

Quadriceps Strength and Knee Function After Anterior Cruciate Ligament Reconstruction with Quadriceps Tendon Bone Autograft: A Preliminary Report

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ABSTRACT

Introduction. The purpose of this study was to evaluate quadriceps strength and knee function after anterior cruciate ligament (ACL) reconstruction using a quadriceps tendon bone (QTB) autograft.

Methods. Preliminary data were extracted from an ongoing prospective cohort study in which the operative extremity was compared to non-operative extremity. Patients from 14 to 40 years of age who had an ACL reconstruction with QTB autograft volunteered to have knee assessment including quadriceps isokinetic strength measures and functional knee testing at 6 and 12 months post-operatively. Paired t-tests were conducted to compare post-operative strength and function scores on participants who had minimum one-year post-surgical follow-up.

Results. Patients had a significant recovery of quadriceps strength as determined by isokinetic testing and single leg hop test. For 31 participants, quadriceps strength of the operative leg measured at 60 deg/sec was 63% of the non-operative leg at six months, increasing to 79% at one year ($p < 0.001$); when measured at 180 deg/sec, these values were 68% at six months, increasing to 82% at one year ($p < 0.001$). For 30 participants, single leg hop functional scores of the operative leg were 80% of the non-operative leg at six months, increasing to 91% at one year ($p < 0.001$).

Conclusions. After QTB autograft for ACL reconstruction, there were significant gains in quadriceps strength and knee function from six months to one year post-operative. These findings indicated the QTB is an acceptable ACL reconstruction option.

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INTRODUCTION

An estimated 200,000 anterior cruciate ligament (ACL) injuries are reconstructed each year in the United States.¹ While surgical reconstruction is the current standard treatment for ACL tears in active patients, there is debate regarding which autograft is the best choice for the procedure. Options include bone patella tendon bone (BPTB), hamstring tendon (HT), quadriceps tendon bone (QTB), or all soft

tissue quadriceps tendon (QT).

The gold standard for ACL reconstruction has been BPTB or HT autograft,² but the harvest of either graft may be associated with significant morbidity. For example, the disadvantages of the BPTB graft include patellofemoral pain, increased risk of patella fracture, and predisposition to knee arthrosis.^{1,3} On the other hand, HT autograft has been associated with weakness in knee flexion,¹ tunnel widening,⁴ and the potential for deficient graft width.⁵

Quadriceps-based autografts have been used for ACL reconstruction with increasing frequency owing to less graft harvest morbidity. In one study, just 9% of patients had residual discomfort at the donor site,⁶ in another study, anterior knee pain was even less common, occurring in about 6% of those who had QTB autograft.⁷ In addition to a favorable donor site morbidity profile, a systematic review of 15 clinical trials by Hurley et al.⁸ showed that the QTB autograft had statistically similar outcomes compared to BPTB and HT autografts, including comparable knee stability, knee function, and re-rupture rates. Investigations such as these assessing quadriceps strength after a QTB ACL reconstruction typically have used isokinetic strength measures.⁶⁻¹⁰

A preliminary analysis in an ongoing study at our institution was conducted to determine the efficacy of QTB autograft in ACL reconstructions. The purpose of the ongoing prospective cohort study was to test the strength of the donor quadriceps muscle after QTB ACL grafting, comparing isokinetic strength and function of the operative leg to the non-operative leg. Combining isokinetic quadriceps strength data with functional testing data may improve our understanding of how strength deficits affect the recovery process.

METHODS

Patient Selection. A cross-section of data was selected from an ongoing cohort study in which the operative extremity (experimental) was compared to non-operative extremity (control). Inclusion criteria were patients who suffered a torn ACL, were between the ages of 14 and 40 years, and who had minimum one-year post-surgical follow-up. Informed consent was obtained at the six-week post-operative appointment. Study participants were incentivized with a modest stipend and agreed to have knee function and quadriceps strength testing at six months and one-year post-surgery. The study was approved by the University of Kansas Medical Center (KUMC) Institutional Review Board.

Patients were excluded due to previous ACL injury of either knee, multiple knee ligament tears, previous knee surgery of injured or contralateral knee, or history of any fracture of the lower extremity that caused deformity or hindered activity. Patients were not excluded if they had a concomitant meniscus tear.

Surgical Technique. Participants had the ACL injury treated surgically with a QTB graft performed by one of two sports medicine fellowship-trained surgeons. The procedure performed was an arthroscopic-assisted ACL reconstruction. The central portion of the quadriceps tendon was harvested using an open incision over the anterosuperior aspect of the knee. Graft size was dependent on patient size with average width being 8-10 mm. A 10-mm-length superior patella bone plug in continuity with the quadriceps tendon also was harvested. The patella defect was filled with bone graft and the quadriceps tendon defect was closed. While the graft was prepared for insertion,

arthroscopic ACL tunnel preparation was performed using separate tibial and femoral tunnel drill sites. The prepared quadriceps tendon was placed in the tunnels and secured on the femoral side and the tibial side with interference screws.

Rehabilitation. Post-operatively, all patients followed a standardized rehabilitation process. The first phase of the rehabilitation protocol focused on controlling knee swelling, passive and active knee range of motion (ROM), and quadriceps strengthening exercises such as heel slides and quad sets. A hinged knee brace was used during the initial rehabilitation period and, thereafter, a functional brace was used at the surgeon's discretion. The second phase of rehabilitation was focused on progressive knee ROM, restoring normal gait, and protecting graft fixation. Phase three involved preparing the patient for activities and was focused on progressive weight training, balance, and proprioception. The first three phases of rehabilitation took place between post-operative day one and 12 weeks post-operative if all rehabilitation milestones were met. To protect the ACL graft, no impact activities such as running, jumping, pivoting, or cutting were permitted until phase three had been completed.

After three months, patients were advanced to activities such as jogging and running in a straight line, further strengthening and proprioception training, and balance training. During the rehabilitation program, each patient was evaluated individually for return to sports at six months post-surgery based on ligament laxity, isokinetic strength testing, and functional testing.

Outcome Measures. The 2000 International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form is a 10-item survey that evaluates symptoms, highest level of sports activity, and knee function. Responses to each item are scored using an ordinal method, such that a score of 0 is given to responses that represent the lowest level of function or highest level of symptoms. The instrument is scored by summing the rating for each item with the calculated value ranging from 0 to 100. The 2000 IKDC score is interpreted as a measure of function such that higher scores represent higher levels of function and lower levels of symptoms. A score of 100 means no limitation with activities of daily living or sports activities and the absence of symptoms. Higgins et al.¹¹ found that the 2000 IKDC score was a reliable and valid instrument worthy of consideration for use in a broad patient population.

The Lysholm Knee Scoring Scale is an eight-item survey designed to give the clinician information on the participant's ability to manage everyday life. Each item response option is assigned a value and scores are totaled based on the respondent's selections. Scores range from 0 to 100 with higher scores indicating greater ability to manage daily activities. Test-retest reliability for the overall Lysholm score is ICC = 0.94 (95% confidence interval, 0.88 - 0.96).¹²

At six months and one-year post-surgery, study participants had comprehensive evaluation by a single physical therapist (RCM). All tests were performed on both operative and non-operative legs for control comparison. First, the KT-1000 arthrometer was used to test for ligamentous stability of the graft. Second, quadriceps strength was assessed using a Biodex™ System 3 Isokinetic device. Finally, functional testing was comprised of the single leg hop test and Lower Extremity Functional Test (LEFT) as described by Davies et al.¹³

Data Collection. Study data were collected and managed using Research Electronic Data Capture (REDCap®) system hosted at KUMC.^{14,15} Participant demographics included patient age, gender, body mass index (BMI), history of tobacco use, sport played when injured, and mechanism of injury. Participant responses to questionnaires administered at baseline (prior to surgery) also were included and post-operatively at 6 and 12 months. The questionnaires included the 2000 IKDC score, Lysholm score, and Tegner scores. The Tegner scores were excluded later from analysis because many participants failed to follow instructions for completing that outcome form.

Measured outcome data for the isokinetic strength tests and the functional tests for both operative leg and non-operative side also were entered into the REDCap® system. Parameters included KT-1000 ligament stability scores, isokinetic strength peak torque scores, the single leg hop tests, and the LEFT outcomes. For the isokinetic strength and the single leg hop data, side-to-side comparisons were done by calculating the Limb Symmetry Index (LSI). LSI is the mean score for the operative leg divided by the mean score for the non-operative leg times 100. $LSI \geq 90$ indicates that performance of the operative leg is $\geq 90\%$ of the non-operative side, generally corresponds to a favorable result, and suggests the patient may be ready to return to sports activity.¹⁶ In addition, the IKDC ratings associated with the KT-1000 stability tests were categorized as normal (0-2 mm), nearly normal (3-5 mm), abnormal (6-10 mm), or severely abnormal (> 10 mm).

Statistical Analysis. Descriptive statistics were used to summarize all measures. Categorical measures were reported as frequencies (n) and percentages (%). Continuous measures were reported as means, standard deviations (SD), and ranges with minimum and maximum values. Bivariable analyses were conducted to compare post-operative strength and function scores using paired t-tests. Analysis of variance for repeated measures was conducted to compare IKDC scores over time. Analyses were conducted in IBM SPSS Statistics, version 26 using two-sided tests with alpha level of 0.05.

RESULTS

Demographics of patients in the study cohort are shown in Table 1. Mean age at time of injury was 19 with a range of 14 to 28 years. There were 12 men and 19 women in the study with an average BMI of 23. Most participants incurred sport-related knee injuries. The 31 patients who completed one-year strength and knee function testing were included in the bivariate analysis of the preliminary data.

Table 1. Participant demographics (n = 31).

Characteristic	Value
Age at time of injury ^a	19.0 (4.3); 14 - 28
Body mass index (BMI) ^a	22.9 (3.2); 18 - 32
Gender, male ^b	12 (38.7)
Leg injured, right ^b	16 (51.6)
Activity when injured ^b	
Recreation	4 (12.9)
Sports	27 (87.1)
Work related	0

^aValues are mean (standard deviation); minimum - maximum.

^bValues are n (%).

Self-reported assessments of those who completed the study showed improvement in outcome measures over time (Table 2). Mean pain rating of the injured knee decreased over time, from 22 at baseline to 7 at one year. Mean IKDC score and mean Lysholm score increased from 69 to 88 and from 0.81 to 0.91, respectively. Almost half of participants (48%) had achieved an excellent rating on the Lysholm scale one year after surgery. A linear upward trend was observed for the mean 2000 IKDC Subjective Knee Evaluation from 69 at baseline, to 79 at six months after surgery, to 88 at one-year post-operative. For the 18 paired observations not shown in the table, analysis of variance for repeated measures showed significant between-subject effects ($p < 0.001$) demonstrating continued improvement in overall function after ACL reconstruction.

Table 2. Lysholm Knee Scores.

Outcome Measure	Baseline (n = 26)	Six Months (n = 19)	One Year (n = 27)
Pain Rating ^a			
Injured knee, past 24 hours	22.19 (27.32); 0 - 80	14.67 (17.86); 0 - 67	6.89 (15.73); 0 - 77
Uninjured knee, past 24 hrs	6.73 (19.73); 0 - 100	2.72 (10.1); 0 - 43	1.04 (2.6); 0 - 11
Pain rating difference	15.46 (30.74); -65 - 72	11.94 (20.98); -32 - 67	5.19 (15.57); -5 - 77
Lysholm Knee Score ^a	0.81 (0.21); 0.28 - 1.00	0.87 (0.09); 0.68 - 1.00	0.91 (0.09); 0.69 - 1.00
Lysholm Knee Rating ^b			
Excellent (95 - 100%)	9 (34.6)	4 (21.1)	13 (48.1)
Good (84 - 94%)	6 (23.1)	9 (47.4)	10 (37)
Fair (65 - 83%)	6 (23.1)	6 (31.6)	4 (14.8)
Poor (< 65%)	5 (19.2)	0 (0)	0 (0)
Mean IKDC Score ^a	68.5 (26.0); 12.6 - 100.0	78.9 (15.1); 43.7 - 100.0	88.0 (12.4); 41.4 - 100.0

^aValues are mean (standard deviation); minimum - maximum.

^bValues are n (%).

Post-operative isokinetic strength tests at six months and one year for the 31 subjects who completed the study are shown in Table 3. Significant differences were observed for the LEFT, the single leg hop test, and Biodex™ peak torque at 60 deg/sec and 180 deg/sec ($p < 0.001$ for each comparison). The mean LEFT outcome was about nine seconds faster from six months to one year post-operative. LSI for the single leg hop test was 80% at six months and 91% at one year indicating readiness to return to sports activity. LSI for the Biodex™ peak torque at 60 deg/sec was 63% at six months post-operative and 79% at one year after surgery. Similarly, LSI for Biodex™ peak torque at 180 deg/sec was 68% at six months and 82% at one year. Thus, these tests indicated that participants achieved overall increased strength and function during the period of observation.

An evaluation of side-to-side difference of the manual max KT-1000 test using the IKDC rating showed the operative leg was normal (0-2 mm) or nearly normal (3-5 mm) in 90% of patients at six months and at one year post-operative (Table 4). Only 3 of 31 patients (10%) had abnormal (6-10 mm) IKDC scores and no patients were rated severely abnormal (> 10 mm).

Regarding individual item responses, 24% of patients reported they could perform only light activities as the most strenuous activity at baseline, improving to 9% at one year post-operative. Conversely, while only 14% could perform very strenuous activities at six months after surgery, 57% reported being able to do so at one year post-operative. Regarding knee stiffness, 29% reported no stiffness at six months, which improved to 54% at one year post-operative. Most reported that the operated knee did not lock or catch, 75% at six months and 89% at one year after surgery.

DISCUSSION

This cross-sectional study was derived from an ongoing prospective cohort study designed to test the strength and function of the donor quadriceps muscle after ACL grafting with a QTB. The study demonstrated that ACL reconstruction using a QTB autograft does not produce significant quadriceps strength deficit. Indeed, the preliminary evidence showed there were significant gains in quadriceps strength from six months to one year post-operative. Improved knee function between six months and one year post-operative was demonstrated by satisfactory ligament stability, near full recovery of quadriceps strength, single leg hop test outcomes equivalent to the non-operative leg, and significant improvement in the LEFT performance. Patient-reported outcomes also demonstrated significant improvement from the initial visit to six months and one year post-operative.

Historically, BPTB and HT grafts have been the mainstay of treatment for ACL ruptures. The use of the QTB graft has been gaining popularity due to fewer adverse effects and superior biomechanical strength.¹⁷ However, until recently, there has been a paucity of evidence supporting the use of this autograft. Our study demonstrated that the QTB graft was a suitable alternative graft option as there was minimal loss of quadriceps strength and knee function after quadriceps tendon harvest.

Table 3. Bivariate analysis of postoperative isokinetic strength and functional knee tests (n = 31 except as noted).

Outcome Measure	Six-Month Follow-Up ^a	One-Year Follow-Up ^a	Difference ^b	p Value
LEFT (seconds)	133.2 (27.3); 101.3 - 215.1 ^c	124.5 (21.8); 167.7 - 180.7 ^d	16.1 (9.5)	< 0.001
Single leg hop test				
Non-operative leg (cm)	49.6 (9.6); 26.3 - 66.7 ^d	50.7 (10.2); 27.0 - 66.3	7.4 (7.0)	< 0.001
Operative leg (cm)	39.9 (11.3); 15.7 - 64.7 ^d	46.4 (11.6); 14.3 - 60.7	1.7 (4.8)	0.061
Limb symmetry index (LSI)	79.9 (14.8); 41.8 - 97.8 ^d	90.6 (11.6); 53.1 - 106.3	11.6 (11.8)	< 0.001
Biodex peak torque, 60 deg/sec				
Non-operative leg	119.0 (31.2); 57.3 - 201.1	130.0 (40.0); 64.4 - 243.1	11.0 (18.8)	0.003
Operative leg	76.0 (34.1); 34.5 - 183.6	104.0 (41.8); 48.1 - 195.4	28.0 (17.2)	< 0.001
Limb symmetry index (LSI)	62.8 (17.4); 31.2 - 102.5	78.7 (14.0); 50.3 - 108.3	15.8 (12.8)	< 0.001
Biodex peak torque, 180 deg/sec				
Non-operative leg	83.5 (26.2); 21.8 - 164.5	91.1 (29.2); 20.7 - 160.9	7.6 (10.6)	< 0.001
Operative leg	55.8 (23.4); 25 - 129.6	74 (27.2); 23.5 - 140.5	18.2 (11)	< 0.001
Limb symmetry index (LSI)	67.8 (18.1); 31.8 - 124.8	81.5 (12.3); 57.4 - 113.5	13.6 (10.6)	< 0.001
KT-1000, 15 lbs (mm)				
Non-operative leg	3.4 (1.7); 1 - 9	3.5 (1.4); 1.5 - 8	0.1 (1.3)	0.781
Operative leg	3.9 (1.8); 2 - 9	3.7 (1.4); 2 - 8	-0.2 (1.5)	0.367
KT-1000, 20 lbs (mm)				
Non-operative leg	5.1 (1.9); 2.5 - 11	5.0 (1.8); 2.5 - 9	-0.1 (1.3)	0.612
Operative leg	6.0 (2.1); 3 - 12	5.9 (2.2); 3 - 12	-0.1 (1.9)	0.706
KT-1000, 30 lbs (mm)				
Non-operative leg	6.7 (2); 4 - 14	6.5 (2.1); 3.5 - 12	-0.2 (1.5)	0.522
Operative leg	8.0 (2.7); 5 - 15	7.8 (2.5); 4 - 14	-0.2 (1.9)	0.544
KT-1000 manual max (mm)				
Non-operative leg	8.2 (2.7); 4 - 15	8.2 (2.2); 4.5 - 14	0.0 (1.4)	0.898
Operative leg	10.0 (2.6); 6 - 15	10.0 (2.6); 5.5 - 15	0.0 (2.4)	0.970
Side-to-side difference	2.3 (2.1); 0 - 8	2.3 (1.9); 0 - 6	0.0 (1.8)	0.884

^aValues are mean (standard deviation); minimum - maximum.

^bValues are paired mean difference (standard deviation).

^{c,d}Comparisons are based on n = 31 except for ^cn = 15 and ^dn = 30.

LEFT = Lower Extremity Functional Test

Limb Symmetry Index = (mean score of operative leg / mean score of non-operative leg) x 100.

Statistical significance is reached if p < 0.05.

Table 4. IKDC scores at follow-up evaluations (n = 31).

IKDC Score	Six Months	One Year
Normal (0-2 mm)	21 (67.7)	19 (61.3)
Nearly normal (3-5 mm)	7 (22.6)	9 (29.0)
Abnormal (6-10 mm)	3 (9.7)	3 (9.7)
Severely abnormal (> 10 mm)	0	0

Values are n (%).

IKDC = International Knee Documentation Committee.

Moreover, the QTB autograft has been shown to have a higher load to failure than the BPTB autograft. In a biomechanical study, Shani et al.¹⁷ found the QTB graft tolerated a load of 2,186 N before failure compared to 1,581 N before failure in the BPTB autograft. Another study demonstrated the maximum load to failure for a quadrupled semitendinosus graft was 1123 N, quadrupled gracilis tendon graft was 1068 N, and combined gracilis and semitendinosus quadrupled graft was 806 N.¹⁸ Among these constructs, the QTB had the highest load to failure, even higher than the native ACL, which Markatos et al.¹⁹ quantified as 1725 N.

Other studies have compared quadriceps strength in QTB and BPTB patient cohorts. For example, at 6 to 23 months post-surgery, Hunnicutt et al.³ found no difference in isokinetic strength in the QTB and BPTB autograft groups. The investigators also found that knee extensor isokinetic strength at 60 deg/sec was a median of 70% of the contralateral leg. This compared well to our findings at six months and one-year post-operative and dispelled the concern that quadriceps function may be compromised after a QTB autograft harvest.

Fisher et al.²⁰ assessed knee extensor and flexor muscle strength in two patient cohorts having QTB and HT autografts. At one year after ACL reconstruction, the study demonstrated that there was a significantly lower quadriceps strength and a significantly higher hamstring strength in the QTB group compared to the HT group. The authors suggested having a higher hamstring to quadriceps strength ratio in the QTB group may be associated with lower stress on the maturing ACL graft and thus may protect against graft failure postoperatively.

Determining safe return-to-sports parameters has been much debated in the literature. Grindem et al.²¹ suggested that determination of return to level I sports should be based on time from surgery as well as functional testing. They opined that safe return to sports may be expected with 90% return of quadriceps strength at nine months after ACL reconstruction. Reinjury rates were not increased by additional improvement in quadriceps strength or further delay in return to sports. Using this metric and the functional testing reported in our study, we may predict that sufficient quadriceps strength is regained post-operatively to permit safe return to sports.

In another study, Novaretti et al.²² demonstrated that quadriceps strength deficit six months after surgery did not predict return to pre-injury sports level. In fact, the authors argued against using strength assessment as a metric for return to sports. Regardless of the criteria used for return to sports, whether time, strength, or a combination of the two, our present study supported the use of QTB as a reasonable graft choice for ACL reconstruction.

Our study was limited by the small number of participants who completed the preliminary assessment. This may be attributed in part to the pandemic, since the study was conducted during the peak incidence of COVID-19 at our location, when participants were reluctant to have personal contact with members of the research team. To mitigate the drop-out rate, we considered using handheld dynamometers to obtain strength measurements during routine clinic follow-ups. However,

these measurements would have been less accurate and more highly variable than those obtained in separate extended evaluations by the physical therapist. The Biodex™ strength data and the functional test results collected at these separate encounters provided the best assessment of the knee after ACL reconstruction.

Despite this limitation, our preliminary results provided crucial information for the ongoing study. An updated effect size for a power analysis allowed us to calculate the number of participants required for the ongoing study. Using the effect sizes from the average single leg hop test for the operative leg, with 80% power to detect a paired mean difference of 1.7 (sd 4.8) between six months and one year and alpha level set at 5%, computations showed that about 65 participants would be required. Assuming a dropout rate of 30%, the total sample size to be recruited for the ongoing study would be about 100 participants.

CONCLUSIONS

This preliminary study showed that using QTB autograft for ACL reconstruction did not cause significant quadriceps strength deficit. Moreover, significant gains in quadriceps strength and knee function were observed from six months to one year post-operative. These findings, taken together with the lower morbidity of QTB autograft harvest, indicated that the QTB was an acceptable option for ACL reconstruction.

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