Effect of Eccentric Strengthening After Anterior Cruciate Ligament Reconstruction on Quadriceps Strength

Lindsey K. Lepley and Riann M. Palmieri-Smith

Clinical Scenario: Interventions aimed at safely overloading the quadriceps muscle after anterior cruciate ligament (ACL) reconstruction are essential to reducing quadriceps muscle weakness that often persists long after the rehabilitation period. Despite the best efforts of clinicians and researchers to improve ACL rehabilitation techniques, a universally effective intervention to restore preinjury quadriceps strength has yet to be identified. A muscle’s force-producing capacity is most optimal when an external force exceeds that of the muscle while the muscle lengthens. Hence, the potential to improve muscle strength by overloading the tissue is greater with eccentric strengthening than with concentric strengthening. Traditionally, the application of early postoperative high-intensity eccentric resistance training to the ACL-reconstructed limb has been contraindicated, as there is potential for injury to the ACL graft, articular cartilage, or surrounding soft-tissue structures. However, recent evidence suggests that the application of early, progressive, high-force eccentric resistance exercises to the involved limb can be used to safely increase muscle volume and strength in ACL-reconstructed individuals. As a result, eccentric strengthening may be another attractive alternative to traditional concentric strengthening to improve quadriceps strength after ACL reconstruction.

Focused Clinical Question: In patients who have undergone ACL reconstruction, is there evidence to suggest that eccentric exercise positively affects postoperative quadriceps strength?

Keywords: knee, postoperative quadriceps strength, negative resistance

Clinical Scenario

Interventions aimed at safely overloading the quadriceps muscle after anterior cruciate ligament (ACL) reconstruction are essential to reducing quadriceps muscle weakness that often persists long after the rehabilitation period. Despite the best efforts of clinicians and researchers to improve ACL rehabilitation techniques, a universally effective intervention to restore preinjury quadriceps strength has yet to be identified. A muscle’s force-producing capacity is most optimal when an external force exceeds that of the muscle while the muscle lengthens. Hence, the potential to improve muscle strength by overloading the tissue is greater with eccentric strengthening than with concentric strengthening. Traditionally, the application of early postoperative high-intensity eccentric resistance training to the ACL-reconstructed limb has been contraindicated, as there is potential for injury to the ACL graft, articular cartilage, or surrounding soft-tissue structures. However, recent evidence suggests that the application of early, progressive, high-force eccentric resistance exercises to the involved limb can be used to safely increase muscle volume and strength in ACL-reconstructed individuals. As a result, eccentric strengthening may be another attractive alternative to traditional concentric strengthening to improve quadriceps strength after ACL reconstruction.

Focused Clinical Question

In patients who have undergone ACL reconstruction, is there evidence to suggest that eccentric exercise positively affects postoperative quadriceps strength?

Summary of Search, “Best Evidence” Appraised, and Key Finding

• The literature was searched for studies of level 3 evidence or higher that investigated the effect of an eccentric-exercise intervention on quadriceps strength in ACL-reconstructed participants.
• Two high-quality randomized control trials and 2 cohort studies were included.
• All 4 studies supported the use of eccentric strengthening to improve quadriceps strength after ACL reconstruction.
Clinical Bottom Line

There is strong evidence to suggest that the use of eccentric exercises after ACL reconstruction positively affects postoperative quadriceps strength. Compared with concentric exercise, eccentric exercise on the involved limb may result in greater quadriceps strength immediately after ACL reconstruction and up to 1 year postsurgery.

Strength of Recommendation: Based on the Centre for Evidence-Based Medicine, there is level 3 evidence to support the use of eccentric exercise to improve quadriceps strength after ACL reconstruction.

Search Strategy

Terms Used to Guide Search Strategy

- Patient/Client group: ACL or anterior cruciate ligament
- Intervention/Assessment: eccentric training or eccentric exercise
- Comparison: none
- Outcome: quadriceps strength

Sources of Evidence Searched

- PubMed
- CINHAL
- SPORTDiscus
- Pertinent studies cross-referenced to identify articles that met inclusion criteria but were not located during the original database search

Inclusion and Exclusion Criteria

Inclusion Criteria

- Studies with a cohort of subjects who had undergone unilateral ACL reconstruction
- Studies using eccentric strengthening to increase postoperative quadriceps strength
- Level 3 evidence or higher
- Limited to humans
- Limited to English
- Published in the last 10 years (2002 to February 4, 2012)

Exclusion Criterion

- Studies that did not report isometric or isokinetic quadriceps strength in response to an eccentric-exercise intervention

Results of Search

Four relevant studies were located and categorized as shown in Table 1 (based on Levels of Evidence, Centre for Evidence-Based Medicine, 2011).

Best Evidence

The studies listed in Table 2 were identified as best evidence and selected for inclusion in this critically appraised topic (CAT). These studies were selected because they had a level of evidence of grade 3 or higher, and studied an eccentric-exercise intervention, and reported the effect of the intervention on quadriceps strength in the ACL-reconstructed limb.

Implications for Practice, Education, and Future Research

The 4 studies reviewed in this CAT support the use of eccentric strengthening after ACL reconstruction to improve postoperative quadriceps strength. In patients recovering from ACL reconstruction, this CAT also indicates that eccentric exercise is more effective at restoring quadriceps strength than concentric exercise. However, due to the variation in time to initiate eccentric exercise and the devices used to eccentrically train the participants, the true effect of eccentric strengthening on quadriceps strength in the ACL-reconstructed limb is still unknown.

Early postoperative eccentric strength training on the ACL-reconstructed limb was compared with concentric strength training in 2 of the studies included in this CAT. Based on the available literature, eccentric strength training on the ACL-reconstructed limb seems to produce greater quadriceps strength immediately after ACL reconstruction and up to 1 year postsurgery. It should be noted, however, that results from the 1-year-postoperative study are a follow-up on the same cohort of ACL-reconstructed subjects from the initial study. Although additional subjects were recruited and added to the data reported from the 1-year-postoperative study.

Table 1 Summary of Study Designs of Articles Retrieved

<table>
<thead>
<tr>
<th>Level of evidence</th>
<th>Study design</th>
<th>Number located</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Randomized control trial</td>
<td>2</td>
<td>Gerber et al⁵</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Gerber et al⁶</td>
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<tr>
<td>3</td>
<td>Cohort</td>
<td>2</td>
<td>Coury et al⁷</td>
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<td></td>
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<td>Brasileiro et al⁸</td>
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</tbody>
</table>
Table 2  Characteristics of Included Studies

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Gerber et al⁵</th>
<th>Gerber et al⁶</th>
<th>Coury et al⁷</th>
<th>Brasileiro et al⁸</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>32 ACL-reconstructed patients randomly assigned to concentric (TRAD; n = 16; 7 female, 9 male; age 31.0 ± 9.8 y) or eccentric exercise (ECC; n = 16; 7 female, 9 male, age 29.4 ± 9.4 y) intervention. Subjects matched by surgical procedure, sex, and age.</td>
<td>40 ACL-reconstructed patients randomly assigned to concentric (TRAD; n = 20; 8 female, 12 male; age 29.3 ± 9.7 y) or eccentric exercise (ECC; n = 20; 8 female, 12 male; age 29.3 ± 9.7 y) intervention. Subjects matched by surgical procedure, sex, and age.</td>
<td>5 male ACL-reconstructed subjects (age 32 ± 7.8 y, height 1.73 ± 0.003 m, weight 80 ± 14 kg) were recruited 9 ± 1.3 mo postsurgery, and 10 male healthy controls (age 21.5 ± 2.8 y, height 1.68 ± 0.004 m, weight 65 ± k kg) were recruited for postintervention gait comparisons.</td>
<td>9 sedentary ACL-reconstructed men (age 31.3 ± 5.8 y) were recruited 9.4 ± 0.7 mo postsurgery.</td>
</tr>
<tr>
<td>Exclusion criteria: History of lower extremity fracture or ACL surgery, concomitant PCL injury, or significant articular cartilage damage or meniscal injury.</td>
<td>Exclusion criteria: History of lower extremity fracture or ACL surgery, concomitant PCL injury, or significant articular cartilage damage or meniscal injury.</td>
<td>Exclusion criteria: ACL: other associated injuries, pain, or effusion in the ACL limb or uninvolved limb. Controls: history of knee injury, equilibrium disorders, and/or current knee pain.</td>
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</tr>
<tr>
<td>Intervention</td>
<td>Initiation: 3 wk postsurgery</td>
<td>Initiation: 3 wk postsurgery</td>
<td>Initiation: 9 mo postsurgery</td>
<td>Initiation: 9 mo postsurgery</td>
</tr>
<tr>
<td>Device: ECC group used an eccentric ergometer (Eccentron). TRAD group used a concentric ergometer.</td>
<td>Device: ECC group used an eccentric ergometer (Eccentron). TRAD group used a concentric ergometer.</td>
<td>Device: ACL reconstructed subjects used a Biodex System 3 isokinetic dynamometer.</td>
<td>Device: Biodex System 3 isokinetic dynamometer</td>
<td></td>
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<tr>
<td>Length of intervention: 12 wk</td>
<td>Length of intervention: 12 wk</td>
<td>Length of intervention: 12 wk</td>
<td>Length of intervention: 12 wk</td>
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<tr>
<td>Dose: 2–3 times per wk for 30 min</td>
<td>Dose: 2–3 times per wk for 30 min</td>
<td>Dose: 2 times per wk, 3 sets of 10 repetitions at a velocity of 30°/s</td>
<td>Dose: 2 times per wk, 3 sets of 10 repetitions at a velocity of 30°/s</td>
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</tbody>
</table>
Outcome measures

**Primary outcome:** Quadriceps peak torque assessed via an isokinetic dynamometer concentrically at 60°/s.

**Secondary outcomes:** Hop distance on the ACL-reconstructed limb. Knee effusion quantified by midpatellar joint circumference. Knee stability quantified via a KT-1000 knee arthrometer. Self-reported outcomes assessed via the ADLS-KOS, Tegner Activity Scale, and Lysholm Knee Rating Scale.

**Primary outcome:** Quadriceps femoris and gluteus maximus muscle CSA quantified via MRI measured 3 wk and 1 y postsurgery on the ACL-reconstructed limb.

**Secondary outcomes:** Quadriceps peak torque assessed via an isokinetic dynamometer concentrically at 60°/s. Hop distance on the ACL-reconstructed limb. Knee effusion quantified by midpatellar joint circumference. Knee stability quantified via a KT-1000 knee arthrometer. Self-reported outcomes assessed via the ADLS-KOS, Tegner Activity Scale, and Lysholm Knee Rating Scale.

Primary outcome: Quadriceps peak torque measured via an isokinetic dynamometer eccentrically at 30°/s and 120°/s and isometrically. Data collected at baseline (9 mo postsurgery) and after the intervention.

**Secondary outcomes:** Quadriceps muscle activity quantified by EMG. Quadriceps femoris CSA quantified via MRI.
Main findings

**Primary findings:** Compared with preoperative testing, ECC subjects demonstrated significantly greater quadriceps peak torque after the intervention at 26 wk ($P \leq .001$), but the TRAD group did not ($P = .74$).  

**Secondary findings:** Hop distance—compared with preoperative testing, the ECC group mean’s distance increased significantly after the intervention ($P < .01$) but the TRAD group’s did not ($P = .17$). Knee effusion—no significant differences were noted before surgery, after surgery, or between the ECC and TRAD groups ($P > .05$). Knee laxity—no significant differences in anteroposterior laxity were observed between groups at 15 or 26 wk postsurgery ($P > .05$). Self-reported outcomes—no significant group-by-time interactions were found for scores on the ADLS-KOS ($P > .05$). Tegner scale decreased to a lesser extent in the ECC group than in the TRAD group at 26 wk postsurgery ($P = .02$).

Secondary findings

**Primary findings:** From 3 wk postsurgery, quadriceps femoris muscle volume of the ACL-reconstructed limb increased significantly in both groups ($P \leq .001$). Quadriceps femoris muscle volume increased by more than 50% in the ECC group compared with the TRAD group ($P \leq .001$). Gluteus maximus volume also increased significantly from 3 wk postsurgery to 1 y after ACL reconstruction ($P \leq .001$) and improved by more than 50% in the ECC group compared with the TRAD Group ($P < .05$).  

**Secondary findings:** Strength—quadriceps peak-torque gains were significantly greater in the ECC group than in the TRAD group ($P < .05$). Knee valgus angles—increased in the ACL-reconstructed group after the intervention from 12° of knee adduction at baseline to 24° postintervention ($P < .05$). Control subjects walked with 15° of knee adduction, indicating that ACL subjects walked with more knee adduction than healthy controls after the intervention.

Table 2 (continued)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Gerber et al⁵</th>
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<th>Coury et al⁷</th>
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<tbody>
<tr>
<td>Level of evidence</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Validity score</td>
<td>PEDro 6/10</td>
<td>PEDro 6/10</td>
<td>PEDro 4/10</td>
<td>PEDro 3/10</td>
</tr>
</tbody>
</table>

Abbreviations: ACL indicates anterior cruciate ligament; PCL, posterior cruciate ligament; ADLS-KOS, Activity of Daily Living Scale–Knee Outcome Survey; CSA, cross-sectional area; PEDro, Physiotherapy Evidence Database Scale.
the majority of participants had gains in quadriceps strength reported at both time points (Table 2). Eccentric strengthening programs initiated approximately 9 months postreconstruction also seem to positively influence quadriceps strength. The results from all 4 studies are in line with previous literature that has demonstrated that eccentric strengthening is more effective at overloading the muscle, resulting in a greater potential for muscle hypertrophy.

**Clinical Considerations**

Clinicians implementing eccentric-exercise protocols after ACL reconstruction should consider the device that will be used to deliver the intervention, the intensity of the exercise, and the time after ACL reconstruction to initiation of the eccentric strengthening.

**Eccentric-Exercise Device**

Devices and time in which devices were used to initiate eccentric-strengthening programs after ACL reconstruction varied across studies. An eccentric ergometer with motor-propelled pedals that moved toward (negatively loaded) the participants while they resisted the pedals (Eccentron, Denver, CO) was used in 2 studies, while other research used an isokinetic dynamometer. Although results using the eccentric ergometer were superior to those found using the concentric ergometer, no direct comparison of an eccentric ergometer with an isokinetic dynamometer is currently available. Hence, it is unknown which device is better or if they are equally effective at producing improvements in quadriceps strength. Another device variation among studies was the range of motion used to deliver the intervention. At this point in time, only 1 research group has provided specific range-of-motion recommendations (20–60°). Although there is short-term evidence that eccentric exercise can be employed safely within this range of motion, the long-term effects of this protocol are currently unknown. Aside from these results, clinicians will need to consider the availability of the device when developing an eccentric-exercise protocol. Given that the eccentric ergometer is a specialized device, the availability of this equipment may be limited in traditional clinic settings.

**Time to Initiation of Eccentric Exercise**

Interventions using an isokinetic dynamometer initiated treatment approximately 9 months after ACL reconstruction, while interventions using an eccentric ergometer initiated treatment 3 weeks after surgery on the involved limb. It is possible that investigations using an isokinetic dynamometer delayed onset of treatment initiation due to the nature of the device involving an open-kinetic-chain (OKC) exercise. Given that the potential for strain on the ACL graft is higher during OKC exercises than in the closed kinetic chain, OKC exercises have been discouraged in the early postoperative stages. Clinicians deciding to implement an eccentric exercise protocol after ACL reconstruction will need to take equipment limitations and time postsurgery into consideration.

**Intensity of Eccentric Exercise**

The 2 studies that trained subjects via an eccentric ergometer used the Borg Rating of Perceived Exertion Scale to grade intensity, whereby subjects were allowed to gradually progress to a “hard” intensity over the course of a 12-week intervention. The 2 studies that used the isokinetic dynamometer had participants perform 3 sets of 10 maximal eccentric contractions at 30°/s twice a week for 12 weeks.

**Safety**

It is important to note that there is mounting evidence that eccentric exercises can be employed safely after ACL reconstruction. However, the long-term safety and effectiveness of eccentric exercise is unknown. Future investigations should consider using more advanced measurements of safety after ACL reconstruction, such as enzyme-linked biomarkers or magnetic resonance imaging to assess knee-joint health.

**Clinical Recommendation**

In the course of clinical practice, we conclude that eccentric strengthening after ACL reconstruction is an effective therapy that can positively influence quadriceps strength. Future trials using eccentric strengthening after ACL reconstruction should measure the effect of eccentric strengthening on other important ACL outcome measures such as quadriceps activation and lower extremity mechanics.

**References**

5. Gerber JP, Marcus RL, Dibble LE, Greis PE, Burks RT, Lastayo PC. Safety, feasibility, and efficacy of negative


