at the end of the plinthe: thus the thigh supported, knee flexed to 90°. The opposite leg was also in a position of supported hip/knee flexion, which may have altered the pelvis position, compared to this investigation where the participants were prone. Obviously, different positions result in different outcomes. For example, hip external rotation measured in prone averages 9° less than sitting (Simoneau et al., 1998) and 5° less than supine. Consistency in positioning and method of measurement appear to be vital.

Table 3
Average (SD) range of hip joint rotation and extension for a young adult male population, as published in the literature.

Authors	Active/ passive	Age (years)	IR	ER	TotR	Ext
Simoneau et al., 1998	A	18–26	32(9)° prone	44(7)° prone	76(10)° prone	———
			30(7)° seated	35(8)° seated	65(8)° seated	———
Roach and Miles, 1991	A	25–39	33(7)° seated	34(8)° seated	77°[a] seated	22(8)° prone
Manning and Hudson, 2009	P	26(3.5)	25(6)° supine	44(3)° supine	69°[a] supine	17.5(2)° prone
Malliaras et al., 2009	P	15–21	34(11)° prone	48(10)° supine[b]	82°[a] mixed	———

[a] No total rotation numbers were published; this is simply an addition of IR and ER, thus no SD is available.
[b] Supine measurement was obtained with the hip joint in neutral flexion/extension, and the knee flexed over the end of the plinthe.

5. Clinical relevance

The goniometer is found to be an acceptable measuring device for supine hip extension and prone lying internal and external rotation, when compared to the Vicon MX motion capture system. This link between the laboratory and clinical measurement systems may give individuals confidence to carry out hip research in a much less "high-tech" environment. Percentile data gives insight into what constitutes normal, limited, or excessive hip mobility, facilitating comparisons of these groups in further studies investigating the influence of hip mobility. Unlike the typical multi-axial capsular pattern of hip restriction generally found in the elderly, limitation of motion in either extension or rotation is not necessarily predictive of a similar restriction in the other direction.

Conflict of interest statement

The authors acknowledge that we do not have any financial or personal relationships with other people or organizations that could inappropriately influence the work described in the current manuscript.

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