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Description of a Weight-Bearing Method to Assess Hip Abductor and External Rotator Muscle Performance

Altered pelvofemoral biomechanics resulting from deficits in hip muscle performance has been linked to numerous lower extremity conditions.[3,8,10,13,15,20,27,28] The hip muscles, specifically the abductors and external rotators, not only provide local structural stability to the hip joint but are also important in maintaining proper segmental alignment of the lower extremity during weight-bearing tasks.[5,21,26] Inability of the hip abductors and external rotators to produce adequate torque during weight-bearing activities can lead to pelvic drop, excessive hip adduction, excessive hip internal rotation, and an increase in the knee valgus angle.[10,16,19,20,25,27] In addition, a number of studies have shown that hip abductor muscle performance is significantly correlated with postural stability and locomotion function in older adults[2] and persons who have undergone arthroplastic surgery of the lower extremity joints.[17,31]

Hip abductor muscle performance typically is quantified using a motor-driven or a handheld dynamometer in a non–weight-bearing, sidelying position. Although most investigators have concluded that these assessment methods are reasonably reliable,[12,14,23,30,32,33] a number of limitations regarding the clinical application of the assessments have been reported.[33] First, proper stabilization and orientation of the lower limb are difficult to maintain during a maximal contraction in the sidelying position. Specifically, it is difficult to keep the amount of flexion/extension of the hip joint and the rotation of the pelvis consistent.[23,32] Second, patients often complain that the sidelying position is uncomfortable. The discomfort resulting from compressing the contralateral hip joint against the testing table in the sidelying testing position makes generating maximal abduction force difficult, especially for those

⊙ **STUDY DESIGN:** Measurements, descriptive.

⊙ **OBJECTIVES:** To describe a weight-bearing method to assess bilateral hip abductor and external rotator muscle performance.

⊙ **BACKGROUND:** The hip abductors and external rotators are important in maintaining lower extremity alignment during weight-bearing tasks. As such, there is a need for a method to assess hip muscle performance in weight bearing.

⊙ **METHODS:** The weight-bearing method of assessing hip muscle performance utilized a force transducer connected to a nonstretchable fabric strap positioned around the distal ends of both thighs (proximal to the lateral epicondyles). The force generation capacity was recorded with the participants in a semi-squat position (30° of hip flexion and 50° of knee flexion). To establish the reliability of the measurement, 20 participants were tested on 2 separate days, and intraclass correlation coefficient (model 3,1) and standard error of measurement were calculated to evaluate test-retest reliability and intersession consistency. The level of agreement between the muscle perfor-

mance values obtained using the weight-bearing method and the traditional non–weight-bearing method of testing hip abduction in sidelying (dynamometer) was assessed using a linear correlation model.

⊙ **RESULTS:** The weight-bearing method of assessing hip muscle performance was reliable (intraclass correlation coefficient = 0.99; 95% confidence interval: 0.97, 0.99) and consistent (standard error of measurement, 0.02 N/kg). The measured strength using the weight-bearing method was moderately associated with hip abduction strength values measured in non–weight bearing (r = 0.75, P<.01).

⊙ **CONCLUSION:** The proposed weight-bearing method of assessing hip abductor and external rotator muscle performance can be used as a simple, economic, and reliable method to assess hip muscle strength. *J Orthop Sports Phys Ther 2013;43(6):392-397. Epub 18 March 2013. doi:10.2519/jospt.2013.4412*

⊙ **KEY WORDS:** *gluteus maximus, gluteus medius, strength*

with bilateral hip pain.[4] Third, motor-driven dynamometers are expensive and immobile, making them impractical in many clinical settings. Fourth, the non–weight-bearing testing position does not replicate the typical function of the hip abductor muscles during weight bearing, which work in conjunction with the hip external rotators when the hip joint is in a flexed position.[11,22]

Given the limitations of the currently available assessments for quantifying hip muscle performance, the primary purpose of this research report was to describe a method to assess hip abductor and external rotator muscle performance in a weight-bearing position. Furthermore, 3 secondary aims were carried out. First, we investigated the test-retest reliability of the proposed method for quantifying hip abductor and external rotator muscle performance. Second, we quantified the activation levels of the primary hip abductor and external rotator muscles (superior portion of the gluteus maximus [sGMAX], gluteus medius [GMED], and tensor fascia latae [TFL]) during the weight-bearing test to ensure that the muscle strength assessed by the proposed method was the result of hip abductor and external rotator activity. Third, we assessed the level of agreement between the hip muscle strength measured using the proposed weight-bearing method and the conventional non–weight-bearing test for quantifying hip abductor strength.

METHODS

Subjects

TWENTY INDIVIDUALS (10 WOMEN, 10 men) between 24 and 42 years of age participated in this study (**TABLE**). Participants who exhibited any of the following were excluded: (1) any history of lower extremity or back surgery, (2) any concurrent condition causing pain or discomfort during physical activity, (3) neurological conditions that would influence an individual's ability to perform the required testing procedures, and (4)

TABLE	PARTICIPANT INFORMATION AND HIP MUSCLE PERFORMANCE		
	Male (n = 10)	Female (n = 10)	Overall (n = 20)
Age, y*	30.1 ± 4.4	30.4 ± 4.6	30.3 ± 4.4
Height, cm*	180.0 ± 7.6	164.5 ± 8.0	172.3 ± 11.0
Weight, kg*	77.7 ± 9.7	56.6 ± 7.4	67.2 ± 13.7
Normalized weight-bearing strength, N/kg†	3.0 ± 0.6 (2.2-4.2)	2.6 ± 0.5 (2.1-3.4)	2.8 ± 0.6 (2.1-4.2)
Normalized non–weight-bearing strength, N/kg†	3.1 ± 0.9 (2.1-4.3)	2.9 ± 0.5 (2.2-3.6)	2.9 ± 0.6 (2.1-4.3)

Values are mean ± SD.
†*Values are mean ± SD (range).*

any other medical conditions that would impair an individual's ability to perform maximal force exertion. Prior to participation, the objectives, procedures, and risks of the study were explained to each participant. The study protocol was approved by the Institutional Review Board of the University of Southern California Health Sciences Campus, and informed consent was obtained from each participant.

Instrumentation

The proposed muscle performance test was designed to quantify the force-generating capacity of the hip abductor and external rotator musculature in a weight-bearing position (**FIGURE 1A**). The force was measured using a uniaxial force transducer (model LCCA-1K; OMEGA Engineering, Inc, Stamford, CT) connected to a nonstretchable fabric strap positioned around the distal ends of both thighs, just proximal to the lateral epicondyles. The skin under the strap was protected using a thin, foam-backed, self-adhesive band (NuStim Wrap; Applied Technology International, Ltd, Exton, PA). The strap and the connectors had a maximum capacity of 2227 N, and the tensile capacity of the transducer was rated to 4454 N. The transducer provided force values in Newtons, with an accuracy of 0.037% and precision of 0.02% (full scale).

Care was taken to ensure that the transducer was in series with the strap, parallel to the line of force application. The signal from the force transducer was sampled digitally at 1000 Hz. Real-time feedback of force generation was dis-

played to the participant on a computer monitor throughout testing (LabVIEW Version 8.0.1; National Instruments Corporation, Austin, TX) (**FIGURE 1B**).

Electromyographic (EMG) signals were recorded for the hip musculature, including the sGMAX, GMED, and TFL. EMG data from the dominant limb, defined as the preferred limb to perform a single-leg jump, were collected at 1500 Hz using preamplified bipolar surface electrodes. Electrodes for each muscle consisted of two 9-mm Ag/AgCl with a 20-mm interelectrode spacing (Norotrode 20; Myotronics-Noromed, Kent, WA). The MA-420 preamplifiers (Motion Lab Systems, Inc, Baton Rouge, LA) have a double-differential input design (common-mode rejection ratio greater than 100 dB at 65 Hz, gain at 1 kHz × 20% ± 1%, input impedance greater than 100 000 000 Ω) and a signal bandwidth of 20 to 3000 Hz. EMG signals were transmitted from the first-stage preamplifier to a second-stage receiver unit attached to the back of the subject (MA-133; Motion Lab Systems, Inc). From the receiver unit, the signal was hardwired to a 16-bit analog-to-digital converter (MA-300; Motion Lab Systems, Inc).

Non–weight-bearing isometric strength of the hip abductors was assessed using a motor-driven dynamometer (CYBEX with HUMAC NORM; Computer Sports Medicine Inc, Stoughton, MA). The dynamometer provided force values in Newtons, with a precision of 0.02% (full scale). The sampling frequency was 100 Hz.

Procedures

Data were collected at the Jacquelin Perry Musculoskeletal Biomechanics Research Laboratory at the University of Southern California. Subjects participated in 2 data-collection sessions. On the first visit, participants were tested using both the weight-bearing and the non–weight-bearing positions. The sequence of the 2 muscle performance assessments was randomized. On the second visit, participants were only tested using the weight-bearing method. The average ± SD interval between visits was 4.4 ± 2.9 days. The subjects were instructed not to participate in strenuous physical activity between testing sessions. EMG activation of the hip musculature during the weight-bearing test was assessed during the second testing session in a subset of 10 participants (6 women, 4 men).

Weight-Bearing Hip Abductor Muscle Performance Test

Weight-bearing hip abductor and external rotator muscle performance was assessed by a single examiner. The assessment was performed with the participant in a squat position (50° of knee flexion and 30° of hip flexion). These angles were established using a goniometer and were selected based on the results of a pilot work, which demonstrated that the highest force values could be produced in this position. Participants were instructed to maintain their natural lumbar lordotic curvature; to place their feet parallel to each other, shoulder-width apart; and to fold the arms in front of the chest (**FIGURE 1**). The force transducer and strap connector assembly were positioned just proximal to the lateral epicondyles. Care was taken to ensure that the knee was vertically aligned over the foot. The length of the testing strap was adjusted to accommodate this position. During testing, participants were asked to maintain this posture without moving their head, feet, or trunk.

Prior to performing each maximum-effort contraction, participants were instructed to maintain a baseline tension of
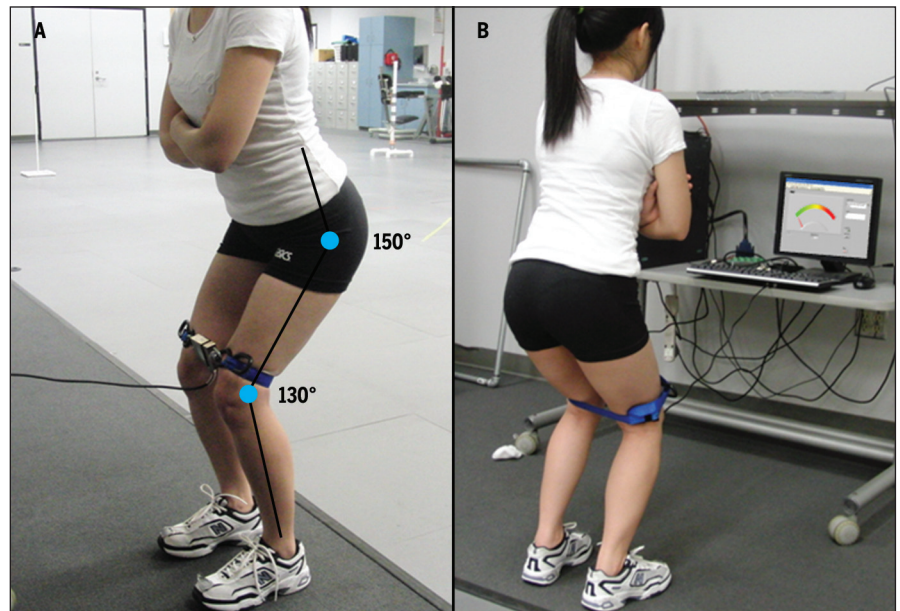

FIGURE 1. (A) Hip abductor/external rotator performance assessment in the weight-bearing position (30° of hip flexion, 50° of knee flexion). (B) Testing setup with visual force production feedback interface.

13 N to remove the slack from the testing strap connections. Participants were then instructed to push outward against the resistance strap "as fast and hard as possible" and to maintain this maximum effort for 5 seconds. Verbal encouragement was given to facilitate maximum effort, and real-time feedback of force generation was provided to the subjects on a computer screen (**FIGURE 1B**). Prior to data collection, practice trials were provided until the participants were comfortable with the testing procedure. Data were collected for a total of 3 trials.

Non–Weight-Bearing Muscle Performance Test

Isometric hip abduction strength of the participant's dominant lower limb was assessed using a motor-driven dynamometer in a standard position, as recommended by the manufacturer. Participants were placed sidelying on the testing table, with the tested hip placed superior and in a neutral position (0° of flexion, abduction, and rotation) (**FIGURE 2**). The axis of the dynamometer was aligned with the hip joint center in the frontal plane.[24] The lower end of the resistance pad was positioned just proximal
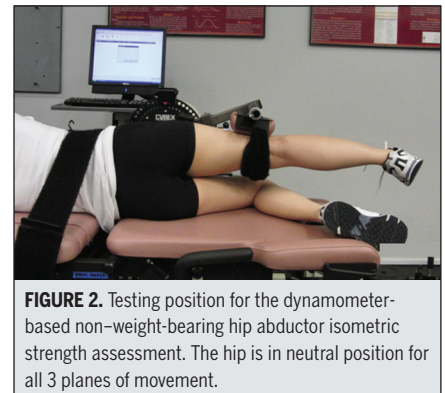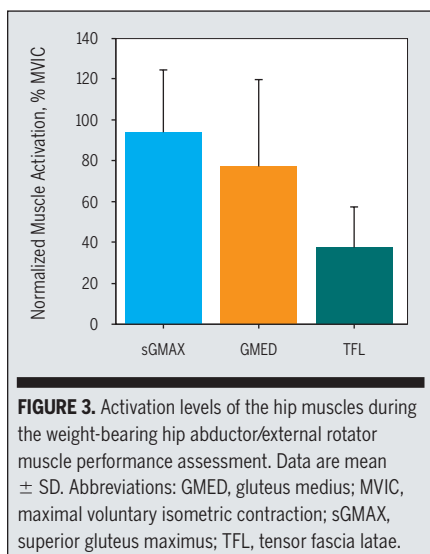

FIGURE 2. Testing position for the dynamometer-based non–weight-bearing hip abductor isometric strength assessment. The hip is in neutral position for all 3 planes of movement.

to the participant's lateral femoral epicondyle and secured to the distal thigh with straps. The trunk and pelvis of the participant were strapped to the testing table to minimize motion during testing. Participants performed 2 practice trials before 3 maximum isometric contractions were obtained.

For both the weight-bearing and non–weight-bearing tests, verbal encouragement was given to facilitate maximum effort, and force feedback was provided to the subjects on a computer screen. One minute of rest was provided between all weight-bearing and non–weight-bearing trials. The duration of each isometric exertion was 5 seconds. The force trace

FIGURE 3. Activation levels of the hip muscles during the weight-bearing hip abductor/external rotator muscle performance assessment. Data are mean ± SD. Abbreviations: GMED, gluteus medius; MVIC, maximal voluntary isometric contraction; sGMAX, superior gluteus maximus; TFL, tensor fascia latae.

of each weight-bearing and non–weight-bearing trial was inspected visually to ensure that the execution of the test was adequate. The peak force produced during each of the weight-bearing and non–weight-bearing trials was then identified and used for statistical analysis.

EMG Assessment

Prior to applying the surface EMG electrodes, the skin was lightly abraded and cleaned with isopropyl ethanol alcohol. Electrodes for the sGMAX were placed on the most prominent portion of the muscle belly, 3 to 6 cm inferior from the posterior superior iliac spine. The electrodes were aligned toward the greater trochanter, following the sGMAX muscle fiber orientation. Electrode placement for the GMED was midway along the line between the iliac crest and the greater trochanter on the muscle belly. For the TFL, the muscle belly was palpated as the participant performed resisted hip flexion, abduction, and internal rotation in the supine position. Electrodes were placed on the muscle belly 2 to 4 cm distal to the anterior superior iliac spine, following the muscle fiber direction. All ground electrodes were placed on electrically silent bony surfaces.

To standardize the EMG signal levels among participants, maximal voluntary isometric contractions (MVICs) were

performed. For the sGMAX, the MVIC test was conducted in a prone position, with both of the participant's legs off the edge of the testing table. The hip was positioned in 45° of flexion and the knee was flexed to 90°. A resistance strap was attached to the femur, just proximal to the popliteal surface. During the test, participants were instructed to extend the tested hip, pushing against the resistance strap while keeping the knee flexed.

For the GMED, participants were placed sidelying on the testing table, with the tested hip placed superior and in a neutral position (0° of hip flexion, abduction, and rotation). A resistance strap was positioned at the participant's lateral femoral epicondyle. Participants were instructed to push up against the strap while keeping the knee extended.

For the TFL, the MVIC trials also were performed in the sidelying position. A belt was looped around the participant's distal thigh region and the testing table to provide resistance. In this position, the participant was instructed to push in a diagonal direction, thereby performing a combination of isometric hip flexion and abduction against the belt. Two 5-second MVIC trials were collected for each muscle. The participants were given at least 1 minute of rest between MVIC trials.

Data Analysis

The average peak force values obtained from the 3 weight-bearing and non–weight-bearing trials were used for statistical analysis. For the non–weight-bearing trials performed on the dynamometer in a sidelying position, the force caused by the weight of the lower limb was added to the force produced during the test. As such, the gravitational influence on the lower limb was accounted for in this non–weight-bearing condition.

EMG signals recorded during the weight-bearing trials were filtered using a 35- to 500-Hz digital band-pass filter and then full-wave rectified. Mean EMG signal amplitude during the third second of the 5-second testing trial was normalized to the mean amplitude of the high-

est 1-second EMG amplitude during the MVIC trials. The highest 1-second EMG amplitude during the MVIC trials represented 100% muscle activation. The average normalized muscle activation level from the 3 trials was used for analysis.

Statistical Analysis

The test-retest reliability of obtaining the peak force using the weight-bearing method was assessed using a 2-way random intraclass correlation coefficient ($ICC_{3,1}$). Intersession consistency was quantified using the standard error of measurement (SEM).[18] The percentage of the SEM to the measured mean value also was calculated.

The level of agreement between the force values obtained using the weight-bearing and non–weight-bearing strength test methods was assessed using a linear correlation model (2-tailed; significance level, .05). The EMG activation levels of the 3 hip muscles were presented using descriptive statistics (ie, mean and standard deviation). All statistical analyses were conducted using SPSS Statistics Version 19.0 (IBM Corporation, Armonk, NY).

RESULTS

THE WEIGHT-BEARING MUSCLE PERformance assessment demonstrated excellent test-retest reliability (ICC = 0.99; 95% confidence interval: 0.97, 0.99). On average, the mean ± SD force measured during the first session (2.8 ± 0.6 N/kg) was similar to the force measured during the second testing session (2.8 ± 0.6 N/kg). The SEM was 0.02 N/kg, which was 0.7% of the measured mean value. The SEM for the nonnormalized force data was 6.8 N. During the weight-bearing test, the mean ± SD activation levels for the sGMAX, GMED, and TFL were 93.6% ± 30.8%, 77.0% ± 42.3%, and 37.5% ± 19.8% MVIC, respectively (**FIGURE 3**).

The normalized hip abduction and external rotation force with the weight-bearing method (mean ± SD, 2.8 ± 0.6

N/kg; range, 2.1-4.2 N/kg) was similar to the force values obtained using the non–weight-bearing method (2.9 ± 0.6 N/kg; range, 2.1-4.3 N/kg). Additionally, hip abductor and external rotation strength measured by the weight-bearing method was found to be significantly correlated with results from the conventional, non–weight-bearing, dynamometer-based assessment for hip abduction (r = 0.75, P<.01) (**FIGURE 4**).

DISCUSSION

THE WEIGHT-BEARING METHOD FOR assessing hip abductor and external rotator strength demonstrated excellent test-retest reliability and a low SEM. The low SEM relative to the measured mean value indicates that the test gave consistent results between testing sessions.[29] The reliability for the weight-bearing method was comparable to that established for a hip abductor strength assessment using a handheld dynamometer.[33] In addition, the reliability of the measurements with the weight-bearing method was slightly higher than that reported for isometric hip abductor strength testing in sidelying (ICC = 0.90).[32] The slightly lower test-retest reliability of the sidelying testing method may be, in part, due to the fact that proper positioning and stabilization of the hip and pelvis are difficult to achieve in a non–weight-bearing position. In contrast, the testing position used for the proposed weight-bearing method placed the subject in a position that minimized the need for external stabilization. The higher test-retest reliability might have been the result of the more stable testing position.

Assessment of the hip muscle EMG signals revealed that the most active muscle during the weight-bearing test was the sGMAX. In comparison, GMED activation was 16.6% lower, and TFL activation was 56.1% lower. The gluteus minimus was not considered in the current study, as the activity of this muscle could not be evaluated using surface elec-
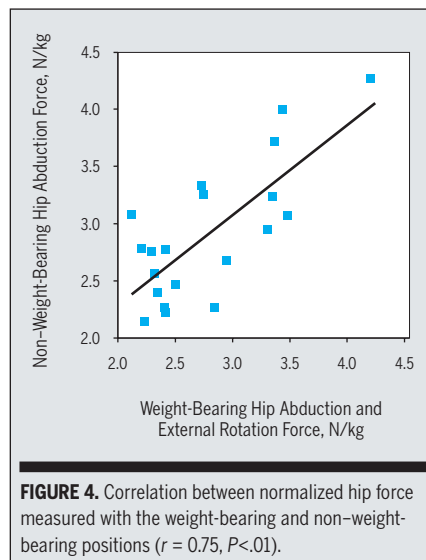

FIGURE 4. Correlation between normalized hip force measured with the weight-bearing and non–weight-bearing positions (r = 0.75, P<.01).

trodes. Although the gluteus minimus is a hip abductor, it has been shown that the primary function of this muscle is to stabilize the femoral head within the acetabulum. The contribution of its activity with respect to hip abduction torque production is relatively small when compared to the other hip abductors.[1,7,9]

The fact that the sGMAX exhibited the highest activation and the TFL had the lowest may be explained by the fact that the testing position also encouraged the generation of hip external rotation torque as opposed to only hip abduction torque. Given that the sGMAX is also the primary external rotator of the hip, the higher activation observed in this muscle was expected.[6] In contrast, the TFL is an internal rotator of the hip. As such, the TFL would not be expected to contribute to the production of any hip external rotation torque imposed by the weight-bearing test. Thus it can be argued that the weight-bearing assessment challenges the gluteal muscles to a greater extent than the TFL.

The force values measured using the weight-bearing method were significantly correlated with values obtained for hip abduction strength measured using a dynamometer in non–weight bearing. However, it should be noted that only 56.3% of the variance in the dynamometer-based test could be explained by the

results obtained from the weight-bearing test. The reason that the agreement between the 2 assessment methods was only moderate may be related to the differences in hip abductor muscle recruitment in the weight-bearing compared to the non–weight-bearing testing positions.[32] Additionally, the hip external rotators likely contributed to the force measured during the weight-bearing assessment, as subjects performed the test in 30° of hip flexion.

The simplicity of the weight-bearing method is an advantage for assessing performance of the hip musculature in clinical physical therapy practice; however, a limitation of the method is that the test is performed using both lower extremities. The nature of this bilateral setup implies that the measured force is determined by the weaker side. However, it should be noted that the non–weight-bearing method of assessing hip abductor muscle performance has the same limitation. For example, Widler et al[32] reported that there is considerable activation of the contralateral (not-tested) GMED during the non–weight-bearing assessments. Specifically, the authors reported that the contralateral-to-ipsilateral ratio of GMED activation was approximately 90% to 130% when evaluated in 3 different testing positions designed to assess unilateral hip abductor strength. This suggests that stabilization afforded by the contraction of the contralateral hip abductor is important for ipsilateral abductor force production, and that bilateral activation is inevitable, regardless of testing position.

CONCLUSION

A WEIGHT-BEARING METHOD TO ASsess hip abductor and external rotator muscle performance was presented. The proposed weight-bearing method was shown to be reliable and exhibited a moderate level of agreement with the traditional non–weight-bearing method of measuring hip abductor force in sidelying. We propose that the as-

sessment of hip muscle performance in weight bearing may be more meaningful than conventional non–weight-bearing assessments. Future studies will be directed toward determining whether hip abductor and external rotator muscle performance measured in weight bearing can predict hip joint mechanics during functional activities. ◉

■ KEY POINTS

FINDINGS: The proposed weight-bearing method to measure hip abductor/external rotator strength was shown to be reliable and exhibited a moderate level of agreement with the traditional non–weight-bearing assessment of the hip abductors in sidelying.

IMPLICATIONS: The weight-bearing method can be used as a simple and economic alternative for assessing hip muscle performance.

CAUTION: The test was not designed to test unilateral hip abductor strength. In addition, only healthy individuals participated in this study.

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