Recruitment and Activity of the Pectineus and Piriformis Muscles During Hip Rehabilitation Exercises

An Electromyography Study

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Background: The pectineus muscle has been reported to function primarily as a hip flexor and secondarily as a hip internal rotator; the piriformis muscle has been reported to function as an abductor and external rotator of the hip. The recruitment and activations of these muscles during hip rehabilitation exercises have not been detailed.

Hypothesis: The authors hypothesized that they would measure the highest pectineus activation during exercises involving hip flexion, with moderate pectineus activation during exercises with hip internal rotation. They also hypothesized that they would measure the highest piriformis activation during exercises involving hip abduction and/or external rotation.

Study Design: Descriptive laboratory study.

Methods: Ten healthy volunteers completed 13 hip rehabilitation exercises with electromyography (EMG) electrodes inserted under ultrasound guidance into the pectineus and piriformis muscle bellies. The EMG signals were recorded and exercise activation levels were reported as a percentage of a maximum voluntary contraction (MVC).

Results: Both the highest peak pectineus activation (62.8% ± 26.6% MVC) and the highest mean pectineus activation (33.1% ± 17.4% MVC) were measured during the supine hip flexion exercise. Moderate activation was found during the single- and double-legged bridge and both phases of the stool hip rotation exercise. The highest peak piriformis activation was observed in the single-legged bridge (MVC, 35.7% ± 25.7%), and the highest mean piriformis activation was observed in the prone heel squeeze (MVC, 24.3% ± 8.2%). Similar moderate activation levels were found for single-legged hip abduction and resisted hip extension.

Conclusion: The pectineus was highly activated during hip flexion exercises and moderately activated during exercises requiring rotational hip stabilization in either direction, rather than with internal hip rotation only. The piriformis was most activated during static external rotation and abduction while the participants' hips were in slight extension. These observations indicate that the pectineus and piriformis are both muscles that contribute to hip stabilization.

Clinical Relevance: The findings indicate that the pectineus and piriformis function as hip-stabilizing muscles and can be used to specifically address pectineus and piriformis muscle rehabilitation. The authors believe that strengthening and conditioning of these muscles should aid in the restoration of hip function and stability after injury or arthroscopic surgery.

Keywords: pectineus; piriformis; hip; rehabilitation; electromyography (EMG)

The pectineus and piriformis muscles are deep hip muscles (Figure 1) whose recruitment, activity, and function have not yet been described in detail. It is not fully understood which functional movements produce activation of these muscles or what intensity of muscular contraction is necessary to perform each activity. The ability to quantify the activations of these deep hip muscles during specific rehabilitation exercises could help to expedite a safe and healthy return to functional activities through the use of rehabilitation. In addition, quantitatively identifying pectineus and piriformis activation will provide details regarding the overall muscular contributions of both muscles as they relate to hip stability, movement, and function. More specifically, the ability to define activation levels for individual exercises would enable us to better understand the nuances of the unique movements for each exercise and draw conclusions about each muscle's function during daily activities.

The basic muscular functions of the pectineus have previously been described, based on anatomy. The pectineus muscle has been reported to function primarily as a hip flexor and adductor while also having a secondary role as

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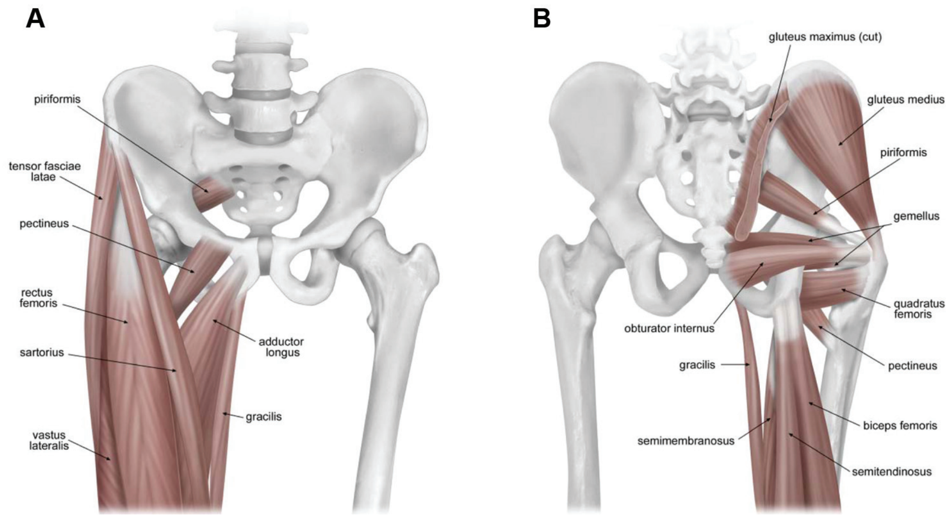

Figure 1. The pectineus and piriformis muscles. These muscles are both deep hip muscles with anterior and posterior anatomic attachments. (A) Anterior view of the pectineus and piriformis muscles with surrounding musculature. (B) Posterior view of the pectineus and piriformis muscles with surrounding musculature.

an internal rotator.[1,6,19] However, there is no known information regarding its activation during specific hip exercises and movements.

The description of specific piriformis muscle activation is also scant. It has been reported that the piriformis muscle primarily acts as an external rotator but also functions as a hip abductor.[6,19] The piriformis has also been described as primarily a "restraining" muscle of the hip, increasing pressure on the acetabulum when activated and potentially aiding in hip stability by compressing the femoral head medially.[30]

Reported rehabilitation protocols after arthroscopic hip surgery are generally uniform, although not extensively described in the orthopaedic literature, with patients receiving similar protocols despite different surgeons, facilities, and surgical procedures.[||] In general, weightbearing is initially restricted with attention to early mobility, followed later by active range of motion and eventually strengthening exercises.[27] It has been reported that external rotation should be limited immediately after surgery to avoid tension on the anterior capsular structures of the hip.[8,18,25] There are also several recommendations of limiting active hip flexion for approximately 1 month after operation in an effort to prevent hip flexor tendinitis.[8,27] Reportedly, this protocol has yielded positive results; however, the activation of specific deep hip musculature is not fully understood during rehabilitation exercises and has only been described in detail for the gluteus medius and the iliopsoas muscles.[26]

Weak hip musculature has been reported to alter biomechanics in gait, lead to increased discomfort, and impair functional activities.[14,19] In addition, decreased hip strength has been reported to affect knee kinematics, causing pain and discomfort during physical activities.[31] Based on previous descriptions of the anatomy and function of the pectineus and piriformis, weakness of these muscles could potentially affect stability at the femoroacetabular joint as well as lower body kinematics.[1,6,19,30] To properly address potential weakness of the pectineus and piriformis muscles in various rehabilitation exercises, it is important to understand the activity of the healthy pectineus and piriformis musculature during these exercises.

The purpose of this study was to describe the pectineus and piriformis muscle activation levels during 13 rehabilitation exercises designed to strengthen the hip musculature. By conducting this investigation, we aimed to obtain a more detailed understanding of 2 deep hip muscles for which the recruitment and activation have not yet been described in detail. We hypothesized that we would see the highest pectineus muscle activation during rehabilitation exercises that employed hip flexion while also observing pectineus activation with hip internal rotation. We also hypothesized that we would see the highest

[||]References 7, 8, 24, 25, 27, 29, 32, 34.

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piriformis muscle activation during exercises that incorporated abduction and/or external rotation.

METHODS

Participant Preparation

Ten healthy volunteers (5 men and 5 women; mean [SD] age 28.7 [6.0] years; mean [SD] height 1.72 [0.13] meters; mean [SD] weight 67.4 [11.6] kilograms) participated in this study. They were simultaneously evaluated for iliopsoas and gluteus medius muscle activation with indwelling electromyography (EMG), which has been previously reported in a separate study.[26] All participants provided written consent prior to preparation, testing, and evaluation in accordance with the Vail Valley Medical Center Institutional Review Board.

The recruitment and activation of the pectineus and piriformis muscles were measured using EMG during 13 hip rehabilitation exercises. Electromyography of the pectineus and piriformis muscles was conducted using indwelling fine-wire electrodes (0.07-mm Teflon-coated, nickel chromium alloy wire; VIASYS Healthcare, Madison, Wisconsin) placed within the muscle bellies using a 25-gauge needle under ultrasound guidance to ensure accurate intramuscular placement and patient safety. The pectineus electrodes were inserted 1 fingerbreadth lateral to the pubic tubercle into the muscle belly.[22] The piriformis electrodes were inserted deep to bone at the midpoint of a line between the posterior inferior iliac spine and the posterior superior margin of the greater trochanter and then withdrawn slightly into the muscle belly.[22] The locations of the electrodes were confirmed by ultrasound pictures evaluated by a radiologist blinded to the study. The EMG signals were collected at 1200 Hz and preamplified at the skin surface (Bagnoli-8, DelSys, Boston, Massachusetts; common-mode rejection ratio (CMRR) >84 dB; input impedance >10 MO).

Experimental Protocol

Three isometric maximum voluntary contractions (MVCs) aimed at maximally recruiting the pectineus and piriformis muscles were recorded to initiate each testing session by the standard method for manual muscle testing of the isolated pectineus and piriformis muscles.[13] Three-second contractions were followed by 5-second rests between contractions. Both the pectineus and piriformis MVC exercises were conducted in the seated position. The MVC for the pectineus was recorded through a seated, resisted hip flexion and adduction test. The MVC for the piriformis was recorded with a seated, resisted hip abduction and external rotation test. Manual resistance was provided by the examiner, and participant force exertion was measured via a handheld dynamometer (Hoggan MicroFET2; Hogan Health Industries, West Jordan, Utah), which has been reported to be a validated method to measure isolated muscle strength.[16] Maximum voluntary contraction trials were accepted if all 3 peak forces were within 5% of one another.

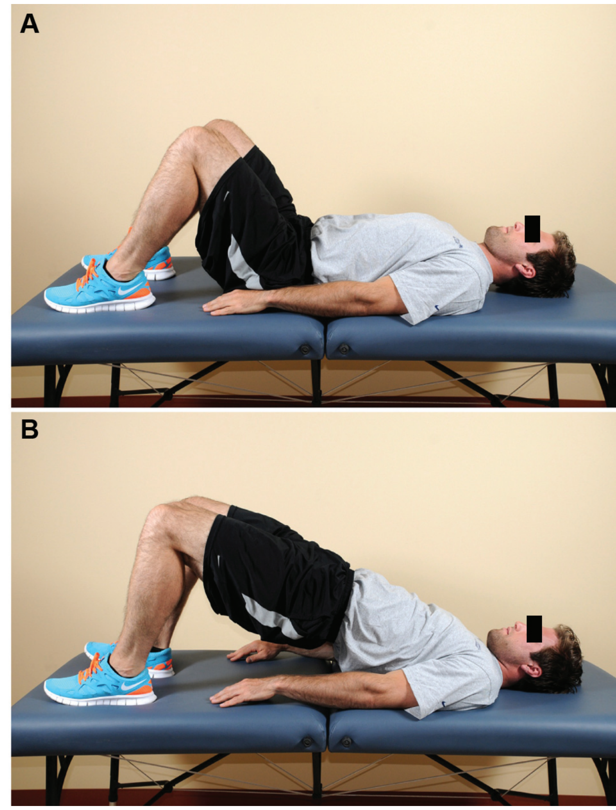

Figure 2. Double-legged bridge. (A) The participant's knees and hips were flexed 90° and 45°, respectively, with feet placed flat on the table shoulder width apart. (B) The participant's hips and knees were then extended until the hips were at 0° in a neutral position. The participant returned to the starting position with hips and knees in flexion.

The 13 hip rehabilitation exercises performed for this study included 1 standing exercise (the stool hip rotation), 3 exercises in the supine position (double-legged bridge [Figure 2], single-legged bridge [Figure 3], and supine hip flexion [Figure 4]), 5 side-lying exercises (side-lying hip abduction with external rotation [Figure 5], side-lying hip abduction with internal rotation, side-lying hip abduction against a wall, hip clam exercise with hips flexed at 45°, and hip clam exercise with hip in neutral), and 4 exercises in the prone position (prone heel squeeze [consisting of 1 concentric phase for the exercise] [Figure 6], resisted terminal knee extension, resisted knee flexion, and resisted hip extension [Appendix A, available in the online version of this article at http://ajs.sagepub.com/supplemental/]). The exercises described here have all been accompanied with images in a previously reported study[26]; however, for brevity, we have provided images only for the exercises that elicited the 3 highest activations for each muscle.

All 13 exercises have been reported to be used in protocols for recovery from hip injury or arthroscopic hip surgery and are applied during various phases of rehabilitation.[34] The exercises were executed slowly and methodically with the aid of a metronome to reduce EMG

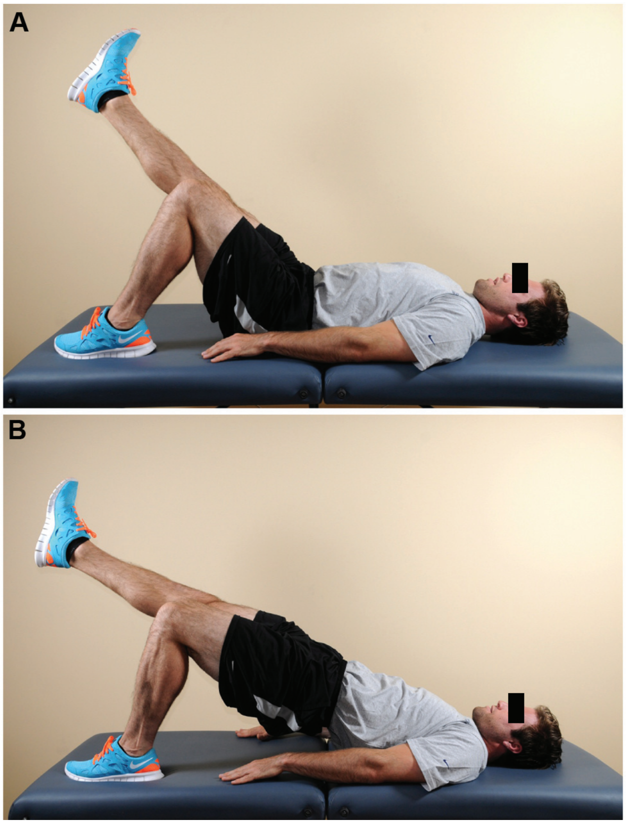

Figure 3. Single-legged bridge. (A) The start position is similar to the double-legged bridge except the non–test leg is maintained in a straight leg position with the thigh parallel with the test leg thigh throughout the performance of the exercise. (B) The participant's hip and knee of the test leg were extended until hips were at 0° in a neutral position. This required maintenance of a neutral pelvic position in all 3 planes. The participant returned to the starting position with the hip and knee of the test leg in flexion.

amplitude variations resulting from speed differences during exercise performance. The order of exercise completion was randomized for each participant.

To record the motions and facilitate the separation of the EMG signal into concentric and eccentric exercise phases of the individual exercises, we concurrently collected kinematics for the performed exercises using 53 retro-reflective markers, attached to select anatomic landmarks in a modified Helen Hays marker set (Figure 7).[12] A 10-camera motion analysis system (Motion Analysis Corp, Santa Rosa, California) was used to capture 3-dimensional marker trajectories at 120 Hz, which were subsequently low-pass filtered at 10 Hz with a fourth-order Butterworth filter.

Analysis

A 50-ms, root mean squared (RMS) moving window (1-ms increments) was used to rectify the EMG data. The EMG envelopes were calculated by filtering the RMS signal at 2 Hz for the MVC trials and 5 Hz for the rehabilitation

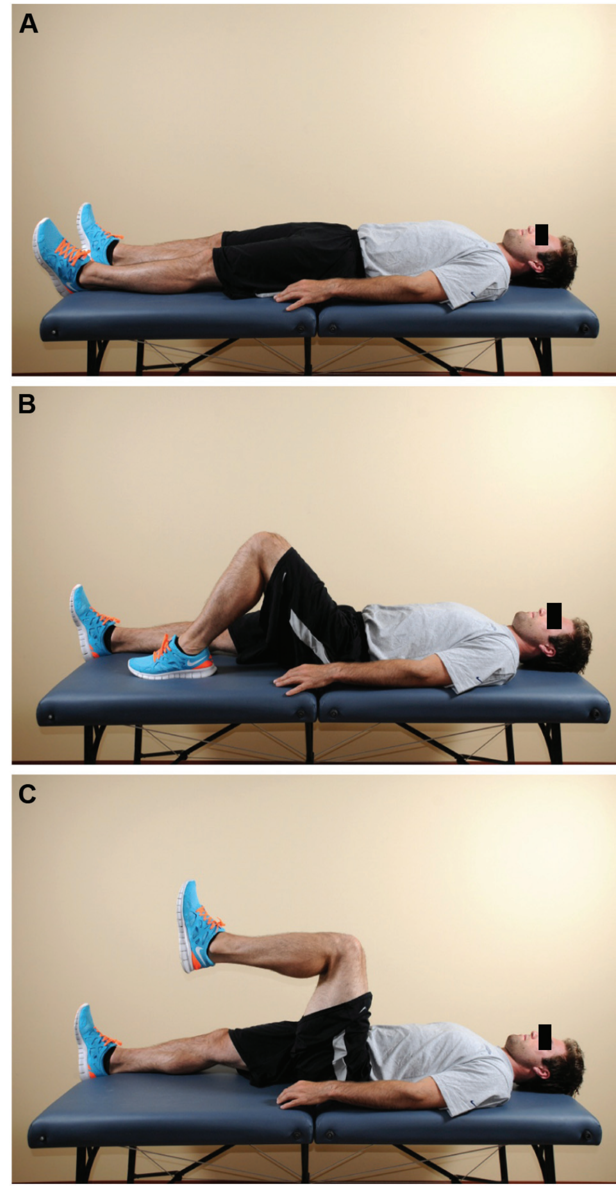

Figure 4. Supine hip flexion. (A) The start position is supine with both legs flat resting on the table. (B) The test leg heel was then slid proximally along the table until the knee was flexed to approximately 90° and the hip to approximately 45°. (C) Maintaining the knee at 90°, the hip of the test leg continued flexing to approximately 90° while the foot was lifted off the table. The exercise was completed by returning the test leg to hip flexion of 45° and sliding the heel distally until the leg was lying straight on the table.

exercises.[20] The difference in cutoff frequency was chosen because the MVC trials had low frequency activations (static isometric contractions of 3 seconds), whereas the rehabilitation exercises consisted of higher frequency repetitions. Maximum EMG reference values (100% MVC) were calculated by averaging the peak EMG amplitudes from the 3 MVC trials for each muscle. The hip

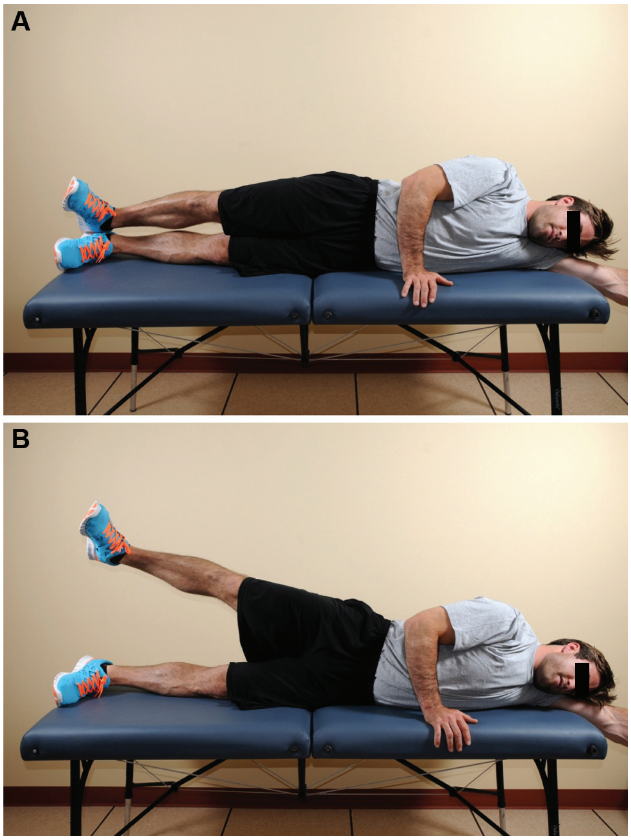

Figure 5. Side-lying hip abduction (external rotation). The exercise was performed with the hip in external rotation (≈15°). (A) The start position is side lying on the non–test side with the lower back in a neutral position in all 3 planes. (B) The participant performed abduction of the hip to approximately 30°, maintaining the external rotation, and then returned to the starting position.

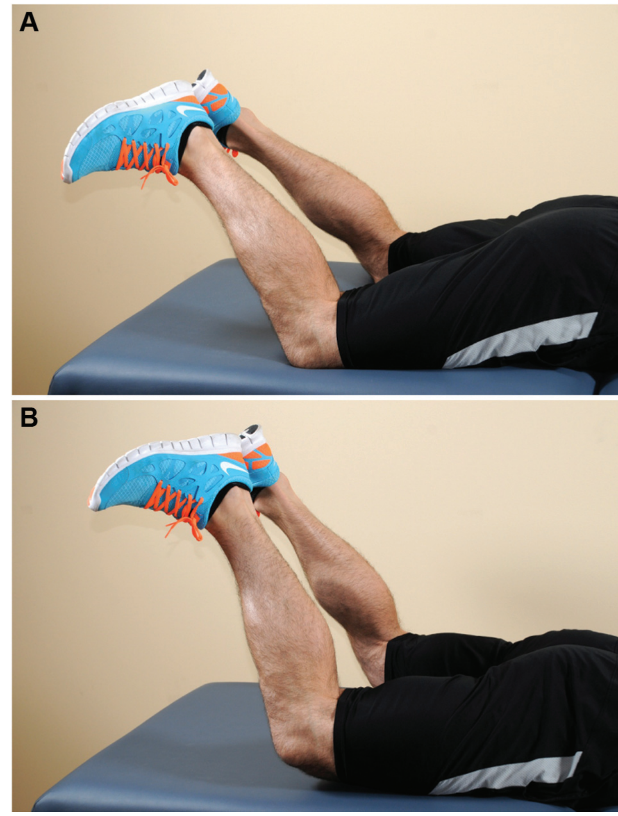

Figure 6. Prone heel squeeze. (A) The start position is prone with the participant's hips slightly abducted and externally rotated, the knees flexed to 45°, and the participant's heels touching to begin the exercise. (B) The participant pressed his or her heels into one another and raised his or her thighs off of the examination table in slight hip extension for 6 seconds. The participant then slowly returned to the starting position.

rehabilitation exercise EMG data were separated into concentric and eccentric phases using the motion capture software (Cortex; Motion Analysis Corp). Each phase was analyzed separately to determine peak and mean EMG amplitudes, which were expressed as a percentage of the reference value (% MVC). For each phase, the resulting peak and mean EMG amplitudes were averaged across the 5 repetitions per trial for each participant and then averaged across the participants to make generalized conclusions about pectineus and piriformis activation during the rehabilitation exercises. All EMG processing was performed using custom software written in MATLAB (The MathWorks, Natick, Massachusetts). Muscle activation was classified by intensity as minimal (0%-20% MVC), moderate (21%-50% MVC), or high (>50% MVC) from the peak EMG amplitude elicited by each exercise.[5,26]

A 2-way analysis of variance (ANOVA) with independent factors of exercise (13 exercises) and phase (concentric or eccentric) was calculated for the peak and mean EMG amplitudes for both the pectineus and piriformis muscles. If a significant main effect was found, Bonferroni-corrected post hoc comparisons between the exercises were performed. The statistical significance threshold was set at .05.

RESULTS

Pectineus Muscle Activation

Among our original sample of 10 participants tested, we observed the highest muscular activation of the pectineus muscle during the supine hip flexion exercise with a peak EMG amplitude of 62.8% ± 26.6% MVC in the concentric phase and 55.4% ± 22.4% MVC in the eccentric phase of the exercise. The highest mean EMG amplitudes for the pectineus muscle also occurred in the supine hip flexion exercise with a mean EMG amplitude of 33.1% ± 17.4% MVC in the concentric phase and 28.0% ± 15.3% MVC in the eccentric phase of the exercise. Exercises that involved hip abduction and/or hip extension were observed to have low levels (<20%) of pectineus activation except for the single-legged bridge (peak amplitudes = 26.5%), which involves hip extension to neutral from a flexed position but requires concerted hip stabilization

Figure 7. Retro-reflective anatomic marker arrangement. 53 markers were configured in a modified Helen Hayes marker set.

(Table 1). Double-legged bridge pectineus activation was <20% peak activation. Ranking the individual exercises for pectineus activation was done through a composite analysis of peak and mean EMG amplitudes for the concentric and eccentric phases of each hip exercise. The exercises were ranked in descending order, with supine hip flexion being ranked as the best pectineus activator (Table 2).

Peak and mean EMG amplitudes varied significantly between the exercises ($P < .001$). Post hoc analyses revealed that supine hip flexion activated the pectineus significantly more than all other exercises ($P < .001$) for both the peak and mean EMG amplitude. In addition, the single-legged bridge activated the pectineus muscle significantly more than the prone heel squeeze and any of the side-lying abduction variants in the mean EMG amplitude ($P < .006$). There were no other significant differences between the exercises for pectineus activation.

Piriformis Muscle Activation

Six of the original 10 participants (4 men and 2 women; mean [SD] age 30.2 [7.5] years; mean [SD] height 1.76 [0.14] meters; mean [SD] weight 66.4 [14.4] kilograms) had acceptable EMG signals to be evaluated for piriformis muscle activation. Of the 10 participants tested, 4 were removed from EMG data analysis because the EMG signals were either nonresponsive to muscle activation or demonstrated significant intermittent spikes and other artifacts during motion. In 1 participant, frequent spasms occurred due to muscle irritation from the inserted electrodes. The piriformis muscle was the only muscle with which we had these issues and we believe this may have been related to the retraction of the electrodes after insertion up to the bone.

The highest piriformis muscle activation occurred during the resisted hip extension, with a peak EMG of 36.4% ± 30.4% MVC in the concentric phase of the exercise. The peak EMG with the highest activation during the eccentric phase was observed during the single-legged bridge exercise (35.7% ± 25.7% MVC). The side-lying hip abduction in external rotation and the prone heel squeeze exercise were observed to have similar levels of peak EMG amplitude to those of the resisted hip extension and the single-legged bridge (Table 3). The mean piriformis muscle EMG activations were highest during the prone heel squeeze in the concentric phase at 24.3% ± 8.2% MVC and during the single-legged bridge in the eccentric phase at 18.3% ± 8.6% MVC. Ranking the exercises for the piriformis activation was performed by a composite analysis of peak and mean EMG amplitudes for the concentric and eccentric phases of each exercise. The exercises were ranked in descending order, with the prone heel squeeze being ranked as the highest piriformis activator (Table 4).

For the piriformis, only mean EMG amplitudes varied significantly between the exercises ($P < .001$), whereas peak EMG amplitude variations were not significant ($P > .08$). Post hoc analyses for the mean EMG amplitude revealed that the prone heel squeeze activated the piriformis significantly more than the traditional hip clam, stool rotations, resisted knee extension, resisted knee flexion, and supine hip flexion ($P < .005$). In addition, the single-legged bridge activated the piriformis muscle significantly more than the supine hip flexion ($P < .005$). There were no other significant differences between the exercises for the levels of piriformis activation.

DISCUSSION

We confirmed part of our first hypothesis by observing the highest pectineus activation during the supine hip flexion exercise. However, although we found that the pectineus was activated with hip internal rotation, we also found pectineus activation with hip external rotation and in exercises requiring static hip stabilization. Therefore, the secondary role of the pectineus only as a hip internal rotator was not supported. We confirmed our second hypothesis by observing similarly high levels of piriformis activation in exercises involving hip abduction and external rotation. Interestingly, the highest piriformis activation was observed during the resisted hip extension exercise, and similarly high activation levels were observed in the single-legged bridge, prone heel squeeze, and side-lying abduction in external rotation (peak EMG activation differences within 4% EMG), which all require hip extension.

Until now, pectineus muscle function has been described in limited detail as primarily a hip flexor and adductor.[19] Our observed data would support the theorized function of the pectineus as a hip flexor. However, we are

TABLE 1
Peak and Mean Electromyography Amplitudes for the Pectineus Muscle[a]

	Concentric Phase		Eccentric Phase	
Exercise	PA	MA	PA	MA
Supine hip flexion	62.8 (26.6)	33.1 (17.4)	55.4 (22.4)	28.0 (15.3)
Single-legged bridge	20.2 (21.1)	13.6 (14.5)	26.5 (25.9)	14.3 (15.9)
Stool hip rotations	20.9 (15.8)	9.1 (7.5)	21.8 (12.4)	10.2 (6.4)
Double-legged bridge	15.2 (10.4)	9.7 (9.3)	19.8 (19.2)	10.2 (9.8)
Hip clam—neutral	10.4 (7.9)	7.1 (5.3)	20.1 (26.5)	7.2 (7.1)
Traditional hip clam	10.6 (8.0)	8.2 (7.5)	15.1 (11.2)	6.9 (5.0)
Resisted hip extension	13.3 (10.6)	7.4 (7.2)	13.2 (10.5)	5.9 (3.7)
Resisted knee flexion	10.3 (10.6)	6.9 (5.8)	12.5 (10.9)	6.4 (4.0)
Resisted knee extension	11.8 (9.8)	5.4 (3.7)	11.8 (8.7)	5.3 (3.3)
SL hip abduct—ER	10.4 (9.6)	5.8 (4.1)	8.5 (5.6)	4.6 (2.7)
Prone heel squeeze	9.8 (8.0)	4.2 (2.6)	NA	NA
SL hip abduct—wall	10.7 (13.7)	5.0 (4.2)	7.2 (5.6)	4.0 (2.5)
SL hip abduct—IR	9.1 (5.1)	4.2 (1.8)	10.5 (6.7)	4.3 (2.3)

[a]Activation was analyzed in the concentric and eccentric phases of exercise. Values are presented as mean (SD). ER, external rotation; IR, internal rotation; MA, mean amplitude; NA, not applicable; PA, peak amplitude; SL, side lying.

TABLE 2
Activation Rankings for the Pectineus Muscle During 13 Rehabilitation Exercises[a]

		Concentric Phase		Eccentric Phase	
Final Rank	Exercise	PA	MA	PA	MA
1	Supine hip flexion	1	1	1	1
2	Single-legged bridge	3	2	2	2
3	Double-legged bridge	2	4	3	3
4	Stool hip rotations	4	3	5	4
5	Hip clam—neutral	9	7	4	5
6	Traditional hip clam	8	5	6	6
7	Resisted hip extension	5	6	7	8
8	Resisted knee flexion	11	8	8	7
9	Resisted knee extension	6	10	9	9
10	SL hip abduct—ER	10	9	11	10
11	Prone heel squeeze	12	11	NA	NA
12	SL hip abduct—IR	7	12	12	12
13	SL hip abduct—wall	13	13	10	11

[a]Rankings were formulated by compiling the rankings for each individual exercise broken down by peak and mean amplitudes for the concentric and eccentric phases. ER, external rotation; IR, internal rotation; MA, mean amplitude; NA, not applicable; PA, peak amplitude; SL, side lying.

unable to address the theory that the pectineus is an adductor because we did not examine any exercises that incorporated a substantial level of hip adduction. By a significant margin, the greatest observed levels of activation for the pectineus were during the supine hip flexion exercise, an exercise designed to isolate hip motion to flexion. Certain rehabilitation protocols have been reported to limit postsurgical hip flexion,[8,23] potentially having a negative effect on the pectineus by leading to poor conditioning of the muscle.

The pectineus has also been described as having a secondary functional role as a hip internal rotatator.[19] Although we did observe moderate to low pectineus activation during hip internal rotation, we also observed comparable activation during hip external rotation. The single- and double-legged bridge exercises, which required static rotation stabilization in a neutrally positioned hip and incorporated weightbearing, moderately activated the pectineus muscle. The higher peak activation for the single-legged bridge is possibly due to the additional work the pectineus must perform to maintain neutral hip rotation as gravity would cause the hip to drop into external rotation. We did not observe noteworthy pectineus activation during exercises that incorporated static hip rotation without any weightbearing, such as side-lying hip abduction with internal rotation or side-lying hip abduction with external rotation. This would suggest that

TABLE 3
Peak and Mean Electromyography Amplitudes for the Piriformis Muscle[a]

	Concentric Phase		Eccentric Phase	
Exercise	PA	MA	PA	MA
Prone heel squeeze	34.5 (9.6)	24.3 (8.2)	NA	NA
Single-legged bridge	34.5 (25.3)	20.0 (14.0)	35.7 (25.7)	18.3 (8.6)
SL hip abduct—ER	32.9 (40.0)	21.3 (26.1)	28.7 (34.6)	15.8 (18.3)
Resisted hip extension	36.4 (30.4)	17.4 (11.5)	23.2 (12.8)	11.0 (5.8)
SL hip abduct—wall	26.0 (27.8)	14.1 (14.2)	19.1 (9.2)	9.3 (7.1)
SL hip abduct—IR	23.3 (33.7)	13.3 (19.0)	16.3 (23.4)	9.3 (12.6)
Double-legged bridge	18.2 (15.4)	9.7 (6.5)	14.4 (10.9)	7.1 (3.2)
Hip clam—neutral	19.6 (23.3)	9.4 (11.4)	13.6 (15.6)	6.3 (7.3)
Traditional hip clam	15.0 (20.6)	7.9 (10.3)	14.1 (16.8)	6.8 (7.2)
Stool hip rotations	15.7 (14.2)	5.6 (4.6)	17.4 (18.8)	6.2 (5.1)
Resisted knee extension	16.7 (15.2)	5.7 (5.5)	20.7 (29.6)	5.5 (7.3)
Resisted knee flexion	6.4 (3.2)	3.9 (2.2)	7.4 (4.1)	4.2 (2.7)
Supine hip flexion	14.9 (26.2)	2.5 (3.4)	6.1 (7.6)	1.9 (2.3)

[a]Activation was analyzed in the concentric and eccentric phases of exercise. Values are presented as mean (SD). ER, external rotation; IR, internal rotation; MA, mean amplitude; NA, not applicable; PA, peak amplitude; SL, side lying.

TABLE 4
Activation Rankings for the Piriformis Muscle During 13 Rehabilitation Exercises[a]

		Concentric Phase		Eccentric Phase	
Final Rank	Exercise	PA	MA	PA	MA
1	Prone heel squeeze	2	1	NA	NA
2	Single-legged bridge	3	3	1	1
3	SL hip abduct—ER	4	2	2	2
4	Resisted hip extension	1	4	3	3
5	SL hip abduct—wall	5	5	5	4
6	SL hip abduct—IR	6	6	7	5
7	Double-legged bridge	8	7	8	6
8	Hip clam—neutral	7	8	10	8
9	Traditional hip clam	11	9	9	7
10	Stool hip rotations	10	11	6	9
11	Resisted knee extension	9	10	4	10
12	Resisted knee flexion	13	12	11	11
13	Supine hip flexion	12	13	12	12

[a]Rankings were formulated by compiling the rankings for each individual exercise broken down by peak and mean amplitudes for the concentric and eccentric phases. ER, external rotation; IR, internal rotation; MA, mean amplitude; NA, not applicable; PA, peak amplitude; SL, side lying.

although the pectineus has been biomechanically described as an internal rotator,[19] functionally it may act more as a stabilizing muscle that maintains static rotation in activities involving even slight weightbearing. We had only 1 isolated hip internal/external rotation exercise, and therefore further investigation is needed to evaluate the functional activation of the pectineus as it applies to hip rotation.

The pectineus is likely an important contributing muscle in many dynamic sports involving agility and acceleration based on our findings that it is primarily activated in hip flexion and moderately activated during weightbearing or during motions requiring hip stabilization for rotational control. The high degree of hip flexion associated with sprinting and the hip rotational stabilization required in pivoting movements[4,17,35] are likely both influenced by the strength and overall health of the pectineus muscle. On the basis of our observations, the pectineus likely stabilizes the hip in dynamic activities such as dance, soccer, and basketball, which require explosive accelerations and directional changes, and in ice skating, especially for the starts and directional changes associated with skating.[2,9-11] Away from sport, the pectineus could protect against falling, aiding in the maintenance of balance and cushioning after a misstep through hip flexion and/or hip stabilization to correct gait imbalance.[3,35]

The piriformis muscle had the highest activation levels during exercises that emphasized stabilization of the hip through the maintenance of a static degree of external rotation during exercises such as the prone heel squeeze and the single-legged bridge. In addition, the piriformis was similarly activated when an exercise included abduction, such as the side-lying hip abduction, and especially also in external rotation. Interestingly, the highest piriformis activation levels occurred in exercises that were conducted with the participants' hips in extension or for exercises that required hip extension. This finding was not anticipated. The most likely function of the piriformis would seemingly be as an external rotation stabilizer preventing internal rotation with the hip in a neutral through an extended position. Athletically, this would translate to producing a maintained degree of external rotation during the toe-off portion of running, jumping, or the skating stride, preventing or reducing hip internal rotation coming out of these athletic positions through a stride.[28,33]

Understanding the activation of the piriformis is important because of the potential role it may have in stabilizing and supporting the hip by exerting pressure on the acetabulum through femoral head compression into the joint.[30] Although limiting hip external rotation may help preserve surgically repaired tissues,[27] based on our findings, it may also impair the conditioning of the piriformis. A potential consequence of a weak piriformis would be increased valgus forces on the knee, resulting from the absence of a strong hip stabilizer to maintain hip external rotation, allowing the hip to internally rotate. This is a speculative conclusion, but the effect of increased hip internal rotation during landing has been reported to result in increased knee forces and an increased risk of knee injury.[15,21] Further studies would be required to verify the hypothesis that piriformis strength has an influence on valgus knee forces.

As increased attention is placed on potential pathologic abnormalities and interventions of the hip, there is an increased need for understanding the function of the musculature surrounding the hip to effectively and efficiently evolve hip rehabilitation protocols. The stabilizing or motion effect hip muscles have on the joint and lower extremity is often based on their location and size without functional studies to support these assumptions.[1,6] The ability to gain knowledge about when and to what extent muscles are activated during hip rehabilitation will allow us to decide when and how to exercise these muscles. This may include isometric, concentric, or eccentric stabilization exercises or greater incorporation of functional movements such as gait. Proper gait involves pelvic movement on all 3 planes, including flexion and rotation, which is likely influenced by healthy functioning pectineus and piriformis muscles controlling but not overrestraining pelvic rotation. From this study, utilization of isometrics in early rehabilitation for stabilization of the femoral head into the acetabulum and eccentric exercises for the piriformis to control rotation in weightbearing exercises is appropriate. Further studies to assess the concentric activation of the iliopsoas compared with the pectineus would be useful to assess which muscle acts as a primary flexor or if they act equally.[26]

We recognize there are some limitations to our study. We had a small number of participants and would have benefited from the ability to use more individuals in our data analysis. Another limitation to our study was the absence of hip adduction exercises among the rehabilitation protocol. This could have provided further insight to the muscular activation under observation, especially with regard to the pectineus muscle that has been reported to also function as a hip adductor. In addition, we had only 1 exercise combining internal and external hip rotation, where a greater number of rotational exercises could have further validated the role of the pectineus muscle as a hip rotator. The most significant limitation to our study was the problems with the piriformis EMG electrode insertion. In 4 of the 10 participants, we were unable to obtain proper EMG signals from the piriformis muscle, or the electrodes caused muscle spasms that prevented accurate EMG recordings. This may be due to our insertion method, which consisted of inserting the needle deep into the muscle followed by a slight retraction of the electrodes. On the basis of our experience, we highly recommend to not retract fine-wire electrodes once they are inserted because of the high risk of signal loss. However, the strength of this study was that the data compiled were meticulously collected under ultrasound guidance and carefully processed, providing new and valuable insights into 2 deep muscles of the hip that have previously had little activation and functional descriptions.

CONCLUSION

The activation levels of the pectineus and piriformis muscles during 13 rehabilitation exercises were described by this study, providing valuable insights for future rehabilitation programs and an understanding of the function of the 2 deep hip muscles. The pectineus was highly activated during exercises involving hip flexion and slightly activated during exercises requiring stabilization and weightbearing. In order, the exercises that evoked the greatest activation levels in the pectineus muscle were supine hip flexion, the single-legged bridge, and the double-legged bridge. The piriformis was most activated when the hip was performing hip stabilization requiring the maintenance of external rotation and while abducting with the hip in external rotation. However, hip extension also significantly activated the piriformis. The exercises that caused the highest activation levels in the piriformis were the prone heel squeeze, side-lying hip abduction in external rotation, the single-legged bridge, and resisted hip extension. In conclusion, because the pectineus and piriformis muscles were both found to provide stabilization, the pectineus muscle was highly involved in hip flexion, and the piriformis was highly involved in extension, we believe that these deep hip muscles likely have an important role in hip function and stability in daily life and athletic pursuits.

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