Title:

A Biomechanical Investigation of selected Lumbo-Pelvic Hip tests: Implications for the examination of walking

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A Biomechanical Investigation of selected Lumbo-Pelvic Hip tests: Implications for the examination of walking

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Abstract

Objectives: The purpose of this study was to compare Lumbo-Pelvic Hip ranges of motion during the Trendelenburg, Single Leg Squat and Corkscrew Tests to walking and to describe the 3-dimensional Lumbo-Pelvic Hip motion during the tests. This may help clinicians to select appropriate tests when examining gait.

Methods: An optoelectronic movement analysis tracking system was used to assess the Lumbo-Pelvic Hip region of 14 healthy participants while performing Trendelenburg, Single Leg Squat and Corkscrew Tests and walking. The Lumbo-Pelvic Hip 3-dimensional ranges of movement for the clinical tests were compared to walking using a repeated measures analysis of variance (ANOVA) with pairwise comparisons.

Results: No significant differences were found between the pelvic obliquity during the Trendelenburg Test and walking (T Test: L, 11.3^0 +/-4.8, R, 10.8^0 +/- 5.0^0 vs Walk: L, 8.3^0 +/- 4.8^0, R 8.3^0 +/- 5.1^0, L, P=.143, R, P=.068). Significant differences were found between the hip sagittal plane range of movement during the Single Leg Squat and walking (SLS: L, 44.2^0 +/-13.7^0, R, 41.7^0 +/-10.9^0 vs Walk: 38.6^0 +/-7.0, R 37.8^0 +/-5.1^0,P<.05),the hip coronal plane range of movement (SLS: L, 9.1^0 +/-5.8, R, 9.0^0 +/- 4.6^0 vs Walk: L, 9.4^0 +/- 2.3^0, R 9.5^0 +/- 2.0^0, P<.05), and the hip coronal plane range of movement during the Corkscrew Test and walking (Corkscrew: L, 5.7^0 +/-3.3^0, R, 5.7^0 +/-3.2^0 vs Walk: L, 9.4^0 +/- 2.3^0, R 9.5^0 +/- 2.0^0, P<.05).

Conclusions: The results of the present study showed that, in young asymptomatic participants with no known Lumbo-Pelvic Hip pathology, the pelvic obliquity during the Trendelenburg Test and walking are similar. During the Single Leg Squat the hip moved more in the sagittal plane and less in the coronal plane when compared to walking. There was more movement in the hip transverse plane movement during the Corkscrew Test than during walking. These results suggest for the Trendelenburg Test to be interpreted as normal the pelvis should achieve at least 10^0 of pelvic obliquity, during the Single Leg Squat the hip should move through 43^0 in the sagittal plane and under 10^0 in the coronal plane, and for the Corkscrew Test to be interpreted as normal the hip should move through 6^0 of rotation, and the trunk through 27^0 of rotation.

Key Indexing Terms: Lumbo-Pelvic Hip; Range of Motion; Articular; Biomechanical Phenomena

1. Introduction

Clinicians commonly use tests including the Trendelenburg,[1] Single Leg Squat [2] and Corkscrew Tests during the examination of the Lumbo-Pelvic and Hip complex. These tests are used to examine the movements of the Lumbar, Pelvic and Hip regions in a weight bearing position.[1, 2, 3, 4] They may be used in isolation,[5, 6] or to compliment the examination of functional tasks including walking.[3, 7] The clinical assumption is that the Lumbar, Pelvic and Hip movements generated during these tests are similar to those of walking.[3] However, there are few biomechanical investigations of the normative kinematics of these tests, and a limited number of previous studies that compare the kinematics of these tests to walking.[8]

The Trendelenburg Test is interpreted by observing pelvic obliquity during the test.[3, 9] Two previous studies have objectively defined when the pelvic drop (obliquity) becomes positive. Asayama stated that a "*tilt angle*" (pelvic obliquity) of greater than 2^0 indicated a positive Trendelenburg Test.[5] Westhoff stated that "*Pelvic drop to the swinging limb during single stance phase of more than 4^0 and / or maximum (peak value) pelvic drop in the stance phase of more than 8^0*" [10] indicated a positive test. There are no published data quantifying sagittal and transverse plane pelvic movement during the Trendelenburg Test. The Single Leg Squat is currently interpreted by observing hip range of movement in the sagittal and coronal planes. Only one author, Livengood, has objectively defined when the Single Leg Squat becomes positive. Hip flexion greater than 65^0, hip abduction / adduction greater than 10^0, knee valgus / varus greater than 10^0. [4] There are no published data for sagittal, coronal and transverse plane pelvic movement during the Single Leg Squat. The Trendelenburg Test requires neuromuscular control of the pelvis in the coronal plane and the Single Leg Squat control of the hip in the sagittal plane. Interestingly there are currently no existing tests for neuromuscular control of the pelvis requiring hip internal-external rotation movement in the transverse plane documented within the musculoskeletal literature. Hence a novel clinical test for the assessment of the Lumbo-Pelvic and Hip region in the transverse plane has started to be used within clinical practice. This test has been termed the "Corkscrew Test". The method for performing the Corkscrew Test is based upon the Single Leg Squat [4] and its interpretation is based upon the Single Leg Squat criterion in combination with kinematic values found within the walking literature.[11, 12, 13] The participant stands on the limb being evaluated, with the contralateral leg lifted off the ground, as if walking. The participant rotates the weight bearing hip first into maximal hip internal rotation, then external rotation, and returns to the start position in less than 6 seconds. The Corkscrew Test is a new test hence there is currently no kinematic data to support its use in clinical practice.

Pathologies affecting the Lumbo-Pelvic and Hip complex include Ankylosing Spondylitis,[14, 15] Perthe's Disease,[16, 17] and Slipped Femoral Epiphysis.[18, 19, 20] These pathologies have been found to be three times more prevalent in late teenage males when compared to females [14, 17, 21, 20] and associated with changes in gait.[3] In order to recommend the use of these tests within clinical practice there is a need to establish the normal ranges of movement for the tests, particularly in young males, and to compare these to those found during walking. Previous studies of these clinical tests [5, 10] and gait [11, 12, 13] have described the ranges of movement to one standard deviation. Individuals found to exhibit ranges of movement in excess of one standard deviation from the clinical test's normative value could be interpreted as exhibiting an abnormal movement pattern. This will allow clinicians to interpret the tests, identify abnormal responses, subgroup individuals and better understand their role in the examination of gait.

The purpose of this study was to investigate the biomechanical characteristics of the Trendelenburg, Single Leg Squat and Corkscrew Tests and their relationship to the kinematics of walking. It was hypothesised that, the pelvic obliquity achieved during the Trendelenburg Test, the hip sagittal and coronal plane range of movement during the Single Leg Squat and the hip rotation range during the Corkscrew Test should be similar to these parameters when walking.

2. METHODS

2.1 Participants

14 healthy male participants were recruited (age 20.5 +/- 2.0 years, 1.76 +/- 0.13m height, mass 73.9 +/- 9.0kg) who had no pain or neuromusculoskeletal disorder. Demographic data were recorded. Data were collected from both limbs of each participant. Volunteers gave written informed consent before data collection. All data collection conformed to the Declaration of Helsinki. The study was approved by the Faculty of Health Research Ethics Committee, University of Central Lancashire.

2.2 Instrumentation

Kinematic data were collected using a 10-camera ProReflex system (QualisysMedical AB, Gothenburg, Sweden) at 100 Hz. Force data were collected using an AMTI force platform (Advanced Mechanical Technology, Inc, Watertown, MA, model BP400600). Force data was used to define the events of heel strike and toe off.

2.3 Modelling of the Lower Limbs and Joints

The segments of the lower limbs were modelled based on the calibrated anatomical systems technique (CAST).[22] The landmarks used included, (Fig 1), medial and lateral femoral epicondyles, greater trochanter, anterior and posterior superior iliac spines of the pelvis. Clusters of 4 markers mounted on rigid plastic shells were attached to each segment, Figure 1.

Figure 1: Marker placement based on the Calibrated Anatomical Systems Technique (CAST)

After placing all of the markers, a calibration was performed that consisted of data collection for 1 second with the participant standing in the anatomic position. This defined the anatomic coordinate systems that enabled the position and orientation of each segment in space to be identified.[22] Local coordinate systems were defined for all segments of the model, with the y-axis equal to anterior-posterior, x-axis equal to medial-lateral, and z-axis equal to proximal-distal. The centres of the knee and ankle joints were calculated as the mean distance between the medial and lateral joint markers. The centre of the hip joint was calculated based on pelvic depth and width using the regression equations developed by Bell et al.[23, 24] Joint kinematics were calculated using a Cardan/Euler method with an XYZ order of rotations.

2.4 Procedures

Testing was divided into two groups of tests; the "clinical tests" were the Trendelenburg Test, Single Leg Squat and Corkscrew Test. The "functional test" was walking. The order of the clinical tests was randomized using a pseudo-random number generator.[25]

2.5 Protocol

Prior to commencing the tests, each participant was provided with standardised oral instructions. For the clinical tests participants completed 3 practice trials to become familiar with the procedure, followed by 3 trials of each test.

2.5.1 Clinical tests - Trendelenburg Test, Single Leg Squat and Corkscrew Test

Participants were asked to stand on the edge of the laboratory force plates near the centre of the data collection area; this formed the start position for the test. Participants were not instructed which leg to use first during the tests. Participants completed the tests by stepping onto the laboratory force plates, performing the test on both limbs consecutively and stepping back off the force plates to the start position. This reflected how the tests are routinely completed in clinical practice, Figures 2-4.

Figure 1: Study Trendelenburg Test method; (A) start / finish position (B) Trendelenburg Test position [3]

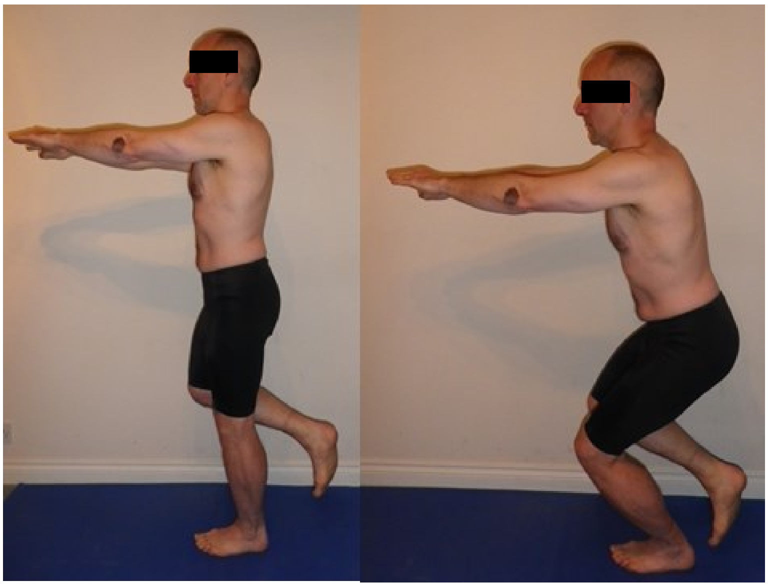

Figure 2: Study Single Leg Squat method; (A) start / finish position (B) Squat position [26]

Figure 3: Study Corkscrew Test method; (A) start / finish position (B) Corkscrew position

Data capture commenced when the participant started to step onto the force plate for a duration of; 75 seconds for the Trendelenburg Test, 40 seconds for the Single Leg Squat and 15 seconds for the Corkscrew Test. The participants were allowed 30 seconds rest between clinical tests in order to avoid fatigue. The markers were left in position on the participants between the functional and clinical tests to minimize any errors in marker placement.

2.5.2 Functional walking test

Participants were asked to stand at a preset position 5m from the data collection area; this formed the start position for the test. The finish position for the test was 10m from the start position. Participants were not instructed which leg to take the first step with.

Data capture commenced when the participant was approximately 1m outside of the data collection area and stopped when the participant reached the finish position. This ensured the participants were in a steady state of gait. The participants were allowed a 1 minute rest between functional tests in order to avoid fatigue.

2.6 Data Processing

The movement data were exported toVisual3D (C-Motion, Inc, Germantown, MD) for processing. The movement data were filtered using a second-order, low-pass Butterworth filter with a 6 Hz cut-off frequency. The trunk, lumbar, thoracic, and hip angles were calculated relative to the local coordinate system, and the pelvic angles were calculated relative to the global coordinate system. The local coordinate system data provides information about movement of one segment relative to the next, whereas the global coordinate system data provides information on the orientation of the segment relative to the ground.

For all tests the data were normalised for time to 101 points. For walking this was between heel strike to toe off, for the Trendelenburg Test the range movement starting from maximum pelvic obliquity over a 30 seconds duration, for the Single Leg Squat between minimum and maximum hip flexion and for the Corkscrew Test between minimum and maximum hip rotation.

2.7 Statistical Analysis

Repeated-measures analysis of variance with post hoc pairwise comparisons were used to identify significant differences when comparing the ranges of movement found in the clinical tests with those of walking. The Bonferroni adjustment was used to account for multiple comparisons and to reduce the possibility of type I errors. Adjusted P values were reported. The α level was set at .05.

3. Results

Table 1: Normative data of the clinical tests and pairwise comparisons between the clinical tests and walking.

The mean and standard deviations for the clinical tests and pairwise comparisons between the clinical tests and walking are presented in Table 1. Significant differences were seen between the Trendelenburg Test and walking in the coronal and transverse planes for the lumbar, thoracic and trunk ranges of motion. For the pelvis in the sagittal and transverse planes and for the hip in all three cardinal planes.

For the Single Leg Squat significant differences were also found in the lumbar spine in the sagittal and transverse planes, thoracic spine in the coronal plane and trunk in all three cardinal planes ranges of motion. For the pelvis in the coronal and transverse planes and at the hip in the sagittal and transverse planes.

Significant differences were also seen between the Corkscrew Test and walking in the transverse planes for the lumbar and thoracic ranges of motion. For the trunk in the coronal and transverse planes, for the pelvis in the sagittal and transverse planes and for the hip in the sagittal and coronal planes.

4. Discussion

The Trendelenburg Test is currently interpreted by the orientation of the pelvis compared to the horizontal (pelvic obliquity),[3] therefore pelvic obliquity is currently a value normally quoted within research [5, 10] and a clinically important parameter for clinicians when examining the components of walking.[3] Current research states that the Trendelenburg Test is positive if the pelvic obliquity is between 2^{0}[5] and 4^{0}.[10] The pelvic obliquity found in this study was large and symmetrical for the Trendelenburg Test; left 11.3^{0} (SD= 4.81), right 10.8^{0} (SD= 4.96). The existing evidence base advocates lower values of pelvic obliquity for the interpretation of the test when compared to this study.

This disagreement may be explained by the population studied; Asayama's participants were post Total Hip Arthroplasty, Westhoff's study used participants with Legg Calve Perthe's disease, but this current study was of healthy participants. However if the angle that needs to be achieved is amended to fit within 1 standard deviation of the results of this study then the pelvic obliquity value would become 6^{0} and hence would be in keeping with the previous studies. Based on this current studies results it could therefore be suggested that the Trendelenburg Test should interpreted as positive if the participant is unable to achieve a value of 10^{0} or more for pelvic obliquity.

The Hardcastle and Nade method for performing the Trendelenburg Test does not describe the required position or movements of the other regions during the test. There have been no previous studies that have reported the trunk, lumbar, thoracic, pelvis or hip range of movement in the sagittal, coronal or transverse planes during the Trendelenburg Test. However it is a common clinical assumption that the participant should maintain an upright posture and minimal movement in all planes during the test. This study found the lumbar, thoracic, trunk, pelvis and hip ranges of movement to be small and symmetrical in the three cardinal planes of movement during the

Trendelenburg Test. Hence when performing the Trendelenburg Test clinically there should be no observable movement of the participant except at the pelvis in the coronal plane. Consequently during the Trendelenburg Test the participant should appear to be in a position of pelvic obliquity but not moving.

When considering clinical assessment of walking the Trendelenburg Test was found to be an appropriate proxy for examining the lumbar, thoracic and trunk sagittal plane ranges of movement, the pelvis coronal plane range of movement and both the lumbar coronal plane and pelvic obliquity components. Trendelenburg originally developed his test to examine the pelvic obliquity component of walking. This study confirmed that the Trendelenburg Test is appropriate for examining the pelvic obliquity of walking as Trendelenburg intended it for. For the Trendelenburg Test to be interpreted clinically as normal the pelvis should achieve a position of at least 10^0 of pelvic obliquity and there should be no observable movement of the participant in any of the three cardinal planes whilst maintaining this position.

Currently the Single Leg Squat is interpreted as excellent if the individual exhibits over 65^0 of hip flexion and a coronal plane range of movement of less than 10^0.[4] The hip flexion ranges of movement found in this study were large and symmetrical for the Single Leg Squat; left 44.2^0 (SD=13.70), right 41.7^0 (SD=10.89), and moderate and symmetrical in the coronal plane; left 9.1^0 (SD=5.76), right 9.0^0 (SD=4.55).

The limited number of previous studies available has advocated higher values for hip sagittal range of movement and similar coronal plane ranges of movement for the interpretation of the test. However the previously published Single Leg Squat papers were not kinematic studies. The values published by Livengood [4] were derived from clinical experience. Interestingly if the hip flexion angle that needs to be achieved is amended to fit within 1 standard deviation then the hip sagittal plane ranges of movement would become 56^0 but still remain lower than previous studies stated value.

Based on the kinematic data generated in this study it could be recommended that the Single Leg Squat should interpreted as normal if the individual is able to achieve 43^0 of hip sagittal plane range of movement, whilst maintaining under 10^0 of hip coronal plane movement.

The Livengood method for performing the Single Leg Squat does not describe the required position or movements of the other regions during the test. There have been no previous studies that report trunk, lumbar, thoracic, or pelvic range of movement in the sagittal, coronal or transverse planes during the Single Leg Squat. However it is a common clinical assumption that participants should maintain an upright posture and exhibit minimal movement in the three cardinal planes. This study found the trunk, lumbar, thoracic, and pelvis ranges of movement to be moderate and symmetrical in the three cardinal planes of movement during the Single Leg Squat. Hence when using the Single Leg Squat during clinical assessment, some movement of the participant in all of the regions is normal with a large movement of the hip in the sagittal plane.

When considering examining walking the Single Leg Squat was found to be an appropriate proxy for examining the lumbar coronal plane, thoracic sagittal and transverse plane, and hip coronal plane ranges of movement. Therefore this study has found that the Single Leg Squat is an appropriate test to examine the hip for coronal plane range of walking. However its utility is limited to the coronal plane as it was not found to be a good representation of walking for the hip in the sagittal or transverse planes. For the Single Leg Squat to be interpreted as normal the hip should move through 43^0 in the sagittal plane, not exceed 10^0 of hip coronal plane movement, and allow a small amount of movement in the trunk and pelvis in all other planes.

There are no previous kinematic studies of the movements occurring during the Corkscrew Test.

The hip transverse plane range of movement values found in this study were large and symmetrical for the Corkscrew Test; left 8.3^0 (SD=3.50), right 6.4^0 (SD=3.30). It was presumed a priori that the hip transverse plane movements during the Corkscrew Test and walking would be similar, 10^0. The hip coronal plane range of movement was predicted to be similar to that observed during the Single Leg Squat, 10^0 [4]. However both the hip transverse plane movements; left 8.3^0 (SD=3.50), right 6.4^0 (SD=3.30), and coronal plane movements; left 5.7^0 (SD=3.26), right 5.7 (SD=3.17), found in this study were smaller than those predicted a priori. Most of the transverse plane movement occurred in the trunk; left 26.1^0 (SD=17.40), right 28.8^0 (SD=16.00), and therefore the Corkscrew Test appears to be a greater challenge of trunk rather than hip transverse plane movement. Subsequent to this study the Corkscrew Test could be interpreted as positive if the individual is unable to achieve 6^0 of hip rotation. However if the angle that needs to be achieved is amended to fit within 1 standard deviation then the hip transverse plane range of movement would become 9^0 and hence would be in keeping with the values predicted a priori.

The current method for performing the Corkscrew Test does not describe the required position or movements of the other regions during the test. There have been no previous studies that have reported on the trunk, lumbar, thoracic, pelvis or hip kinematics during the Corkscrew Test. However, as the test is becoming more commonly used in clinical practice it is being assumed by clinicians that participants should maintain an upright posture during the test. This study found the sagittal and coronal plane ranges of movement to be symmetrical and either moderate or small for all of the regions during the Corkscrew Test.

When using the Corkscrew Test clinically therefore there should be some observable movement of the participant in each of the regions and cardinal planes with a large amount of movement being observed in the trunk and thoracic spine in the transverse plane.

When considering walking the Corkscrew Test was found to be an appropriate proxy for examining the trunk and lumbar sagittal plane ranges of movement. For the Corkscrew Test to be assessed as normal the hip should move through 6^0 of rotation, and the trunk through 27^0 of rotation. There should be some observable movement of the participant in the each of the three cardinal planes whilst maintaining this position.

From this study; the Trendelenburg Test and Single Leg Squat were found to examine different, complementary ranges of Lumbo-Pelvic and Hip movement. The clinical application of this is that, when used in isolation these tests do not allow a full examination of the individual. However, when used in combination, these two tests enable examination of all but one region and plane. The only parameter that this combination of tests was found inappropriate to examine was the thoracic sagittal plane range of movement. However none of the clinical tests were appropriate for this parameter. Clinicians may wish to use alternative tests to examine this parameter of walking.

5. Conclusion

Clinicians commonly use Lumbo-Pelvic Hip tests to examine components of the walking gait cycle.[1] However, little was known about the exact biomechanics of the tests and their relationship to the gait cycle. This study established that, when a clinician uses these clinical tests; for the Trendelenburg Test to be interpreted as normal the pelvis should achieve a position of at least 10^0 of pelvic obliquity and there should be no observable movement in any of the three cardinal planes whilst maintaining this position. For the Single Leg Squat to be interpreted as normal the hip should move through 43^0 in the sagittal plane and under 10^0 in the coronal plane. For the Corkscrew Test to be interpreted as normal the hip should move through 6^0 of rotation, and the trunk through 27^0 of rotation. Individuals who exhibit movements in excess of these normative values could be interpreted by clinicians as having hypermobility in that region, those who demonstrate less movement could be interpreted as being hypomobile. This would aid subgrouping patients in clinical practice leading to targeted interventions which may improve outcome in musculoskeletal patients.

The pelvic obliquity during the Trendelenburg Test and the hip coronal plane range of movement during the Single Leg Squat are similar to these components of walking. Hence the Trendelenburg Test is an appropriate proxy clinical test for examining the pelvic obliquity component of walking and the Single Leg Squat for the hip coronal plane range of movement. However the hip flexion range of movement found during the Single Leg Squat and hip rotation during the Corkscrew Test were different to walking. Therefore the Single Leg Squat and Corkscrew Tests should not be used to examine these components of walking. Such information needs to be considered when using these tests clinically. Using the Trendelenburg Test and Single Leg Squat in combination allows clinicians to more fully examine the Lumbo-Pelvic Hip components of walking.

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