Comparison Of Muscle Activation Levels Between Healthy Individuals And Persons Who Have Undergone Anterior Cruciate Ligament Reconstruction During Different Phases Of Weight-Bearing Exercises

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Abstract

STUDY DESIGN: Cross-sectional, controlled laboratory study. BACKGROUND: Quantification of muscular activation during different phases of functional activities is important to understand activation deficits in individuals who have undergone anterior cruciate ligament reconstruction (ACLR). OBJECTIVES: To compare activation levels of the vastus medialis (VM), medial hamstrings (MH), and gluteus medius (GMed) muscles during the different phases of weight-bearing tasks between individuals who had undergone ACLR and healthy controls. METHODS: Surface electromyography was used to measure the activation levels of the VM, MH, and GMed muscles in 16 participants who had undergone ACLR (average time since surgery, 4 years) and 15 healthy participants during the reach and return phases of the Star Excursion Balance Test (SEBT) and the ascending and descending phases of a step-down task (SDT). Repeated-measures analyses of variance were performed to determine whether muscle activation levels differed between groups during different phases of the tasks. RESULTS: There were significant group-by-phase interactions for the GMed during both the SEBT and SDT. Gluteus medius activation was lower for the ACLR group during the return phase of the posteromedial direction of the SEBT compared to the control group (P = .03). During the SDT, GMed activation was higher for the ACLR group during the ascending phase than during the descending phase (P<.001), while the control group showed no difference between phases (P = .71). CONCLUSION: Individuals who had undergone ACLR have similar VM and MH activation compared to healthy individuals during different phases of the SDT and SEBT. However, phase differences for GMed activity and decreased GMed activity relative to healthy individuals were observed among ACLR participants.

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RESULTS: There were significant group-by-phase interactions for the GMed during both the SEBT and SDT. Gluteus medius activation was lower for the ACLR group during the return phase of the posteromedial direction of the SEBT compared to the control group ($P = .03$). During the SDT, GMed activation was higher for the ACLR group during the ascending phase than during the descending phase ($P<.001$), while the control group showed no difference between phases ($P = .71$).

CONCLUSION: Individuals who had undergone ACLR have similar VM and MH activation compared to healthy individuals during different phases of the SDT and SEBT. However, phase differences for GMed activity and decreased GMed activity relative to healthy individuals were observed among ACLR participants. *J Orthop Sports Phys Ther 2016;46(11):984-992. Epub 11 Oct 2016. doi:10.2519/jospt.2016.5896*

KEY WORDS: *anterior cruciate ligament, electromyography, gluteus medius, knee joint, Star Excursion Balance Test*

Anterior cruciate ligament (ACL) reconstruction (ACLR) is a common treatment to re-establish knee joint stability in physically active individuals following ACL injury.[1] The goal of ACLR is to return patients to their preinjury levels of physical activity with normal knee function. However, it has been reported that following ACLR, patients exhibit alterations in knee muscle function during daily activities even after they return to preinjury activity levels.[19,26,27] These alterations in knee muscle function are thought to be the result of postsurgical adaptations that aid in dynamic knee stability during the performance of functional activities.[18,19,26,27]

Nontraumatic ACL injuries frequently occur during high-demand activities such as cutting and landing maneuvers.[2,3,22] As a result, many studies have focused on the activation of the quadriceps and hamstring muscles, as well as gluteal muscles, during these tasks.[16,19,24,26] While many of these studies have observed between-group differences,[10,19,26,27] others have not,[6,24] resulting in conflicting findings regarding differences in muscle activation between individuals who have undergone ACLR and healthy individuals.

There is limited knowledge describing the muscle activation patterns of individuals who have undergone ACLR while performing weight-bearing (WB)

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exercises, such as lunging, squatting, and stepping, that are widely used during ACLR rehabilitation.[7] Weight-bearing exercises are commonly used in ACLR rehabilitation because they are thought to be safer for graft healing than are non-WB exercises and to replicate functional activities.[28] Quadriceps and hamstring muscle activation levels prior to and 5 weeks following ACLR have been evaluated during WB exercises.[25] At 5 weeks post-ACLR, greater hamstrings activation and similar quadriceps activation in the ACL-reconstructed limb during static standing and squatting exercises were observed when compared to those in the uninjured limb and in healthy individuals.[25] The literature has also reported lower quadriceps activity and greater medial hamstring (MH) activity during single-leg squat exercises in individuals who have undergone ACLR compared to healthy controls, and these activation differences have been reported to persist approximately 4 years postsurgery.[16]

Although the gluteus medius (GMed) plays an important role in controlling lower extremity alignment during WB activities,[17] there is limited research of gluteal muscle activity after ACL injury and subsequent surgery. Hall et al[11] observed greater GMed activation during stair descent in individuals with a history of ACLR compared to healthy individuals 5 years postsurgery. These authors proposed that increased GMed activation might be a compensatory response to decreased postural control, particularly during unilateral WB.[8]

Contradictory results among existing electromyographic (EMG) studies in the ACLR population may be due in part to the wide variety of tasks and phases of muscular contraction analyzed and the common practice of investigating muscle activation levels without dividing the exercises into phases. Therefore, it is difficult to generalize the results of these studies to patients who have undergone ACLR or apply these results to ACLR rehabilitation. Given that functional WB activities consist of different phases (eg, descent and ascent, reach and return), investigating muscle activity separately during each phase of the movement may better detect phase-dependent muscle activity deficits following ACLR.[4]

TABLE 1 PARTICIPANT DEMOGRAPHICS

Characteristic	ACLR	Healthy
Sex, n		
Male	8	8
Female	8	7
Age, y*	26.9 ± 10.3	26.3 ± 6.6
Height, cm*	174.3 ± 10.0	171.6 ± 10.8
Body mass, kg*	77.6 ± 15.0	75.1 ± 9.2
Time from surgery to experiment, y*	4.2 ± 3.5	...
Graft, n		...
Hamstring	5	
Quadriceps	8	
Allograft	3	

Abbreviation: ACLR, anterior cruciate ligament reconstruction.
**Values are mean ± SD.*

The primary aim of the current study was to describe and compare the activation levels between individuals with a history of ACLR and healthy individuals for the vastus medialis (VM), MH, and GMed muscles during different phases of WB tasks that involve single-limb squatting, specifically, the Star Excursion Balance Test (SEBT) and a step-down task (SDT). Based on previous literature, it was hypothesized that there would be greater MH and GMed muscle activation and lower VM muscle activation in both the reach and return phases of the SEBT and the descending and ascending phases of the SDT in individuals with a history of ACLR compared to healthy individuals.

METHODS

Participants

Sixteen participants with a history of ACLR and 15 healthy controls were included in this study (**TABLE 1**). In the ACLR group, 3 participants had concomitant medial and lateral meniscus injuries, 1 participant had a lateral meniscus injury, and 1 participant had a medial meniscus injury. Participants were recruited from within the University of Kentucky and surrounding community using flyers and word of mouth. Participants who had undergone ACLR were excluded if they had an ACL revision, posterior cruciate ligament injury and/or reconstruction, or a previous injury or surgery to the contralateral limb. Healthy participants were excluded if they had previous lower extremity surgery, a lower extremity injury in the last 6 months, and/or a neurological problem that could affect physical activity. Written informed consent was obtained from all participants, as approved by the University of Kentucky Institutional Review Board.

Test Procedures

Electromyography A surface EMG system (TELEmyo DTS; Noraxon USA, Inc, Scottsdale, AZ) was used to measure the activation levels of the VM, MH, and GMed muscles during the functional tasks. Bipolar Ag/AgCl surface electrodes were placed at an interelectrode distance of 2 cm. The electrode width was 1 cm, the common-mode rejection ratio was greater than 80 Db, and the input impedance was greater than 10 mΩ. The sampling rate for EMG data was 1000

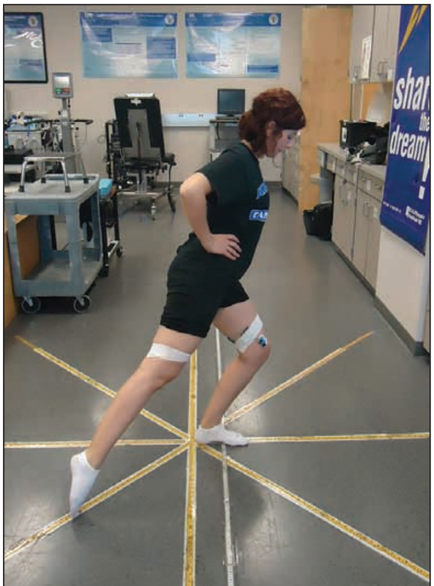

FIGURE 1. Star Excursion Balance Test (anterior and posteromedial reach directions).

Hz. Synchronized video capture with a frame rate of 30 frames per second (Webcam C500; Logitech International SA, Lausanne, Switzerland) was used to determine the ascending and descending phases and the reach and return phases of the functional tasks.

Prior to electrode placement, the participants warmed up for 5 minutes on a stationary bicycle at a self-selected speed. Then, the electrode sites of the body were prepared by shaving any hair on the skin, abrading the skin with fine sandpaper, and cleaning the skin with 70% isopropyl alcohol to minimize the skin impedance. The placement of electrodes for each muscle was done according to SENIAM's European Recommendations for Surface Electromyography.[13] For the VM, the electrodes were placed distally to the anterior superior iliac spine at a mark equivalent to 80% along a line drawn between the anterior superior iliac spine and the medial joint line anterior to the border of the medial collateral ligament. The placement of the electrodes for the MH was at 50% of the line between the ischial tuberosity and the medial epicondyle of the tibia. For the GMed, the electrodes were placed at 50% of the distance between the iliac crest and the greater trochanter of the femur. After the placement, the electrodes were fixed on the skin with nonadhesive athletic tape (PowerFlex; Andover Healthcare, Inc, Salisbury, MA) to prevent any displacement during the exercises.

Maximum Voluntary Isometric Contraction Testing Maximum voluntary isometric contractions (MVICs) were recorded prior to functional testing. To measure the MVIC for the VM, the participants were seated on a chair in 90° of hip flexion and 60° of knee flexion and secured with straps across the trunk and thigh and above the ankle joint.[12] During testing, the participants were instructed to push the lower leg against the strap as they extended their leg. The MVIC for the MH was performed in the prone position, with the knee flexed to 45°.[9] Manual resistance was applied just proximal to the posterior ankle. During testing, the participants were instructed to flex their leg against resistance. For the GMed, the MVIC was recorded from the stance leg during standing hip abduction.[5] A strap was placed around the participant's ankle. During testing, the participants were instructed to place their full weight on the stance leg and to abduct the other leg against the strap while maintaining the knee in extension.[5] For each MVIC, participants performed 1 practice trial, and then performed 3 repetitions of a 5-second MVIC. During the test, the participants received standardized verbal encouragements to produce maximum effort. Thirty seconds of rest was given between each contraction.

Functional Tasks All functional testing was performed on the involved limb of the individuals who had undergone ACLR and on the dominant limb of the healthy individuals, which was defined as the leg used to kick a ball.

Star Excursion Balance Test Participants were instructed to stand in the center of a grid, from which tape lines extended outward to a distance of 100 cm, marked in millimeters. The angle between 2 lines was set at 135°. The participants were instructed to reach as far as possible along each of the 2 lines, make a light toe touch on the line without shifting weight, and return to the center of the grid, while maintaining stable single-leg balance. Measurements were taken from the most distal aspect of the toes. Four practice trials were given for each limb for each direction.[20] Participants then performed 3 trials in the 2 directions for each limb. The average of the 3 reach distances in each direction was normalized to leg length (anterior superior iliac spine to medial malleolus) and was analyzed as percent leg length (**FIGURE 1**). The posterolateral direction of the test was not included, as pilot testing revealed that there was contact between electrodes between the legs, which contaminated the measurement of the VM EMG signal.

Step-down Task The participants performed a step-down from an adjustable platform ranging from 5.1 to 20.3 cm in height, adjusted so that the support leg reached 60° of knee flexion with the contralateral heel touching the floor. To normalize the rate of movement, a metronome was set to 75 beats per minute. Participants were instructed to lower down to heel contact on one beat and return to level with the platform within another beat, constituting 1 repetition. If the investigators observed compensatory movement strategies, participants were verbally cued to avoid lateral trunk lean or trunk rotation. In addition, participants were warned if the heel did not make ground contact or if they attempted to push off the ground to propel themselves upward while returning to level with the platform (**FIGURE 2**). After the initial repetition, the next 5 consecutive repetitions were used for analysis.

The SEBT and SDT were divided into different phases based on synchronized video recordings. The reach phase of the SEBT was defined as the period from when the reach foot moved past the stance leg to when the toe of the reach foot touched down on the grid. The return phase was defined as the period from toe touch to when the reach foot passed the stance leg, returning to the start position of the test. For the SDT, the time from the terminal extension of the stance leg to heel contact of the stepping leg was defined as the descending phase, while the time from heel contact of the stepping leg to terminal extension of the stance leg was defined as the ascending phase of the test.

EMG Signal Processing

Electromyographic data processing was accomplished using Noraxon MyoResearch XP Master Edition software (Noraxon USA, Inc). The EMG signals were band-pass filtered (10-500 Hz) and smoothed using a root-mean-square moving-window function with a time constant of 25 milliseconds. For each of the MVIC trials, the maximum value obtained over the 5-second maximum effort was recorded, and the average of 3 MVIC trials was used for normalization of the EMG data obtained during the tasks. For each trial of each task (3 trials for the SEBT, 5 trials for the SDT), the mean signal amplitude of each phase of the task was divided by the MVIC value for each muscle of interest (**FIGURE 3**). The average of the trials, expressed as a percentage of MVIC, was used for statistical analysis.

Statistical Analysis

Statistical analyses were performed in IBM SPSS Version 21.0 (IBM Corporation, Armonk, NY). Data were expressed as means and SDs for descriptive data. Intraclass correlation coefficients (model 3,1) and standard errors of measurement for the normalized EMG signal amplitudes (percent MVIC) for the 3 repetitions of the SEBT and 5 repetitions of the SDT for each muscle and each phase were used to determine the consistency between trials. Independent *t* tests were used to compare reach distance (percent leg length) between the ACLR and healthy groups for both directions of the SEBT. Two-way repeated-measures analyses of variance (ANOVAs) with 1 between-subject factor (group: ACLR or healthy) and 1 within-subject factor (phase: descending/reach or ascending/return) were performed to investigate for main effects or for interactions between group and phase. A total of 9 repeated-measures ANOVAs were performed, 1 for each muscle (VM, MH, GMed) during each task (SEBT anterior, SEBT posteromedial, and SDT). A Bonferroni post hoc test was used when a significant interaction and/or main effects were observed. Significance levels were set at $P<.05$.

RESULTS

TABLE 2 provides descriptive statistics for each group for maximum muscle activation level, expressed as a percentage of MVIC, for the VM, MH, and GMed at each phase of each task. Intraclass correlation coefficients (model 3,1) for intertrial reliability and standard errors of measurement expressed as percent MVIC are shown in **TABLE 3** for each muscle, each task, and each group. Intraclass correlation coefficients for all conditions ranged from

FIGURE 2. Step-down task.

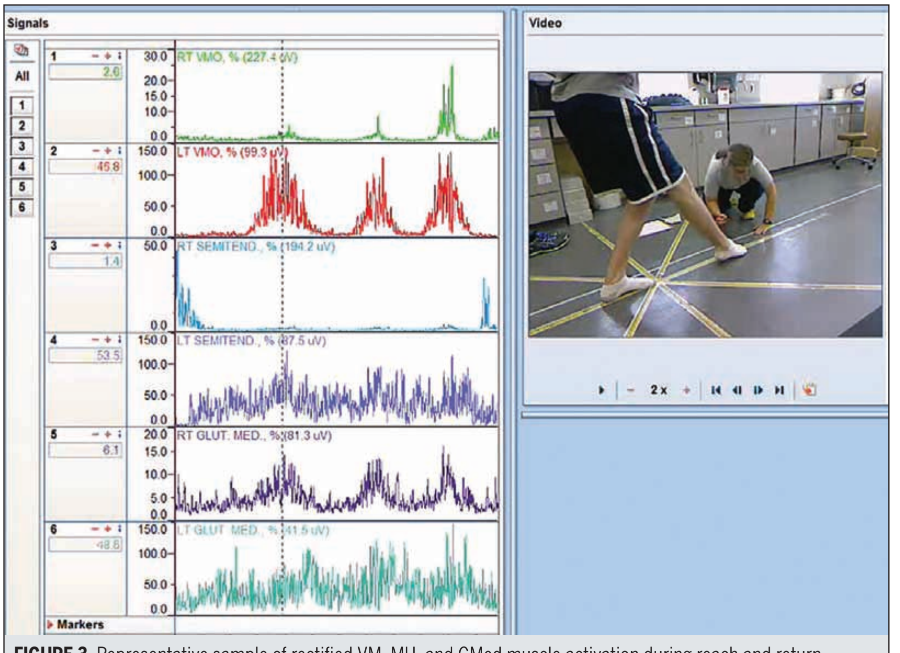

FIGURE 3. Representative sample of rectified VM, MH, and GMed muscle activation during reach and return phases of the anterior direction of the Star Excursion Balance Test. The dashed line represents the change from the reach phase to the return phase. Values represent the mean activation level (percent maximum voluntary isometric contraction) across each phase. Abbreviations: GMed, gluteus medius; MH, medial hamstrings; VM, vastus medialis.

TABLE 2 Vastus Medialis, Medial Hamstring, and Gluteus Medius Activation Levels During Phases of Each Test by Group*

Test/Muscle/Phase	ACLR	Healthy
SEBT anterior		
Vastus medialis		
Reach	38.4 ± 26.6	44.4 ± 23.2
Return	51.1 ± 34.3	56.5 ± 28.8
Medial hamstrings		
Reach	21.5 ± 15.1	15.4 ± 8.8
Return	18.9 ± 14.5	13.7 ± 7.3
Gluteus medius		
Reach	24.3 ± 10.2	17.9 ± 8.8
Return	28.4 ± 16.2	27.1 ± 11.8
SEBT posteromedial		
Vastus medialis		
Reach	42.1 ± 19.1	45.2 ± 21.2
Return	71.3 ± 37.4	62.4 ± 23.0
Medial hamstrings		
Reach	9.8 ± 4.7	11.1 ± 7.1
Return	14.5 ± 7.4	17.1 ± 11.7
Gluteus medius		
Reach	32.5 ± 8.8	36.2 ± 11.6
Return	37.0 ± 10.3†	47.2 ± 14.9†
Step-down test		
Vastus medialis		
Descending	30.4 ± 25.7	38.4 ± 31.2
Ascending	58.4 ± 35.3	65.3 ± 26.8
Medial hamstrings		
Descending	12.6 ± 9.3	7.2 ± 4.8
Ascending	11.3 ± 8.7	7.3 ± 4.8
Gluteus medius		
Descending	23.1 ± 9.4‡	27.5 ± 11.4
Ascending	32.8 ± 14.5‡	28.2 ± 10.4

Abbreviations: ACLR, anterior cruciate ligament reconstruction; SEBT, Star Excursion Balance Test.
**Values are mean ± SD percent maximum voluntary isometric contraction.*
†The ACLR participants exhibited lower gluteus medius activity during the return phase of the movement when compared to the healthy participants.
‡The ACLR group exhibited greater gluteus medius activation during the ascending phase than during the descending phase.

0.63 to 0.98, with corresponding standard errors of measurement ranging from 1.3% to 16.5% MVIC.

There were no significant differences between groups in terms of reach distance for anterior (ACLR, 69.5% ± 8.0%; healthy, 72.1% ± 10.1%; $P = .44$) and posteromedial (ACLR, 80.4% ± 9.6%; healthy, 77.6% ± 7.5%; $P = .39$) directions of the SEBT.

SEBT in the Anterior Direction

There were no significant group-by-phase interactions for the activation levels for the VM ($F_{1,29} = 0.02$, $P = .90$), MH ($F_{1,29} = 0.19$, $P = .66$), or GMed ($F_{1,29} = 2.85$, $P = .10$). A main effect for group also was not observed for activation levels of the VM ($F_{1,29} = 0.33$, $P = .57$), MH ($F_{1,29} = 0.19$, $P = .66$), and GMed ($F_{1,29} = 0.87$, $P = .36$).

SEBT in the Posteromedial Direction

There was a significant group-by-phase interaction with respect to GMed muscle activation during the posteromedial reach of the SEBT ($F_{1,29} = 6.17$, $P = .02$). Post hoc testing revealed lower GMed activity during the return phase of the movement in ACLR participants compared to the healthy participants ($P = .03$) (**FIGURE 4**).

There were no group-by-phase interactions in the VM ($F_{1,29} = 1.86$, $P = .18$) or the MH ($F_{1,29} = 0.42$, $P = .52$) during the posteromedial reach of the SEBT. Main effects for group also were not observed for the VM ($F_{1,29} = 0.11$, $P = .74$) and MH ($F_{1,29} = 0.46$, $P = .50$) activation levels.

Step-down Task

There was a significant group-by-phase interaction for GMed activation ($F_{1,29} = 11.99$, $P = .002$). Post hoc testing revealed that the ACLR group exhibited greater GMed activation during the ascending phase than during the descending phase ($P < .001$). However, the control group showed similar GMed activation levels during the ascending and descending phases of the test ($P = .71$) (**FIGURE 5**).

There was no group-by-phase interaction in the VM ($F_{1,29} = 0.01$, $P = .91$) or MH ($F_{1,29} = 0.03$, $P = .85$) during the SDT. Main effects for group were not significant for the VM ($F_{1,29} = 0.58$, $P = .45$) and MH ($F_{1,29} = 2.34$, $P = .14$) activation levels.

DISCUSSION

The main objective of this study was to compare the activation of hip and knee muscles during different phases of WB tasks between individuals who had undergone ACLR and healthy controls. We observed that individuals who had previously undergone ACLR had similar VM and MH muscle activations during functional tasks when compared to healthy individuals. However, the findings for GMed activation were variable. For the SEBT posteromedial reach, the individuals who had under-

TABLE 3	Intertrial Reliability and SEM Values of Each Test by Group			
	ACLR		Healthy	
Test/Muscle/Phase	$ICC_{3,1}$	SEM*	$ICC_{3,1}$	SEM*
SEBT anterior				
Vastus medialis				
Reach	0.93	6.9	0.95	6.4
Return	0.87	12.4	0.85	10.9
Medial hamstrings				
Reach	0.93	4.0	0.95	1.9
Return	0.90	4.6	0.63	4.4
Gluteus medius				
Reach	0.90	3.2	0.95	1.9
Return	0.85	6.3	0.74	6.0
SEBT posteromedial				
Vastus medialis				
Reach	0.87	6.8	0.76	10.4
Return	0.80	16.5	0.85	8.9
Medial hamstrings				
Reach	0.98	2.0	0.83	2.9
Return	0.81	2.8	0.86	4.4
Gluteus medius				
Reach	0.83	3.8	0.88	4.0
Return	0.79	4.8	0.87	5.4
Step-down test				
Vastus medialis				
Descending	0.96	5.1	0.95	8.3
Ascending	0.96	6.9	0.95	5.9
Medial hamstrings				
Descending	0.90	2.9	0.72	3.4
Ascending	0.95	1.9	0.92	1.3
Gluteus medius				
Descending	0.89	3.1	0.81	5.0
Ascending	0.84	5.7	0.81	4.4

Abbreviations: ACLR, anterior cruciate ligament reconstruction; ICC, intraclass correlation coefficient; SEBT, Star Excursion Balance Test; SEM, standard error of measurement.
**Values are percent maximum voluntary isometric contraction.*

gone ACLR demonstrated lower GMed activation compared to healthy individuals. For the SDT, individuals who had undergone ACLR showed greater GMed activation during the ascending phase compared to the descending phase, while healthy individuals demonstrated similar activation during the ascending and descending phases of the SDT. Our findings did not support our hypothesis that individuals who had undergone ACLR would show greater MH and GMed and lower VM muscle activation compared to the healthy group in different phases of the functional tasks.

Quadriceps and hamstring muscle activation specific to different phases of the SEBT and/or SDT in individuals who had undergone ACLR has not been previously reported. Tagesson et al[25] investigated VM and hamstring muscle activations during a single-leg squat exercise, without dividing the exercise into phases, in ACLR individuals 5 weeks after surgery. These authors observed that hamstring activation was greater in the involved limb than in the uninvolved limb during a single-leg squat, while VM activation was similar between limbs. The authors concluded that increased hamstring activation enhanced joint compression, increasing joint stiffness to reduce excessive stress to the healing graft in the early period after ACL surgery.[15,25] Based on the results of the present study, evaluating patients a minimum of 1 year and an average of 4 years after ACLR surgery, it appears that the differences observed by Tagesson et al[25] may be transient and

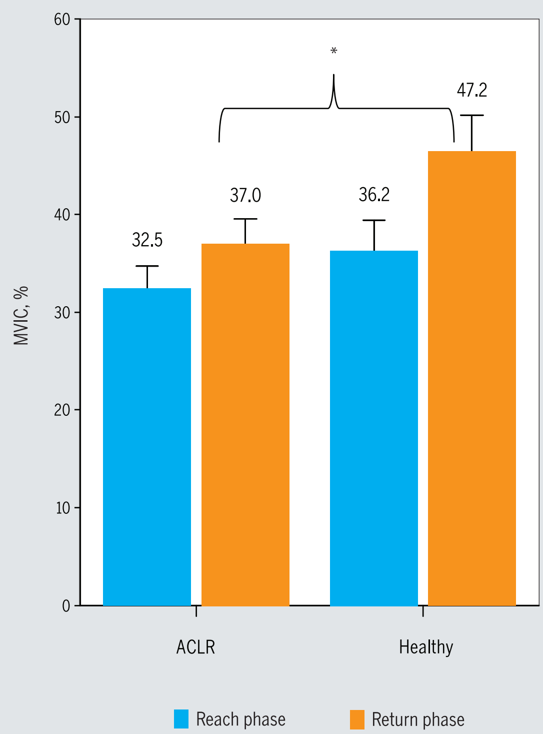

FIGURE 4. Gluteus medius activation during reach and return phases of the posteromedial direction of the Star Excursion Balance Test. Values are mean ± standard error percent MVIC. *ACLR participants exhibited lower gluteus medius activity during the return phase of the movement when compared to the healthy participants (*P* = .03). Abbreviations: ACLR, anterior cruciate ligament reconstruction; MVIC, maximum voluntary isometric contraction.

may not represent long-term adaptations to muscle function.

In another investigation of individuals who had undergone ACLR (mean time since surgery, 3.7 years), Madhavan and Shields[16] reported lower quadriceps activation but greater hamstring activation during a dynamic resisted single-leg squat exercise with perturbations when compared to the healthy individuals. It was postulated that lower quadriceps activity and greater hamstring activity were adaptations to protect the reconstructed ligament against excessive tibial anterior translation. However, in the present study, individuals who had undergone ACLR at a similar mean postoperative time point exhibited hamstring and quadriceps muscle activation similar to those of healthy control participants. The differences between the present study and the work of Madhavan and Shields[16] may be due to the differences between performing a normal squat and a resisted squat, in which resistance (17% of body weight) and perturbations were dynamically applied at the knee joint. The tasks in our study were all performed with body weight and without any additional resistance or perturbations. It is possible that at an average of 4 years following ACLR, the VM and MH muscle activation levels may reach normal levels for both the reach and return phases and the ascending and descending phases of squatting tasks performed with body weight in a controlled environment.

Although the GMed has been shown to be a very important muscle for lower extremity alignment during functional activities, we are aware of only 1 study that has investigated GMed activation after ACLR during step ascent and descent.[11] Hall et al[11] reported greater GMed activation in individuals who had undergone ACLR during stair descent when compared to healthy individuals. In contrast, we observed that participants who had undergone ACLR exhibited lower GMed activation than healthy participants during the return phase of the SEBT posteromedial reach. Multiple theories offer insight regarding why these findings did not support our hypothesis that GMed activation would be increased among individuals who had undergone ACLR. We hypothesized that SEBT reach distance might explain the GMed activation differences observed between groups, such that the farther the participants reached, the greater the demands of the task and the more muscle activation was needed for returning to upright stance. However, reach distances as measured by the percent of leg length did not differ between groups. Finally, we considered that variations in trunk movement could affect muscle activation levels while performing the test. Previous research has shown that forward movement of the upper body decreases the demand of the GMed during single-leg stance.[21] Although kinematic data were not collected as part of the current study, anecdotally, individuals who had undergone ACLR in this study were observed to demonstrate more forward trunk lean than healthy participants while performing the return phase of the SEBT. Had this movement been systematically recorded, it may have been useful in explaining the observed group-by-phase interactions for the GMed. It is recommended that future investigations include a measure of trunk motion when evaluating GMed activation levels.

For the SDT, individuals who had undergone ACLR exhibited greater GMed activation in the stance leg during the ascending phase than during the descending phase of the task. However, healthy individuals showed no difference between phases in terms of GMed activation. Simenz et al[23] investigated GMed activation during ascending and descending phases of resisted step-up exercises (step-up, crossover step-up,

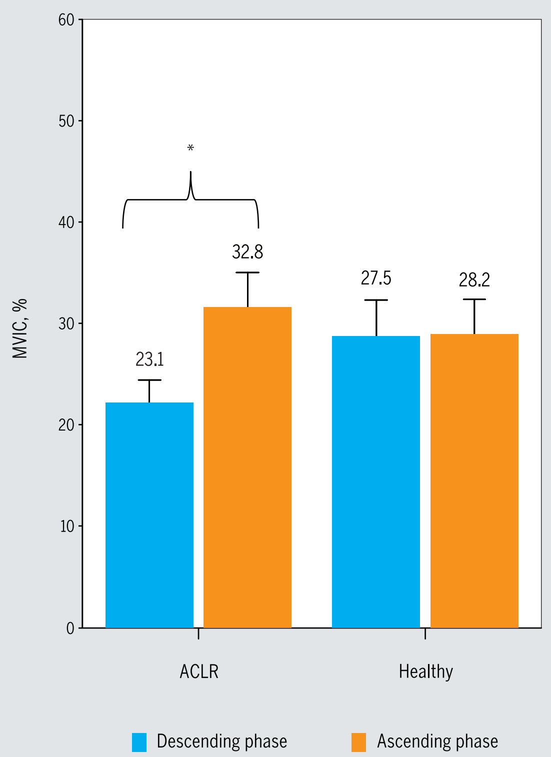

FIGURE 5. Gluteus medius muscle activation during ascending and descending phases of the step-down task. Values are mean ± standard error percent MVIC. *ACLR group exhibited greater GMed activation during the ascending phase than during the descending phase (*P*<.001). Abbreviations: ACLR, anterior cruciate ligament reconstruction; MVIC, maximum voluntary isometric contraction.

lateral step-up, and diagonal step-up) in healthy individuals. Similar to our results for the ACLR group, Simenz et al[23] reported that the GMed exhibited greater activation during ascending phases of all exercises. The step height used by Simenz et al[23] was 45.7 cm, compared to the heights of 5.1 to 20.3 cm (depending on subject height to achieve the appropriate knee angle) utilized in the current study. Therefore, the higher steps and extra demand utilized by Simenz et al[23] may have significantly increased the demands of the task, resulting in higher GMed activity. In the present study, the presence of between-phase differences between individuals who had undergone ACLR and healthy controls suggests that the individuals who had undergone ACLR may require greater motor unit recruitment during the ascending phase of the SDT to generate more relative muscle force due to impaired GMed strength.[14]

Limitations

Trunk and lower extremity positions can significantly influence the demands and functions of the muscles of interest during the SEBT and SDT. We did not objectively monitor trunk and lower extremity alignment. We attempted to standardize participants' pelvic and trunk postures in vertical alignment through corrective feedback of verbal and physical cuing during the SDT and SEBT. However, given the free-standing nature of the tasks, complete control of extraneous trunk movement was not feasible. Therefore, we cannot definitively document how potential variation in body postures between groups may have affected our results. Similarly, verbal cuing may have obscured abnormal activation patterns that may have occurred had free movement, with no coaching, been permitted. Finally, it is important to acknowledge the limitations of the cross-sectional nature of this study. We cannot determine whether altered muscle activation levels were present prior to ACLR. It is possible that the observed differences may have been present prior to injury and do not represent post-ACLR neuromuscular changes. Large long-term cohort studies would be necessary to examine both preinjury risk factors and long-term changes related to muscle function among individuals who experience an ACL injury.

CONCLUSION

Participants who had undergone ACLR exhibited decreased GMed activation levels during the return phase of the posteromedial direction of the SEBT and similar VM and MH muscle activation when compared to healthy participants. Contrary to previous literature, evidence of altered VM and MH muscle activation when performing WB tasks was not found approximately 4 years after ACLR surgery. Activation of the GMed should be evaluated in persons who have undergone ACLR, and consideration should be given for including GMed activation exercises as part of post-ACLR rehabilitation. ◉

KEY POINTS

FINDINGS: Individuals who had undergone ACLR exhibited similar VM and MH activation compared to healthy individuals during different phases of the SEBT and SDT. Gluteus medius activation was lower in individuals who had undergone ACLR during the return phase of the posteromedial direction of the SEBT.

IMPLICATIONS: Variations in GMed muscle activation levels among individuals who had undergone ACLR during functional tasks may represent compensatory neuromuscular adaptations postsurgery.

CAUTION: Trunk and lower extremity movements were not monitored objectively. Varying body movements may have influenced the demands of the muscles examined.

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