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Which Exercises Target the Gluteal Muscles While Minimizing Activation of the Tensor Fascia Lata? Electromyographic Assessment Using Fine-Wire Electrodes

Abnormal hip kinematics and impaired hip muscle performance have been associated with various musculoskeletal disorders, such as patellofemoral pain,^{34,40,46,50} iliotibial band syndrome,^{16,37} anterior cruciate ligament injuries,²⁰ low back pain,^{23,25}



and hip joint pathology.^{18,26} For example, several studies have reported that there is significant weakness in hip abduction, external

rotation, and extension, with associated increases in hip internal rotation and knee abduction, during functional tasks in persons with patellofemoral pain compared to pain-free individuals.^{5,10,13,19,22,34,43,44,46,47,50} Based on the apparent association between hip dysfunction and lower extremity injury, there has been an increased focus on hip muscle strengthening as part of rehabilitation protocols.^{14,17,28,35,48,49}

The primary muscle actions at the hip are well known. The middle portion of the gluteus medius (GMED) is an abductor and the gluteus maximus (GMAX) is an extensor and external rotator.³⁶ However, the superior portion of the GMAX (SUP-GMAX) also acts as a hip abductor during gait.²⁷ As such, enhancing performance of the GMED and GMAX has been recommended to control excessive hip adduction and internal rotation during weight-bearing activities.¹²

Recent studies have sought to de-

● **STUDY DESIGN:** Controlled laboratory study, repeated-measures design.

● **OBJECTIVES:** To compare hip abductor muscle activity during selected exercises using fine-wire electromyography, and to determine which exercises are best for activating the gluteus medius and the superior portion of the gluteus maximus, while minimizing activity of the tensor fascia lata (TFL).

● **BACKGROUND:** Abnormal hip kinematics (ie, excessive hip adduction and internal rotation) has been linked to certain musculoskeletal disorders. The TFL is a hip abductor, but it also internally rotates the hip. As such, it may be important to select exercises that activate the gluteal hip abductors while minimizing activation of the TFL.

● **METHODS:** Twenty healthy persons participated. Electromyographic signals were obtained from the gluteus medius, superior gluteus maximus, and TFL muscles using fine-wire electrodes as subjects performed 11 different exercises. Normalized electromyographic signal amplitude was compared among muscles for each exercise, using multiple 1-way repeated-measures analyses

of variance. A descriptive gluteal-to-TFL muscle activation index was used to identify preferred exercises for recruiting the gluteal muscles while minimizing TFL activity.

● **RESULTS:** Both gluteal muscles were significantly ($P < .05$) more active than the TFL in unilateral and bilateral bridging, quadruped hip extension (knee flexed and extending), the clam, sidestepping, and squatting. The gluteal-to-TFL muscle activation index ranged from 18 to 115 and was highest for the clam (115), sidestep (64), unilateral bridge (59), and both quadruped exercises (50).

● **CONCLUSION:** If the goal of rehabilitation is to preferentially activate the gluteal muscles while minimizing TFL activation, then the clam, sidestep, unilateral bridge, and both quadruped hip extension exercises would appear to be the most appropriate. *J Orthop Sports Phys Ther* 2013;43(2):54-64. Epub 16 November 2012. doi:10.2519/jospt.2013.4116

● **KEY WORDS:** EMG, gluteus maximus, gluteus medius, hip

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termine which exercises are best for activating the gluteal muscles.^{1,2,6-8,15,29} Recommended exercises have included the side bridge, wall squat, forward step-up, quadruped upper and lower extremity lift, standing hip abduction (weight bearing on the target/opposite extremity), and sidelying hip abduction.^{1,2,6,15,29} A limitation of these studies is that all of them used surface electromyography (EMG) to assess muscle activity. The use of surface electrodes to detect muscle activity has the potential to contaminate the desired muscle's EMG signal with that of nearby muscles (ie, cross-talk). Fine-wire electrodes limit cross-talk because, unlike surface electrodes, which are applied to the overlying skin, they are inserted directly into the target muscle.⁴⁵ Bogey et al⁴ reported that the EMG signal detected using fine-wire electrodes was specific to the target/sampled muscle, and that the normalized intramuscular signal was representative of the entire muscle.

A second limitation of the studies that have evaluated GMED and GMAX activity during various therapeutic exercise programs is that, with the exception of 2 studies,^{9,29} they did not simultaneously quantify tensor fascia lata (TFL) activity. The TFL, in addition to being an abductor, is an internal rotator of the hip. The TFL can also exert a lateral force on the patella via connections to the iliotibial band, which is connected to the patella and the lateral patellar retinaculum.^{24,30,31} Excessive hip internal rotation and lateral patellar displacement have been linked to conditions such as patellofemoral pain.^{40-42,46} In addition, atrophy of the GMAX muscle relative to the TFL has been observed in persons with degenerative hip joint pathology.¹⁸ For certain conditions, therefore, it would appear appropriate to design rehabilitation programs using therapeutic exercises that promote activity of the GMED and GMAX while minimizing recruitment of the TFL.

A review of the literature revealed that 3 studies have performed direct statistical comparisons of EMG signal amplitudes among hip muscles for different

therapeutic exercises.^{2,29,39} However, only 1 study used fine-wire EMG, and descriptive comparisons were made between the GMED and iliopsoas and did not include the TFL.³⁹ To our knowledge, no prior study has compared gluteal muscle and TFL activation across a broad spectrum of exercises using fine-wire EMG. In addition, no study specifically investigated the SUP-GMAX. As such, the purpose of the current study was to investigate hip abductor muscle activation using fine-wire EMG for a selected number of therapeutic exercises. In particular, we sought to determine which exercises would best activate the GMED and SUP-GMAX while minimizing TFL activity. Information gained from this study may be useful for planning therapeutic exercise programs specific to certain lower extremity musculoskeletal disorders.

METHODS

TWENTY HEALTHY VOLUNTEERS (10 men and 10 women) between the ages of 18 and 50 years (mean \pm SD age, 27.9 ± 6.2 years) participated. Subjects were recruited from the University of Southern California (Los Angeles, CA) and Western University of Health Sciences (Pomona, CA) communities. Subjects were excluded if they reported any musculoskeletal disorders of the trunk or lower extremities, or any neurological conditions. Prior to participation, all subjects were given a detailed explanation of the study and signed an informed consent form approved by the Institutional Review Boards of the University of Southern California and Western University of Health Sciences. The rights of subjects were protected.

Instrumentation

EMG data were collected using an MA-300-16 EMG system (Motion Lab Systems, Inc, Baton Rouge, LA), with a common-mode rejection ratio of greater than 110 dB at 65 Hz, MA-416 discrete preamplifiers, a gain of $1 \text{ kHz} \times 20\% \pm 1\%$, and an input impedance of greater

than 1 M Ω . The raw EMG signal was recorded at a sampling rate of 1560 Hz.

The fine-wire electrodes consisted of pairs of presterilized, disposable, 50- μm nickel-chromium alloy wires, nylon-insulated except for 2 mm of exposed wire at their ends, which were inserted into the muscle.³³ Disposable 25-gauge needles were used as cannulas to place the electrodes within the muscles of interest.

Procedures

The skin over the lateral hip and buttock of the dominant lower extremity (that used to kick a ball) was cleaned with rubbing alcohol. Fine-wire electrodes were then inserted into the SUP-GMAX, GMED, and TFL muscles. Electrode locations for these muscles were based on the recommendations of Delagi and Perotto¹¹ and Lyons et al.²⁷ Briefly, the electrode insertion for the SUP-GMAX was superior and lateral to the midpoint of a line drawn between the posterior superior iliac spine and the posterior greater trochanter. The GMED electrode was inserted 2.5 cm distal to the midpoint of the iliac crest (ie, middle portion). The TFL electrode was inserted distal and slightly lateral to the anterior superior iliac spine and medial and superior to the greater trochanter. The reference electrode was placed over the C7 spinous process.

The electrode wires were taped to the skin, with a loop of wire created at the insertion site to prevent accidental dislodging during movements.³³ The free ends of the wire electrodes were stripped of insulation using fine sandpaper, where they were attached to metal terminals connecting the rest of the detection system. The metal terminals were taped to the skin of the lateral thigh. The wire electrodes were inserted by a physical therapist who was receiving certification in kinesiological EMG in the state of California. This individual was supervised by 2 other physical therapists who had a combined 50 years of experience as certified kinesiological EMG practitioners. Confirmation of electrode placement in the appropriate muscle was made using

electrical stimulation of the target muscles and observation and palpation of the contractile responses. The muscles were stimulated via the wire electrodes at the wires' attachments to the preamplifier terminals.

Upon verification of an EMG signal for each muscle, maximum voluntary isometric contractions (MVICs) of 5 seconds' duration were performed for each muscle in random order. One MVIC trial was performed for each muscle. The EMG signal collected during MVIC testing was used to normalize the EMG signal for each muscle. The highest EMG signal amplitude was used for each muscle, regardless of the MVIC test position/activity in which it was obtained.

Neither the functional differentiation of the GMAX nor the best position for eliciting its maximum activity has been well established; therefore, multiple test positions were used for MVIC testing of the SUP-GMAX. For 1 of the tests, maximal hip extension was resisted using a strap across the distal posterior thigh, with the upper body prone on a treatment table and the hip at an angle of 45° of flexion and the knee at 90° of flexion. The SUP-GMAX also was tested, such that hip extension was resisted with the subject lying fully prone, with the knee flexed to 90°. The MVIC for the GMED was obtained during resisted hip abduction while subjects were sidelying on the treatment table on the side opposite to that being tested, with the posterior pelvis and scapulae back against an adjacent wall. Subjects exerted maximal abduction force against a strap across the distal lateral leg, in a position of 30° of hip abduction, with the hip and knee at 0° of flexion. The MVIC for the TFL was obtained in the same sidelying position used for the GMED, except that the hip was positioned in 45° of flexion and 30° of abduction. Subjects exerted a maximal force against the strap in a diagonal plane, about 45° between the sagittal and coronal planes. Manual resistance was added to the strap to help ensure that the subjects were achieving a maximal effort.

Following MVIC testing, subjects performed 11 exercises in a random order: hip abduction in sidelying (ABD), clam with elastic resistance around thighs (CLAM), bilateral bridge (BiBRG), unilateral bridge (UniBRG), hip extension in quadruped on elbows with knee extending (QKE), hip extension in quadruped on elbows with knee flexed (QKF), forward lunge with erect trunk (LUNGE), squat (SQUAT), sidestep with elastic resistance around thighs in a squatted position (SIDESTEP), hip hike (HIKE), and forward step-up (STEP-UP). Descriptions of each exercise can be found in the **APPENDIX**. Prior to data collection, subjects were familiarized with the testing protocol and received instruction in and practiced the exercises to ensure proper performance. On rare occasion, an exercise had to be repeated because of a "false start" or lack of synchronization between the subject and the examiners or metronome.

A metronome was set at 40 beats per minute to pace the exercises, with the exception of the SIDESTEP, which was paced at 80 beats per minute. Five repetitions of each exercise were performed, with the exception of the SIDESTEP, in which 3 sets of 2 strides (**APPENDIX**) were completed in each direction. For each exercise, the concentric and eccentric phases of the repetitions each comprised 1 metronome beat, and there was 1 beat of rest between each repetition. An event marker was manually triggered during each exercise. This was used, along with visual inspection of the recorded signal, which was the reference standard,²¹ to assist in determining the beginning and end of each repetition. A rest of at least 2 minutes was given between each exercise.

EMG Analysis

Raw EMG signals were imported into MATLAB software (The MathWorks, Inc, Natick, MA) for processing. EMG data were band-pass Butterworth filtered at 35 to 750 Hz. The use of the high-cut/low-pass boundary of the filter (750 Hz) followed recommended guidelines³²;

however, the low-cut/high-pass boundary was slightly higher than that recommended by these guidelines, due to issues involving low-frequency artifact in our laboratory, though it followed other recommended guidelines for considering low-frequency artifact.³⁸ The amplitude of the EMG signal was obtained by deriving the root-mean-square (RMS) of the signal over a 75-millisecond moving window, resulting in full-wave rectification and smoothing of the raw signal. For statistical comparisons, the normalized EMG signal amplitude during the exercises was expressed as a percentage of EMG obtained during the MVIC. The highest EMG signal amplitude obtained for each muscle during any MVIC testing procedure described above was used for normalization purposes. The highest EMG signal was defined as the highest mean RMS obtained over a consecutive 1-second period of the MVIC test.

The primary dependent variable of interest was the mean RMS (% MVIC) from each muscle for each exercise repetition. After obtaining the mean RMS for each repetition of a given exercise, the mean of the repetitions was used in the statistical analysis. Intrarater reliability of obtaining the mean RMS of each muscle of interest using the visual estimation of contraction time (as described above) was assessed by reanalyzing a portion of the data set on a second occasion (5 subjects, 2 exercises, 5 repetitions). Using the intraclass correlation coefficient (model 3,1), reliability was found to be excellent for the SUP-GMAX (0.99), GMED (0.99), and TFL (0.99).

The signal-to-noise ratio was calculated from a portion of the collected EMG data, based on the following equation: $20\log_{10}(\text{signal}_{\text{RMS}}/\text{noise}_{\text{RMS}})$, where *signal* is the mean over the time course of the contraction and *noise* is the baseline activity. Based on these data, the signal-to-noise ratio was determined to be 20.2 dB.

Statistical Analysis

A 3-way analysis of variance (ANOVA) (sex by exercise by muscle) was initially

TABLE 1

NORMALIZED ELECTROMYOGRAPHIC AMPLITUDE OF EACH MUSCLE FOR EACH EXERCISE*

Exercise	Tensor Fascia Lata	Gluteus Medius	Superior Gluteus Maximus
Sidelying hip abduction	32.3 ± 13.1	43.5 ± 14.7 (<i>P</i> = .012) [†]	23.7 ± 15.3 (<i>P</i> = .033) [‡]
Bilateral bridge	8.2 ± 7.4	15.0 ± 10.5 (<i>P</i> = .011) [†]	17.4 ± 11.9 (<i>P</i> = .008) [†]
Clam	11.4 ± 11.4	26.7 ± 18.0 (<i>P</i> = .006) [†]	43.6 ± 26.1 (<i>P</i> < .001) [†]
Hip hike	31.4 ± 14.4	37.7 ± 15.1 (<i>P</i> = .196)	17.7 ± 15.2 (<i>P</i> = .001) [‡]
Lunge	21.6 ± 14.5	19.3 ± 12.9 (<i>P</i> = .623)	20.1 ± 11.1 (<i>P</i> = .728)
Quadruped hip extension, knee extending	15.6 ± 9.3	27.3 ± 14.9 (<i>P</i> < .002) [†]	28.5 ± 16.6 (<i>P</i> < .007) [†]
Quadruped hip extension, knee flexed	18.7 ± 10.6	30.9 ± 15.2 (<i>P</i> = .001) [†]	30.1 ± 12.5 (<i>P</i> = .012) [†]
Sidestep	13.1 ± 7.1	30.2 ± 15.7 (<i>P</i> = .002) [†]	27.4 ± 16.7 (<i>P</i> = .002) [†]
Squat	4.6 ± 3.8	9.7 ± 7.3 (<i>P</i> = .017) [†]	12.9 ± 7.9 (<i>P</i> < .001) [†]
Step-up	21.4 ± 11.4	29.5 ± 14.9 (<i>P</i> = .065)	22.8 ± 15.6 (<i>P</i> = .754)
Unilateral bridge	18.1 ± 12.9	30.9 ± 20.7 (<i>P</i> = .007) [†]	34.6 ± 16.8 (<i>P</i> = .001) [†]

*Values are mean ± SD percent maximum voluntary isometric contraction.

[†]Significantly greater than tensor fascia lata (*P* < .05).

[‡]Significantly less than tensor fascia lata (*P* < .05).

performed to determine if there was a difference in muscle activation across the various exercises and muscles between men and women. This analysis revealed that there were no main effects or interaction effects with regard to sex. As such, data from both sexes were combined for all analyses.

Based on our research question, 1-way repeated-measures ANOVAs were used to compare the EMG signals among the muscles of interest for each exercise. As the purpose of this study was to assess the difference between each of the gluteal muscles and the TFL within each exercise, specific paired comparisons among the muscles were planned a priori. Therefore, if the 1-way ANOVAs revealed a significant difference in EMG signal among the muscles for a given exercise, simple contrast tests were used to analyze the paired comparisons, with the TFL as the reference for comparison (ie, each gluteal muscle was compared to the TFL). The alpha level was .05 for all tests of significance.

The gluteal-to-TFL muscle activation (GTA) index, a novel descriptive analysis, was performed to quantify the combined relative activation of the gluteal muscles

compared to the TFL for each exercise. Specifically, the GTA index used the mean normalized EMG values to create relative activation ratios of both the SUP-GMAX and GMED compared to the TFL (ie, SUP-GMAX/TFL and GMED/TFL). The relative activation ratio for each gluteal muscle was multiplied by that muscle's mean normalized EMG value, summed, and then divided by 2 to provide the GTA index: $\{[(GMED/TFL) \times GMED] + [(SUP-GMAX/TFL) \times SUP-GMAX]\}/2$.

The GTA index is similar in principle to activation indexes created for other muscle combinations to assess muscle activation relationships (eg, cocontraction of muscles crossing the knee during running and cutting maneuvers³). Given the GTA index equation, an exercise with a high GTA index would be one in which there were high normalized EMG amplitudes of both gluteal muscles, and both of these amplitudes were higher compared to the TFL amplitude. In contrast, an exercise could produce higher EMG amplitudes of the gluteal muscles relative to the TFL but at the same time produce relatively low EMG amplitudes overall. In this instance, the GTA index would be considerably lower.

RESULTS

TABLE 1 PROVIDES THE NORMALIZED mean EMG amplitudes for each muscle for each exercise, and identifies any significant differences among the muscles in each exercise, based on the 1-way repeated-measures ANOVAs and simple contrast tests.

The 1-way repeated-measures ANOVAs were statistically significant for the following exercises: ABD (*P* < .001), BiBRG (*P* < .001), CLAM (*P* < .001), HIKE (*P* < .001), QKE (*P* = .002), QKF (*P* = .003), SIDESTEP (*P* < .001), SQUAT (*P* = .001), and UniBRG (*P* = .004). The 1-way repeated-measures ANOVAs for the LUNGE and STEP-UP exercises were not statistically significant (*P* = .853 and .135, respectively).

For all of the exercises in which the ANOVA was significant, with the exception of ABD and HIKE, contrast test results revealed that both the GMED and SUP-GMAX had significantly higher normalized EMG amplitudes than the TFL. For ABD, the contrast tests revealed that the normalized EMG amplitude for the GMED was significantly greater than the TFL (*P* = .012); however, the SUP-GMAX was significantly less than the TFL (*P* = .033). For HIKE, the contrast tests revealed that the normalized EMG amplitude for the GMED was not significantly different from the TFL (*P* = .196); however, the SUP-GMAX was significantly less than the TFL (*P* = .001).

Five exercises demonstrated a GTA index of at least 50: CLAM, SIDESTEP, UniBRG, QKE, and QKF. In contrast, the 6 remaining exercises exhibited a GTA index of less than 40: ABD, STEP-UP, BiBRG, SQUAT, HIKE, and LUNGE. The ranking of exercises using the GTA index is displayed in TABLE 2.

DISCUSSION

THE PURPOSE OF THE CURRENT investigation was to compare the EMG signal amplitudes of the hip abductor muscles during selected thera-

TABLE 2

GLUTEAL-TO-TFL INDEX FOR EACH EXERCISE

Exercise	Gluteal-to-TFL Activation Index
Clam*	115
Sidestep*	64
Unilateral bridge*	59
Quadruped hip extension, knee extending*	50
Quadruped hip extension, knee flexed*	50
Sidelying hip abduction	38
Step-up	32
Bilateral bridge*	32
Squat*	28
Hip hike	28
Lunge	18

Abbreviation: TFL, tensor fascia lata.

*Exercises in which both gluteal muscles demonstrated significantly higher normalized electromyographic signal amplitude than the TFL.

peutic exercises to determine which exercises would most activate the GMED and SUP-GMAX while minimizing activation of the TFL. The current investigation is based on the premise that excessive activation of the TFL during therapeutic exercises may be counterproductive in the treatment of persons with musculoskeletal disorders in which excessive hip internal rotation may be a contributing factor.

The results of the ANOVA and contrast tests demonstrated that the majority of the exercises evaluated preferentially activated the gluteal muscles while limiting recruitment of the TFL. These exercises included the QKF, QKE, UniBRG, BiBRG, SQUAT, SIDESTEP, and CLAM. All of these exercises produced greater than 50% higher normalized EMG amplitudes for both gluteal muscles compared to the TFL. During ABD, only the GMED exhibited significantly greater normalized EMG amplitude than the TFL. For the STEP-UP, LUNGE, and HIKE, normalized EMG amplitudes of the gluteal muscles and the TFL were not statistically different, with the exception of the SUP-GMAX, which exhibited lower normalized EMG amplitude compared to the TFL during HIKE.

The greatest normalized EMG am-

plitudes for the GMED occurred during the ABD and HIKE exercises. These results are in agreement with data reported by Bolgla and Uhl,⁶ who recommended both of these exercises for activating the GMED. However, these authors did not measure activation of the TFL. In the current study, the greatest normalized EMG amplitudes of the TFL also were observed during both of these exercises. During ABD, the GMED was significantly more active than the TFL; however, there was no statistically significant difference between these 2 muscles for HIKE. Nonetheless, activity of the TFL was significantly greater than that of the SUP-GMAX in both exercises. Our findings for the ABD exercise are also in agreement with the surface EMG study of McBeth et al,²⁹ who reported that the GMED had significantly greater activity than the TFL and that the TFL had significantly greater activity than the GMAX.

The normalized EMG amplitude for the SUP-GMAX was highest in the CLAM exercise and second highest in UniBRG. This finding may be attributed to the fact that these exercises incorporate greater amounts of hip external rotation and extension compared to the other exercises evaluated. Both the SUP-GMAX and the GMED had significantly

greater activity than the TFL. In contrast to the current study, McBeth et al²⁹ found no significant differences between the TFL and gluteal muscles during the CLAM exercise. However, it should be noted that McBeth et al²⁹ used a different type of resistance for this exercise than that used in the current study and a general surface-electrode placement for the GMAX rather than specifically targeting the SUP-GMAX.

Although ABD and HIKE require greater amounts of hip abduction than other exercises tested, the SUP-GMAX was not activated to levels consistent with the GMED and TFL. The SUP-GMAX may be more of a secondary hip abductor in these exercises compared to the GMED and TFL, with less activation required (particularly at submaximal loads).

At face value, the amount of gluteal activation compared to the TFL may appear to be adequate to recommend exercises for rehabilitation programs in which the goal is to emphasize activation of the GMED and SUP-GMAX while minimizing TFL activity. However, another consideration in making exercise recommendations is the actual normalized EMG amplitude levels of the muscles during the different exercises. Of the 7 exercises in which both gluteal muscles showed significantly greater EMG amplitude than the TFL, the BiBRG and SQUAT produced relatively low normalized EMG amplitudes of both the GMED and SUP-GMAX. For example, the normalized EMG amplitude levels of all the tested muscles in the BiBRG exercise were approximately half of those in the UniBRG. During the SQUAT exercise, the gluteal muscles demonstrated even lower normalized EMG amplitudes. As such, we developed the GTA index to better characterize exercises based on their ability to preferentially activate the gluteals relative to the TFL, while exhibiting high normalized EMG amplitudes.

Of the exercises examined, the CLAM, SIDESTEP, UniBRG, QKE, and QKF exercises had GTA index values of 50 or greater (TABLE 2). These exercises would,

therefore, be most desirable to produce high levels of GMED and SUP-GMAX activity while minimizing activation of the TFL. The designation of 50 as the GTA index cutoff value to indicate a “desirable” exercise was based, in part, on where the data clustered and the results of the parametric statistical testing (except for the 2 exercises with high relative activation ratios but low signal amplitudes and, therefore, low GTA indexes). In addition, these 5 exercises produced EMG signal amplitudes greater than 25% MVIC for each of the gluteals and less than 20% MVIC for the TFL.

The CLAM had the highest SUP-GMAX normalized EMG amplitude and one of the lowest TFL amplitudes of all the exercises examined. These factors contributed to its having the highest GTA index. This finding is consistent with the fact that the CLAM requires more hip external rotation and abduction than the other exercises. In addition, it was 1 of 2 exercises performed with external resistance (elastic tubing). The SIDESTEP had one of the lowest TFL normalized EMG amplitudes, which contributed to its having the second highest GTA index. The SIDESTEP was performed in a squat position with elastic tubing around the distal thighs, and both the position and resistance might have augmented activation of the gluteals. Cambridge et al⁹ studied a similar exercise and reported that the TFL had lower surface EMG signal amplitude than the GMED but greater amplitude than the GMAX. This is contrary to our findings, in which the TFL had significantly lower EMG signal amplitudes than both the GMED and SUP-GMAX. However, Cambridge et al⁹ did not perform statistical comparisons among the muscles, nor did they specifically assess the SUP-GMAX. Thus, it is not possible to accurately determine the nature of the relationships among the muscles in their study and compare the 2 studies.

The ABD, STEP-UP, HIKE, and LUNGE exercises produced GTA indexes less than 40 (TABLE 2). In addition, these

exercises did not demonstrate significantly greater normalized EMG amplitude of both gluteal muscles compared to the TFL, based on statistical testing. As such, these exercises are not recommended to preferentially activate the GMED and SUP-GMAX while minimizing activation of the TFL.

The BiBRG and SQUAT exercises would have been considered favorable based on the results of the ANOVAs and contrast tests, as well as the relative activation ratios of the gluteals to the TFL. However, these exercises were in the lower tier of the GTA index ranking (TABLE 2). This was the result of low normalized EMG amplitudes of the gluteal muscles during these exercises. The relatively low GTA index values for each of these 2 exercises call into question their usefulness for rehabilitation purposes when the training favors higher activation levels. If the BiBRG and SQUAT were performed with greater resistive loads, it is likely that their GTA indexes would increase, as would the activity levels of all of the muscles with greater resistive loads; however, the relative activation ratios would not be expected to change as long as the exercises were properly performed. Such an increase in activation of the gluteal muscles with no change in relative activation ratios would, by definition (see equation), cause the GTA index to increase.

TABLE 2 presents the tested exercises in descending order of magnitude of the GTA index, illustrating how the GTA index could be used to make recommendations for therapeutic exercise prescription. However, the GTA index should be used with caution and in combination with the results of the inferential statistics, as well as an assessment of the relative activation of both gluteal muscles to the TFL. The reason for this qualification is that the GTA index can be artificially high even if the TFL EMG signal amplitude is relatively high. This could be so if the EMG amplitude of one of the gluteal muscles were low while that of the other were high relative to the am-

plitude of the TFL. For example, if both the SUP-GMAX and the TFL had normalized EMG amplitudes of 60% MVIC and that of the GMED was only 10%, the GTA index value would be 62.5 (still relatively high). Therefore, the GTA index should not be considered in isolation as a means of rating exercises based on relative gluteal-to-TFL muscle activity unless it has been calculated only for those exercises in which both gluteal muscles demonstrated a normalized EMG amplitude significantly greater than that of the TFL. Based on the framework presented earlier, a desirable exercise would be one in which the normalized EMG amplitude of both the GMED and SUP-GMAX muscles was greater than that of the TFL.

A limitation of the current study is that the CLAM and SIDESTEP exercises used elastic resistance that was not quantified in absolute or relative terms. Also, it is possible that without the added resistance, these exercises would have had lower normalized EMG amplitudes and GTA indexes. However, as with BiBRG and SQUAT, it appears that any exercises that were beneficial, based on the relative activation of the gluteal muscles to the TFL, but had a less desirable GTA index because of overall low actual activation might become desirable (achieve higher GTA indexes) by increasing the applied resistance. It should also be noted that this study was performed on a sample of healthy, uninjured individuals. Whether the findings may be generalized to specific patient populations remains to be seen. In addition, we did not quantify activation of the gluteus minimus, which represents approximately 20% of the total hip abductor cross-sectional area. Based on its origin and insertion, however, there is no reason to suspect that activation of the gluteus minimus for any of the exercises evaluated would differ from that of the GMED.

CONCLUSIONS

IF THE GOAL OF REHABILITATION IS TO preferentially activate the gluteal muscles while minimizing TFL activation,

then the CLAM, SIDESTEP, UniBRG, QKE, and QKF exercises appear to be most appropriate. This is based on the fact that all of these exercises produced significantly greater normalized EMG in both the GMED and the SUP-GMAX muscles relative to the TFL. ●

KEY POINTS

FINDINGS: The GMED and SUP-GMAX muscles were significantly more active than the TFL in UniBRG and BiBRG, QKF and QKE, CLAM, SIDESTEP, and SQUAT. The GTA index was highest for the CLAM, SIDESTEP, UniBRG, and both quadruped exercises.

IMPLICATIONS: If the goal of rehabilitation is to preferentially activate the gluteal muscles while minimizing TFL activation, then the CLAM, SIDESTEP, UniBRG, and both quadruped hip extension exercises appear to be most effective.

CAUTION: This study was conducted using a sample of healthy, pain-free subjects. Results may differ in persons with various musculoskeletal disorders and selective hip weakness.

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APPENDIX



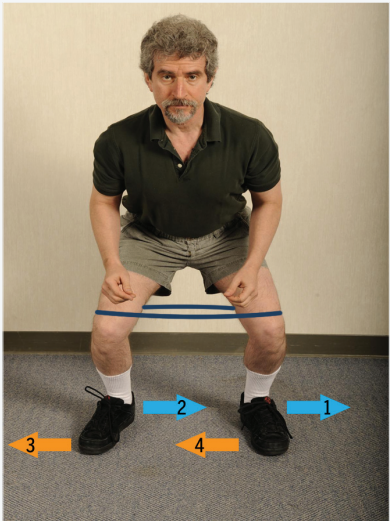
EXERCISES PERFORMED IN THE STUDY

Exercise	Description	Image
Hip abduction in sidelying	Starting position was lying on a treatment table, on the side opposite the tested limb. The table was placed along a wall. The lower extremity on the table was flexed to 45° at the hip and 90° at the knee. The subject's back and plantar foot were against the wall for control of position and movement. The subject then abducted the tested hip to approximately 30° and then returned the limb to the table. To control for the correct movement, the subject kept the heel in light contact with the wall (via a towel) while sliding it along the wall, with the toes pointed horizontally away from the wall.	

APPENDIX



Exercise	Description	Image
Clam in sidelying, with elastic resistance around thighs	Starting position was lying on a treatment table on the side opposite the tested limb. The table was placed along a wall. Both limbs were flexed to 45° at the hip and 90° at the knee, with the tested limb on top of the other limb. The subject's back and plantar surface of the foot were placed against the wall for control of position and movement. The subject raised the tested limb's knee up off the other limb, such that the hip was in 30° of abduction, before returning to the starting position while keeping both heels in contact with each other and the wall. Subjects performed this activity with blue-colored Thera-Band (The Hygenic Corporation, Akron, OH) tubing around the distal thighs, with no stretch or slack on the tubing prior to raising the limb. The elastic resistance was used because the motion involved is a multiplanar arc that is only minimally resisted by gravity.	
Bilateral bridge	Starting position was hook-lying with the knees at 90° of flexion, hips at 45° of flexion, 0° of rotation and abduction, trunk in neutral, and feet flat on the table. The subject then pushed both feet into the table to raise the pelvis until a position of 90° of knee flexion was achieved bilaterally before returning to the starting position. The hips remained at 0° of rotation and abduction during the exercise, with the trunk in neutral.	
Unilateral bridge	Starting position was unilateral hook-lying, as that described for the bilateral bridge, except that the nontested lower limb remained on the table (0° at the hip and knee). The subject then pushed with the tested limb's foot into the table to raise the pelvis until a position of 90° of knee flexion was achieved ipsilaterally, before returning to the starting position. The nontested lower limb moved up and down with the pelvis, without changing the positions of its joints. The hips remained at 0° of rotation and abduction during the exercise, with the pelvis and trunk in neutral.	
Hip extension in quadruped on elbows with knee extending	Starting position was quadruped, with the upper body supported by the elbows and forearms, and the knees and elbows at approximately 90° of flexion. The subject then lifted the tested lower limb up and backward, extending the hip and knee to 0°, and then returned to the starting position.	
Hip extension in quadruped on elbows with knee flexed	This exercise was performed in the same manner as described for quadruped with knee extending, except that the subject maintained the knee in 90° of flexion throughout the exercise.	

APPENDIX

Exercise	Description	Image
Forward lunge with erect trunk	Starting position was standing with the knees and hips at 0° in the sagittal and coronal planes, with the feet/toes pointed straight ahead in midline. The subject then stepped forward with the tested limb to position it at 90° of knee and hip flexion, with the other limb at 90° of knee flexion and 0° at the hip (knee not contacting the floor). The knees moved over the second toe of the ipsilateral limb so that the limbs moved in the sagittal plane. The floor was marked to facilitate correct foot and knee placement, and a pillow was placed as a contact guide for the knee of the nontested limb.	
Squat	Starting position was standing with the knees and hips at 0° in the sagittal plane, with slight hip external rotation, such that the feet/toes pointed laterally from midline approximately 15°. The distance between the feet in the coronal plane was two thirds of the length from the greater trochanter to the floor (measured in the erect standing position), so that the hips were in slight abduction. Subjects then squatted so that the knees and hips were at approximately 90° of flexion, with the knees moving in a direction parallel to the toes (ie, over the second toe of the ipsilateral limb).	
Sidestep with elastic resistance around the thighs in a squatted position	Starting position was in a squatted position, as described above for the squat. The subject then stepped to the side with one limb, followed in the same direction by the other limb, both step lengths approximately 50% of the starting-position distance between the feet (see squat). Knees were kept aligned with the ipsilateral second toe. If a sidestep with each limb in succession was considered a stride, then the subject performed a total of 2 strides in one direction, followed by 2 strides in the opposite direction to return to the starting position. This activity cycle was performed a total of 3 times. The same method of elastic resistance was used in this exercise as in the clam exercise, because there was otherwise little resistance to the sideways movement.	

[RESEARCH REPORT]

APPENDIX

Exercise	Description	Image
Hip hike	Starting position was standing on an elevated platform, with the knees and hips at 0° in the sagittal and coronal planes, and the feet/toes pointed straight ahead in midline. The subject remained weight bearing on the tested lower limb while alternately raising and lowering the other limb off the edge of the platform (by raising and lowering the pelvis), maintaining the knees at 0°.	 A person wearing a dark green polo shirt and khaki shorts is standing on a black step. They are performing a hip hike, with their right leg on the step and their left leg raised off the ground. The step has the word 'STEP' printed on it.
Forward step-up	Starting position was with the foot of the tested limb on a step, at a height resulting in approximately 90° of knee flexion with the tibia vertical. The subject then pushed the tested foot down on the step to raise the nontested foot off the floor to the level of the step, without resting the nontested foot on the step. At this point, the subject was in unilateral weight bearing on the tested limb such that the tested limb's knee and hip were both at 0°, with the trunk erect. The subject then returned to the starting position. During the entire exercise, the body was maintained in the sagittal plane, with the tested limb's knee over the ipsilateral toes.	 A person wearing a dark green polo shirt and khaki shorts is performing a forward step-up exercise on a black step. They are in a unilateral weight-bearing position on their right leg, with their left leg raised off the ground. The step has the word 'STEP' printed on it.

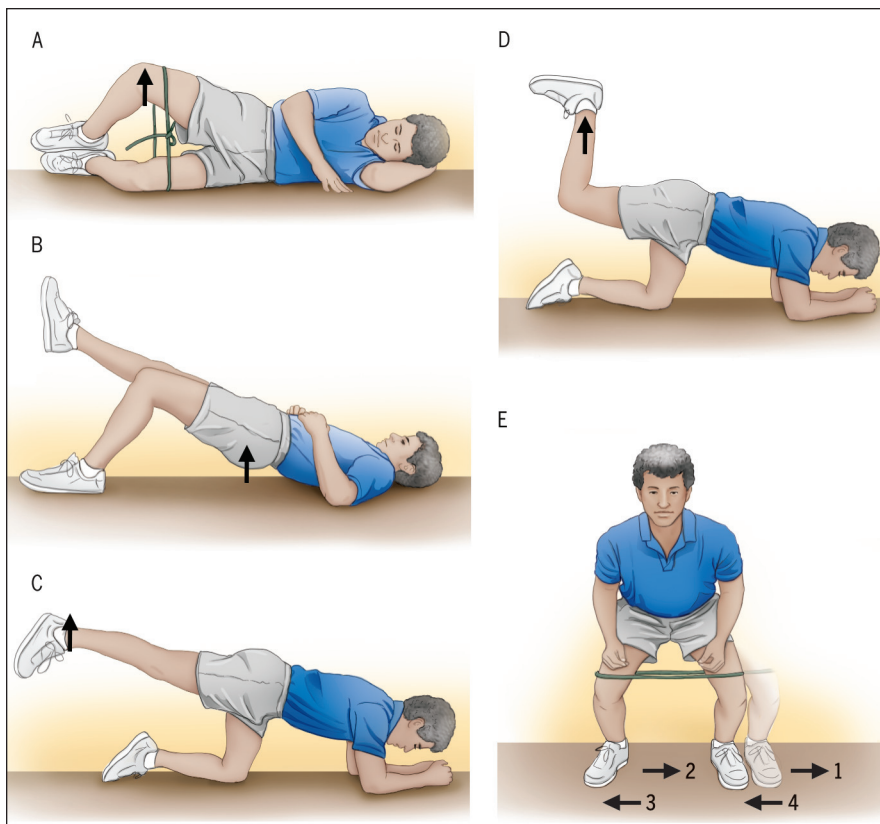
Strengthening Your Hip Muscles

Some Exercises May Be Better Than Others

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Weak hip muscles lead to poor hip motion, and poor hip motion can cause knee, hip, and back pain. By exercising to strengthen the hip muscles that control how your hip moves, you can reduce your pain in these parts of your body. The 2 key muscles to include in your exercise program are the gluteus maximus (the chief muscle on the back of your hip—your buttocks) and the gluteus medius (the main muscle on the side of your hip). However, it is often

difficult to strengthen these muscles without also strengthening a muscle called the tensor fascia lata, which is located toward the front of the hip. Too much activation of that muscle may create unwanted hip motion that may worsen knee, hip, or back pain. A study published in the February 2013 issue of *JOSPT* provides information intended to help physical therapists and their patients select exercises that target the buttock muscles without causing other unwanted muscle actions.



HIP EXERCISES. (A) Clam exercise: while lying on your side with knees bent, rotate the top leg upward; (B) single-leg bridge exercise: while lying on your back with one knee bent and the other leg straight, lift your buttocks off the floor or table using the knee that is bent, while keeping the other leg straight; (C and D) hip extension exercises on all fours: while on hands and knees, extend one leg upward—this exercise can be done with the leg straight (harder) or with the knee bent (easier); (E) sidestep exercise: while in a slight squat position, take small steps sideways while keeping your toes pointed forward.

NEW INSIGHTS

In this study, the researchers had 20 healthy people perform 11 different hip exercises commonly used for both fitness and rehabilitation. While the participants performed the exercises, fine wires were used to record the amount of electrical activity within the 3 muscles. This indicated how much each muscle was working. The researchers' goal was to discover which exercises used the gluteus maximus and gluteus medius muscles the most, while minimizing the action of the tensor fascia lata. They found that 5 specific exercises worked best: the clam, the single-leg bridge, hip extension while on both hands and knees (with the knee bent or straight), and the sidestep.

PRACTICAL ADVICE

Patients with certain types of knee, hip, or back pain may benefit from focusing on the 5 exercises recommended by these researchers. Your physical therapist can help determine which of these exercises are best for you and customize a treatment program based on your diagnosis, your level of pain, and your current and desired hip function. Even if you do not have any pathology or pain, you may want to incorporate these 5 exercises in your general fitness or strength program.

For this and more topics, visit *JOSPT Perspectives for Patients* online at www.jospt.org.

This *JOSPT Perspectives for Patients* is based on an article by Selkowitz et al, titled "Which Exercises Target the Gluteal Muscles While Minimizing Activation of the Tensor Fascia Lata? Electromyographic Assessment Using Fine-Wire Electrodes," *J Orthop Sports Phys Ther* 2013;43(2):54-64. doi:10.2519/jospt.2013.4116.

This Perspectives article was written by a team of *JOSPT's* editorial board and staff, with Deydre S. Teyhen, PT, PhD, Editor, and Jeanne Robertson, Illustrator.



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