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Rehabilitation Exercise Progression for the Gluteus Medius Muscle With Consideration for Iliopsoas Tendinitis

An In Vivo Electromyography Study

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Investigation performed at the Steadman Philippon Research Institute, Vail, Colorado

Background: It is common for hip arthroscopy patients to demonstrate significant gluteus medius muscle weakness and concurrent iliopsoas tendinitis. Restoration of gluteus medius muscle function is essential for normal hip function.

Hypothesis: A progression of hip rehabilitation exercises to strengthen the gluteus medius muscle could be identified that minimize concurrent iliopsoas muscle activation to reduce the risk of developing or aggravating hip flexor tendinitis.

Study Design: Descriptive laboratory study.

Methods: Electromyography (EMG) signals of the gluteus medius and iliopsoas muscles were recorded from 10 healthy participants during 13 hip rehabilitation exercises. The indwelling fine-wire EMG electrodes were inserted under ultrasound guidance. The average and peak EMG amplitudes, normalized by the peak EMG amplitude elicited during maximum voluntary contractions, were determined and rank-ordered from low to high. The ratio of iliopsoas to gluteus medius muscle activity was calculated for each exercise. Exercises were placed into respective time phases based on average gluteus medius EMG amplitude, except that exercises involving hip rotation were avoided in phase I (phase I, initial 4 or 8 weeks; phase II, subsequent 4 weeks; phase III, final 4 weeks).

Results: A continuum of hip rehabilitation exercises was identified. Resisted terminal knee extension, resisted knee flexion, and double-leg bridges were identified as appropriate for phase I and resisted hip extension, stool hip rotations, and side-lying hip abduction with wall-sliding for phase II. Hip clam exercises with neutral hips may be used with caution in patients with hip flexor tendinitis. Prone heel squeezes, side-lying hip abduction with internal hip rotation, and single-leg bridges were identified for phase III.

Conclusion/Clinical Relevance: This study identified the most appropriate hip rehabilitation exercises for each phase to strengthen the gluteus medius muscle after hip arthroscopy and those to avoid when iliopsoas pain or tendinitis is a concern.

Keywords: hip rehabilitation; electromyography; gluteus medius muscle; iliopsoas muscle

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The gluteus medius muscle is one of the strongest lower extremity muscles.²² Appropriate strength of the gluteus medius muscle has been positively linked to improved performance.^{1,14,19} A weak or fatigued gluteus medius muscle results in excessive pelvic rotation and femoral internal rotation,²³ consequently leading to pain or injury.^{3,15,17,18} Proper strength and conditioning of this muscle is also important because it influences hip,² knee,^{3,15,16} and lower back¹⁷ function. Physical examination of patients with hip pain often reveals weakness or inhibition of the gluteus medius muscle and this strength loss increases after hip surgery. Further, we have often found gluteus medius muscle weakness to be accompanied by iliopsoas muscle tendinitis and believe that these clinical entities may be functionally linked.

Iliopsoas pain or tendinitis is common during postoperative rehabilitation.²¹ Although there is limited evidence, it is plausible that the rehabilitation exercises addressing gluteus medius weakness may also aggravate an inflamed iliopsoas muscle. The selection of the appropriate exercises

to strengthen the gluteus medius muscle, while reducing activation of the iliopsoas muscle, is difficult because the relative activation of these muscles during the performance of hip rehabilitation exercises is currently unknown. Therefore, our purpose was to investigate gluteus medius and iliopsoas muscle activity during hip rehabilitation exercises and design a continuum of gluteus medius muscle exercises for progressive strengthening that also recognizes iliopsoas muscle activation. Our hypothesis was that a progression of hip rehabilitation exercises to strengthen the gluteus medius muscle could be identified that minimized concurrent iliopsoas muscle activation.

METHODS

Participant Preparation

Ten healthy individuals (5 males, 5 females; age, 28.7 ± 2.0 years; height, 1.72 ± 0.04 m; weight, 67.4 ± 4.3 kg) participated in this study. All participants provided written consent before participation, in accordance with the Institutional Review Board at the Vail Valley Medical Center.

Muscle activation of the gluteus medius and iliopsoas muscles was measured during the performance of 13 hip rehabilitation exercises. With use of a sterile technique, fine-wire electrodes (0.07-mm Teflon-coated, nickel-chromium alloy wire, VIASYS Healthcare, Madison, Wisconsin) were placed intramuscularly via a 25-gauge needle into the muscle bellies of the gluteus medius and iliopsoas muscles. The intramuscular electrodes were inserted under ultrasound guidance to ensure correct placement into the muscle and for patient safety. The gluteus medius electrodes were inserted approximately 1 inch distal to the midpoint of the iliac crest. The iliopsoas electrode was inserted 2 fingerbreadths lateral to the femoral artery and 1 fingerbreadth below the inguinal ligament. A radiologist who was blinded to the study confirmed the locations of the electrodes from inspection of the digital ultrasound pictures. The electromyography (EMG) signals were collected at 1200 Hz and preamplified at the skin surface (Bagnoli-8, DelSys, Boston, Massachusetts; common mode rejection ration [CMRR] >84 dB; input impedance >10 MO).

Experimental Protocol

The testing session began with a series of 3 isometric maximum voluntary contractions (MVC) for each muscle. The 3-second maximum contractions were interspersed with 3 to 5 seconds of rest. The MVC for the gluteus medius was measured with the participant standing with slight hip external rotation and abducting the hip as hard as possible. The MVC for the iliopsoas was measured with the individual sitting on the edge of a table with full hip and knee flexion and flexing the hip as hard as possible. The examiner provided manual resistance and the consistency of the participant effort was measured with a hand-held force transducer (MicroFET2, Hoggan Health Industries, West

Jordan, Utah). The MVC trial was accepted if the 3 peak forces fluctuated less than 5%.

The 13 exercises included the double-leg bridge, single-leg bridge, prone heel squeeze, supine hip flexion, side-lying hip abduction with internal rotation, side-lying hip abduction with external rotation, side-lying hip abduction against a wall, traditional hip clam, hip clam with hip in neutral, resisted terminal knee extension, resisted hip extension, resisted knee flexion, and stool hip rotation. All exercises were completed in a slow, controlled manner with the aid of a metronome to minimize EMG amplitude variations attributable to differences in speed while performing the exercises. The exercise order was randomly selected for each individual, and each participant performed 2 trials with 5 repetitions each.

The *double-leg bridge* began with the participant in the supine position on an examination table with the feet flat on the table and the knees and hips flexed to accommodate the position of the feet. The participant extended the hips and knees until the hips were in a neutral position and the knees were flexed near 90° (Figure 1A). The participant then returned to the starting position by flexing at the knees and hips.

The *resisted terminal knee extension* exercise started with a bolster under the distal tibia and the knee flexed to approximately 30°. The participant extended the knee by contracting the knee extensor muscles while the examiner provided resistance to the back of the knee (Figure 1B). The examiner maintained resistance on the back of the knee to flex the knee back to the starting position while the participant resisted with the knee extensor muscles.

The *resisted knee flexion* exercise began with the leg straight and resting on the examination table. The participant flexed the knee by contracting the knee flexor muscles while the examiner provided resistance to distal end of the tibia (Figure 1C). The examiner maintained resistance on the distal end of the tibia to extend the knee back to the starting position while the participant resisted with the knee flexor muscles.

The *resisted hip extension* exercise began with the knee flexed to 90°, with the thigh resting on the examination table. The participant extended the hip by contracting the hip extensor muscles while the examiner provided anterior resistance to the distal end of the posterior thigh (Figure 2A). The examiner maintained resistance on the distal end of the posterior thigh to flex the hip back to the starting position while the participant resisted with the hip extensor muscles.

The *traditional hip clam* exercise began from the side-lying position with the non-test side on the examination table with the hips and knees flexed to 45°. While the inside of the heels remained in contact and in line with the participant, the test leg performed hip abduction and external rotation (Figure 2B). The participant returned to the starting position by adducting and internally rotating the hip.

The *hip clam with the hip in neutral* began from the side-lying position, with the non-test side on the examination table with the hips in neutral and the knees flexed to 90°, positioning the feet behind the participant. While the



Figure 1. Exercises recommended for phase I rehabilitation after hip arthroscopy: A, double-leg bridge; B, resisted terminal knee extension; C, resisted knee flexion.

inside of the heels remained in contact, the test leg performed hip abduction and external rotation (Figure 2C). The participant returned to the starting position by adducting and internally rotating the hip.

The *stool hip rotation* exercise was performed while standing, and the knee of the test leg resting at 90° with approximately 20% body weight on a rolling stool with the hip externally rotated 30° (Figure 2D). The hip was

internally rotated through a 60° range of motion ending at 30° of internal rotation (Figure 2E). The participant returned to the starting position by externally rotating through a 60° range of motion and ending at 30° of external hip rotation.

The *prone heel squeeze* was performed with the participant prone on an examination table with the hips slightly abduced, the knees flexed to approximately 70°, and the inside of the heels touching together. The participant pressed the heels together and slightly lifted the knees off the table (Figure 3A). The position was held for 3 seconds and then the participant slowly returned to the starting position.

The *side-lying hip abduction with internal rotation* exercise began from the side-lying position with the non-test side on the examination table, the lower back in a neutral position, and the hip of the test leg internally rotated approximately 15°. Maintaining hip internal rotation, the participant performed 30° of hip abduction (Figure 3B) and then returned to the starting position by lowering the leg (hip adduction) to the starting position. The *side-lying hip abduction with external rotation* exercise was performed identically to the leg raise with internal rotation, except the hip of the test leg was externally rotated approximately 15° (Figure 3C).

The *side-lying hip abduction against a wall* exercise began from the side-lying position with the non-test side on the examination table, with the lower back and hips in a neutral position and the backside of the body adjacent to a wall. Maintaining neutral lower back and hip positions, the participant performed 30° of hip abduction while the heel was continuously pressed into the wall via hip extension (Figure 3D) and then returned to the starting position by lowering the leg (hip adduction) and maintaining constant heel pressure against the wall.

The *single-leg bridge* was performed identical to the double-leg bridge exercise, but the hip of the non-test leg was in neutral and the knee was extended throughout both phases of the exercise (Figure 3E). Care was taken to visually ensure that the hips remained level throughout the performance of the exercise.

The *supine hip flexion* exercise began with the participant supine on the examination table with both legs extended and lying flat on the table (Figure 4A). The hip and knee of the test leg flexed while the heel moved proximally on the table (heel slide). When the hip and knee attained approximately 45° of flexion (Figure 4B), the heel was lifted off of the table while the hip continued to flex to 90° of flexion (Figure 4C). The participant returned to the starting position by extending the hip to 45° and allowing the heel to contact the table. The heel moved distally along the table while the hip and knee extended to neutral positions.

The *resisted terminal knee extension* exercise, *hip extension* exercise, and *knee flexion* resistance exercise were each performed with the participant prone on the examination table. The examiner provided moderate resistance throughout the range of motion of each exercise.

For the purpose of recording the motions and to separate the EMG signal into the 5 repetitions per trial and



Figure 2. Exercises recommended for phase II rehabilitation after hip arthroscopy: A, resisted hip extension; B, traditional hip clam; C, hip clam with the hips in neutral; and D and E, stool hip rotations (D, internal rotation end point; E, external rotation end point).

into the concentric and eccentric phases of each exercise, kinematics were concurrently collected of the performed exercises. Fifty-three retro-reflective markers were attached to select anatomic landmarks in a modified Helen Hays marker set.¹¹ A 10-camera motion analysis system (Motion Analysis, Santa Rosa, California) captured 3-dimensional marker trajectories. These marker trajectories were low-pass filtered at 10 Hz with a fourth-order Butterworth filter and the marker that most appropriately delineated the motion repetitions and phases was selected for each exercise.

Analysis

All EMG data were processed with a 50-millisecond, root-mean-square (RMS) moving window (1-millisecond increments) using custom software (MATLAB, The MathWorks, Natick, Massachusetts). Maximum EMG reference values that represented 100% MVC were calculated from the MVC trials for each muscle by averaging the peak EMG signal of the 3 MVC repetitions. The EMG data measured during the rehabilitation exercises were analyzed to determine average and peak EMG amplitudes for each repetition and expressed as a percentage of the reference value (% MVC). The peak EMG amplitude elicited from each

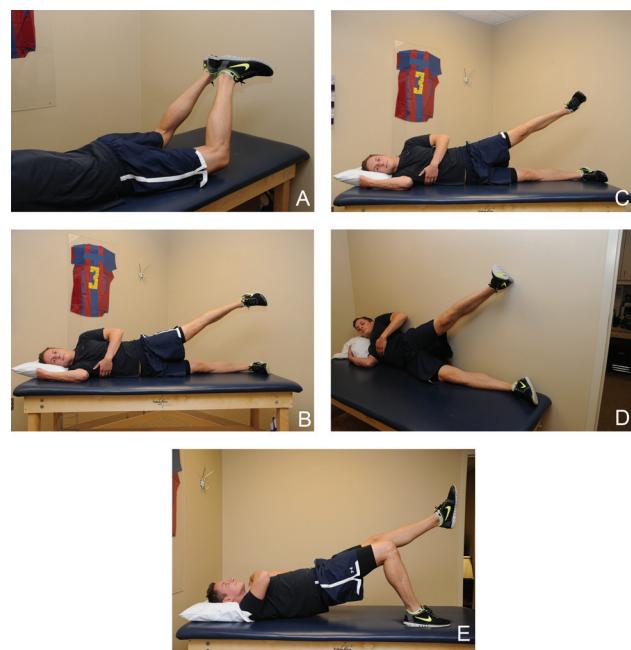


Figure 3. Exercises recommended for phase III rehabilitation after hip arthroscopy: A, prone heel squeeze; B, side-lying hip abduction with internal rotation; C, side-lying hip abduction with external rotation; D, side-lying hip abduction against the wall; and E, single-leg bridge.

rehabilitation exercise categorized the intensity of muscle activation as minimal (0%-20% MVC), moderate (21%-50% MVC), or high (>50% MVC).⁴

Descriptive statistics were calculated for peak and average EMG amplitudes for each phase of each exercise across the 5 repetitions. These values were used to determine an exercise continuum of gluteus medius muscle activation and the activation ratio between the iliopsoas and the gluteus medius muscles. Exercise continuums were designed for peak and average gluteus medius activation during the concentric and eccentric phases.^{4,5} Within each continuum, muscle activity was rank-ordered by exercise and regression analysis determined whether a significant linear increase was present ($P \leq .05$). The 4 regression analyses (peak and average gluteus medius activation, concentric and eccentric phase) were then incorporated into an overall continuum with equal weighting given to average and peak EMG amplitudes, and to concentric and eccentric phases. The exercise that consistently elicited the greatest EMG activity for the gluteus medius muscle represented the top-ranking exercise.

An activation ratio was calculated for each hip rehabilitation exercise by dividing peak iliopsoas EMG amplitude (% MVC) by the peak gluteus medius EMG amplitude (% MVC). The higher the ratio, the higher the iliopsoas muscle activation was in relation to the gluteus medius activation. Ratios greater than 1.0 indicated that the iliopsoas muscle was activated more than the gluteus medius muscle. Exercises were placed into respective time phases based upon average gluteus medius EMG amplitude,

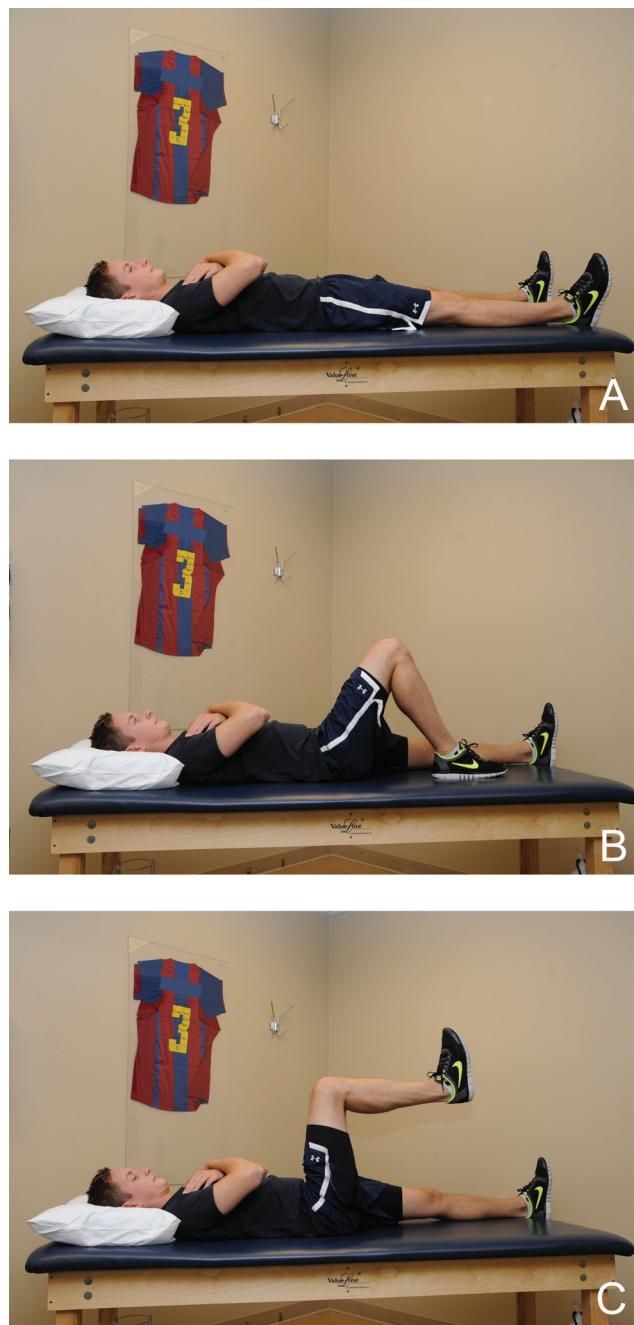


Figure 4. Supine hip flexion exercise: A, initial position; B, intermediate position following the heel slide; and C, final position.

except that exercises involving hip rotation were avoided in phase I.

RESULTS

Group means and standard errors for average and peak EMG amplitudes for the gluteus medius and iliopsoas

muscles during the 13 hip rehabilitation exercises are reported in Table 1. Peak gluteus medius muscle activity ranged from 16% to 73% MVC and average gluteus medius muscle activity from 3% to 35% MVC. The single-leg bridge, the prone heel squeeze, and the side-lying hip abduction whether performed with internal hip rotation, against a wall, or with external hip rotation were considered to have high peak gluteus medius muscle activation (>50% MVC). All other exercises demonstrated moderate gluteus medius activation (21%-50% MVC) except the resisted knee flexion and terminal knee extension exercises, which demonstrated minimal activation (<20% MVC).

Peak iliopsoas muscle activity ranged from 3% to 48% MVC, while average iliopsoas activity ranged from 1% to 18% MVC. Supine hip flexion, side-lying hip abduction performed against the wall, side-lying hip abduction with external rotation, and hip clam exercises demonstrated moderate iliopsoas muscle activation (>20%). All other exercises demonstrated minimal iliopsoas muscle activity.

All regression analyses demonstrated a significant increase in gluteus medius activation among the rank-ordered exercises ($P < .05$). The rank orders based on the average and peak activations and the concentric and eccentric phases were incorporated into an overall continuum for gluteus medius muscle activity (Table 2). The side-lying hip abduction performed with hip internal rotation and prone heel squeeze had equal average rankings. The higher rank was given to the side-lying hip abduction performed with hip internal rotation because it had the greatest peak gluteus medius EMG activity. Figure 5 demonstrates the peak and average muscle activation levels for the gluteus medius for both the concentric and eccentric phases of the exercises in the final rank-order.

The activation ratio for each exercise in final rank-order is graphically illustrated in Figure 6. The activation ratio ranged from 0.1 to 5.3. The prone heel squeeze, single-leg bridge, and the side-lying hip abduction with internal rotation had the lowest ratios of 0.1 (activation of the gluteus medius muscle 10 times greater than the iliopsoas muscle). The supine hip flexion exercise showed the greatest ratio (5.3).

DISCUSSION

A continuum of hip rehabilitation exercises was identified based on in vivo gluteus medius muscle activation in healthy individuals. In addition, supine hip flexion, side-lying hip abduction with external hip rotation, and the hip clam exercises were identified to also activate the iliopsoas muscle considerably and should be avoided in the face of concurrent hip flexor irritation. Therefore, the rank order for the remaining exercises was found to be (from low activation to high activation): resisted terminal knee extension, resisted knee flexion, stool hip rotations, hip clams with a neutral hip, double-leg bridges, resisted hip extension, side-lying hip abduction with heel against the wall, prone heel squeeze, side-lying hip abduction with internal hip rotation, and single-leg bridges. These exercises can be designated into a typical phase I through III postoperative rehabilitation program.

TABLE 1
Peak and Average (With Standard Error in Parentheses) EMG Amplitudes for the Gluteus Medius and Iliopsoas Muscles During the Concentric and Eccentric Phases of 13 Hip Rehabilitation Exercises^a

Exercise	Muscle	Concentric Phase		Eccentric Phase	
		PA	AA	PA	AA
Single-leg bridge	GMD	72.5 (18.4)	35.1 (10.7)	51.1 (3.8)	24.0 (8.1)
	ILI	6.3 (1.3)	2.5 (0.5)	6.0 (0.5)	2.1 (0.4)
SL hip abduction–IR	GMD	65.8 (16.8)	33.3 (8.6)	44.1 (3.1)	20.1 (4.8)
	ILI	9.2 (2.7)	3.6 (1.0)	10.3 (1.7)	3.3 (1.3)
Prone heel squeeze	GMD	55.2 (15.2)	27.2 (8.4)	54.7 (4.7)	30.9 (9.0)
	ILI	8.6 (4.6)	2.3 (0.8)	2.9 (0.2)	1.4 (0.3)
SL hip abduction–wall	GMD	58.1 (12.9)	31.4 (7.1)	43.3 (2.6)	20.5 (4.2)
	ILI	21.1 (6.4)	7.8 (3.0)	15.2 (1.6)	6.3 (2.5)
SL hip abduction–ER	GMD	55.4 (14.1)	23.3 (5.6)	39.4 (3.6)	12.7 (2.9)
	ILI	29.2 (8.0)	16.0 (5.6)	23.8 (2.4)	11.2 (2.9)
Resisted hip extension	GMD	39.6 (6.3)	23.3 (3.3)	39.1 (1.7)	15.7 (2.4)
	ILI	15.1 (4.8)	4.4 (1.1)	18.0 (2.3)	3.9 (1.0)
Traditional hip clam	GMD	43.4 (13.0)	16.7 (4.3)	32.3 (3.4)	11.2 (2.9)
	ILI	22.9 (4.4)	11.9 (2.6)	17.7 (1.0)	8.0 (2.2)
Double-leg bridge	GMD	26.2 (7.7)	10.8 (2.8)	21.7 (1.7)	8.3 (2.0)
	ILI	12.8 (5.0)	3.0 (1.0)	9.7 (1.0)	2.7 (0.8)
Hip clam–neutral	GMD	28.4 (8.6)	12.5 (3.6)	17.9 (1.5)	6.3 (1.9)
	ILI	18.0 (3.9)	7.8 (2.6)	14.3 (0.6)	4.8 (0.8)
Stool hip rotations	GMD	22.9 (8.9)	6.7 (2.0)	21.7 (2.0)	7.9 (2.2)
	ILI	12.4 (3.9)	3.4 (0.8)	11.7 (1.2)	3.5 (0.8)
Resisted knee flexion	GMD	17.3 (4.3)	8.9 (2.4)	15.6 (1.2)	7.5 (1.8)
	ILI	10.7 (3.1)	4.1 (1.2)	10.7 (1.0)	3.7 (0.9)
Supine hip flexion	GMD	23.8 (13.5)	3.3 (0.8)	17.9 (2.9)	3.1 (0.7)
	ILI	45.1 (11.0)	17.5 (3.9)	48.4 (5.3)	14.6 (4.3)
Resisted knee extension	GMD	19.7 (4.9)	7.1 (2.0)	15.5 (1.3)	5.2 (1.1)
	ILI	9.6 (3.7)	3.5 (1.2)	8.6 (1.2)	3.8 (1.7)

^aEMG, electromyography; GMD, gluteus medius muscle; ILI, iliopsoas muscle; PA, peak amplitude; AA, average amplitude; SL, side-lying; IR, internal rotation; ER, external rotation.

TABLE 2
EMG Amplitude Ranks and Final Rank Order for Gluteus Medius Muscle Activation and Final Rehabilitation Phase Assignment^a

Final Rank	Exercise	Concentric Phase		Eccentric Phase		Rehabilitation Phase
		PA	AA	PA	AA	
1	Single-leg bridge	1	1	2	2	III
2	SL hip abduction–IR	2	2	3	4	III
3	Prone heel squeeze	5	4	1	1	III
4	SL hip abduction–wall	3	3	4	3	II
5	SL hip abduction–ER	4	5	5	6	II
6	Resisted hip extension	7	6	6	5	II
7	Traditional hip clam	6	7	7	7	II
8	Double-leg bridge	9	9	8	8	I
9	Hip clam–neutral	8	8	11	11	II
10	Stool hip rotations	11	12	9	9	II
11	Resisted knee flexion	13	10	12	10	I
12	Supine hip flexion	10	13	10	13	I
13	Resisted knee extension	12	11	13	12	I

^aEMG, electromyography; PA, peak amplitude; AA, average amplitude; SL, side-lying; IR, internal rotation; ER, external rotation.

The rank-ordered exercises are discussed here in the context of hip rehabilitation following hip arthroscopy. The goals of phase I of postoperative rehabilitation are to

ensure mobility of the joint and to minimize general muscle atrophy, while also protecting the integrity of the repaired structures of the joint. The goals of phase I were

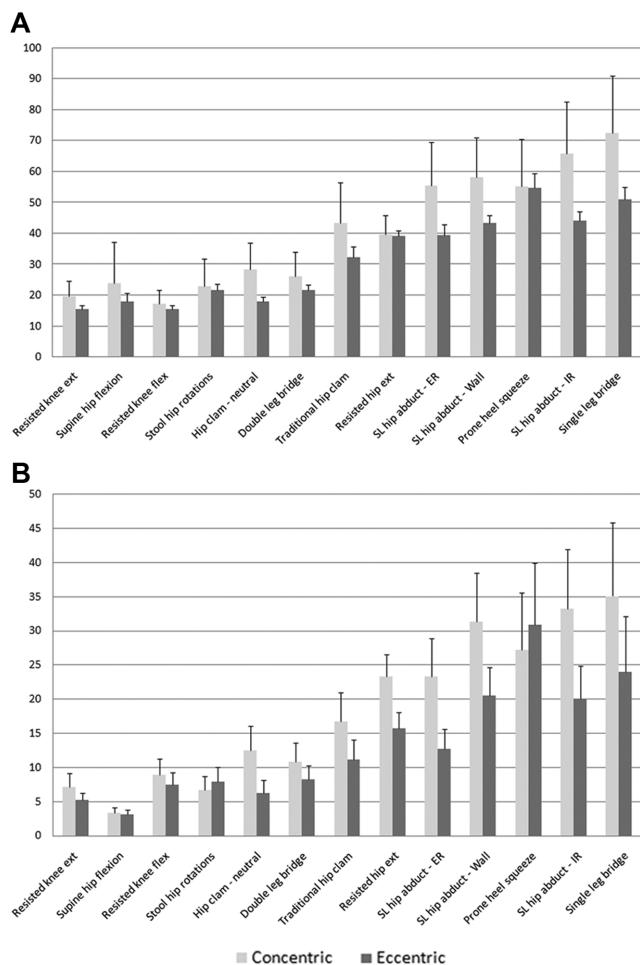


Figure 5. Peak (A) and average (B) electromyography (EMG) amplitude (%maximum voluntary contractions [MVC]) and standard errors recorded from the gluteus medius muscle during the concentric and eccentric phases for 13 hip rehabilitation exercises in the rank order of increasing activity. ER, external rotation; ext, extension; IR, internal rotation; SL, sidelying.

early gluteus medius muscle reactivation and avoidance of hip external rotation past 45° to protect capsular repair or plication. Phase I ranges from the first 4 weeks after surgery up to 8 weeks for a concurrent microfracture procedure. During this phase, exercises to facilitate muscle activity initially include isometrics, resisted terminal knee extensions, and resisted knee flexion. These exercises activate the gluteus medius minimally according to our data. Exercises can be progressed by adding double-leg bridges because of their controlled motion, moderate activation of the gluteus medius, and low iliopsoas activation. After hip arthroscopy, hip extension and hip external rotation are typically restricted during this phase and patients are on crutches or partially weightbearing; therefore, exercises that require these motions or weightbearing are avoided during this phase.

In phase II (typically starting at week 5 or 9 after surgery), the focus is on muscular stabilization of the hip

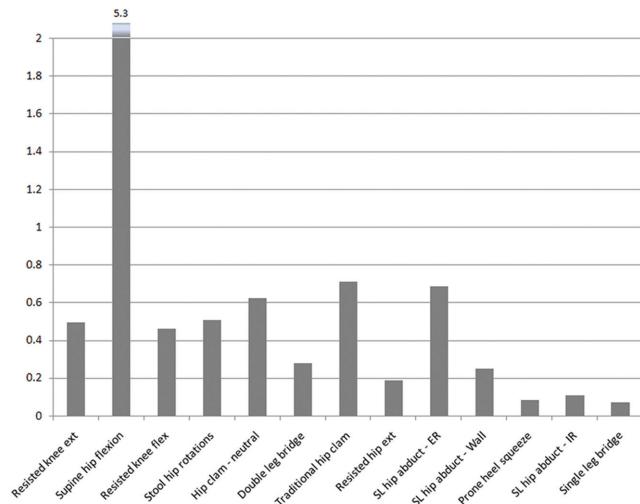


Figure 6. Activation ratio for the 13 hip rehabilitation exercises calculated by dividing the iliopsoas peak activation by the gluteus medius peak activation for each exercise. A higher activation ratio indicates relatively increased iliopsoas activation. ER, external rotation; ext, extension; IR, internal rotation; SL, sidelying.

under relatively controlled conditions. The goals of phase II were the addition of hip rotation exercises (short external rotators) and to further develop gluteus medius muscle strengthening to aid with activities of daily living. Stool hip rotations can be initiated, because the patients are now fully weightbearing. Hip clams either with neutral or flexed hips and resisted hip extension are now started to generate more gluteus medius muscle activation, because hip external rotation and hip extension are allowed starting in phase II. However, caution should be exercised in cases where hip flexor tendinitis is present. Increased gluteus medius activation may be provided by side-lying hip abduction exercises with wall sliding.

Phase III exercises are designed to fully regain strength in the hip joint musculature and to work on global lower extremity strength. The goals of phase III were to work on a full return of gluteus medius muscle functioning with a plan to return to full sports or labor activities and normalize cocontraction of the hip abductors and adductors to avoid imbalance. Prone heel squeezes, side-lying hip abduction with internal rotation, and single-leg bridges can be started to activate the gluteus medius highly while minimally activating the iliopsoas muscle. During this phase, closed chain exercises such as various forms of squatting, leg presses, and lunges are initiated to strengthen the entire lower extremity.

One of most common exercises for strengthening the gluteus medius muscle is hip abduction, either standing, side-lying, or with some other variation.^{2,8,10,15} The variations to the side-lying hip abduction exercise in the current study with hip internal rotation, hip external rotation, or sliding along a wall demonstrated high EMG activation (>50% MVC of peak activation), supporting that these

are all good exercises to exercise the gluteus medius. The variations of internal or external hip rotation may change the mechanical advantage of the hip abductor muscles. The gluteus medius muscle is made up of 3 parts of nearly equal volume with 3 distinct muscle fiber directions and separate innervations.^{7,9} Thus, by rotating the hip, at least 1 portion of this muscle will have a mechanical advantage to perform hip abduction. However, during external hip rotation while performing hip abduction, the iliopsoas is much more activated and therefore this exercise should be avoided when flexor tendinitis is present.

The stool hip rotation exercise stimulated moderate gluteus medius muscle activity during both internal and external hip rotation. With the pelvis stabilized and the hip in neutral, the anterior and posterior portions of the gluteus medius muscle internally and externally rotate the femur relative to a stationary pelvis.⁶ Conversely, the gluteus medius muscle can also rotate the pelvis about a transverse axis relative to a fixed femur.^{9,20} Both of these scenarios function to produce hip internal or external rotation. However, the production of these rotary hip motions when the pelvis is stationary would likely require lower gluteus medius muscle activation because the mass of the leg is considerably less than the upper body, and may explain why the stool hip rotation exercise only demonstrated gluteus medius muscle activity of 22% MVC. In addition, the smaller hip rotator muscles should be active during this exercise as well. This exercise may be the most appropriate at the beginning stages of rehabilitation when strengthening exercises are initiated.

Gluteus medius muscle activation was consistently the lowest during the supine hip flexion exercise. This exercise was performed in the sagittal plane with the patient supine and was primarily controlled by the hip flexors. The heel-sliding component required slight pressure of the heel into the examination table and consequently elicited moderate levels of gluteus medius muscle activation. Core stabilization concurrent with hip flexion is the focus of this exercise and large gluteus medius muscle activation was not expected. This exercise provided a good reference for the activation levels of the iliopsoas during the gluteus medius exercises. For instance, the average iliopsoas activity during the side-lying hip abduction with the hip externally rotated was almost the same as during the supine hip flexion exercise (16% vs 18% MVC, respectively, for the concentric phase), while most other exercises were half that activation or less.

This study also determined that iliopsoas activation was increased for some hip strengthening exercises during the early phase of rehabilitation, and therefore may potentially aggravate any concurrent hip flexor tendinitis. Supine hip flexion, the side-lying hip abduction performed with external rotation, hip clams, and the side-lying hip abduction performed against the wall demonstrated moderate iliopsoas activation. Iliopsoas muscle activation was elicited because these exercises either required hip flexion or hip external rotation. It is unlikely that the performance of these exercises after hip arthroscopy will cause hip flexor tendinitis; rather, it is more probable that this clinical issue would be present before surgery from the altered

movement patterns used to compensate for hip pain or mechanical range of motion constraints.^{12,13}

In this study, the rehabilitation exercises were presented in the context of hip arthroscopy. However, these data may also provide useful information for nonoperative treatment or rehabilitation after other hip surgical procedures. These other procedures may impose different functional limitations and timing restriction (eg, different restrictions on weightbearing) and, therefore, the exercises may be assigned to other phases of the rehabilitation program. However, the progression of muscle activation remains applicable to the exercises as described. Another limitation of this study is that the data were collected using healthy individuals, who may or may not exhibit the same muscle activation patterns as the patients undergoing the rehabilitation protocol after arthroscopy. It is possible, particularly in early rehabilitation, that activation patterns may be altered. However, especially in the later rehabilitation phases, the patients' function is nearly normal and activation patterns should become normal as well. A study in patients postoperatively would elucidate this issue and is recommended for future study.

SUMMARY

We identified a continuum of gluteus medius muscle activation for 13 common hip rehabilitation exercises and evaluated concurrent iliopsoas activation in light of iliopsoas tendinitis, which is often present after hip arthroscopy. Based on these data, we identified resisted terminal knee extension and resisted knee flexion for early phase I and double-leg bridges for later in phase I. For early phase II, resisted hip extension and stool hip rotations, and later the side-lying hip abduction exercise with wall sliding, were identified as appropriate exercises. Hip clam exercises with hip extension can be used with caution in case of hip flexor tendinitis. Prone heel squeezes, side-lying hip abduction with internal hip rotation, and single-leg bridges are recommended for phase III.

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