

Case Series

Establishing Normal Variances and Expectations for Quadriceps Limb Symmetry Index Benchmarks Based on Time from Surgery After Anterior Cruciate Ligament Reconstruction.

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The anticipated timeline for muscle strength as well as return to running and sports are some of the most common inquiries by patients undergoing anterior cruciate ligament reconstruction. Despite the popularity of this procedure, the answers to these inquiries are not well described in the literature. The purpose of this study was to evaluate the range of quadriceps strength percentage and function benchmarks at various points after anterior cruciate ligament reconstruction surgery based on sex, age, and graft.

Design

Observational Cohort Study

Methods

Patients who underwent anterior cruciate ligament reconstruction (ACLR) were evaluated at various points after their surgery with handheld dynamometer assessments. Additional hop and balance testing was performed and patients were evaluated for clearance for running and sport via a physical therapist directed functional movement assessment (FMA). The progression of quadriceps symmetry throughout the postoperative period was examined with multi-level models, estimates of time to reach 70%, 80%, and 90% quadriceps symmetry were obtained from the fitted model.

Results

A total of 164 patients were evaluated. Patients either received bone-tendon-bone (BTB) autograft (n=118) or BTB allograft (n=46) for their ACL graft. Average age was 31.1 years-of-age (SD: 13.6). Males undergoing ACLR using BTB autograft (n=53) were able to achieve 80% quadriceps symmetry earlier than females (n=65) (5.7 months vs 7.1 months), were cleared to return to run sooner (5.6 months vs 6.8 months) and passed an FMA exam earlier (8.5 months vs 10 months). Males undergoing ACLR with allograft (n=13) were able to achieve 80% quadriceps symmetry earlier than females (n=33) (3.9 months vs 5.4 months) and were cleared to run sooner (4.5 months vs 5.8 months).

Conclusion

Patients undergoing BTB autograft obtain 80% quadriceps symmetry at an average of 5.7 months for males and 7.1 months for females. Individuals under the age of 25 obtain their quadriceps symmetry faster and are cleared to return to running faster than individuals over 25. Male sex is associated with decreased amount of time to obtain clearance for

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running and for full activity. Male sex is associated with decreased amount of time to regain quadriceps symmetry however this was not significant.

Level of Evidence

4 (Case series)

INTRODUCTION

Skilled post-operative rehabilitation after anterior cruciate ligament reconstruction (ACLR) with a specific focus on quadriceps strength symmetry has been a topic of increased attention especially in athletes returning to a pivoting sport.¹⁻⁴ A variety of return-to-sport (RTS) assessments and protocols have been suggested with evidence suggesting a decreased risk of reinjury based on passing certain criteria including quadriceps strength symmetry.^{2,5} Limb symmetry index (LSI) testing has become one of the most common ways to assess strength between limbs to help the patient and clinician customize exercise progressions.^{1,4,5} Pre-operatively and post-operatively, one of the more common inquiries patients have is when they would be estimated to reach certain quadriceps strength milestones to allow them to progress to activities like running and other activities.

The purpose of this study was to evaluate the range of quadriceps strength percentage and function benchmarks at various points after anterior cruciate ligament reconstruction surgery based on sex, age, and graft. The hypothesis was that most patients, especially autograft ACL reconstructions, will not reach 80% quadriceps symmetry until 4-6 months post-operatively.

METHODS

After institutional review board approval, a REDCap database was established to collect demographic and outcomes data. Patients who underwent ACLR were evaluated at various points after surgery by one of the author team physical therapists and informed consent was obtained from the patient. Rights of the patient were protected. Surgeries were performed by various surgeons with unknown surgical technique other than type of graft utilized.

A handheld dynamometer (HHD) (MicroFET2 - Hoggan Scientific, Salt Lake City, Utah) was stabilized against an open-chain knee extension machine arm that was locked in a fixed position at 60 degrees of flexion (Figure 1).

This fixed position provides a more universal medium for strength examination and reduces the dependency on the measurer. Examiners included four experienced sports physical therapists who used the same setup and HHD device. All patients performed maximum effort knee extension against the HHD for three trials of five-second contractions and the average of these trials was recorded. Timing of this testing varied by patient physical comfort and ability to perform single leg strength training exercises such as step-downs, split squats, and single-leg dead lift without significant pain. This usually started 8-12 weeks form surgery. Clearance to initiate a walk-to-run progression was initiated when the patient had minimal to no effusion on



Figure 1. Patient set-up with knee-extension machine locked at 60 degrees of flexion with HHD placed between tibia and arm of the machine.

physical exam (Sweep test), had no pain with loading the knee with walking/light impact, stationary hop mechanics showed adequate load absorption (judged by physical therapist), and when the quadriceps index was at least 80%. Clearance to full activity and agility sport (if applicable) was when the patient underwent a standardized functional movement assessment (FMA) and the patient exhibited no pain, no effusion, quadriceps index over 90%, tolerated jogging, and hop testing (single leg, triple leg, crossover hop) was greater than 90% compared to the uninvolved limb, with good mechanics (as judged by the physical therapist: including no significant dynamic knee valgus or hip drop, appropriate knee excursion, and able to stick landing without loss of balance, etc). The same series of tests was used by all physical therapists and patients.

Descriptive statistics including mean and standard deviation for continuous variables and frequency and proportion for categorical variables were calculated to characterize the study group. The progression of quadriceps symmetry throughout the postoperative period was examined with multi-level models. A varying intercept at the patient level was included to account for repeated observations along with a varying slope for postoperative months to allow the effect of time on symmetry to vary across patients. Estimates of time to reach 70%, 80%, and 90% quadriceps symmetry were obtained from the fitted model,

Table 1. Multivariate model of quadriceps strength symmetry.

	coefficient	95% CI LL	95% CI UL	p-value
Months	0.035	0.03	0.039	<0.001
Graft (Autograft)	-0.051	-0.096	-0.007	0.026
Sex (Male)	0.053	0.013	0.093	0.001

CI= confidence interval, LL= lower limit, UL= upper limit

Table 2. Average estimated time to quad strength symmetry and activity based on graft type and sex

	BTB Autograft	Allograft
Female	n=65	n=33
Quad 70% (avg; months)	4.1	2.3
Quad 80% (avg; months)	7.1	5.4
Quad 90% (avg; months)	10.2	8.4
Avg cleared to run (percentage, avg. months)	50 (77%), 6.8 months	17 (52%), 5.8 months
Passed FMA/RTS (percentage, avg. months)	19 (29%), 10.0 months	2 (6%), 8.3 months
Male	n=53	n=13
Quad 70% (avg; months)	2.6	0.9
Quad 80% (avg; months)	5.7	3.9
Quad 90% (avg; months)	8.7	7.0
Avg cleared to run (percentage, avg. months)	38 (72%), 5.6 months	9 (69%), 5.0 months
Passed FMA/RTS (percentage, avg. months)	14 (26%), 8.5 months	1 (8%), 6.2 months

BTB= bone-tendon-bone, FMA= functional movement assessment, RTS= return to sport

which included fixed effects for graft and sex. To explore the role of age, the model was extended to include patients of age less than 25 and patients 25 or greater. Results of inferential analyses are presented with 95% confidence intervals. All analyses were performed using R version 4.2.1 (R Core Team 2022) and the following packages: lme4⁶ and ggeffects.⁶

RESULTS

A total of 164 patients were evaluated (98 female, 66 male) who underwent ACL reconstruction. Patients either received bone-tendon-bone (BTB) autograft (n=118) or BTB allograft (n=46) for their ACL graft. Average age was 31.1 years-of-age (SD: 13.6). The multilevel model for progression of quadriceps symmetry over postoperative period is presented in [Table 1](#).

The estimated time to reach quadriceps symmetry thresholds were evaluated by sex and graft type ([Table 2](#), [Figure 1](#)).

A group of age under 25 years was added to the model to better reflect high school and collegiate athletes ([Table 3](#)).

On average, patients undergoing ACLR using BTB autograft (n=65) were estimated to achieve 70% quad symmetry at an average of 4.1 months, 80% at 7.1 months, and 90% at 10.2 months. Females were cleared to run at an average of 6.8 months and were able to pass a FMA exam at an average of 10 months. On average, males undergoing ACLR using BTB autograft (n=53) were estimated to achieve 70% quad

symmetry at an average of 2.6 months, 80% at 5.7 months, and 90% at 8.7 months. Males were cleared to run at an average of 5.6 months and were able to pass a FMA exam at an average of 8.5 months.

Patients undergoing ACL allograft were evaluated and separated by sex. On average, females undergoing ACLR using allograft (n=33, mean age 48.7 +/-7.0) were estimated to achieve 70% quad symmetry at an average of 2.3 months, 80% at 5.4 months, and 90% at 8.4 months. Average time to be cleared to return to running for female allografts was 5.8 months. Only two of 33 (6%) female patients were able to pass a FMA exam at an average of 8.3 months. On average, males undergoing ACLR using allograft (n=13, mean age 50.9 +/- 8.1) were estimated to achieve 70% quad symmetry at an average of 0.9 months, 80% at 3.9 months, and 90% at 7.0 months. Average time to be cleared for running for male allografts was 4.5 months (+/-2.0 months). Only 1 of 13 (8%) male patients passed an FMA exam at an average of 6.2 months.

Females under the age of 25 years-of-age (n=48, mean age 18.8 +/- 2.7) undergoing ACLR using BTB autograft were estimated to achieve 70% quad symmetry at an average of 3.91 months, 80% at 6.96 months, and 90% at 10.0 months. Average clearance to return to running was 4.7 months (+/-2.7) and clearance to full activities 9.0 months (+/- 1.7). Males under the age of 25 years-of-age (n=29, mean age 21.0 +/- 3.1) undergoing ACLR using BTB autograft were estimated to achieve 70% quad symmetry at an average of 2.40 months, 80% at 5.44 months, and 90%

Table 3. Estimate return to activity after ACLR by age group and sex. Values are given as mean (standard deviation). Time to clearance is expressed as postoperative months.

Demographics				Running			Unrestricted Activity	
Sex	Graft	Age Group	N	Age	N	Time to Clearance	N	Time to Clearance
Male	Autograft	<25	25	20 (+/- 2.8)	17	4.7 (+/- 2.6)	6	6.6 (+/- 2.6)
Male	Autograft	25&>	28	32 (+/- 5.7)	21	6.0 (+/- 2.0)	8	9.8 (+/- 2.4)
Female	Autograft	<25	48	19 (+/- 2.6)	38	6.4 (+/- 2.3)	16	9.0 (+/- 1.7)
Female	Autograft	25&>	17	32 (+/- 6.5)	12	8.4 (+/- 2.6)	4	13.6 (+/-2.4)

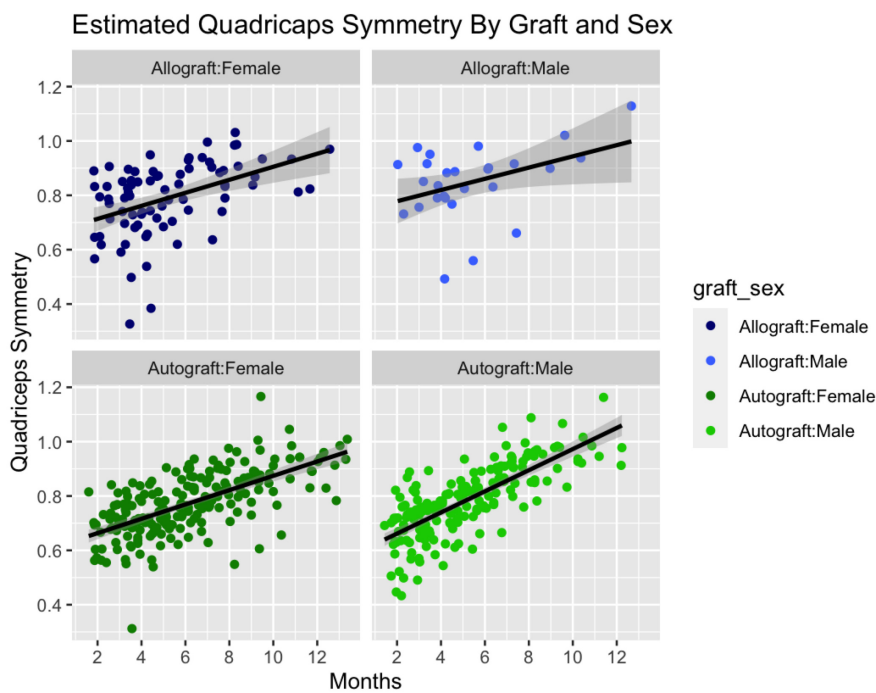


Figure 2. Multivariate model of quadriceps symmetry based on graft and sex

at 8.49 months. Average clearance to return to running was 3.3 months (+/-1.8) and clearance to full activities 6.6 months (+/- 2.6). Tables 3 and 4 further illustrates this breakdown by age.

Table 5 further evaluates the probability of patient testing out with various quadriceps percentages at different points after surgery based on confidence intervals.

DISCUSSION

The rehabilitation of ACL surgery is a widely discussed clinical phenomena with a myriad of methods and reviews articles available.⁷⁻⁹ One of the most important factors that makes a clinical difference not only on patient reported outcomes but also ACL re-injury rates is quadriceps strength.¹⁰⁻¹² With only 55-80% of athletes reported to return to competitive sports there is opportunity for

providers to optimize the recovery of patients with the goal of increasing the percentage of athletes that return to their pre-injury level of competition.¹³⁻¹⁵ Recognition of the importance of quadriceps strength symmetry can help decrease complications in athletes at the time of their return to sport and create a more accurate guideline for patients and providers to refer to during their recovery period rather than chronological guidelines.^{2,5}

The results of this study demonstrate a slower estimated progression of quadriceps strength return in patients who underwent BTB autografts in comparison to BTB allograft procedures regardless of age or sex. It took both males and females under 25 who underwent a BTB autograft over two months longer on average to reach the same quadriceps milestones (70%, 80%, 90%) as those who underwent allografts. This result is expected due to the increased trauma the knee experiences during graft harvest in patients un-

Table 4. Estimated quadriceps strength symmetry by month separated by over/under age 25.

Female			Male		
	BTB Autograft	Allograft		BTB Autograft	Allograft
Age <25			Age <25		
Quad 70% (avg; months)	3.91	1.84	Quad 70% (avg; months)	2.40	0.32
Quad 80% (avg; months)	6.96	4.88	Quad 80% (avg; months)	5.44	3.37
Quad 90% (avg; months)	10.00	7.92	Quad 90% (avg; months)	8.49	6.41
25 and greater			25 and greater		
Quad 70% (avg; months)	4.43	2.35	Quad 70% (avg; months)	2.91	0.84
Quad 80% (avg; months)	7.47	5.40	Quad 80% (avg; months)	5.96	3.88
Quad 90% (avg; months)	10.52	8.44	Quad 90% (avg; months)	9.00	6.93

BTB= bone-tendon-bone

Table 5. Quad symmetry estimates by regression estimates and confidence intervals.

BTB Autografts							
Female				Male			
Months	Quad Symmetry	95% CI LL	95% CI UL	Months	Quad Symmetry	95% CI LL	95% CI UL
3	0.66	0.63	0.7	3	0.72	0.68	0.75
6	0.77	0.74	0.8	6	0.82	0.79	0.85
9	0.87	0.84	0.9	9	0.93	0.89	0.96
12	0.98	0.94	1.01	12	1.03	0.99	1.07

Allografts							
Female				Male			
Months	Quad Symmetry	95% CI LL	95% CI UL	Months	Quad Symmetry	95% CI LL	95% CI UL
3	0.72	0.67	0.76	3	0.77	0.72	0.82
6	0.82	0.78	0.86	6	0.87	0.82	0.92
9	0.92	0.88	0.97	9	0.98	0.93	1.03
12	1.03	0.98	1.08	12	1.08	1.02	1.14
Regression Estimates							
	coefficient	95% CI LL	95% CI UL	p-value			
Months	0.035	0.030	0.039	<0.0001			
Graft (Autograft)	-0.051	-0.096	-0.007	0.0260			
Sex (Male)	0.053	0.013	0.093	0.0098			

dergoing reconstruction using autografts. While a difference was observed between the estimated average recovery time for males and females, the difference in average time was not significantly different. Hannon et al. stated that age and sex only added 0.8% of variance for quad strength which is supported by the results of the current investigation.¹⁶ In counseling patients (and parents of younger patients), describing evidence-based expectations are important to establish especially given the notably high risk of re-injury (including contralateral injury) or ACL re-tear in the under-20 years-of-age population.¹⁷⁻²⁰

LIMITATIONS

Limitations of this study include that only a small patient population that underwent allograft procedures. With only 13 males over 25 undergoing allograft reconstructions, the results may not be entirely representative of the recovery timeline for the larger population. Another limitation includes the separation of patients into cohorts based on age to represent athletic status may similarly misrepresent the larger population. A total of only three patients out of a possible 46 allograft patients passed an FMA exam though

all 46 attempted testing. It is unclear if patients simply elected to discontinue PT before passing it having achieved their relative goals or if they simply could not pass this in general. In order to fully account for outliers in overall quadriceps strength, future studies could separate patients based on pre-surgical quadriceps strength instead of age. Strengths of this study include the objective assessment of muscle strength and evaluation of hop mechanics by four experienced sports medicine physical therapists via the same methodologies.

CONCLUSION

Patients undergoing BTB autograft are estimated to obtain 80% quadriceps symmetry at an average of 5.7 months for males and 7.1 months for females. Individuals under the

age of 25 obtain their quadriceps symmetry faster and are cleared to return to running faster than individuals over 25. Male sex is associated with decreased amount of time to obtain clearance for running and for full activity. Male sex is associated with a decreased amount of time to regain quadriceps symmetry however this was not significant.

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REFERENCES

1. Ithurburn MP, Altenburger AR, Thomas S, Hewett TE, Paterno MV, Schmitt LC. Young athletes after ACL reconstruction with quadriceps strength asymmetry at the time of return-to-sport demonstrate decreased knee function 1 year later. *Knee Surg Sports Traumatol Arthrosc.* 2018;26(2):426-433. doi:10.1007/s00167-017-4678-4
2. Lopley LK. Deficits in quadriceps strength and patient-oriented outcomes at return to activity after ACL reconstruction: A review of the current literature. *Sports Health.* 2015;7(3):231-238. doi:10.1177/1941738115578112
3. Schwery NA, Kiely MT, Larson CM, et al. Quadriceps strength following anterior cruciate ligament reconstruction: normative values based on sex, graft type and meniscal Status at 3, 6 & 9 Months. *Int J Sports Phys Ther.* 2022;17(3):434-444. doi:10.26603/001c.32378
4. Zwolski C, Schmitt LC, Quatman-Yates C, Thomas S, Hewett TE, Paterno MV. The influence of quadriceps strength asymmetry on patient-reported function at time of return to sport after anterior cruciate ligament reconstruction. *Am J Sports Med.* 2015;43(9):2242-2249. doi:10.1177/0363546515591258
5. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med.* 2016;50(13):804-808. doi:10.1136/bjsports-2016-096031
6. Capin JJ, Snyder-Mackler L, Risberg MA, Grindem H. Keep calm and carry on testing: a substantive reanalysis and critique of 'what is the evidence for and validity of return-to-sport testing after anterior cruciate ligament reconstruction surgery? A systematic review and meta-analysis.' *Br J Sports Med.* 2019;53(23):1444-1446. doi:10.1136/bjsports-2019-100906
7. Lüdecke D. ggeffects: Tidy data frames of marginal effects from regression models. *Journal of Open Source Software.* 2018;3(26):772. doi:10.21105/joss.00772
8. Abrams GD, Harris JD, Gupta AK, et al. Functional performance testing after anterior cruciate ligament reconstruction: A systematic review. *Orthop J Sports Med.* 2014;2(1). doi:10.1177/2325967113518305
9. Glattke KE, Tummala SV, Chhabra A. Anterior Cruciate Ligament Reconstruction Recovery and Rehabilitation: A Systematic Review. *J Bone Joint Surg Am.* 2022;104(8):739-754. doi:10.2106/jbjs.21.00688
10. Rambaud AJM, Ardern CL, Thoreux P, Regnaud JP, Edouard P. Criteria for return to running after anterior cruciate ligament reconstruction: a scoping review. *Br J Sports Med.* 2018;52(22):1437-1444. doi:10.1136/bjsports-2017-098602
11. Goto S, Garrison JC, Hannon JP, et al. Quadriceps strength changes across the continuum of care in adolescent male and female athletes with anterior cruciate ligament injury and reconstruction. *Phys Ther Sport.* 2020;46:214-219. doi:10.1016/j.ptsp.2020.08.016
12. Harput G, Ulusoy B, Yildiz TI, et al. Cross-education improves quadriceps strength recovery after ACL reconstruction: a randomized controlled trial. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(1):68-75. doi:10.1007/s00167-018-5040-1
13. Potts G, Reid D, Larmer P. The effectiveness of preoperative exercise programmes on quadriceps strength prior to and following anterior cruciate ligament (ACL) reconstruction: A systematic review. *Phys Ther Sport.* 2022;54:16-28. doi:10.1016/j.ptsp.2021.12.004
14. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br J Sports Med.* 2014;48(21):1543-1552. doi:10.1136/bjsports-2013-093398
15. Hughes JD, Burnham JM, Hirsh A, et al. Comparison of short-term biodex results after anatomic anterior cruciate ligament reconstruction among 3 autografts. *Orthop J Sports Med.* 2019;7(5):2325967119847630. doi:10.1177/2325967119847630
16. Hannon JP, Wang-Price S, Goto S, et al. Twelve-week quadriceps strength as a predictor of quadriceps strength at time of return to sport testing following bone-patellar tendon-bone autograft anterior cruciate ligament reconstruction. *Int J Sports Phys Ther.* 2021;16(3):681-688. doi:10.26603/001c.23421

17. Barber-Westin S, Noyes FR. One in 5 Athletes sustain reinjury upon return to high-risk sports after ACL reconstruction: a systematic review in 1239 athletes younger than 20 years. *Sports Health*. 2020;12(6):587-597. [doi:10.1177/1941738120912846](https://doi.org/10.1177/1941738120912846)

18. Hartigan EH, Zeni J Jr, Di Stasi S, Axe MJ, Snyder-Mackler L. Preoperative predictors for noncopers to pass return to sports criteria after ACL reconstruction. *J Appl Biomech*. 2012;28(4):366-373. [doi:10.1123/jab.28.4.366](https://doi.org/10.1123/jab.28.4.366)

19. Noyes FR, Barber-Westin SD. Neuromuscular retraining in female adolescent athletes: effect on athletic performance indices and noncontact anterior cruciate ligament injury Rates. *Sports*. 2015;3(2):56-76. [doi:10.3390/sports3020056](https://doi.org/10.3390/sports3020056)

20. Padua DA, DiStefano LJ. Sagittal plane knee biomechanics and vertical ground reaction forces are modified following ACL injury prevention programs: a systematic review. *Sports Health*. 2009;1(2):165-173. [doi:10.1177/1941738108330971](https://doi.org/10.1177/1941738108330971)