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# The Relationship Between Hip-Abductor Strength and the Magnitude of Pelvic Drop in Patients With Low Back Pain

Karen D. Kendall, Christie Schmidt, and Reed Ferber

**Context:** It has been theorized that a positive Trendelenburg test (TT) indicates weakness of the stance hip-abductor (HABD) musculature, results in contralateral pelvic drop, and represents impaired load transfer, which may contribute to low back pain. Few studies have tested whether weakness of the HABDs is directly related to the magnitude of pelvic drop (MPD). **Objective:** To examine the relationship between HABD strength and MPD during the static TT and during walking for patients with nonspecific low back pain (NSLBP) and healthy controls (CON). A secondary purpose was to examine this relationship in NSLBP after a 3-wk HABD-strengthening program. **Design:** Quasi-experimental. **Setting:** Clinical research laboratory. **Participants:** 20 (10 NSLBP and 10 CON). **Intervention:** HABD strengthening. **Main Outcome Measures:** Normalized HABD strength, MPD during TT, and maximal pelvic frontal-plane excursion during walking. **Results:** At baseline, the NSLBP subjects were significantly weaker (31%;  $P = .03$ ) than CON. No differences in maximal pelvic frontal-plane excursion ( $P = .72$ ), right MPD ( $P = 1.00$ ), or left MPD ( $P = .40$ ) were measured between groups. During the static TT, nonsignificant correlations were found between left HABD strength and right MPD for NSLBP ( $r = -.32$ ,  $P = .36$ ) and CON ( $r = -.24$ ,  $P = .48$ ) and between right HABD strength and left MPD for NSLBP ( $r = -.24$ ,  $P = .50$ ) and CON ( $r = -.41$ ,  $P = .22$ ). Nonsignificant correlations were found between HABD strength and maximal pelvic frontal-plane excursion for NSLBP ( $r = -.04$ ,  $P = .90$ ) and CON ( $r = -.14$ ,  $P = .68$ ). After strengthening, NSLBP demonstrated significant increases in HABD strength (12%;  $P = .02$ ), 48% reduction in pain, and no differences in MPD during static TT and maximal pelvic frontal-plane excursion compared with baseline. **Conclusions:** HABD strength was poorly correlated to MPD during the static TT and during walking in CON and NSLBP. The results suggest that HABD strength may not be the only contributing factor in controlling pelvic stability, and the static TT has limited use as a measure of HABD function.

**Keywords:** Trendelenburg, gait, kinematics, gluteus medius

Friedrich Trendelenburg first described an abnormal gait pattern in patients with congenital dislocations of the hip in 1895.<sup>1</sup> He hypothesized that this “swing-

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ing” or “waddling” gait pattern resulted from the inability of the weight-bearing hip-abductor (HABD) muscles to keep the pelvis horizontal.<sup>2</sup> The Trendelenburg test (TT) has subsequently become a common clinical test used to evaluate hip and low back pain.<sup>3–5</sup> Specifically, the TT indirectly assesses functional HABD strength and the ability of these muscles to support the transfer of load during single-leg stance.<sup>5</sup> A positive TT test is reported when the contralateral pelvis drops, resulting in subsequent adduction of the hip and lateral flexion of the trunk over the standing leg to maintain balance.<sup>5</sup> It has been theorized that a positive TT indicates weakness of the HABD muscles and that the drop in pelvic position may be a contributing factor to low back or hip pain.<sup>3</sup> However, very few studies have directly tested this hypothesis.

In 1985, a standard method of performing the TT was described for patients with neurological or mechanical disorders of the hip and spine.<sup>6</sup> Those authors subjectively quantified the magnitude of pelvic drop (MPD) during a static TT and strength of the gluteus medius muscles in a group of 50 healthy controls and 103 patients with various neuromuscular disorders. However, several methodological discrepancies are apparent in this study, including a lack of a priori normal and abnormal response criteria and poorly defined clinical photography, electromyographical, and video-analysis procedures. Moreover, the authors did not report any HABD-strength data. Thus, despite its proposal of a standard method of performing the TT, limited information regarding the relationship between HABD strength and the response during the TT can be gleaned from the study.

Petrofsky<sup>7</sup> objectively measured the MPD associated with the TT, aiming to understand the direct relationship to gluteus medius strength, and reported that after a gait-retraining and -strengthening program, increases in gluteus medius strength and decreases in MPD were measured. Therefore, these results of that study support the hypothesis that the gluteus medius may play a role in the stability of the pelvis. However, the examiners were not blinded to group allocation for the strength-data collection, and the accuracy in measuring the MPD can be improved using current biomechanical-analysis techniques. Moreover, the subjects in the study had incomplete spinal-cord injuries, leaving the applicability of the results to the general population and the low-back-pain population in question.

Finally, in a more recent study, isometric HABD strength and frontal-plane hip motion were correlated during a single-leg squat and during the TT in 50 healthy controls.<sup>8</sup> A weak correlation was reported between the TT and HABD strength, leading those authors to conclude that use of the single-leg squat and TT is not as useful as functional screening measures for HABD strength.

Based on previous literature, the relationship between HABD strength and MPD during the TT is inconclusive. To date, the TT remains a subjective clinical measure of pelvic stability and an indirect measure of HABD strength. Theoretically, increased HABD strength should reduce the MPD, increase pelvic stability, and thus have a positive effect on reducing NSLBP. However, no study has directly tested this hypothesis.

Therefore, the primary purpose of this study was to examine the relationship between HABD strength and MPD during a static TT and mean maximal pelvic frontal-plane excursion during walking in subjects with NSLBP and healthy controls (CON). We hypothesized that reduced HABD strength would be negatively correlated with MPD for the NSLBP and CON. A secondary purpose was to examine this relationship in NSLBP patients after a 3-week HABD-strengthening program. At baseline, we

hypothesized that the NSLBP subjects would demonstrate reduced HABD strength, increased static MPD, and increased mean maximal pelvic frontal-plane excursion compared with CON. We also hypothesized that after the 3-week strengthening protocol, the NSLBP subjects would exhibit an increase in strength and a subsequent decrease in static MPD and mean maximal pelvic frontal-plane excursion.

## Methods

### Design

The design was a quasi-experimental intervention.

### Participants

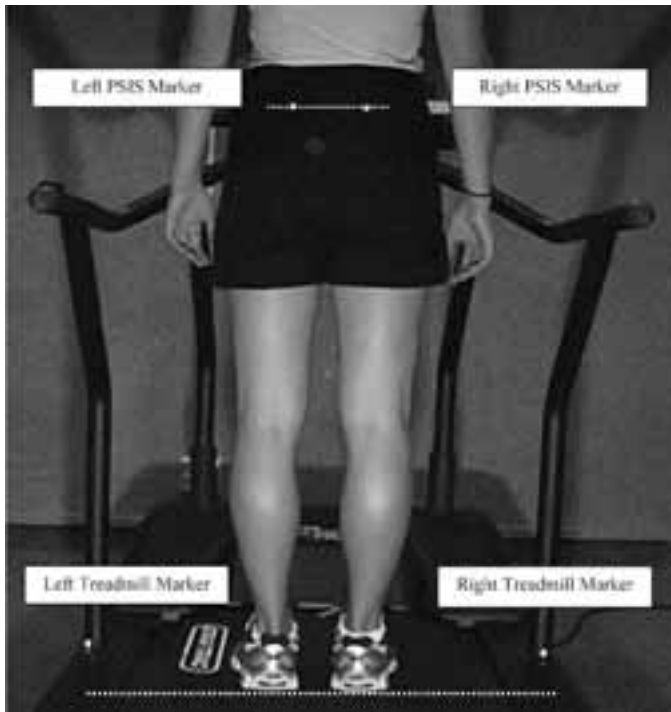
An a priori sample-size power analysis ( $\beta = .20$ ,  $\alpha = .05$ , desired effect size = .66) determined that 10 to 13 participants per group would be necessary to achieve statistical significance. Twenty-two participants were recruited and completed the study: 12 nonacute NSLBP subjects (pain occurring for more than 6 wk) and 10 CON. The CON group had a median age of 26 years (range 22–47) and consisted of 2 men and 8 women. The NSLBP group had a median age of 32 years (range 21–51) and consisted of 2 men and 8 women. Inclusion criteria for the NSLBP patients included no pelvic malalignment as determined by a certified athletic therapist (K.K.); no leg-length discrepancy greater than 1.5 cm; no prior history of surgery to the lumbar spine, pelvis, or lower extremity; and no previously diagnosed scoliosis or discogenic, vestibular, or neurological pathology. The definition of NSLBP was consistent with Choi et al<sup>9</sup> as pain occurring between the costal margin to the gluteal folds with a severity of at least 3 cm on a 10-cm visual analog scale (VAS). Ten CON subjects meeting the same exclusion criteria also participated. All participants signed a written informed consent that was approved by the University of Calgary Conjoint Health Research Ethics Board.

### Procedures

Both the NSLBP and CON subjects performed the same baseline procedure. Two retroreflective markers were secured on a tightly fitted neoprene belt placed directly on the skin over the hip and waist areas. The marker placement on the posterior superior iliac spines (PSIS) bilaterally was determined by palpation by an experienced certified athletic therapist (K.K.). The horizontal line between the markers represented pelvic position and was compared with the markers placed on the treadmill at the level of the belt representing the horizontal (Figure 1). Subjects performed a baseline standing trial, 2 static TT trials, and a 30-second walking trial at a speed of 1.34 m/s. For the baseline standing trial, they were asked to stand with weight evenly distributed on both feet, hip width apart, while the baseline horizontal position of the pelvis was recorded. The static TT was then performed based on methods described in several clinical orthopedic textbooks.<sup>3–5</sup> Two modifications to the test were made to help standardize the measurements: Subjects were asked to place their hands on their hips and alternately flex right and left hip to 50° of flexion and hold the position of hip flexion for 5 seconds while the biomechanical data were recorded. The hip-flexion angle was controlled by measuring and placing

tape across the treadmill arms representing  $50^\circ$  of hip flexion, which the subjects had to reach and touch with their knee. Next, subjects walked comfortably, without hand support, on the treadmill at 1.34 m/s while data were recorded for 30 seconds. Pilot testing using the described marker set and the modified version of the static TT with 6 CON subjects revealed that between-days variability in MPD during the static TT and frontal-plane excursion during walking ranged from  $0.15^\circ$  to  $0.35^\circ$ , which supports the use of this modified method and marker setup.

After the biomechanical analysis, HABD strength was measured using a force dynamometer (Lafayette manual muscle tester, Model 01163, Lafayette, IN) using a “make test” with straps and according to the method described by Ireland et al.<sup>10</sup> This method has been reported as reliable,<sup>11</sup> and subjects were measured while side lying with the leg in contact with the table flexed  $90^\circ$  at the hip and knee. A stabilization strap was placed over the hips, and the dynamometer was placed under the strap 3 cm above the lateral malleolus of the test limb. The test limb was positioned parallel to the treatment table, directly in line with the hip. One submaximal practice trial followed by 3 maximal voluntary isometric contractions with a 30-second rest period between trials was performed. The average of the 3 maximal-contraction trials was used for the analysis, with all trials being within a 10% coefficient of variation of one another. All force measures were converted into Newtons and then normalized with the following equation: Muscle strength = force

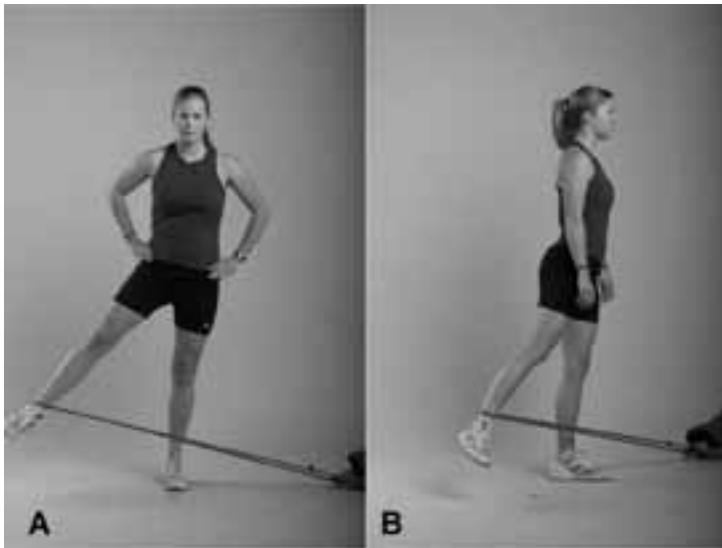


**Figure 1** — Marker setup.

(N)/body mass (kg)<sup>2/3</sup>. This method of adjusting muscle strength to normalize for differences in various estimates of body size has been shown to be the most reliable and valid method regardless of subjects' sex, age, or level of physical activity.<sup>12</sup>

The NSLBP patients were asked to complete a home-based 3-week hip-abductor-strengthening protocol including 2 specific HABD-strengthening exercises using Resist-A-Bands (Figure 2). The exercises were hip abduction at 0° extension and combined hip abduction and hip extension. The Resist-A-Band resistance was determined by a certified athletic therapist (K.K.) individually for each patient, based on the color of Resist-A-Band that the NSLBP patient was able to use to complete 10 to 15 repetitions with proper form and reported fatigue of the hip-abductor muscle. This resistance was kept constant over the 3-week program. The NSLBP patients were asked to complete 3 sets of 10 repetitions daily over the 3-week period. All NSLBP patients were retested 3 weeks later, and the testing sequence was repeated.

Two-dimensional (2D) video capture was performed with a 60-Hz camera (Canon GL2, Canon Canada Inc). Digitization was completed using Vicon Peak Motus version 9.2.0 software (Vicon Motion Systems Inc, Centennial, CO), and the baseline standing position, MPD while performing the static TT, and maximal pelvic frontal-plane excursion were calculated. The MPD was calculated as the angle subtended by a line between the 2 PSIS markers representing the level of the pelvis and a line between the 2 treadmill markers representing the horizontal of the treadmill (Figure 3). The MPD on the right (drop of the right side of the pelvis) was calculated during performance of the static TT on the left stance leg. The MPD on the left (drop of the left side of the pelvis) was calculated during performance of the static TT on the right stance leg. Both right and left MPD were corrected for baseline position of the pelvis. Maximal pelvic frontal-plane excursion during



**Figure 2** — Hip-abductor exercises. (A) Abduction at 0° extension. (B) Abduction at 45° extension.



**Figure 3** — Biomechanical diagram. (A) Static Trendelenburg standing on left leg with right pelvic drop. (B) Static Trendelenburg standing on right leg with left pelvic drop. LPSIS/RPSIS, left/right posterior superior iliac spine markers; LTREAD/RTREAD, left/right treadmill markers.

walking was calculated as the sum of maximal left and right pelvic drop during 1 full gait cycle and was corrected for baseline position of the pelvis. Mean maximal pelvic excursion was calculated over 5 consecutive footfalls.

### Statistical Analysis

The test-sample data were not normally distributed, so nonparametric statistics were used for the data analysis. Outlier assessment was completed, and 1 woman from the NSLBP group was removed because strength-data results fell 3 SDs below the average after the 3-week strengthening program because of reported sickness. The biomechanical data from a second woman from the NSLBP group were also excluded from the correlation analysis because of being 3 SDs above the average measure of maximal pelvic frontal-plane excursion. Wilcoxon-Mann-Whitney *U* tests were used to examine differences in right and left MPD and mean maximal pelvic frontal-plane excursion between NSLBP and CON. Differences in average strength and mean maximal pelvic frontal-plane excursion for the NSLBP group after the 3-week strengthening program were examined using the Wilcoxon signed-rank tests for paired data comparisons. Spearman rank correlations were used to investigate the relationship between average normalized HABD strength and mean maximal pelvic frontal-plane excursion during walking at baseline and between the static TT and normalized HABD strength for both right- and left-specific tests. The level of significance was set at  $\alpha = .05$ .

### Results

A summary of the demographic and primary outcome measures by group and after strengthening is presented in Table 1. Groups were similar in weight ( $P = .94$ ), age ( $P = .32$ ), and height ( $P = .86$ ). At baseline, NSLBP patients reported a median VAS score of 5.9 cm with a range 2.2 to 8.7 on the 10-cm scale and completed the maximal strength testing and biomechanical analysis without reported increases in pain.

At baseline, the NSLBP patients demonstrated 31% less mean normalized HABD force output (median 6.6 N/kg<sup>2/3</sup>) than CON (median 9.5 N/kg<sup>2/3</sup>;  $P = .03$ ). However, no significant differences in mean maximal pelvic frontal-plane excursion during walking ( $P = .72$ ), static right MPD ( $P = 1.00$ ), or static left MPD ( $P = .40$ ) were measured between groups. Nonsignificant negative correlations were found between left normalized HABD strength and right MPD for NSLBP patients

Table 1 Results Summary

	NSLBP Patients (n = 10)					
	Controls (n = 10), baseline		Baseline		3-Week Follow-Up	
	Median	Range	Median	Range	Median	Range
Age, y	26	22–47	32	21–51	32	21–51
Height, cm	168	162–178	171	156–180	171	156–180
Weight, kg	61	53–91	61	55–90	61	55–90
VAS rating, cm	0	0	5.9	2.2–8.7	1.8	0–6.5
Right MPD, left Trendelenburg test, ° <sup>a</sup>	–2	–4.8 to 1.2	–1.9	–7.0 to 1.7	–1.7	–6.6 to 2.0
Left MPD, right Trendelenburg test, ° <sup>a</sup>	–2.2	–4.3 to 0.7	–1.6	–5.6 to 2.6	–1.0	–5.5 to 10.6
Maximal pelvic excursion, °	7.1	3.5–8.8	6.7	5.5–10.4	6.5	5.6–10.6
Normalized strength HABD, N/kg <sup>2/3</sup>	9.5	7.2–11.9	6.6 <sup>b</sup>	5.4–7.7	7.4 <sup>c</sup>	6.3–8.4

NSLBP, nonspecific low back pain; VAS, visual analog scale; MPD, maximal pelvic drop; HABD, hip abductors.

<sup>a</sup> Negative values indicate a hip hike; positive values indicate a pelvic drop.

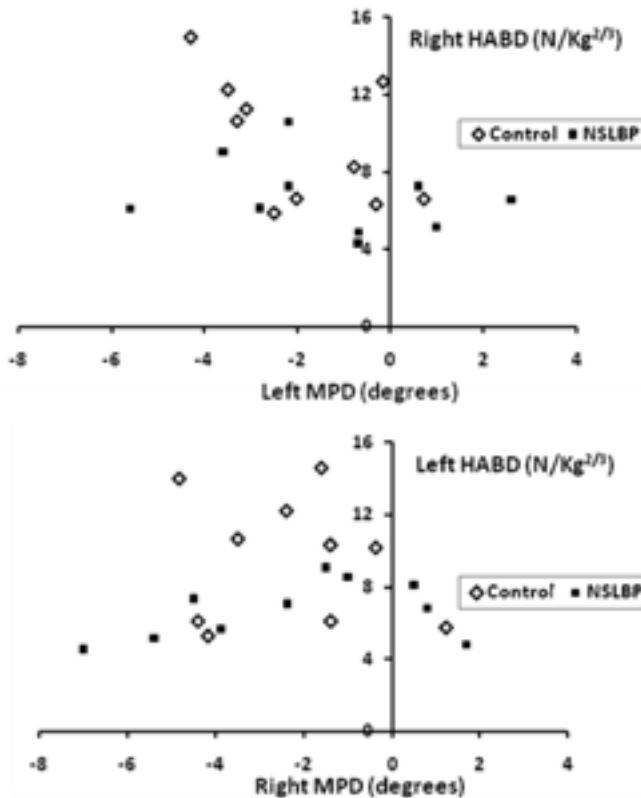
<sup>b</sup> NSLBP patients were significantly weaker at baseline than controls.

<sup>c</sup> Significant increases in HABD strength after a 3-wk strengthening program for NSLBP.

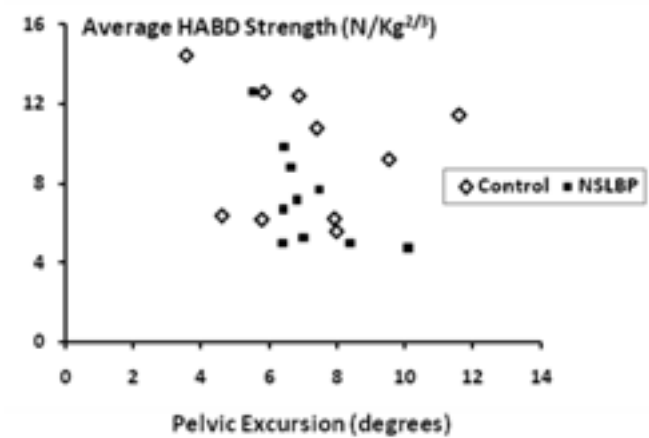


( $r = -.32$ ,  $P = .36$ ) and CON ( $r = -.24$ ,  $P = .48$ ; Figure 4). Similarly, nonsignificant negative correlations were found between right normalized HABD strength and left MPD for NSLBP patients ( $r = -.24$ ,  $P = .50$ ) and CON ( $r = -.41$ ,  $P = .22$ ) during performance of the static TT (Figure 4). In addition, nonsignificant negative correlations were found between mean normalized HABD and mean maximal pelvic frontal-plane excursion for NSLBP patients ( $r = -.04$ ,  $P = .90$ ) and CON ( $r = -.14$ ,  $P = .68$ ) during walking (Figure 5).

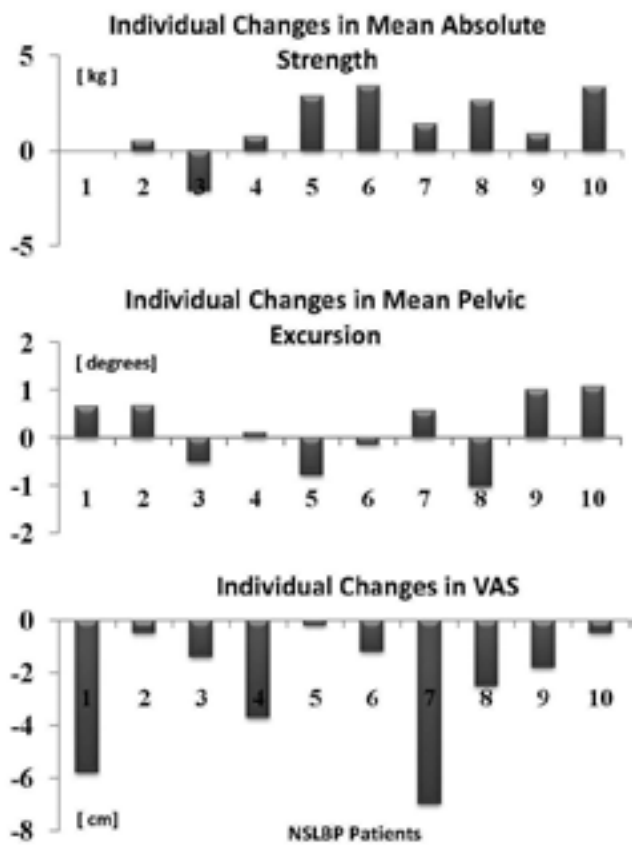
After the 3-week HABD-strengthening protocol, NSLBP patients demonstrated a 12% improvement in normalized strength (baseline  $6.6 \text{ N/kg}^{2/3}$ , 3-wk follow-up  $7.4 \text{ N/kg}^{2/3}$ ;  $P = .02$ ). No significant differences in mean maximal pelvic frontal-plane excursion during walking ( $P = .92$ ) or right MPD ( $P = .35$ ) or left MPD ( $P = .33$ ) during the static TT were found after the 3-week strengthening program. A 48% reduction in pain was reported after the strengthening protocol (median VAS at 3-week follow-up: 1.8 cm). A summary of the individual changes in HABD strength, maximal pelvic frontal-plane excursion, and VAS after the 3-week strengthening program in NSLBP patients is presented in Figure 6.



**Figure 4** — Scatter plots depicting relationship between hip-abductor (HABD) strength and magnitude of pelvic drop (MPD) during performance of the static Trendelenburg test.



**Figure 5** — Scatter plot depicting relationship between hip-abductor (HABD) strength and pelvic excursion during walking.



**Figure 6** — Individual changes in strength, pelvic excursion, and visual analog scale (VAS) scores after 3 weeks of hip-abductor-strengthening exercise. NSLBP, nonspecific low back pain.

## Discussion

Considering the paucity of studies investigating the direct relationship between HABD strength and MPD and the continued use of the TT as a functional measure of HABD strength, the primary purpose of this study was to examine the relationship between HABD strength and MPD during the static TT and during walking in patients with NSLBP and healthy controls. Considering also that the TT is used as a test of pelvic stability while transferring loads within the pelvis, and impaired load transfer within the pelvis has been identified as a potential cause of NSLBP,<sup>13</sup> this relationship was studied in patients with NSLBP. The secondary purpose was to examine this relationship in NSLBP patients after a 3-week HABD-strengthening program.

The TT has classically been used as a measure of functional strength of the HABD and the ability of these muscles to stabilize the pelvis during single-leg stance.<sup>5</sup> Abduction of the thigh is a result of the actions of the gluteus medius and minimus and the tensor fascia lata.<sup>14</sup> The gluteus medius and minimus have proximal attachments on the external surface of the ilium beneath the gluteus maximus and attach to the lateral and anterior surface of the greater trochanter of the femur.<sup>14</sup> The tensor fascia has its proximal attachment to the anterior superior iliac spine, shares a common attachment via the iliotibial tract to the lateral condyle of the tibia, and acts to help the gluteus medius and minimus abduct and internally rotate the thigh.<sup>14</sup> Theoretically, all 3 muscles, through their anatomy and respective lines of action, should play an important role in stabilizing the hip, preventing hip adduction, and stabilizing the pelvis during single-leg stance and during walking in healthy individuals or patients with NSLBP. Indeed, this is the central premise on which the TT has been based since first proposed in 1895.<sup>1</sup> However, the results of the current study suggest that HABD strength is not significantly correlated to the MPD measured during the static TT or to maximal pelvic frontal-plane excursion during walking. Despite the anatomical theory and classical use of the TT as an indirect measure of functional strength of the HABDs, the results of this study do not provide evidence to support this theory.

Previous research has investigated this relationship during running and walking after experimentally reduced HABD function in healthy subjects.<sup>15,16</sup> For example, Burnet and Pidcoe<sup>15</sup> studied the correlation between maximal isometric gluteus medius torque and frontal-plane pelvic motion during running. They aimed to link isometric gluteus medius strength and the MPD but found that the strength of the gluteus medius was a poor predictor of frontal-plane motion.<sup>15</sup> Nonsignificant negative correlations were reported between gluteus medius strength and peak MPD, which is consistent with the results of the current study. Henriksen et al<sup>16</sup> studied the changes in kinematics in healthy subjects after experimentally reduced HABD function by intramuscular injections of saline solution. Despite a reported 39.6% reduction in peak gluteus medius EMG activation and a significant reduction in internal hip-abductor moment, subjects demonstrated no significant change in pelvic drop and no significant increase in mediolateral trunk sway.<sup>16</sup> In addition, those authors state that no signs of the Trendelenburg gait were observed after injection.<sup>16</sup> However, caution must be taken in the interpretation of that study because the methods used to reduce HABD function also caused local muscle pain such that the changes in gait parameters that occurred may simply reflect an analgesic

gait pattern rather than the true effect of reduced HABD function. Regardless, the results of both aforementioned studies suggest that frontal-plane pelvic stability may not be solely the responsibility of the HABD muscles, and other muscles may play an important role.

Biomechanical modeling studies have investigated individual muscle contributions to whole-body support of the center of mass during walking that may provide insight into the possibilities of other contributing muscle groups.<sup>17</sup> Anderson and Pandy<sup>17</sup> identified the contribution of the HABDs to support during single-leg stance but also suggested that other muscles significantly contribute to whole-body support of the center of mass during walking. At midstance, those authors reported that with significant assistance from passive resistance of bones and joints, the gluteus medius and minimus provided nearly all the support.<sup>17</sup> However, from foot flat to contralateral toe-off, representing the loading phase of gait, the gluteus maximus and the vasti musculature, as well as the gluteus medius and minimus, contribute significantly to whole-body support.<sup>17</sup> Although that study indirectly supports the role of the HABDs in maintaining pelvic stability in midstance (single-leg stance), it also suggests that for the dynamic control of the body during walking, the HABDs must be assisted by other muscles such as the gluteus maximus. An obvious limitation of that article is that it did not discuss the contribution of muscles to individual joint motion of the pelvis, which would be very useful in understanding the specific role of the HABD to frontal-plane pelvic stability. Regardless, these studies provide important information suggesting that the HABDs may not be the only muscles responsible for maintaining pelvic stability during the single-leg-stance phase of gait.

Another possible reason for the poor correlations found between HABD strength and the MPD in the current study could be mediolateral sway of the trunk as a functional compensation during the static TT or during walking. Mundermann et al<sup>18</sup> discussed the implications of increased mediolateral trunk sway for ambulatory mechanics. Investigating a group of healthy subjects who voluntarily increased mediolateral sway of the trunk while walking, those authors reported that increases in lateral lean toward the stance limb can reduce the moments at the hip and knee.<sup>18</sup> In the context of the current study, a lateral trunk lean toward the stance limb during the static TT will shift the center of the mass laterally, shortening the moment arm of the hip, reducing the hip internal-adduction moment, and thus requiring less external hip-abduction moment to maintain stability. Therefore, a possible compensation for HABD weakness may be that individuals will adopt an increase in lateral trunk lean toward the stance limb to reduce the force requirement of the HABD to maintain pelvic stability. Unfortunately, the current study did not place markers on the trunk to measure lateral lean. However, subjects were instructed to maintain a vertical trunk position during the static TT and were asked to repeat the task if excessive lean was observed. Therefore, to directly measure the relationship between HABD and MPD during the static TT, caution must be taken to ensure standardization of the trunk position. Future research involving a more comprehensive biomechanical model is thus necessary to help answer these questions.

The TT is commonly used in the clinical evaluation of NSLBP patients as a functional measure of frontal-plane pelvic stability and the ability of the patient to transfer load into single-leg stance.<sup>13</sup> Instability as a result of improper or insufficient muscle recruitment,<sup>19</sup> movement patterns,<sup>20</sup> and strength,<sup>21</sup> has been related

to sacroiliac-joint and low back pain. Therefore, we hypothesized that NSLBP subjects would exhibit reduced HABD strength, increased static MPD during the TT, and increased maximal pelvic frontal-plane excursion compared with controls at baseline. We also hypothesized that after a 3-week HABD-strengthening protocol, there would be an increase in HABD strength, decreases in MPD, decreases in maximal pelvic frontal-plane excursion, and decreases in pain. The results of the current study only partially support these hypotheses.

At baseline, the NSLBP group exhibited significantly less HABD maximal isometric strength than CON. However, no significant differences in MPD were measured during the static TT, and no significant differences in maximal pelvic frontal-plane excursion were measured during walking between groups. In addition, despite significantly increasing their HABD strength over the 3-week protocol and decreasing pain by 48%, NSLBP patients did not demonstrate changes in MPD. These results suggest that the static TT has limited sensitivity to discriminate increases in the strength of the HABD in this patient population and that the TT has limited use as a functional measure of HABD strength. Future research to better understand the biomechanical and neuromuscular contributors to the etiology and rehabilitation of NSLBP is therefore necessary.

We acknowledge several limitations to the current study. First, biomechanical motion of the pelvis occurs in 3 dimensions, so 2D biomechanical data may not represent true pelvic frontal-plane motion. However, this method of analysis was chosen as representative of the view that clinicians have while observing the TT. We acknowledge that 2D measurement involves movement in the sagittal and transverse planes that will not be accounted for. However, we feel that the simplicity of the 2D measurement will provide more clinically relevant and useful information for practitioners. With respect to using 2D analysis to accurately describe frontal-plane motion, Cornwall and McPoil<sup>22</sup> compared the use of 2D and 3D systems for analysis of the rear-foot motion in the frontal plane and found that 2D analysis can be accurately used. Although similar studies have yet to be done for pelvic motion, based on the findings of Cornwall and McPoil<sup>22</sup> the frontal-plane motions of MPD and pelvic excursion measured in the current study can be accurately defined by 2D analysis. In addition, the range of 2D motion measured in the frontal plane during walking in the current study ( $5.4\text{--}9.8^\circ$ ) is similar to that in a recent 3D study measuring pelvic motion in the frontal plane during running ( $4.0\text{--}12.9^\circ$ ).<sup>15</sup>

The described method of performing the TT has not been previously used in research. However, the method used was based on methods described by clinical assessment textbooks,<sup>3–5</sup> with the addition of the previously described modifications to help ensure standardization in performing the test. Moreover, Hardcastle and Nade<sup>6</sup> have established a standardized method of performing the test, but this method relies on repositioning the patient and support if needed for balance. Therefore, this particular method is not conducive to investigating the direct relationship between HABD and MPD and may not be appropriate from a test–retest reliability perspective. Roussel et al<sup>13</sup> investigated the test–retest reliability of the method of Hardcastle and Nade,<sup>6</sup> but the reliability analysis was completed on patient self-report scores of difficulty performing the test rather than the examiner scores based on patient performance. Therefore, based on the lack of a reliable method of performing the test, we decided that the method described in the article would be most appropriate and was supported by the day-to-day variability estimates.

Based on published clinical measurement, the TT method was standardized such that the magnitude of pelvic drop could be objectively and reliably measured by biomechanical analysis.

HABD strength was measured using a force dynamometer according to the methods described by Ireland et al.<sup>10</sup> and normalized for differences in body size according to Jaric et al.<sup>12</sup> Despite being a valid and reliable method of measuring HABD strength, a maximal isometric force measure may not be ideal when correlating to a dynamic and functional movement. Perhaps a more functional measure of strength of the HABDs would have resulted in a higher correlation with performance on the static TT and with pelvic excursion while walking.

Finally, the current study included patients with NSLBP as defined by Choi et al.<sup>9</sup> Despite this broad definition, the inclusion criteria limited our sample to patients who present with mechanically induced low back pain. As a result, the findings of this study only reflect the characteristics of this subset of patients. However, O'Sullivan<sup>23</sup> highlights the complexity and individual nature of low back pain and supports identifying specific classifications in research regarding the underlying mechanisms of low-back-pain disorders. That author also emphasizes the need for further research into interventions that are directed to these specific classifications and underlying mechanisms of pain.<sup>23</sup> Therefore, the current study provides relevant scientific and clinically important information regarding the TT and MPD in this subset of patients with NSLBP.

## Conclusion

NSLBP subjects demonstrated 31% less HABD force output than CON, yet no significant differences in right or left MPD during the static TT or maximal pelvic frontal-plane excursion during walking were measured between groups. No significant correlations were measured between HABD strength and MPD during performance of the TT or during walking for either NSLBP or CON. Despite significant increases in HABD strength after a 3-week muscle-strengthening protocol, NSLBP patients demonstrated no significant changes in MPD or maximal pelvic frontal-plane excursion. The premise that strength of the HABDs alone is responsible for maintaining a horizontal pelvic position and preventing MPD is not well supported, and the use of the TT as a measure of functional HABD strength is limited.

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