

## [ Athletic Training ]



# Deficits in Quadriceps Strength and Patient-Oriented Outcomes at Return to Activity After ACL Reconstruction: A Review of the Current Literature

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**Context:** Side-to-side quadriceps strength deficits are linked to hazardous lower extremity mechanics and reduced function at a time when individuals are returned to activity after anterior cruciate ligament (ACL) reconstruction. As a result, generalized criteria have emerged in the literature, wherein researchers are recommending that patients be cleared for participation once side-to-side differences in strength are  $\leq 10\%$  of the noninjured limb. Similar recommendations exist for patient-oriented outcomes (ie, self-reported function and hop tests), where deficits of  $\leq 10\%$  are considered ideal at return to activity. It is unclear how many studies actually achieve these clinically recommended results.

**Evidence Acquisition:** Articles that reported quadriceps strength deficits as compared to the contralateral limb were collected from peer-reviewed sources available on Medline and Web of Science databases (1990 through August 2014). Search terms included the following: *anterior cruciate ligament* OR *ACL* AND *muscle weakness*, *anterior cruciate ligament* OR *ACL* AND *strength*; *return-to-activity* AND *strength*; *anterior cruciate ligament* OR *ACL* AND *quadriceps*.

**Study Design:** Clinical review.

**Level of Evidence:** Level 4.

**Results:** Average side-to-side strength deficits at 6 months postreconstruction were  $23\% \pm 8\%$  (range, 3%-40%), while the average at 12 months postsurgery was found to be  $14\% \pm 6\%$  (range, 3%-28%). The average deficits in self-reported function at 6 months (mean,  $14\% \pm 5\%$ ) and 12 months postsurgery (mean,  $13\% \pm 6\%$ ) were also found to be  $>10\%$ . Performance on hop tests was found to be less than optimal at 6 months postsurgery (mean,  $11\% \pm 7\%$ ), but improved at 12 months postsurgery (mean,  $1.3\% \pm 2\%$ ).

**Conclusion:** This review provides an up-to-date account of the typical deficits in strength and patient-oriented outcomes that exist when formalized physical therapy concludes after ACL reconstruction. Based on the studies included, it seems pertinent that researchers and clinicians continue to investigate interventions capable of improving the recovery of quadriceps strength as well as patient-oriented outcomes as the majority of studies report levels that are well below clinical recommendations.

**Keywords:** asymmetry; isokinetic strength; hop tests; self-reported function

It is well known that anterior cruciate ligament (ACL) injury results in both short- and long-term disability. In the short term, quadriceps weakness is rampant,<sup>49</sup> activity levels decline, and quality of life is reduced.<sup>43</sup> Long term, there is evidence that

persistent quadriceps dysfunction is a primary modifiable factor that contributes to the onset of osteoarthritis.<sup>58</sup> After ACL injury, most patients elect to undergo ACL reconstruction, where aggressive postoperative rehabilitation protocols are often

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prescribed to mitigate some of the aforementioned disabilities. These rehabilitation programs typically finish between 6 and 12 months postsurgery. At this time, patients are often permitted to return to their activities, whether this is competitive sports or recreational activity. Although clinical decisions for return to sport/activity vary between clinics, generalized criteria have emerged, wherein researchers are recommending that patients be cleared for participation once side-to-side differences in quadriceps strength are equal to or less than 10% of the contralateral noninjured limb.<sup>1,12,28,42,52</sup> Similar recommendations exist for self-reported function as well as physical function during performance tasks, where deficits of 10% or less are considered ideal at return to activity.<sup>52</sup> Though these recommendations may seem to be conservative in nature, data have shown that side-to-side strength deficits that exceed 10% are associated with decreased self-reported function and lower physical performance.<sup>52</sup> Moreover, side-to-side asymmetries in quadriceps strength have been associated with altered knee mechanics that may lead to reinjury.<sup>12</sup> Given that quadriceps strength is a factor that can be ameliorated with physical therapy, it would be ideal for clinicians to resolve these persistent strength deficits prior to patients being returned to activity. However, despite the continued focus of emphasizing strength gains post-ACL reconstruction and improvements in rehabilitation techniques, it is unknown how many researchers and clinicians actually achieve this recommended criterion at return to activity. Understanding the status of the current literature is important, as it will help to provide a benchmark regarding the effectiveness of clinicians and researchers to treat those with ACL injury and subsequent reconstruction.

Hence, the purpose of this review is to provide a clear, up-to-date account of the amount of strength deficits that exist in the ACL-reconstructed limb when formalized physical therapy concludes by examining the current literature (years 1990 through August 2014). A secondary objective of this review was to examine the self-reported and physical performance-based measures that are reported at return to activity, as these measures can provide a comprehensive overview of patient-oriented outcomes. For the purposes of this review, return to activity was defined as outcomes reported no less than 6 months and no greater than 12 months post-ACL reconstruction. The 12-month cutoff for return to activity was chosen, as the purpose of this review is to provide a current account of the persistent strength deficits that exist at the conclusion of formalized physical therapy. As such, studies that investigated patients more than 1 year postreconstruction were not included.

## PREVALENCE OF QUADRICEPS STRENGTH DEFICITS AT RETURN TO ACTIVITY

Of the 37 studies included in this review,<sup>2,4,7,9-11,13,18-20,25-27,30-35,37,40,44-47,52-57,59-62</sup> only 5 studies<sup>26,27,33,56,60</sup> met clinical recommendations at 6 months postsurgery, indicating that patients commonly return to activity post-ACL reconstruction with side-to-side quadriceps strength deficits that exceed 10% (Appendix 1, available at <http://sph.sagepub.com/>

content/by/supplemental-data). Strength deficits ranged anywhere from 3% to 40% compared with the noninjured limb, with an average strength deficit of  $23\% \pm 8\%$  reported at 6 months postsurgery.<sup>2,4,5,9-11,18,19,26,27,31,32,35,44-46,54,56,59,60,62</sup> Of the 5 studies that met clinical recommendations (ie, side-to-side strength deficits  $\leq 10\%$ ),<sup>26,27,33,56,60</sup> results were not conclusive as investigators used a wide range of concentric isokinetic velocities to quantify quadriceps strength at return to activity. Notably, in these studies, investigators found that side-to-side strength deficits still persisted at lower isokinetic velocities (60 deg/s), although patients displayed less quadriceps strength asymmetry at higher velocities (120, 180, and 240 deg/s).<sup>26,27,33,60</sup>

Though the prevalence of quadriceps strength deficits appears to improve with time, side-to-side asymmetries still persisted at 12 months postsurgery,<sup>2,4,6,9,13,18,25,32,33,37,52,55,59,60,62</sup> with an average strength deficit of  $14\% \pm 6\%$  (range, 3%-28%; Appendix 1) and with only 9 studies meeting clinical recommendations.<sup>2,4,9,13,18,33,53,60,62</sup> Similar to the data reported at 6 months postreconstruction, variations in side-to-side asymmetries were found within the same cohorts when multiple velocities and modes (concentric vs eccentric) of isokinetics were used.<sup>2,4,13,33,60</sup>

When studies were separated by patellar tendon (PT) and hamstring grafts (semitendinosus gracilis [STG] and semitendinosus [ST]), individuals with patellar tendon grafts had an average side-to-side strength deficit of  $25\% \pm 8\%$  (range, 3%-41%) at 6 months postreconstruction<sup>2,4,5,10,11,26,27,31,35,37,40,59,60,62</sup> and  $16\% \pm 6\%$  (range, 3%-28%) at 12 months postsurgery.<sup>2,4,6,13,32,37,55,59-61</sup> In comparison, individuals with STG grafts report an average strength deficit of  $18\% \pm 9\%$  (range, 3%-38%) at 6 months<sup>4,9,11,18,56,59</sup> and  $9\% \pm 5\%$  (range, 3%-17%) at 12 months postsurgery.<sup>4,9,18,59</sup> ST grafts reported an average strength deficit of  $19\% \pm 9\%$  (range, 9%-25%) at 6 months postsurgery<sup>2,11,33,62</sup> and  $12\% \pm 4\%$  (range, 8%-21%) at 12 months postreconstruction.<sup>2,13,33,62</sup>

## PREVALENCE OF SELF-REPORTED DEFICITS AT RETURN TO ACTIVITY

Self-reported function data at return to activity are presented in Table 1. To be included in this review, studies also had to concurrently report quadriceps strength deficits at return to activity. Of the 9 studies that were included,<sup>4,5,13,18,31,40,52,53,59</sup> investigators used a variety of outcome measures to quantify self-reported function including the Cincinnati Knee Score, Lysholm scale, and International Knee Documentation Committee (IKDC) subjective form (Table 1). Briefly, the Cincinnati Knee Score contains 11 functional components and was designed to assess patient symptoms and self-perception of knee function post-ACL injury. Similarly, the 11-point Lysholm scale is commonly used to assess patients' perceptions of function in activities of daily living and during athletic activity. The IKDC is an 18-item scale used to measure a patient's ability to perform dynamic tasks, activities of daily living, and symptoms. Importantly, all these scales have been validated and are commonly employed post-ACL reconstruction to assist

Table 1. Self-reported deficits at return to activity

Authors	Year	n	Graft	Intervention	Time Post-ACLr, mo	Outcomes	Deficits, %	Met Clinical Recommendations
Aune et al <sup>4</sup>	2001	37	STG		6	Cincinnati Knee Score	12.2	No
					12	Cincinnati Knee Score	12.4	No
		35	PT		6	Cincinnati Knee Score	23.7	No
					12	Cincinnati Knee Score	22.2	No
Beard and Dodd <sup>5</sup>	1998	13	PT	Supervised rehabilitation	6	Lysholm	8	Yes
		13	PT	Home rehabilitation	6	Lysholm	10	Yes
Feller and Webster <sup>13</sup>	2003	34	ST		8	IKDC	25	No
		33	ST		12	IKDC	20	No
					12	Cincinnati Knee Score	12.3	No
		30	PT		8	IKDC	20	No
		29	PT		12	IKDC	15	No
					12	Cincinnati Knee Score	15.5	No
Gobbi et al <sup>18</sup>	2003	80	STG		12	Lysholm	9	Yes
Knezevic et al <sup>31</sup>	2014	20	PT		6	IKDC	16.5	No
						Lysholm	10.6	No
Lepley and Palmieri-Smith <sup>40</sup>	2014	54	PT		7.24	IKDC	19.6	No
Schmitt et al <sup>52</sup>	2012	55	Mixed		6.85	IKDC	15.5	No
Segawa et al <sup>53</sup>	2002	62	Mixed		12	Lysholm	3.4	Yes
Witvrouw et al <sup>59</sup>	2001	32	STG		6	Lysholm	15.1	No
					12	Lysholm	9.8	Yes
		17	PT		6	Lysholm	11.1	No
					12	Lysholm	6.5	Yes

ACLr, anterior cruciate ligament reconstruction; IKDC, International Knee Documentation Committee Form; PT, patellar tendon; ST, semitendinosus; STG, semitendinosus gracilis.

clinicians and researchers in making return-to-activity decisions.<sup>8,24,51</sup>

In this review, only 1 study<sup>5</sup> of 5 reported self-reported function deficits that met the criteria of being  $\leq 10\%$  at 6 months postsurgery, whereas 3 studies found acceptable results at 12 months postreconstruction.<sup>18,53,59</sup> Specifically, self-reported deficits at 6 months postreconstruction ranged from 8% to 24%, with a mean self-reported deficit of  $14\% \pm 5\%$  reported in this review.<sup>4,5,18,52,59</sup> At 12 months postsurgery, self-reported deficits ranged from 3% to 22%, with a mean self-reported deficit of  $13\% \pm 6\%$  reported.<sup>4,13,18,53,59</sup> Interestingly, of the studies that found clinically acceptable self-reported function (Table 1),<sup>5,18,53,59</sup> 2 studies reported concurrent strength deficits that exceeded 10% at return to activity (Appendix 1).<sup>5,59</sup> On average across both the 6- and 12-month time points, patients reported worse function on the IKDC scale (mean deficit at 6 months,  $19.32 \pm 2.4$ ; at 12 months,  $17.50 \pm 3.5$ ) compared with the Cincinnati Knee Score (mean deficit at 6 months,  $13.85 \pm 2.3$ ; at 12 months,  $15.6 \pm 4.6$ ) and Lysholm scale (mean deficit at 6 months,  $10.96 \pm 5.0$ ; at 12 months,  $7.17 \pm 2.8$ ).

## PREVALENCE OF PHYSICAL PERFORMANCE DEFICITS AT RETURN TO ACTIVITY

Similar to the criterion for the self-reported data (Table 1), to be included in Table 2, studies had to concurrently report quadriceps strength deficits at return to activity. Studies included in this table utilized quantitative measures to assess physical performance, including the single-leg hop for distance, triple hop for distance, crossover hop for distance, and 6-m timed hop performance measures.<sup>14</sup> The goal of these tests is to hop as far forward as possible while maintaining a controlled landing.<sup>52</sup> Distance hopped on the ACL limb is then compared with the contralateral noninjured limb to detect interlimb asymmetry. These tests are commonly used clinically to quantify performance post-ACL surgery and have been shown to have good measurement reliability in patients after ACL reconstruction.<sup>14,50</sup>

At 6 months postreconstruction, 5 of the 9 included studies<sup>4,18,26,27,31,35,52,59,62</sup> met clinical criteria defined as performance deficits  $\leq 10\%$  of the noninvolved limb.<sup>4,18,27,35,52</sup> This result improved at 12 months postsurgery, wherein all but 2 studies<sup>26,31</sup> found limb symmetries  $\leq 10\%$  of the contralateral noninjured limb. Specifically at 6 months postreconstruction, physical deficits ranged from 3% to 29%, with a mean performance deficit of  $11\% \pm 7\%$  reported in this review.<sup>4,18,26,27,31,35,52,59,62</sup> While at 12 months postsurgery, studies reported a positive physical performance ranging from 14.5% greater than the noninvolved limb to a 3% deficit with the ACL limb.<sup>4,18,26,27,31,35,52,59,62</sup> The mean performance deficit at 12 months was  $1.3\% \pm 2\%$ . Similar to the self-reported data, some studies reported clinically acceptable levels of physical function at return to play, despite displaying strength deficits greater than 10% of the noninvolved limb.<sup>4,18,27,35,52,59</sup> Moreover, similar to the isokinetic strength data, when patients were tested with a multitude of hop tests, results between tasks varied.

## CLINICAL IMPLICATIONS

This review emphasizes the notion that patients commonly return to activity with strength deficits that exceed current clinical recommendations (ie,  $>10\%$  of the contralateral limb). Though these strength deficits improve with time, a majority of patients still display strength asymmetries at 12 months post-ACL reconstruction. Bearing in mind that persistent quadriceps weakness is associated with alterations in pathomechanics that are thought to lead to posttraumatic osteoarthritis<sup>3</sup> and is thought to be a contributing factor to reinjury,<sup>12</sup> the prevalence of quadriceps weakness at return to activity should raise concern in the rehabilitation community, as strength is a modifiable factor that can be mitigated. Importantly, though this clinical cutoff may seem arbitrary in nature, data have shown that side-to-side strength deficits that exceed 10% are associated with decreased self-reported function and lower physical performance.<sup>52</sup> Moreover, patient self-reported function appears to be less than optimal at return to activity (see Table 1), with only 1 study<sup>5</sup> in this review reporting clinically acceptable rates of self-perceived function at 6 months post-ACL reconstruction. Last, although this review suggests that patients generally return to activity with adequate levels of physical function, this finding should be interpreted with caution because of the paucity of studies that report physical function at return to activity (see Table 2).

When specifically examining quadriceps strength deficits, patients are able to meet clinical recommendations at higher velocities (120 and 180 deg/s) despite the fact that concurrent strength asymmetries still persist at lower velocities (60 deg/s; Appendix 1).<sup>2,4,13,26,34,60</sup> At this point in time, it is not entirely clear why strength deficits are more obvious at lower velocities, although investigators have hypothesized that a reduction of torque in quadriceps strength may be due to alterations in neural activity.<sup>22</sup> This discrepancy in quadriceps strength at different velocities promotes the need for clinicians and researchers to evaluate strength at multiple velocities, as strength deficits at varying speeds may go undetected. This recommendation is further supported by recent data from Hsiao et al,<sup>22</sup> wherein investigators found alterations in quadriceps strength deficits at varying velocities as well as at isometric angles post-ACL reconstruction. Taking this a step further, it seems reasonable for clinicians to test the quadriceps eccentrically at return to activity, as this is the primary action of the muscle during dynamic sporting activities.<sup>36</sup> Notably, only 1 study included both concentric and eccentric strength testing.<sup>2</sup> Importantly, though emerging evidence suggests that it is pertinent for clinicians to test the quadriceps using varying isokinetic measures, it is unknown how strength deficits during different isokinetic testing (velocity and mode) extrapolate to functional movement deficits. The best evidence suggests that limb asymmetries detected during isometric (90° angle)<sup>12,52</sup> as well as isokinetic testing (60 deg/s, concentric mode)<sup>48</sup> are linked to hazardous movement patterns post-ACL reconstruction.

Data from this review also indicate that patellar tendon grafts have a tendency to induce greater strength deficits than hamstring graft types at return to activity. However, this finding

Table 2. Physical performance deficits at return to activity

Authors	Year	n	Graft	Intervention	Time Post-ACLR, mo	Outcomes	Deficits, %	Met Clinical Recommendations
Aune et al <sup>4</sup>	2001	37	STG		6	Single-legged hop for distance	3.9	Yes
					12	Single-legged hop for distance	3.1	Yes
		35	PT		6	Single-legged hop for distance	12.3	Yes
					12	Single-legged hop for distance	7.9	Yes
Gobbi et al <sup>18</sup>	2003	80	STG		6	Single-legged hop for distance	10	Yes
					12	Single-legged hop for distance	5	Yes
Keays et al <sup>26</sup>	2000	31	PT		6	Single-legged hop for distance	16.3	No
						Triple hop	12.3	No
Keays et al <sup>27</sup>	2001	31	PT		6	Single-legged hop for distance	12.1	No
						Triple hop	10.4	Yes
Knezevic et al <sup>31</sup>	2014	20	PT		6	Single-legged hop for distance	10.9	No
Krych et al <sup>35</sup>	2014	100	PT	No femoral nerve block	6	Single-legged hop for distance	9	Yes
						Triple hop	8	Yes
		96	PT	Femoral nerve block	6	Single-legged hop for distance	10	Yes
						Triple hop	8	Yes
Schmitt et al <sup>32</sup>	2012	55	Mixed		6.85	Single-legged hop for distance	7	Yes
						Triple hop	3	Yes
						Crossover	7	Yes
						6-meter timed hop	3	Yes
Witvrouw et al <sup>39</sup>	2001	32	STG		6	Single-legged hop for distance	18.9	No
					12	Single-legged hop for distance	+14.5	Yes
		17	PT		6	Single-legged hop for distance	28.9	No
					12	Single-legged hop for distance	8.2	Yes
Yosmaoglu et al <sup>62</sup>	2011	20	ST		6	Single-legged hop for distance	22.7	No
					12	Single-legged hop for distance	8.3	Yes

ACLR, anterior cruciate ligament reconstruction; PT, patellar tendon; ST, semitendinosus; STG, semitendinosus grafts.

should be interpreted with caution, given that this review did not compare results based on a meta-analysis. Notably, several investigations have directly compared the impact of graft type on strength outcomes after ACL reconstruction.<sup>4,29,38</sup> There are no consistent data that indicate that one graft type (patellar tendon or hamstring) is superior to the other.

Of the studies that found the best recovery of quadriceps strength results at 6 months postreconstruction,<sup>26,27,33,56,60</sup> similarities among rehabilitation protocols were found. Specifically, cryotherapy,<sup>56</sup> closed-chain exercises, and restoration of range of motion were emphasized early in the rehabilitation protocol.<sup>26,33,56</sup> Furthermore, exercises that focused on quadriceps strengthening were also encouraged, along with the inclusion of exercises that promoted neuromuscular control<sup>26</sup> (ie, activities that challenged patient balance, agility, and proprioception). In contrast, studies that achieved less than optimal results at 6 months postreconstruction placed participants in postoperative splints (in full extension),<sup>46,59</sup> used a continuous passive motion device,<sup>32,46</sup> and delayed the onset of formalized physical therapy to 1 week postsurgery.<sup>46</sup> Studies that reported the most favorable quadriceps strength at 6 months postsurgery also had the tendency to report the best quadriceps limb symmetry at 12 months postsurgery,<sup>33,60</sup> indicating that early gains in quadriceps strength likely influence outcomes at 1 year postsurgery and that optimizing strength early postsurgery is critical.

Importantly, to quantify quadriceps strength deficits, this review utilized the contralateral, noninjured limb as the “control limb” to compute the quadriceps strength index (ie, [ACL reconstructed limb/contralateral limb] × 100). Though this is a clinically acceptable technique that accounts for strength deficits in the ACL limb, it does not take into account limb dominance or the potential for contralateral strength deficits that are reported after ACL reconstruction.<sup>21</sup> Thus, though the quadriceps index calculation can assist in making decisions about return to play, it is an imperfect measure, and clinicians should be aware that there is the potential for the index to underestimate strength deficits.

When the self-reporting measures were assessed, data from this review suggest that patients are returning to activity with levels of function that are below clinical recommendations (>10%). Taken into context with the persistent level of quadriceps weakness that is observed, these data indicate that low levels of physical as well as poor physiological readiness are common among individuals at return to activity. Interestingly, of the studies that included self-reported function as an outcome measure, the study that seemingly reported the best self-reported outcomes included a component of “patient advice and counseling” throughout the rehabilitation process.<sup>5</sup> Given the importance of providing comprehensive care to patients after a major traumatic injury, the incorporation of counseling alongside the traditional rehabilitation approach seems to be an effective approach to improve patient-oriented outcomes. Another consideration is that although the data included in this review just examined the relationship between the magnitude of quadriceps strength deficits as compared with the noninvolved limb, recent data

suggest that other variables of quadriceps force production should also be taken into consideration, as these variables are good indicators of self-reported function. Specifically, Hsieh et al<sup>23</sup> found that the rate of quadriceps force production, as well as the time to peak force, is more related to self-perceived function than the absolute magnitude of strength deficits. Furthermore, in some cases, studies that found clinically acceptable levels of self-reported function still reported levels of quadriceps strength that were greater than 10% of the noninvolved limb.<sup>5,59</sup> Again, this finding reinforces the need for clinicians and researchers to utilize a multitude of tests and analyses at return to play, as 1 test/data point may not be able to comprehensively examine function.

Finally, although this review indicates that performance on hop tests is within acceptable recommendations at return to activity, few studies included measured these outcomes (9 of 37 studies). Accordingly, these data should be interpreted with caution. Previous work has found that symmetrical quadriceps strength is positively associated with patients that pass return-to-activity criteria,<sup>12</sup> as such mitigating strength asymmetries should improve performance during dynamic tasks.

## CONCLUSION

This review provides a current account of the average strength deficits that exist in the ACL-reconstructed limb when formalized physical therapy concludes. Based on the studies included, it seems pertinent that researchers and clinicians continue to investigate rehabilitation strategies capable of improving the recovery of quadriceps strength in the ACL-reconstructed limb as a majority of studies report levels of quadriceps strength that are well below clinical recommendations. Data emerging from our lab<sup>41</sup> as well as current literature<sup>15-17</sup> indicate that eccentric exercise post-ACL reconstruction is better than traditional concentric exercise at improving the recovery of quadriceps strength. Given the mounting evidence, the incorporation of eccentrics into a rehabilitation program seems like a reasonable next step.<sup>39</sup> Along those same lines, it is important for researchers to quantify the magnitude of quadriceps strength deficits that lead to altered mechanics and the potential for reinjury. Establishing these criteria will help to better define our clinical standards as to what level of quadriceps strength asymmetry is acceptable at return to activity. Taken together, this review of the literature indicates that clinical preparation for return to activity is inadequate. Strength, self-reported function, and physical performance improved from 6 to 12 months postreconstruction, suggesting the rationale that longer rehabilitation programs and delayed return to activity would likely be beneficial to patients post-ACL reconstruction.

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