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original research

Hip Muscle Activity During 3 Side-Lying Hip-Strengthening Exercises in Distance Runners

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Context: Lower extremity overuse injuries are associated with gluteus medius (GMed) weakness. Understanding the activation of muscles about the hip during strengthening exercises is important for rehabilitation.

Objective: To compare the electromyographic activity produced by the gluteus medius (GMed), tensor fascia latae (TFL), anterior hip flexors (AHF), and gluteus maximus (GMax) during 3 hip-strengthening exercises: hip abduction (ABD), hip abduction with external rotation (ABD-ER), and clamshell (CLAM) exercises.

Design: Controlled laboratory study.

Setting: Laboratory.

Patients or Other Participants: Twenty healthy runners (9 men, 11 women; age = 25.45 ± 5.80 years, height = 1.71 ± 0.07 m, mass = 64.43 ± 7.75 kg) participated.

Intervention(s): A weight equal to 5% body mass was affixed to the ankle for the ABD and ABD-ER exercises, and an equivalent load was affixed for the CLAM exercise. A pressure biofeedback unit was placed beneath the trunk to provide positional feedback.

Main Outcome Measure(s): Surface electromyography (root mean square normalized to maximal voluntary isometric contraction) was recorded over the GMed, TFL, AHF, and GMax.

Results: Three 1-way, repeated-measures analyses of variance indicated differences for muscle activity among the ABD ($F_{3,57} = 25.903$, $P < .001$), ABD-ER ($F_{3,57} = 10.458$, $P < .001$), and CLAM ($F_{3,57} = 4.640$, $P = .006$) exercises. For the ABD exercise, the GMed (70.1 ± 29.9%), TFL (54.3 ± 19.1%), and AHF (28.2 ± 21.5%) differed in muscle activity. The GMax (25.3 ± 24.6%) was less active than the GMed and TFL but was not different from the AHF. For the ABD-ER exercise, the TFL (70.9 ± 17.2%) was more active than the AHF (54.3 ± 24.8%), GMed (53.03 ± 28.4%), and GMax (31.7 ± 24.1%). For the CLAM exercise, the AHF (54.2 ± 25.2%) was more active than the TFL (34.4 ± 20.1%) and GMed (32.6 ± 16.9%) but was not different from the GMax (34.2 ± 24.8%).

Conclusions: The ABD exercise is preferred if targeted activation of the GMed is a goal. Activation of the other muscles in the ABD-ER and CLAM exercises exceeded that of GMed, which might indicate the exercises are less appropriate when the primary goal is the GMed activation and strengthening.

Key Words: gluteus medius, electromyography, rehabilitation

Key Points

- The side-lying hip-abduction exercise was the best exercise for activating the gluteus medius with little activation of the tensor fascia latae and anterior hip flexors.
- The clamshell exercise resulted in the greatest activation of the anterior hip flexors with little activation of the gluteus medius and gluteus maximus.
- The side-lying hip-abduction with external rotation exercise might activate and strengthen the tensor fascia latae beyond the goal of rehabilitation.

Both recreational and competitive running have grown in popularity in recent years. The growth might be attributed partly to the known health benefits, the non–equipment-intensive nature, and the ability to individualize both running intensity and duration. Although the increase in physical activity has many health benefits, it also brings the inherent increased risk of lower extremity injuries. Epidemiologic evidence indicates that 19% to 79% of runners will sustain a lower extremity injury,[1–4] and the knee is the most common site of injury.[2,3] The lower leg (25% for male and female runners) and foot (14% for male and 13% for female runners) are the next most commonly injured areas.[3,4] The most frequent injuries affecting runners include patellofemoral pain syndrome (PFPS), iliotibial band syndrome (ITBS), injuries to the gluteus medius muscle (GMed), and greater trochanteric bursitis.[3] Athletic trainers routinely work to prevent, diagnose, and rehabilitate running-related injuries, so they must possess knowledge of the current research in which exercises commonly used to treat these injuries have been investigated.

A contemporary clinical theory that might explain the cause of PFPS and ITBS is that of proximal muscle weakness leading to dynamic valgus of the knee joint.[5] *Dynamic valgus* has been described as a malalignment characterized by pelvic drop, which is inferior movement of the contralateral side of the pelvis during single-legged stance; femoral adduction and internal rotation; genu valgum; tibial internal rotation; and hyperpronation, and it occurs when the hip muscles cannot overcome the external torque caused by gravity acting on the body's center of mass.[5] Researchers believe weakness of the hip musculature, specifically the hip abductors and external rotators, contributes to a person assuming a position of dynamic valgus each time he or she is in single-legged stance.[6,7] Evidence that hip muscle weakness is associated with overuse injuries, such as PFPS[8–12] and ITBS,[13,14] supports this theory. These concepts of hip weakness leading to dynamic valgus and lower extremity injury provide the clinical foundation for why strengthening the hip abductors is a common and important component of preventing and rehabilitating these injuries.

Incorporating hip strengthening into rehabilitation programs for overuse injuries has been associated with positive outcomes, including reduction of symptoms and correction of positional malalignment.[15–21] Clinicians often use a variety of strengthening exercises based on knowledge of anatomical structure and function of the hip, whereas little empirical evidence might exist to confirm the activation of particular muscles during a specific movement.[22] The functional anatomy of the hip is complex, and actions of muscles often change depending on the position of the hip.[23,24] Therefore, clinicians need to thoroughly understand the activity of major muscle groups of the hip during common strengthening exercises.

Side-lying, open-chain exercises often are performed early in the rehabilitation process to produce appropriate neuromuscular control and strength, supporting more functional exercises later. Researchers using electromyography (EMG) have shown that the GMed is most active during a single-plane, side-lying hip-abduction (ABD) exercise as compared with a variety of other exercises (Figure 1).[25–27] However, they did not include the tensor fascia latae (TFL), which is also a primary hip abductor[23]; therefore, the contribution of the TFL to this exercise is not known. Fredericson and Wolf[28] believed that people with GMed weakness might compensate by using the TFL to a greater extent, leading to hypertonicity and potential tightness in the iliotibial band. Therefore, understanding the relative contribution of the TFL and GMed to side-lying exercises is clinically important.

The clamshell (CLAM) activity incorporates open-chain hip abduction and external rotation and often is used very early in rehabilitation when great weakness of the abductors and external rotators exists (Figure 2). Researchers think the combination of abduction and external rotation of the hip leads to strengthening of the gluteus maximus (GMax) and GMed, but very low activity of these muscles has been reported.[25,29] Given the recognized changes in muscle activity when the hip is flexed,[23,24] knowing the activity of the other superficial hip muscles, such as the TFL and AHF, during this exercise is important, but this has not been examined.

From our experiences and informal querying at professional meetings, we have learned that many clinicians have patients perform the ABD exercise with the hip externally rotated and the toes pointed toward the ceiling (ABD-ER) (Figure 3). The theoretical rationale is that introducing hip external rotation will engage the GMax and also minimize the activity of the TFL because it is an internal rotator. This theory has little anatomical basis because the external rotator muscles are not acting against gravity in this position. Furthermore, because the hip is externally rotated, the anterior hip flexors (AHF) are more in the line of action to resist gravity and therefore might be more active during the ABD-ER task. We did not find empirical evidence to support the clinical rationale for using the ABD-ER exercise, so further examination is necessary.

Although the ABD-ER and CLAM exercises commonly are used, the anatomical rationale for muscle activation is weak, and activation of the surrounding musculature in addition to GMed during these exercises is not known. Therefore, the purpose of our study was to compare the EMG activity produced by the GMed, GMax, TFL, and AHF during 3 common hip-strengthening exercises: ABD, CLAM, and ABD-ER exercises. Based on previous research[25–27] and anatomical function,[22] we

Figure 1. Side-lying hip-abduction exercise.

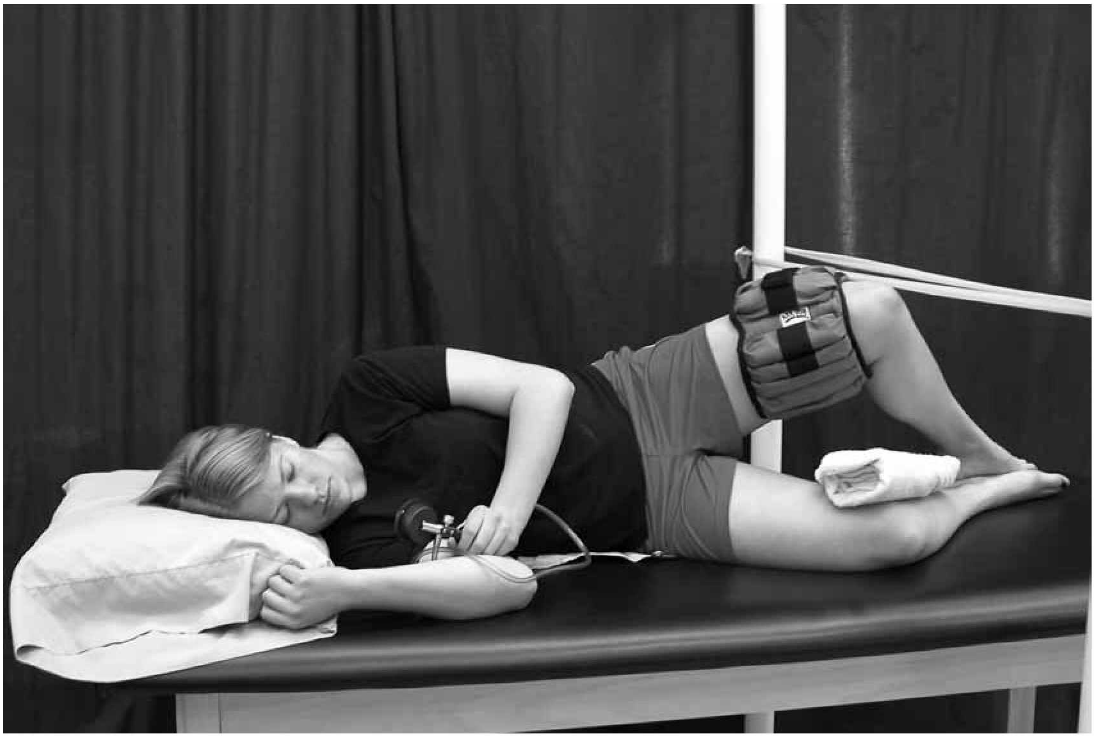

Figure 2. Clamshell exercise.

Figure 3. Side-lying hip abduction–external rotation exercise.

hypothesized that during the ABD exercise, the GMed would be most active, followed by the TFL, and that the AHF and GMax would have low activity. For the CLAM exercise, we hypothesized that the GMed would be the most active, followed by the GMax, TFL, and AHF. For the ABD-ER exercise, we hypothesized that the GMed would be the most active, followed by the TFL, AHF, and GMax.

METHODS

Participants

We recruited 20 distance runners from the community, local running clubs, and collegiate track teams. Runners were chosen because of the high incidence of lower extremity overuse injuries in this population and because of the overall lean physique of most distance runners. For each participant, we collected demographic information (Table 1). People were included if they were aged 18 to 40 years and ran an average of 25 miles (40 km) per week over the 6 weeks before the study. We selected 25 miles per week to more closely match the distances run by recreational runners with the distances run by intercollegiate runners. A person was excluded from the study if he or she had a lower extremity injury within the 6 months before the study that had necessitated modification to the regular training regimen for longer than 7 days, had a lower extremity injury or muscle soreness at the time of the study, had a history of lower extremity surgery, was pregnant, was incorporating hip-strengthening exercises into the training regimen, or had a body mass index of 25 or more. A body mass index of 25 or more classifies a person as overweight and might contribute to increased variability of the EMG signal because overweight people have higher levels of subcutaneous adipose tissue than average-sized people. People with anteverted hips have less EMG activity during the CLAM exercise than people with normal hips[30]; therefore, passive hip internal range of motion also was measured for each participant as a measure of relative femoral anteversion using the procedures described by Kozic et al.[31] The average amount of passive hip internal rotation was 31.27°±9.49°, and only 2 participants had values greater than 42°, indicating an anteverted hip.[30]

Researchers[26] comparing the EMG activity of several exercises have reported a moderate effect (effect size = 0.65). Based on these data, at least 17 participants were necessary to achieve a power of 0.8 with an α level set at .05 for comparing muscles and exercises. We recruited 20 participants to ensure adequate power. All participants provided informed consent, and the study was approved by the Institutional Review Board of the University of Wisconsin–Milwaukee.

Experimental Procedures

Testing took place in a single session in a laboratory setting. Each participant wore loose-fitting running shorts with a built-in brief to allow access to the hip muscles. A chronology of the data collection session is presented in Table 2.

The repetition tempo of the exercises was controlled by an electronic metronome set to 60 beats per minute and consisted of a 1-beat concentric "up" phase, a 1-beat eccentric "down" phase, and a 4-beat rest phase. We chose this tempo because it is consistent with the tempo patients use to perform these exercises in a rehabilitation setting, and it is consistent with tempos used in previous research.[26] To perform the ABD exercise, participants lay on the nondominant side with the test limb in a neutral position and the nondominant leg flexed for stability (Figure 1). The amount of abduction was standardized using a horizontal band that the leg would contact when the participant reached 35° of hip abduction. Participants were cued to point their toes straight ahead throughout the exercise.

To perform the ABD-ER exercise, participants remained in the same side-lying position and were instructed to externally rotate their hips and point their toes up as far as possible before initiating the abduction movement (Figure 3). The reference band remained to indicate when 35° of abduction had been achieved. Participants were instructed to keep the pelvis in a neutral position and not to tip it backward; this was monitored visually and with a Stabilizer Pressure Bio-feedback unit (Chattanooga Group, Inc, Hixson, TN). The unit consists of an inflatable air bag connected to a pressure gauge (Figure 4). When it is placed beneath the trunk between the iliac crest and the distal ribs, changes in body position are reflected in changes in pressure, which the participant views. This provides additional feedback for unwanted changes in body position during exercise and has been shown to decrease substitution from surrounding muscles and to increase activity of the GMed during the ABD exercise.[29] The Stabilizer Pressure Bio-feedback unit was inflated until the pressure reached 40 mm Hg, and the participant and the investigator (J.M.M.) monitored this pressure during the exercises to ensure that it remained between 35 and 45 mm Hg.

To perform the CLAM exercise, participants lay on their sides with the dominant limb up, with both hips flexed to 45°, and with the knees flexed to 90° (Figure 2). Keeping their feet together, they separated their knees and rotated the top leg upward. The reference band was positioned so the top of the knee would touch it when the angle between the lower leg and horizontal was 25°. Participants were instructed to visualize a clamshell opening for this exercise.

Exercise order was counterbalanced to control for any fatigue or learning effect. To minimize any potential learning effect, all participants were taught how to perform the exercises by the same researcher (J.M.M.) and performed 4 practice sets of each exercise before data collection. During all trials, investigators gave oral feedback to correct errors and to assist in the maintenance of proper tempo. After instruction, the first practice set was performed with no weight applied and only oral feedback given. For the second practice set, the Stabilizer Pressure Bio-feedback unit was used to provide feedback for maintaining correct position during the exercise.

For the third practice set, a cuff weight equal to 5% body mass was applied just above the participant's ankle. Although 3% body mass has been used for side-lying hip-abduction exercises in other studies,[26] we chose 5% for our study to ensure

Table 1. Demographic Characteristics of Participants

Characteristic	Men (n = 9)	Women (n = 11)
Age, y	26.6 ± 6.5	26.1 ± 5.2
Height, m	1.75 ± 0.08	1.68 ± 0.03
Mass, kg	69.3 ± 7.1	61.3 ± 6.6
Dominant lower extremity[a]		
Right	8	11
Left	1	0
Average distance run, mi/wk (km/wk)	45.2 ± 17.0 (72.7 ± 27.4)	40.7 ± 13.4 (65.6 ± 21.6)
Body mass index, kg/m²	22.6 ± 1.2 (36.4 ± 1.9)	21.7 ± 1.5 (34.9 ± 2.4)

[a] Defined as the preferred kicking leg.

Table 2. Chronology of Events During the Data Collection Session

1. Informed consent and demographic data collected
2. Exercise instruction and practice
   a. Set 1 included 5 repetitions with oral feedback, without pressure feedback, and without weight.
   b. Set 2 included 5 repetitions with oral feedback, with pressure feedback, and without weight.
   c. Set 3 included 5 repetitions with oral feedback, with pressure feedback, and with 5% body mass.
   d. Participants rested for 10 min.
   e. Set 4 included 5 repetitions with oral feedback, with pressure feedback, and with 5% body mass.
3. Warmup
   Participants jogged moderately for 5 min on a treadmill.
4. Electromyographic electrode application
   a. For the gluteus medius, electrodes were placed directly superior to the greater trochanter of the femur one-third of the distance between the iliac crest and the greater trochanter of the femur.
   b. For the gluteus maximus, electrodes were placed one-half the distance between the posterosuperior iliac spine and the greater trochanters of the femur just superior to the level of the greater trochanters of the femur.
   c. For the tensor fascia latae, electrodes were placed 2 cm inferior and slightly lateral to the anterosuperior iliac spine.
   d. For the anterior hip flexors, electrodes were placed in the femoral triangle just lateral to the femoral pulse below the inguinal ligament and medial to the palpable mass of the quadriceps femoris. This is described as a quasispecific site for recording surface electromyographic activity of the iliopsoas and is representative of the anterior hip flexors.
5. Data collection
   Participants performed 3 5-s repetitions of maximal voluntary isometric contractions for each muscle.
6. Exercise data collection
   a. Participants performed 7 repetitions with oral feedback, with pressure feedback, and with 5% body mass.
   b. Participants repeated the exercise for side-lying hip abduction, side-lying hip abduction–external rotation, and clamshell exercises, with a 1-min rest between exercises.

adequate muscle activation. Investigators[32] have suggested that muscle activation greater than 40% of the maximal voluntary isometric contraction (MVIC) is needed to obtain strength gains. For the CLAM exercise, the cuff weight was secured just proximal to the participant's knee. To create equal torque at the hip between exercises, the weight was increased to account for the shorter resistance moment arm associated with the CLAM exercise. A calculation was made based on an estimation of torque during the ABD and ABD-ER exercises ($T = Fr$), where F equaled the mass of the cuff weight used and r equaled the length between the participant's greater trochanter and lateral malleolus. For the CLAM exercise, r was the distance between the greater trochanter and lateral joint line of the knee. To maintain T as constant compared with the other tasks, a new F was calculated, and this value was used as the weight for the CLAM exercises. Therefore, the torque applied to the hip was consistent within participants between exercises. Although torque values would differ among participants due to leg-length differences, only within-subjects comparisons were made in this study.

Figure 4. Stabilizer Pressure Bio-feedback unit (Chattanooga Group, Inc, Hixson, TN).

After a 10-minute rest, participants performed a fourth practice set of each exercise. They jogged for 5 minutes on a treadmill at a self-selected moderate pace to warm up and increase skin moisture to enhance EMG signal conductivity before electrodes were applied.

The skin was prepared for surface EMG electrode placement by shaving and vigorously rubbing with an alcohol pad. Two active silver chloride electrodes (Medicotest, Ølstykke, Denmark) were placed parallel with each of the muscles' fibers at an interelectrode distance of 2.6 cm, and a differential electrode was placed over the fibular head. Electrodes were placed in standardized positions on the GMed, GMax, TFL, and AHF based on the recommendations of Cram and Kasman,[33] which is a reference commonly used for similar studies (Table 2).[26,27,29] All EMG electrodes were secured with tape, and the skin electrode impedance was measured with a digital multimeter (RadioShack Corporation, Fort Worth, TX). If the impedance exceeded 100 kΩ, we prepared the skin again and replaced the electrodes until the impedance was less than 100 kΩ.[33] The EMG data were collected using a 16-channel EMG system (Run Technologies, Mission Viejo, CA) and were sampled at 1000 Hz with an amplifier gain of 1000. A twin-axis electrogoniometer (Biometrics Ltd, Gwent, United Kingdom) was secured to the lateral hip using double-sided tape with 1 arm on the iliac crest and 1 arm on the greater trochanter of the femur to monitor leg movement. The electrogoniometer data were used only to provide a visual representation of the movement that could be referenced when we visually examined the EMG data. Electrogoniometer data were collected synchronously with EMG data and were sampled at 1000 Hz.

Maximal voluntary isometric contractions in standard manual muscle test positions[34] were performed to confirm that muscle crosstalk was minimal and were used for normalization. Participants performed 3 5-second MVICs with a 10-s rest between contractions and a 1-minute rest between muscles tested. To obtain an MVIC for the GMed, the participants lay on their sides with the test leg up and the bottom hip and knee flexed for stabilization. The test leg was abducted to approximately 35°, and the hip was positioned in slight extension and external rotation. The investigator applied a downward force at the ankle while stabilizing the hip with the other hand. To obtain an MVIC for the TFL, the participants lay supine with the hip flexed and internally rotated maximally with the knee extended. The investigator applied force at the ankle in the direction of hip extension. To obtain an MVIC for the AHF, the participants lay supine with the knees extended. The test leg was positioned in hip flexion and external rotation. The investigator (J.M.M.) applied force at the ankle in the direction of hip extension. To obtain an MVIC for the GMax, the participants lay prone with the knee flexed to at least 90° and the hip maximally extended. The investigator applied a downward force on the posterior thigh near the knee. Participants also performed 1 MVIC while seated with the knee extended so we could confirm that minimal crosstalk occurred for the rectus femoris muscle in the signals for the TFL and AHF. After MVIC data collection, participants rested for 2 minutes before exercise data collection.

The EMG and electrogoniometer data were recorded while the participants performed a final set of 7 repetitions of each exercise in the same manner in which they were practiced. Seven repetitions were used to ensure that at least 3 trials were performed with the correct tempo and form and to ensure optimal signal fidelity. The participants were given a 1-minute rest between exercises.

To confirm our confidence in the placement of the TFL electrodes, we collected post hoc data on MVICs for the TFL and sartorius. Electrodes were placed on the TFL 2 cm inferior and slightly lateral to the anterosuperior iliac crest and were placed on the sartorius 4 cm inferior to the anterosuperior iliac crest on the anterior surface of the thigh.[33]

Data Analysis

The MVICs and EMG data for the exercise trials were bandpass filtered from 10 to 499 Hz using a Butterworth filter in Datapac 2K2 software (Run Technologies). Muscle onset was determined by establishing the mean and standard deviation of a 1-second quiet baseline that occurred before the initiation of each exercise. The muscle was considered *on* when its amplitude exceeded a threshold of 2 standard deviations above the baseline for at least 1 second, which we confirmed by comparing it with the initiation of movement as indicated by the electrogoniometer data. The root mean square (RMS) of the EMG data then was calculated using a 20-millisecond moving window for the entire *on* period for the 3 MVICs and for the exercise trials. The average RMS over a 500-millisecond window surrounding the peak activity was determined for the MVICs and exercise trials.

The first and last repetitions of the exercise trials were excluded from analysis, and the 3 trials with the most consistent EMG signals based on visual inspection were used. Exercise EMG amplitude was expressed as a percentage of the average MVIC for each muscle (%MVIC) because this has been shown to be the most reliable method of EMG normalization for hip abduction exercises.[35] The %MVIC values for the 3 repetitions of each exercise then were averaged within each participant for statistical analysis.[36]

Statistical Analysis

A 1-way, repeated-measures analysis of variance comparing GMed, GMax, TFL, and AHF muscle activity was performed for each of the 3 exercises (ABD, ABD-ER, CLAM) using SPSS (version 13.0; SPSS Inc, Chicago, IL). The α level was set a priori at <.05. If a main effect was found, post hoc pairwise comparisons were performed with a Bonferroni correction for multiple comparisons.

RESULTS

Results indicated differences among muscle activity for the ABD ($F_{3,57}=25.903$, $P<.001$), ABD-ER ($F_{3,57}=10.458$, $P<.001$), and CLAM ($F_{3,57}=4.640$, $P=.006$) (Figure 5). For the ABD exercise, the GMed (79.1% ± 29.9%), TFL (54.3% ± 19.1%), and AHF (28.2% ± 21.5%) were different from each other (P range, .001–.004). The GMax (25.3% ± 24.6%) was less active than the GMed ($P<.001$) and TFL ($P=.004$) but was not different from the AHF ($P=.99$).

For the ABD-ER exercise, the TFL (70.9% ± 17.2%) was more active than the AHF (54.3% ± 24.8%, $P=.03$), GMed (53.03% ± 28.4%, $P=.03$), and GMax (31.7% ± 24.1%, $P<.001$). For the CLAM exercise, the AHF (54.2% ± 25.2%) was more active than the TFL (34.4% ± 20.1%, $P=.05$) and GMed (32.6% ± 16.9%, $P=.002$) but was not different from the GMax (34.2% ± 24.8%, $P=.20$).

The post hoc data collected on MVICs for the TFL and sartorius clearly showed that, whereas the sartorius was somewhat active during the TFL MVIC, it was much less active than the TFL. The sartorius was most active during the "hackey-sack" position of hip flexion, external rotation, and knee flexion.

DISCUSSION

The purpose of our study was to compare the EMG activity produced by the GMed, GMax, TFL, and AHF during 3 hip-strengthening exercises: ABD, CLAM, and ABD-ER. All 3 exercises are used commonly during rehabilitation of lower extremity injuries, and a complete examination of hip muscle activity had not been performed. Our results supported our hypothesis that during the ABD exercise, the GMed would be more active than the TFL, AHF, and GMax. Findings for the ABD-ER and CLAM exercises were not as we expected; the GMed was not highly active during these exercises.

ABD Exercise

The ABD exercise activated the GMed 79.1% ± 29%MVIC. This amplitude is similar to the amplitude DiStefano et al[25] observed using no additional load yet is higher than the amplitudes Bolgla and Uhl[26] (42% ± 27%MVIC), Ekstrom et al[27] (39% ± 17%MVIC), and Cynn et al[29] (25.03% ± 10.25%MVIC) reported. Activity of the TFL during the ABD exercise was also high (54.3% ± 19.1%) and was consistent with its anatomical role as a primary hip abductor.[22] We are the first to include the TFL in the analysis of EMG activity during hip-strengthening exercises, so no comparisons with previous data can be made.

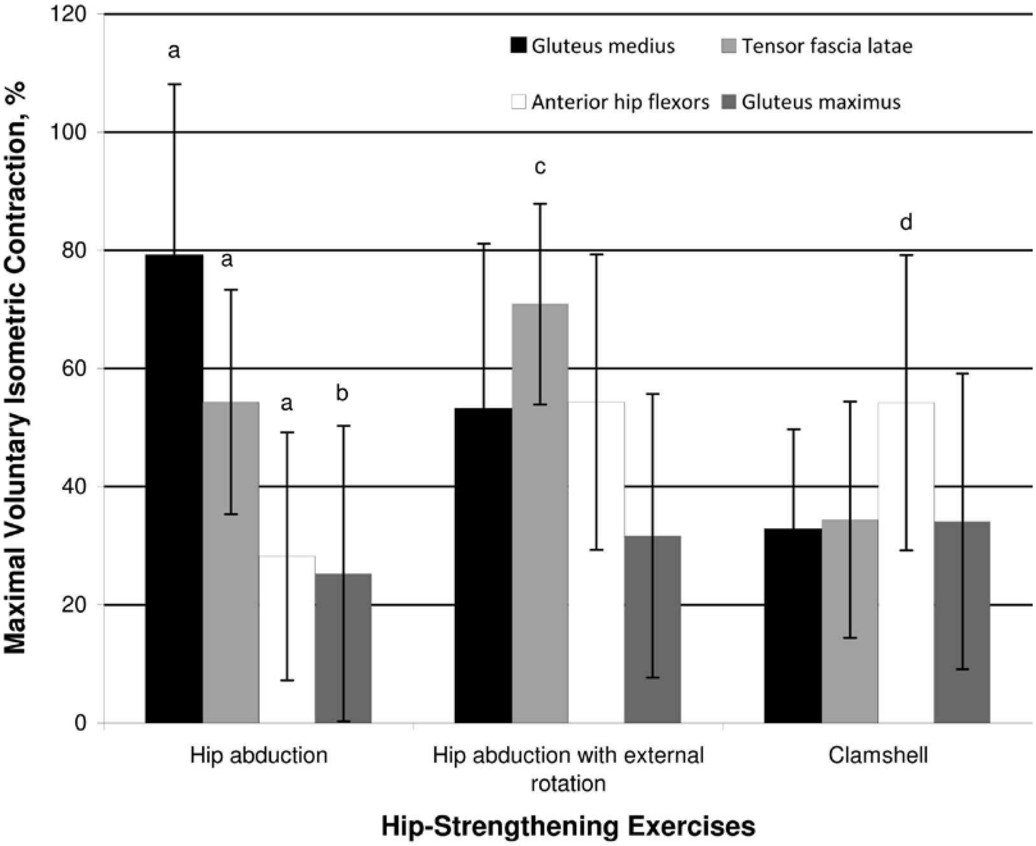

Figure 5. Comparison of muscle activity for side-lying hip abduction, side-lying hip abduction–external rotation, and clamshell exercises. [a]Indicates different from each other. [b]Indicates less than gluteus medius and tensor fascia latae. [c]Indicates greater than all other muscles. [d]Indicates greater than tensor fascia latae and gluteus medius.

The higher activation of the GMed in our study than in previous studies is attributed to 3 factors. We used a load of 5% body mass in an attempt to have activation greater than the 40% threshold necessary for strength gains.[32,37] We also specifically recruited participants who were moderately active, running at least 25 miles (40 km) per week, whereas other investigators have used a sample of convenience.[26,27] Using a pressure biofeedback unit is known to increase the activation of the GMed during ABD exercise by limiting muscle substitution from the quadratus lumborum.[29] Cynn et al[29] reported 46.06%±21.2%MVIC activation of the GMed when they used this unit with no additional load applied to the lower extremity and reported 25.03%±10.25%MVIC when the exercise was performed without the feedback unit. These findings lead us to recommend including a load of at least 5% body mass and the Stabilizer Pressure Bio-feedback unit to maximize the activation and thus the strengthening potential of the GMed during the ABD exercise.

ABD-ER Exercise

The rationale for turning the toe upward and externally rotating the hip in this exercise has been twofold: to engage the GMax as a hip external rotator and to minimize the contribution of the TFL as an abductor. Our data contradicted both of these ideas. We found that the TFL (70.9%±17.2%) was more active than all the other muscles during the ABD-ER exercise. Although both the TFL and GMed contribute to hip abduction, the TFL is also a secondary hip flexor because its line of action is more anterior to the hip joint center than that of the GMed.[38] Therefore, any force acting on the leg to cause hip extension will result in TFL activation to prevent hip extension. Despite the use of the biofeedback pressure cuff and visual and oral feedback, the participants could have rolled their bodies toward their backs while performing the ABD-ER exercise. Gravity acting on the lower limb in this position would pull the hip into extension, demanding activation of the TFL to maintain the neutral position. Greater activation of the AHF also was seen during this exercise, supporting this explanation. Even a small change in body position could have a large effect on muscle activity because of the long lever arm of the lower extremity.

We are the first to examine hip-strengthening exercises that include activity of the TFL. The relevance of this muscle to hip motion is great because it acts as a flexor and abductor throughout the entire range of hip motion in the sagittal plane.[23] The placement of the electrodes 2 cm distal to the anterosuperior iliac spine and slightly lateral on the TFL was based on the guidelines of Cram and Kasman.[33] The anterior aspect of the hip joint is an area where many muscles cross or converge; therefore, despite the customary attempts to minimize cross-talk from other muscles, other muscle activity could have contributed to the signal. Of particular concern was the potential influence that the sartorius might have had on the TFL signal. The sartorius is also a primary hip flexor and secondary abductor.[23] The post hoc data we collected on MVICs for the TFL and sartorius demonstrated that the placements for the TFL and sartorius do yield distinct patterns of activity on surface EMG. Although crosstalk between muscles cannot be eliminated with surface EMG, we are confident that the procedures for TFL electrode placement, interelectrode distance, and visual analysis of the data to minimize the influence of crosstalk were consistent with accepted practices.

The muscles that are considered the primary hip external rotators are the GMax and the deep external rotators (gemellus superior, gemellus inferior, obturator internus, obturator externus, piriformis).[22] The activation of the GMax was quite low during the ABD-ER exercise (31.7%±24.1%) and only slightly greater than during the ABD exercise. These data indicated that externally rotating the leg to activate the GMax has little added benefit. A limitation of our study is that the deep external rotators were not monitored, so no conclusions about their activation can be made. The low GMax activity combined with the high activity of the TFL suggests that the ABD-ER exercise is not superior to the ABD exercise for targeting the GMed and GMax muscles.

CLAM Exercise

The rationale for the CLAM exercise is that it can be performed to strengthen the abductor and external rotator muscles simultaneously. Our data did not support this claim because the CLAM exercise showed different patterns of muscle activation than what was expected. The AHF (54.2%±25.2%) was activated more than the other 3 muscles, and activation of the GMed was quite low (32.6%±16.9%). The GMed activation for the CLAM exercise is in the range of what has been reported.[25] The low activity of the GMed during the CLAM exercise can be explained by changes in the moment arms and actions of the muscles with the hip flexed. The CLAM exercise was performed in 45° of hip flexion, and authors of cadaver-based anatomical studies have demonstrated that beyond 40° of hip flexion, the GMed no longer functions as a primary hip abductor.[25] In more than 40° of hip flexion, the GMed functions as an internal rotator, and hip abduction is performed by the deep external rotators.[23,24]

Nyland et al[30] examined muscle activity of the GMed, GMax, TFL, and vastus medialis during an isometric variation of the CLAM exercise. They reported nonnormalized mean peak EMG amplitude, so direct comparison with our data is impossible. Their primary finding was that people with greater hip anteversion demonstrated less vastus medialis and GMed activity than those with typical anteversion.[30] We also measured hip anteversion using the passive hip internal rotation method and found that only 2 participants had passive hip internal rotation angles larger than 42°, which was the criterion used as a cutoff for increased anteversion.[30] Both participants showed activation levels that were in the middle of the data set. However, the degree of anteversion might have influenced the muscle activation during the various exercises.

The high level of AHF activity (54.2%±25.2%) during this exercise is attributed to the need to maintain the hip in a flexed position while the external rotation movement is performed. No researchers have included examination of AHF activity. In many cases, the goal of this exercise is to strengthen the hip abductors and external rotators, and our data did not support activation of the muscles during this exercise. We conclude that the rationale for performing the CLAM exercise is not supported by anatomical or EMG data; therefore, we question the relevance of the exercise.

Clinical Implications

We are the first researchers to evaluate the muscle activity of the AHF and TFL in addition to the GMed and GMax during side-lying hip-strengthening exercises. The Stabilizer Pressure Bio-feedback unit also has not been used in previous studies. This tool was valuable for providing positional feedback so the exercises could be performed with minimal substitution of other muscles.[29] Our participants showed mastery of the exercises when using the device with little practice. Therefore, using this device clinically might be beneficial.

Although no recommendations can be made for injured populations based on our findings, inferences can be made about the potential to strengthen the studied muscles with these exercises. Because achieving more than 40%MVIC is necessary to produce strength adaptations,[32] the ABD exercise is clearly superior to the other 2 for highly activating the GMed with less activation of other muscles. The ABD-ER and the CLAM exercises did not produce high activation of the GMed, and they activated the TFL and AHF to a greater extent. When strengthening the GMed and external rotators is a goal of rehabilitation, activating the TFL and AHF muscles might not be desirable because they might be used as compensatory muscles. Therefore, we conclude that the ABD exercise is optimal for GMed activation when compared with the ABD-ER and CLAM exercises.

Limitations

All participants in our study were distance runners who ran at least 25 miles (40 km) per week, so our results might not be generalizable to the general population. Distance runners were chosen as participants because they commonly have injuries such as PFPS and ITBS that are treated with hip strengthening. Distance runners also typically have little adipose tissue in the hip region, facilitating the accurate collection of surface EMG.

Although the descriptive data for height and mass indicated a homogeneous sample, slight variations in height and body type would alter the torque applied to the hip during the exercise. This limitation was minimized, however, because all comparisons of muscle activation were made within participants, and no between-subjects comparisons were made.

Although surface EMG carries inherent limitations, such as crosstalk, we took all measures possible to maximize the integrity of the signal. Standard skin preparation was performed, all electrodes were placed by the same examiner, interelectrode distance was minimized, and MVIC contractions were performed to confirm that the recorded activity was consistent with the action of the muscle of interest. Despite these measures, some crosstalk might have existed between muscles.

CONCLUSIONS

The ABD exercise is optimal for activating the GMed with little activation of the TFL and AHF. The CLAM exercise caused the greatest activation of the AHF and very little activation of the GMed and GMax. Similarly, the ABD-ER exercise might induce excess activation and strengthening of the TFL beyond what is desired depending on the goals of rehabilitation. This information can be used to make more informed clinical decisions about exercise selection for strengthening the GMed.

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