Determining Meaningful Changes in Pelvic-On-Femoral Position During the Trendelenburg Test

James W. Youdas, Sara T. Mraz, Barbara J. Norstad, Jennifer J. Schinke, and John H. Hollman

Context: Hip abductor muscle weakness is related to many lower extremity injuries. A simple procedure, the Trendelenburg test, may be used to assess hip abductor performance in patient populations. Objective: To describe the minimal detectable change (MDC) in pelvic-on-femoral (P-O-F) position of the stance limb during the Trendelenburg test. Setting: Laboratory. Participants: 45 healthy women (28 ± 8 years) and 45 healthy men (33 ± 11 years). Main Outcome Measures: P-O-F position in degrees in single-leg stance. Results: Baseline P-O-F position (hip adduction) was 83° ± 3° with a range from 76° to 94°. The intratester reliability (ICC3,1) for measurement of P-O-F position using a universal goniometer was 0.58 with a standard error of measurement (SEM) of 2°. The minimal detectable change (MDC) was calculated to be 4°. Conclusions: If a person’s P-O-F position changes less than 4° between measurements, then the P-O-F position is within measurement error and it can be determined that there has been no change in the performance of the hip abductor muscles when examined by the Trendelenburg test.

Investigators have described musculoskeletal impairments of the low back, knee, and ankle-foot complex related to reduced muscle performance of the hip abductor muscles.1-7 Numerous examiners have measured the performance of the hip abductors using techniques that require the subject to perform pelvic-on-femoral motion in a non-weight-bearing position, which is different from the way the muscles function during walking, jumping, and running.8-12

The Trendelenburg test has been widely used to assess the muscle performance of a patient’s hip abductors while in a single limb-stance position, because the stance hip abductors control pelvic-on-femoral (P-O-F) position (stance-side hip adduction) in the frontal plane.13,14 Hardcastle and Nade described a modified method for conducting the Trendelenburg test.14 Numerous investigators have used the modified Trendelenburg test as an outcome measure of hip abductor muscle function following total hip replacement surgery.15-22 During the modified Trendelenburg test,14 an examiner stands behind a patient and visually “eyeballs” a line joining the right and left iliac crests. Normally when standing on one lower extremity with the trunk maintained erect, the ilium on the non-stance side should elevate so the line
connecting the iliac crests will not be parallel to the ground. If the nonstance ilium is lower than the stance-side ilium, however, then the examiner notes a positive Trendelenburg test due to weakness of the stance side hip abductors. According to guidelines specified by Hardcastle and Nade, the modified Trendelenburg test uses a nominal scale of measurement, wherein the patient’s response is either normal or abnormal. This represents the lowest level of measurement. Nevertheless, a few investigators have reported alternative methods for measuring P-O-F position during the Trendelenburg test using instruments that provide ratio scale values, which are the highest level of measurement.

DiMattia et al examined the validity of the Trendelenburg test as a measurement of hip abductor muscle performance in 50 healthy subjects, 26 men and 24 women. DiMattia et al used reflective markers and a 2-dimensional analysis to quantify the P-O-F position during a 1-second static file of each participant in double-leg stance, followed by a 1-second single-leg static file. Hip adduction angle during double-leg stance (mean ± SD) was 10° ± 4° and 15° ± 4° for single-leg stance. This 5° difference in hip adduction position was based upon group data and not necessarily reflective of the change within a single individual. Data provided by DiMattia et al do not provide a clinician with the minimal amount of change in hip adduction position (P-O-F) that is due to chance variation in the measurement.

Asayama et al measured the tilt angle of the pelvis during performance of the Trendelenburg test to assess performance of hip abductor muscles in 18 subjects with healthy hips using the 3SPACE magnetic sensor system. Sensors were fixed bilaterally at each ASIS and tibial tuberosity. The 3SPACE system measured the angle formed by the intersection of the line between the ASISs and the line between the ASIS and tibial tuberosity on the stance limb. A baseline reference angle was obtained in bilateral upright stance, whereupon the subject then stood on one lower extremity for 30 seconds using guidelines previously described by Hardcastle and Nade. The angle at 30 seconds after beginning the Trendelenburg test was then subtracted from the angle at 0 seconds to yield the tilt angle of the pelvis. Tilt angles ranged from -2º to 12º with a mean tilt angle of 2º. Sophisticated instruments used by DiMattia et al and Asayama et al would not be available to most clinicians for the purpose of obtaining measurements of P-O-F position or pelvic tilt angles.

Youdas et al described the use of the Trendelenburg test as an indicator of hip abductor force potential in healthy adults who completed 45 seconds of resisted sidestepping exercise using an elastic band. With the aid of a universal goniometer (UG), hip abductor muscle performance of the dominant lower extremity was quantified by the change in P-O-F position (stance side hip adduction) during the Trendelenburg test. The difference between the baseline and postexercise measurements for both men and women was significant (P < .05). Data provided by Youdas et al also did not provide a clinician with the minimal amount of change in hip adduction position (P-O-F) due to chance variation in the measurement. Nevertheless, Youdas et al did describe measurement of P-O-F position using a UG, an inexpensive instrument available to clinicians.

Clinicians could benefit from an estimate of the measurement error associated with P-O-F position during the Trendelenburg test. The ability to define a meaningful change in P-O-F position, a clinically significant difference during the Trendelenburg test as measured by a UG, would assist the clinician when making clinical decisions. Presently, the minimal detectable change (MDC) has
not been determined for the amount of P-O-F position (hip adduction) during the Trendelenburg test. Therefore, the purpose of this study was to quantify the MDC for P-O-F hip position during the Trendelenburg test in healthy subjects.

**Methods**

**Subjects**

Ninety subjects, 45 men and 45 women, volunteered to participate in this study. The characteristics of the subjects in the study are summarized in Table 1. To participate in this study, volunteers had to satisfy the following criteria: (1) no history of a lower extremity dysfunction within the last 6 months; (2) normal passive and active motion of both hip, knee, and ankle joints; (3) normal results of a manual muscle test (MMT) of the lower extremity; (4) negative Faber test results; (5) negative Stinchfield test results; (6) the ability to independently assume a single-leg stance for 30 seconds on each lower extremity with a vertical trunk; and (7) no evidence of lower extremity dysfunction as assessed by visual observation of gait on a level surface. This study was approved by the Mayo Foundation Institutional Review Board, and each subject signed an approved consent form.

**Materials**

A UG with double-armed full-circle protractor made of transparent plastic (Fred Sammons, Inc, Burr Ridge, IL) was used to measure the P-O-F position of the stance-leg hip joint. To assist with alignment of the device, the fixed arm was extended from 31.3 cm (12.3 in) to 61.6 cm (24.4 in), whereas the moveable arm was extended from 31.3 cm (12.3 in) to 47 cm (18.5 in). The scale of the protractor was marked in 1° increments.

**Procedures**

All subjects wore a pair of shorts that permitted visualization of the distal thigh and access to the anterior superior iliac spine (ASIS) bilaterally. Measurements of P-O-F position using a UG with extended arms was obtained for each subject. Subject data were collected for both lower extremities. Palpation of both ASISs and the mid-point between the medial and lateral femoral epicondyles was performed by the same investigator for all subjects. Right and left ASISs were palpated and marked with yellow adhesive markers 1.8 cm in diameter (PRES-a-ply® Labels).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Women (n = 45)</th>
<th>Men (n = 45)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>28 ± 8 (22-50)</td>
<td>33 ± 11 (22-70)</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.7 ± 0.8 (1.5-1.9)</td>
<td>1.8 ± 0.7 (1.7-2.1)</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>65.5 ± 10.8 (47.6-104.3)</td>
<td>89.2 ± 15.6 (65.8-156)</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>23.1 ± 2.9 (18.3-32.9)</td>
<td>26.6 ± 4.9 (20.7-42.8)</td>
</tr>
</tbody>
</table>

*Values are mean ± SD (range)
Lake Hiawatha, NJ). A single marker was placed on the anterior surface of the distal thigh at the mid-point between the epicondyles. The markers were used to provide consistent placement of the UG when taking P-O-F measurements.

The Trendelenburg test as described by Hardcastle and Nade\textsuperscript{14} was used to quantify the performance of the hip abductors on the stance limb (Figure 1). Subjects were instructed to stand on one lower extremity with an erect trunk and the opposite hip flexed to about 30° to clear the foot from the ground surface. Once balanced, the subject was instructed to raise the nonstance ilium as high as possible using the hip abductors on the stance side. The subject was instructed to refrain from leaning the trunk toward the weight-bearing hip in an effort to elevate the nonstance ilium. The subjects’ arms were allowed to remain next to their hips. If standing balance was challenged, however, a subject was permitted to lightly place the tip of the index finger from the stance side extremity on the back of a chair for support only. A stop watch was used to ensure that the one-legged stance position was maintained for 30 seconds to elucidate a delay in the P-O-F position due to abnormal performance of the stance side hip abductor muscles. Hardcastle and Nade\textsuperscript{14} operationally defined a normal response when the nonstance ilium was

\textbf{Figure 1} — Measurement of pelvic-on-femoral (P-O-F) position during the Trendelenburg test. The examiner positions the goniometer’s axis over the anterior superior iliac spine (ASIS) of the stance limb. The stationary arm is aligned with the longitudinal axis of the femur and the moveable arm is aligned with an imaginary line interconnecting the right and left ASISs.
Youdas et al.

Elevated as high as hip abduction on the stance side would allow. This position of the pelvis in the frontal plane should be maintained for 30 seconds. An abnormal exam according to Hardcastle and Nade\textsuperscript{14} occurred when the pelvis elevated on the nonstance side but it was not maximal or if the ilium lifted on the nonstance side but it could not be maintained for 30 seconds. Hardcastle and Nade\textsuperscript{14} recommended that the examiner record the time it took for the ilium to fall from its maximally elevated position. Previous researchers\textsuperscript{15-23} did not use a stopwatch to record the time it took for the nonstance ilium to fall. Instead they classified the subject’s performance as either normal or abnormal.

The P-O-F position of the stance lower extremity was measured after 30 seconds of static stance. The goniometer’s pivot point was positioned at the ASIS of the stance limb, whereas the device’s stationary arm was aligned with the stance side ASIS and the mid-point of the stance limb’s distal thigh at the level of the femoral epicondyles. The moveable arm of the goniometer was aligned with the right and left ASISs. The use of the UG with extended arms allowed the examiner to place both moveable and stationary arms over the appropriate bony landmarks. To eliminate bias, the P-O-F measurements were always performed by the same investigator. Because the examiner made repeated measurements of P-O-F position, the UG’s measurement scale was masked to avoid examiner bias. Upon completing the P-O-F measurement, the examiner carefully removed the goniometer from the subject’s pelvic region, avoiding movement of the device’s arms, whereupon another investigator read the measurement scale from the unmasked side. The measurement procedure was repeated for the opposite lower extremity.

Data Analysis

Intratester reliability was established with the first 20 subjects who returned within 48 hours to repeat baseline measurements of P-O-F position. An intraclass correlation coefficient (ICC\textsubscript{3,1})\textsuperscript{28} was calculated to estimate intratester reliability for the measurement of P-O-F position. The standard error of measurement (SEM) was calculated to provide an estimate of the precision of the measurement.\textsuperscript{29} We used the following formula to calculate the SEM: \( \text{SEM} = \text{SD} \times \sqrt{1-\text{ICC}} \).\textsuperscript{30} To quantify a clinically significant difference in P-O-F position, we calculated the minimal detectable change (MDC) or the minimal amount of change considered actual change that exceeds error in the measurement. The MDC\textsubscript{95} is calculated using the following formula:

\[
\text{MDC} = z\text{-score}_{\text{level of confidence}} \times \text{SD}_{\text{baseline}} \times \sqrt{2 \left[ 1 - r_{\text{test-retest}} \right]}
\]


where the \( z\text{-score} \) for the 95\% confidence interval (CI) for the true score about the observed score (MDC\textsubscript{95}) is multiplied by the SD of the P-O-F position, and \( r \) is the form of the intraclass correlation coefficient (ICC\textsubscript{3,1}). The multiplier of \( \sqrt{2} \) accounts for the uncertainty created when using difference scores from measurements at 2 points in time.\textsuperscript{31,32} We used the standard deviation obtained from the measurement of P-O-F position for all 90 subjects, because the SD from a larger group is more representative of the population SD than the estimate from a smaller group.
Results
P-O-F position data were similar for both right and left sides, therefore we chose to report right side data only. Baseline value of P-O-F position (hip adduction) for the men and women, respectively was (mean, ± SD) 84º ± 3º and 82º ± 3º. Since the 2º difference in P-O-F position between men and women was equivalent to the SEM (2º), we elected to collapse the P-O-F position data across gender. Therefore, the baseline P-O-F position (hip adduction) for the 90 subjects, 45 men and 45 women, was (mean, ± SD) 83º ± 3º with a range from 76º to 94º. The intratester reliability (ICC\(_{3,1}\)) for measurement of P-O-F position using a universal goniometer was 0.58 and the SEM was 2º. The MDC\(_{95}\) was calculated to be 4º.

Discussion
The construct underlying the Trendelenburg test during static one-legged stance is the ability of the subject’s stance-side hip abductor muscles to control excessive lowering of the ilium on the nonstance side in the frontal plane over a duration of 30 seconds. During the Trendelenburg test, it is imperative that the subject maintain an erect trunk and level shoulders. Active trunk lean by the subject in the frontal plane toward the stance-side hip will compensate for weakened hip abductors on the stance-limb resulting in elevation of the nonstance ilium. Trunk lean will result in a larger P-O-F position value (less hip adduction) than expected. This would cause the examiner to make a spurious conclusion about the muscle performance of the hip abductor muscles on the stance limb.

The MDC can be used to make clinical decisions about the performance of the hip abductor muscles in single-limb stance when the Trendelenburg test is carried out consecutively over time in an individual patient. MDC values from this study, however, should be applied to P-O-F measurements obtained over 1 to 2 days, because the MDC calculation was based upon between-day reliability.\(^{33}\) We could expect greater measurement error with poorer reliability when making repeated measurements over longer time intervals.\(^{33}\) Based on data from this study, if a person’s P-O-F position changes less than 4º between measurements, then the P-O-F position is within measurement error and it can be determined that there has been no change in the performance of the hip abductor muscles when examined by the Trendelenburg test according to the modified procedure described by Hardcastle and Nade.\(^{14}\) For example, suppose a clinician examined a patient who complained of right unilateral hip joint pain and a “sense of fatigue” in the hip abductor muscles after completing a training run of 5 kilometers. Using the Trendelenburg test and a universal goniometer, the right side P-O-F position value (hip adduction) during single limb stance was 85º. After a 30-minute run on a treadmill, the Trendelenburg test was repeated and the right P-O-F position (hip adduction) was found to be 77º. The patient demonstrated increased right hip adduction, indicating that the right hip abductor muscles had diminished force production capability when controlling the tendency of the left ilium to drop toward the nonweight-bearing extremity. The change in P-O-F position was 8º, which exceeded the MDC. Hence the clinician could argue that the 30-minute period of aerobic exercise on the treadmill had produced a minimal detectable change in hip abductor muscle performance based upon the P-O-F position (hip adduction).
The MDC_{95} reflects the amount of change that is statistically meaningful using the test-retest reliability statistic. Nevertheless, according to Michener, this present study does not provide the clinician with a value of change in P-O-F position considered meaningful to the patient. The amount of change in P-O-F position considered meaningful to a patient has been termed the “minimal clinically important difference” (MCID). Our study design did not allow us to estimate the MCID. To calculate an MCID, P-O-F measurements would need to be calculated before and after a therapeutic procedure designed to increase the performance of the hip abductor muscles along with patient-estimated improvement after the therapeutic intervention.

The ability of a measure to detect change is most relevant to clinicians who need to assess outcomes in patients. Presently, we are not aware of any examples within the literature that describe the use of MDC in an individual patient when reporting change in an impairment such as hip abductor muscle strength. Nevertheless, a few investigators have examined the sensitivity to change of physical performance measures or indices designed to quantify functional limitations such as upper extremity muscle function, low back pain, and walking performance. Recently, Kennedy et al described the sensitivity to change of the 6-minute walk test, timed up-and-go test, stair measure, and a fast self-paced walk test in patients with hip or knee osteoarthritis who eventually underwent total joint arthroplasty. Error associated with each of the 4 measures’ scores and the MDC_{99} were calculated to assist clinicians in assessing change in walking performance within an individual patient following total knee or hip arthroplasty. Unlike the Kennedy et al study, we did not assess MDC on an outcome that measured functional impairment in a group of patients. This was the first report that provided a specific value linked to a clinically significant difference in an impairment used to examine hip abductor muscle performance, however.

**Study Limitations**

Several factors potentially influenced the results of this study. For example, the calculation of ICC_{3,1} for estimating the intratester reliability was dependent upon the variability in P-O-F position between subjects. Our sample of convenience consisted mostly of graduate students in physical therapy and members of a local fitness center, which could have contributed to homogeneity in P-O-F values between subjects. Such homogeneity would have resulted in a smaller between subjects term in the numerator when calculating ICC_{3,1}. The low estimate of intratester reliability (ICC_{3,1} = of 0.58 ) was balanced by a small SEM (2º) suggesting that the inconsistency of the measurement occurred within a small range. Additionally, it was impossible to blind the subjects to routine measurements of hip abductor muscle performance during the Trendelenburg test. For example, increased awareness of P-O-F position during the measurement may have prompted some individuals to self-correct for hip adduction in stance prior to P-O-F angle measurements. Finally, the examiner occasionally experienced difficulty in palpating the ASISs in some individuals with increased abdominal girth, which was previously reported by Youdas et al. This examiner error could reduce the value of the ICC_{3,1} and increase the value of the MDC_{95}. However, mean BMIs for our subjects were in the normal range for the women and near normal range for the men, so on average we did not have many
obese subjects. In some cases, however, if a clinician obtained a 3° change in P-O-F position in a thin patient where measurement error was believed to be small, then a 3° change could be clinically meaningful as an estimate of hip abductor muscle performance. Therefore, despite a MDC₉₅ of 4°, the clinician would need to judge changes in P-O-F position during the modified Trendelenburg position on a case-by-case basis.

Another limitation of the quantified Trendelenburg test when estimating performance of the hip abductor muscle is the presence of a low ceiling and high floor effect. According to our data, the mean P-O-F position during single limb stance was 83° ± 3° with a range between 76° and 94°. During the Trendelenburg test in healthy young adults, the minimal hip strength required for “normal” pelvic alignment in the frontal plane is a P-O-F position of about 83°. Any additional strength would not be identified by the Trendelenburg test performance, a ceiling effect. Similarly, the drop of the ilium on the nonstance side due to weakness of the stance hip abductor muscles would likewise have a limit (a floor effect) beyond which additional weakness would not result in a further drop.

**Conclusion**

The results of our investigation indicate that healthy men and women need to demonstrate at least a 4° change in P-O-F position (hip adduction) between successive measurements of the Trendelenburg test before a clinician could assume a clinically significant difference in hip abductor muscle performance. Considering the 4° change in P-O-F position and the limited ceiling and floor effect associated with the Trendelenburg test, we question the usefulness of this measure to assess hip abductor muscle performance in young healthy adult men and women.

**References**


