Effects of Exercise on Lower Extremity Muscle Function After Anterior Cruciate Ligament Reconstruction

Christopher Kuenze, Jay Hertel, and Joseph M. Hart

Purpose: Persistent quadriceps weakness due to arthrogenic muscle inhibition (AMI) has been reported after anterior cruciate ligament (ACL) reconstruction. Fatiguing exercise has been shown to alter lower extremity muscle function and gait mechanics, which may be related to injury risk. The effects of exercise on lower extremity function in the presence of AMI are not currently understood. The purpose of this study was to compare the effect of 30 min of exercise on quadriceps muscle function and soleus motoneuron-pool excitability in ACL-reconstructed participants and healthy controls.

Methods: Twenty-six (13 women, 13 men) healthy and 26 (13 women, 13 men) ACL-reconstructed recreationally active volunteers were recruited for a case-control laboratory study. All participants completed 30 min of continuous exercise including alternating cycles of inclined-treadmill walking and bouts of squats and step-ups. Knee-extension torque, quadriceps central activation ratio (CAR), soleus H:M ratio, and soleus V:M ratio were measured before and after 30 min of exercise.

Results: There was a significant group × time interaction for knee-extension torque (P = .002), quadriceps CAR (P = .03), and soleus V:M ratio (P = .03). The effect of exercise was smaller for the ACL-R group than for matched controls for knee-extension torque (ACL-R: %Δ = –4.2 [–8.7, 0.3]; healthy: %Δ = –14.2 [–18.2, –10.2]), quadriceps CAR (ACL-R: %Δ = –5.1 [–8.0, –2.1]; healthy: %Δ = –10.0 [–13.3, –6.7]), and soleus V:M ratio (ACL-R: %Δ = 37.6 [2.1, 73.0]; healthy: %Δ = –24.9 [–38.6, –11.3]). Conclusion: Declines in quadriceps and soleus volitional muscle function were of lower magnitude in ACL-R subjects than in healthy matched controls. This response suggests an adaptation experienced by patients with quadriceps AMI that may act to maintain lower extremity function during prolonged exercise.

Keywords: central activation ratio, fatigue, Hoffmann reflex, knee injury

Return to activity after anterior cruciate ligament (ACL) reconstruction (ACL-R) should occur when lower extremity strength and functional performance are symmetrical and equal to preinjury levels. Ideally, rehabilitation focuses on improving knee-joint range of motion, strength, and function, with the goal of return to previous activity level. Unfortunately, neuromuscular deficits may persist beyond completion of traditional postoperative rehabilitation programs due to arthrogenic muscle inhibition (AMI).1,2 AMI is a common neuromuscular deficit observed after ACL reconstruction and may lead to frustrating strength plateaus throughout the rehabilitation process.3,4 Despite the absence of muscle pathology or neurologic injury, muscle tissue surrounding the injured joint is reflexively inhibited to protect the injured joint and limit joint function. The exact mechanisms of AMI are unclear, but it is believed that both joint effusion and soft-tissue damage from the initial injury, as well as ligament reconstruction, can lead to altered afferent output from the knee joint. Quadriceps AMI may cause persistent weakness and altered knee-joint biomechanics.5,6 These alterations may complicate patients’ goals of returning to recreational or competitive athletics due to the potential for joint reinjury or degeneration.7

In the lower extremity, the soleus also experiences changes due to AMI at the knee. Previous investigations have shown soleus motoneuron-pool facilitation in conjunction with quadriceps inhibition in the presence of a joint effusion.8 It was hypothesized that soleus facilitation in the presence of quadriceps AMI was a compensatory response to help maintain the ability to ambulate.8 However, when soleus motoneuron-pool excitability in patients with a history of ACL-R was compared with that in healthy controls, no difference was found.9 The response of the soleus motoneuron pool to exercise in the presence of quadriceps AMI is currently unknown, but previous reports have suggested significant declines in soleus motoneuron-pool excitability after sport-based exercise in healthy active individuals.10 Functionally, soleus activation has been implicated in both knee-joint stability11,12 and functional performance13,14; therefore, in the presence of quadriceps AMI, the soleus may be facilitated to help maintain lower extremity function.

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Previous investigations have used various fatiguing exercise protocols to better understand the effects of simulated athletic participation in healthy \(^{10,15-20}\) and pathological populations.\(^{21-24}\) Lower extremity muscles become weaker and more inhibited after prolonged exercise in healthy individuals.\(^{10,17,23}\) In healthy individuals, decreased quadriceps strength and altered gait biomechanics have been measured after isokinetic fatigue of the hamstrings and quadriceps.\(^{25}\) Declines in soleus motoneuron-pool excitability have also been measured after bouts of athletic activity,\(^{10,26}\) bouts of lumbar extensions,\(^{27}\) and sustained submaximal muscle contraction.\(^{28}\) While the decline in lower extremity muscle function and motoneuron-pool excitability appears to be consistent across studies in healthy participants, without the inclusion of pathological populations the effects of knee injury on lower extremity fatigue remain unclear.

In the presence of AMI, individuals commonly experience a reduced volitional activation of the quadriceps,\(^{1}\) as well as reduced reflexive activation of the soleus\(^{8,29}\) in a rested state, which may have major implications during rehabilitation and for return to previous levels of activity.\(^{30}\) Limited evidence is available regarding alterations in motoneuron-pool excitability and lower extremity muscle function after exercise in pathological populations. After lumbar paraspinous fatigue via multiple bouts of lumbar extensions, significant declines (–9.2\%) in quadriceps activation have been measured in participants with low back pain.\(^{31}\) These declines were found to be significantly greater than those in healthy controls.\(^{31}\) However, in knee-injured populations, the effects of fatigue have been more variable. Prior research has shown reduced fatigability or a resistance to reduction in force generation by the quadriceps during isometric endurance\(^{32}\) and electrically induced fatigue\(^{33}\) tests in ACL-R patients. However, changes in more functional measures of lower extremity muscle activation after standardized exercise protocols and in the presence of quadriceps AMI are currently unknown. Therefore, our purpose was to compare the effect of standardized exercise on quadriceps muscle activation and soleus motoneuron-pool excitability in participants after ACL-R compared with healthy matched controls. We hypothesized that participants with a history of ACL-R would experience greater declines in knee-extension torque, quadriceps central activation ratio (CAR), and soleus motoneuron-pool excitability after exercise than healthy matched controls.

### Methods

#### Design

This was a case-control laboratory study with a pretest, posttest design. The dependent variables measured were quadriceps maximum volitional isometric contraction (MVIC) torque, quadriceps CAR, soleus H-reflex to M-wave (H:M) ratio, and soleus V-wave to M-wave (V:M) ratio.

#### Subjects

Twenty-six (13 women, 13 men) healthy and 26 (13 women, 13 men) ACL-R (8 patellar-tendon autograft, 15 hamstring autograft, 3 allograft) recreationally active volunteers participated in this study (Table 1). Participants in both groups were included if they were between the ages of 18 and 40 years, had a body-mass index less than 35, and were recreationally active (exercised at least 3 times/week for 30 min) as reported on a general health intake form. In the healthy matched control group, participants were excluded if they had a self-reported history of lower extremity joint surgery, lower extremity joint sprain within the past 6 weeks, neurological disorder, cardiopulmonary disorder, or an inability to complete 30 minutes of aerobic exercise. Participants included in the ACL-R group were a minimum of 6 months after unilateral, primary ACL-R and exhibited quadriceps activation failure (CAR ≤ 90\%). They were excluded if they had a multiple ligament reconstruction, significant surgical complication (infection, etc), or history of graft failure. Participants in the ACL-R group had been released from their surgeon’s care, as well as structured rehabilitation by a physical therapist or athletic trainer. All participants were recruited from the university community through flyers and directed mailings after a medical system database review of patients with a history of ACL-R. This study was approved by the university institutional review board, and all subjects provided informed written consent before enrollment.

#### Instrumentation

Soleus Hoffmann reflex (H-reflex) and volitional wave (V-wave) were measured using surface electromyography sampled at 2000 Hz (MP150, Biopac Systems Inc, Santa

### Table 1 Subject Demographics

<table>
<thead>
<tr>
<th></th>
<th>Healthy</th>
<th>ACL-Reconstructed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>24.3 4.3</td>
<td>24.2 4.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.9 10.3</td>
<td>171.0 11.4</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>70.9 13.2</td>
<td>71.2 12.6</td>
</tr>
<tr>
<td>Body-mass index</td>
<td>23.8 2.6</td>
<td>24.2 2.4</td>
</tr>
<tr>
<td>Months since surgery</td>
<td>— —</td>
<td>44.7 39.2</td>
</tr>
<tr>
<td>VAS at screening</td>
<td>0.1 0.3</td>
<td>0.0 0.1</td>
</tr>
<tr>
<td># of competitive athletes</td>
<td>1 —</td>
<td>2 —</td>
</tr>
<tr>
<td># of recreational athletes</td>
<td>25 —</td>
<td>24 —</td>
</tr>
</tbody>
</table>

Abbreviations: ACL, anterior cruciate ligament.
Barbara, CA). A square-wave stimulator (10–200 V) was used to elicit the H-reflex and V-wave (Stimsooc, Biopac Systems Inc). Quadriceps CAR via the superimposed burst technique was measured with a Biodex multimodal dynamometer (System 3, Biodex Medical Systems, Inc, Shirley, NY). Data were exported using a remote-access port and digitized at 125 Hz (MP150, Biopac Systems, Inc). A Grass S88 dual-output square-pulse stimulator (Grass-Telefactor, West Warwick, RI) with the Stimsooc stimulus isolation unit (Biopac Systems, Inc) was used to deliver a 100-millisecond train of 10 square-wave pulses at an intensity of 125 V with a pulse duration of 600 μs at a frequency of 100 pulses/s. Two 8 × 14-cm, rubber, stimulating electrodes coated in conductive gel were placed over the proximal-lateral and distal-medial quadriceps on the involved leg and secured using an elastic compression wrap.

Baseline Measures

Participants reported to the laboratory for a single session that included screening to confirm inclusion and exclusion criteria, as well as the testing session. They then completed baseline testing, which included recording of the soleus H-reflex and V-wave followed by measurement of quadriceps CAR via the superimposed burst technique. The order of testing was not randomized due to the potential influence of maximal exertion and electrical stimulation before measurement of the H-reflex.

Soleus H-Reflex and V-Wave

Signals were amplified from disposable, 10-mm pregelled Ag-AgCl electrodes, which were placed over the midline of the soleus muscle, distal to the gastrocnemius muscle bellies and proximal to the soleus–Achilles musculotendinous junction. The area over the soleus was prepared for electrode placement by shaving the surrounding hair, debriding with fine sandpaper, and cleaning with isopropyl alcohol. EMG electrodes were placed 2 cm apart and parallel with the muscle-fiber orientation. The stimulating electrode was positioned over the tibial nerve in the popliteal fossa and traced on the skin to ensure correct placement during the postexercise testing.

Participants were positioned prone on a treatment table with their knee flexed to approximately 15°, and they were asked to relax throughout the course of testing. Stimuli were delivered by increasing the intensity with a 10-second rest interval after each stimulus until maximum H-reflex (H_max) and M-wave (M_max) amplitude were recorded. Subjects remained in the same testing position during the postexercise testing. A stimulation identical in waveform and 20% greater in intensity than the M-wave stimulation was delivered once maximum contraction was achieved. This stimulation intensity is consistent with a previous investigation that measured alterations in soleus V-wave after tennis activity. Due to the active component of the V-wave testing protocol, it is essential that the stimulation intensity be great enough to elicit activation of all soleus motoneurons during each active contraction to limit the number of stimulations required to achieve a stable and measurable V-wave. EMG data were band-pass-filtered 10 to 500 Hz and notch filtered 59.5 to 60.5 Hz. The means of the 3 highest-amplitude (peak-to-peak voltage) H-reflex, V-wave, and M-wave EMG responses were recorded. A ratio of the mean values for H-reflex to M-wave (H:M) and V-wave to M-wave (V:M) were then calculated. The H:M ratio is thought to represent an estimation of the number of motoneurons an individual can activate (H_max) compared with an estimate of the total motoneuron pool (M_max). Consequently, the V:M ratio is considered similar to the H:M ratio; however, in this case the V-wave includes not only an estimate of reflex activation but also the ability of an individual to volitionally activate the motoneuron pool. When considered together, these measures allow us to better understand the reflexive and volitional components of soleus muscle activation. Maximal M-wave was reestablished postexercise to allow for normalization of H-reflex and V-wave at each measurement time.

Quadriceps CAR

Quadriceps activation was measured using the superimposed burst technique at baseline and after the submaximal-exercise protocol. Participants were seated in the dynamometer chair with the hips and knees flexed to 80° and 60°, respectively. They were secured to the chair using a lap belt and were asked to maintain good seated posture (back straight, shoulders against the chair back) with their hands in their lap. Participants completed several practice trials to become comfortable with the testing protocol. After a short rest period to minimize the potential effects of fatigue, participants were asked to perform an MVIC using their knee extensors. The investigator provided constant verbal encouragement throughout each trial, such as “keep going” and “push harder.” Once the investigator determined that the MVIC had reached a plateau representing the MVIC, an electrical stimulation was delivered to the quadriceps using two 3” × 5” pregelled stimulating electrodes placed over the proximal vastus lateralis and distal vastus medialis. The stimulus is intended to produce a transient increase in torque (T_SIB) known as a superimposed burst, which is then compared with the average torque value for a 250-millisecond window immediately before the stimulation (T_MVIC). These values were then used to calculate the quadriceps CAR:

\[
\text{CAR} = \frac{T_{\text{MVIC}}}{(T_{\text{MVIC}} + T_{\text{SIB}})} \times 100
\]
Theoretically, this percentage is used to quantify the percentage of the quadriceps motoneuron pool that can be volitionally activated.36

**Exercise Protocol**

The exercise protocol consisted of repeated cycles of treadmill walking at a self-selected pace (5 min), bodyweight-resisted squats, and step-ups (1 min). During the walking phases, the treadmill incline was increased 1.0°/min until an incline of 15.0° was achieved. Five cycles (walking and exercise) were completed for a total of 30 minutes of exercise. During the final 30 seconds of each bout of walking, the participants were asked to rate their level of exertion on the Borg scale of perceived exertion (Figure 1).

**Postexercise Testing**

The testing procedures used at baseline were repeated immediately after the functional-exercise protocol. Postexercise measurements were taken within 10 minutes of exercise completion.

**Statistical Analysis**

We performed a sample-size estimation using quadriceps CAR as the primary dependent measure from a previous study.37 A minimum of 24 participants were needed per group to find significant differences with a power of 80% and an alpha level of .05. Statistical analyses were performed using SPSS statistical software (version 17.0, SPSS Inc, Chicago, IL). Separate independent-samples t tests were performed for knee-extension torque, quadriceps CAR, soleus H:M ratio, and soleus V:M ratio at baseline. Separate 2 (group: ACL-R, control) × 2 (time: baseline, preexercise) repeated-measures ANOVAs were performed for knee-extension torque, quadriceps CAR, soleus H:M ratio, and soleus V:M ratio. Baseline-to-postexercise percent-change scores and 90% confidence intervals were used to determine the preexercise-to-postexercise effect of ACL-R compared with healthy controls. The level of significance was set at \( P < .05 \) a priori.

**Results**

**Quadriceps CAR**

Knee-extension torque \( (t_{50} = 3.56, P = .001) \) and quadriceps CAR \( (t_{50} = 4.29, P < .001) \) were significantly lower in the ACL-R group than in the healthy matched controls at baseline. There were significant group × time interactions for knee-extension torque \( (F_{1,50} = 11.16, P = .002) \) and quadriceps CAR \( (F_{1,50} = 5.01, P = .03) \). The reductions in knee-extension torque and quadriceps CAR experienced by the ACL-R group were smaller than those seen in healthy matched controls (Table 2).

**Soleus H-Reflex and V-Wave**

Soleus V:M ratio \( (t_{50} = 2.45, P = .02) \) was significantly lower in the ACL-R group than in the healthy matched controls at baseline; however, there was no difference in H:M ratio \( (t_{50} = 0.67, P = .51) \). There was a significant group × time interaction for soleus V:M ratio \( (F_{1,50} = 5.33, P = .03) \). The reductions in V:M ratio experienced by the ACL-R group were smaller than those seen in healthy matched controls (Table 2). There was no significant group × time interaction for soleus H:M ratio \( (F_{1,50} = 2.32, P = .13) \); however, there was a significant main effect for time \( (F_{1,50} = 34.79, P < .001) \), indicating that scores in both groups declined similarly after exercise.

**Discussion**

We hypothesized that due to the presence of quadriceps AMI, ACL-R participants would experience larger reductions in quadriceps strength and central activation that would be accompanied by soleus facilitation after exercise. The findings of the current study do not support these hypotheses. Both groups experienced a decline in knee-extension torque after exercise, indicating that quadriceps fatigue was present; however, healthy participants experienced a larger-magnitude reduction in knee-extension torque, quadriceps CAR, and soleus V:M ratio than did ACL-R participants (Figure 2). It appears that after exercise, the quadriceps muscles in ACL-R participants are experiencing a response that is consistent with decreased fatigability but may also be representative of a preservation strategy adopted in the presence of quadriceps AMI.

Persistent quadriceps inhibition has been reported in patients after ACL-R; however,1,3,38 only 2 previous studies have directly addressed the fatigability of quadriceps in these patients.32,33 In the subacute phase

![Figure 1](image-url) — Ratings of perceived exertion throughout the exercise protocol were similar between groups. Abbreviations: ACL, anterior cruciate ligament.
Table 2  Between-Groups Comparison of Preexercise and Postexercise Measures of Quadriceps and Soleus Function

<table>
<thead>
<tr>
<th></th>
<th>Group</th>
<th>Preexercise, mean ± SD</th>
<th>Postexercise, mean ± SD</th>
<th>% change</th>
<th>90% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee-extension torque (Nm/kg)</td>
<td>Healthy</td>
<td>3.35 ± 0.84†</td>
<td>2.88 ± 0.85</td>
<td>−14.2*</td>
<td>−19.0, −9.4</td>
</tr>
<tr>
<td></td>
<td>ACL-R</td>
<td>2.59 ± 0.68</td>
<td>2.45 ± 0.61</td>
<td>−4.2</td>
<td>−9.6, 1.2</td>
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<tr>
<td>Quadriceps CAR (%)</td>
<td>Healthy</td>
<td>88.0 ± 7.2†</td>
<td>79.3 ± 11.4</td>
<td>−10.0*</td>
<td>−14.0, −6.0</td>
</tr>
<tr>
<td></td>
<td>ACL-R</td>
<td>75.2 ± 13.4</td>
<td>71.2 ± 13.2</td>
<td>−5.1</td>
<td>−8.6, −1.5</td>
</tr>
<tr>
<td>H:M ratio (%)</td>
<td>Healthy</td>
<td>64.2 ± 16.7</td>
<td>50.7 ± 22.7</td>
<td>−23.4</td>
<td>−32.3, −14.6</td>
</tr>
<tr>
<td></td>
<td>ACL-R</td>
<td>61.1 ± 15.6</td>
<td>53.2 ± 21.2</td>
<td>−14.8</td>
<td>−24.5, −5.1</td>
</tr>
<tr>
<td>V:M ratio (%)</td>
<td>Healthy</td>
<td>19.1 ± 12.6†</td>
<td>13.7 ± 9.8</td>
<td>−24.9*</td>
<td>−41.4, −8.5</td>
</tr>
<tr>
<td></td>
<td>ACL-R</td>
<td>11.0 ± 11.2</td>
<td>10.9 ± 10.2</td>
<td>37.6</td>
<td>−5.1, 80.2</td>
</tr>
</tbody>
</table>

Abbreviations: ACL-R, anterior cruciate ligament reconstructed; CAR, central activation ratio; H:M, H-reflex to M-wave ratio; V:M, V-wave to M-wave ratio.

*Significant group × time interaction (P < .05). †Significant difference between groups at baseline (P < .05).

Figure 2 — Between-groups comparison of preexercise to postexercise change in quadriceps and soleus function. Abbreviations: CAR, central activation ratio; HM, H-reflex to M-wave ratio; VM, V-wave to M-wave ratio. *Significant difference between groups at baseline (P < .05). †Significant group × time interaction (P < .05).
at long-term follow-up (2 y postreconstruction), the quadriceps muscle of the involved limb has been found to be significantly weaker but more resistant to muscle fatigue as measured by the rate of force decline and alterations in electromyographic indicators of fatigue during knee-extension tasks. These findings are consistent with the smaller reductions in both knee-extension torque and quadriceps CAR measured in ACL-R participants during our study. While the ability to preserve quadriceps function throughout exercise may enable an individual to continue physical activity for a longer duration, the potential cost to surrounding structures remains unclear. Recent investigations regarding functional performance after fatiguing exercise in patients after ACL-R have shown significant declines in stability and power despite the apparent resistance to fatigue displayed by the quadriceps muscles compared with healthy controls. The healthy matched controls included in this study exhibited a lower level of quadriceps CAR than has been reported in some studies; our results showed a clear divergence between groups after exercise, with no difference in perceived exertion. We chose to include participants with ACL-R who exhibited a significant level of quadriceps inhibition (CAR < 90%) to highlight the potential interaction between decreased quadriceps function and fatigue-related changes in lower extremity muscle function. To compensate for their decreased ability to generate knee-extension torque, it is possible that participants with a history of ACL-R begin to reorganize functional movement and muscle-activation patterns to preserve an already reduced level of quadriceps function due to the presence of AMI.

In this investigation, healthy and ACL-R participants experienced similar reductions in soleus motoneuron-pool excitability in a rested state (H:M ratio) after exercise. However, similar to knee-extension torque and quadriceps CAR, the magnitude of decline in volitional excitability of the soleus during a maximal contraction (V:M ratio) was smaller in ACL-R than in healthy controls. Local muscle fatigue and more global exercise protocols, similar to the one used in this study, have produced similar reductions in soleus motoneuron-pool excitability and volitional excitability in healthy individuals. However, the findings of this study regarding ACL-R participants are novel. In cadaver models, as well as during jump landings in healthy individuals, the soleus has been found to function synergistically with the hamstring muscle to prevent excessive anterior tibial shearing and therefore reduce the risk of ACL injury. ACL-deficient patients have shown that those classified as high-functioning “copers” tend to display higher activation levels of the plantar flexors during functional movement to stabilize the knee joint and reduce the demand on proximal structures that may not be functioning optimally in the presence of joint injury. In the case of this study, a more complex relationship between reflexive excitability and volitional excitability of the soleus emerges. While soleus motoneuron-pool excitability appears to decline similarly to that in healthy matched controls after exercise, volitional excitability was preserved. In this study, the response to exercise in healthy participants was a progressive decline of volitional and reflexive quadriceps and soleus neuromuscular function. In the ACL-R group, a distinctly different pattern was observed for the measures of soleus and quadriceps function that involved the element of a volitional contraction (ie, CAR and V-wave) than in their healthy counterparts. This may suggest a central reorganization of volitional muscle activation in patients with ACL-R aimed at preserving lower extremity joint function in the presence of major knee-joint injury and AMI. ACL-R participants exhibit lower levels of quadriceps activation at baseline that persist after exercise. However, since none of the patients in the current study were suffering from clinically relevant pain or disability, it is difficult to conclude whether this pattern of reorganization is a detrimental adaptation.

The lack of consistency among exercise protocols used to elicit fatigue-related changes in the lower extremity makes it difficult to compare results across studies or generalize the results of investigations to the recreationally active or athletic populations. In this study, we chose to use a functional-exercise protocol that incorporated a combination of aerobic (uphill walking) and anaerobic (body-weight squats and step-ups) exercise to better approximate participation in recreational sport activity. While more localized single-motion or single-muscle exercise protocols have shown success in producing declines in muscle function and alterations in functional movement, the ability to generalize the results can be somewhat limited. Previous investigations using a protocol similar to that used in this study have shown significant reductions in quadriceps activation, dynamic balance, and gait mechanics in both healthy and pathological populations. A more localized single-motion or single-muscle protocol may have also allowed for a controlled induced fatigue with a specific neurophysiological basis (central vs peripheral sources of fatigue); however, the generalized nature of this lower extremity protocol has allowed us to fatigue multiple muscles during functional exercise that was intended to reproduce the effects of recreational athletic activity.

Conclusion

Participants with a history of ACL-R experienced significantly different lower extremity neuromuscular response to a 30-minute exercise protocol than healthy matched controls. The declines in knee-extension torque, quadriceps CAR, and soleus V:M ratio were of lower magnitude than in healthy matched controls. This response suggests an adaptation experienced by patients with quadriceps AMI that may act to maintain lower extremity function during prolonged exercise.

Acknowledgments

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and provided participant compensation. The results from the current study do not constitute endorsement by the ACSM, and no conflicts of interest have been declared.

References

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Exercise Adaptations After ACL Reconstruction


