Outcomes of Quadriceps Tendon With Patellar Bone Block Anterior Cruciate Ligament Reconstruction in Adolescent Patients With a Minimum 2-Year Follow-up

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Background: The incidence of anterior cruciate ligament (ACL) injury in the adolescent population is increasing. The quadriceps tendon–patellar bone autograft (QPA) has been established as a reliable graft choice for ACL reconstruction in the adult population.

Purpose: To investigate graft failure, ability to return to sport, patient-reported functional outcomes, joint laxity, and subsequent injury among adolescent patients >2 years after primary ACL reconstruction with the QPA.

Study Design: Case series; Level of evidence, 4.

Methods: Consecutive patients who underwent QPA ACL reconstruction performed by a single surgeon were identified from an existing database. Information available in the database included demographics, concomitant/subsequent injuries, surgical procedures, graft failure, return to sport, and Lachman examination collected by medical record review. Pediatric International Knee Documentation Committee (Pedi-IKDC) and Lysholm scores were collected by telephone or during a clinic visit >2 years postoperatively.

Results: The final cohort included 81 of 104 consecutive adolescent patients aged 10 to 18 years (mean ± SD, 15.9 ± 1.7 years at the time of surgery) for whom follow-up information was collected at >2 years after surgery. The cumulative incidence of graft failure within the 36-month follow-up period was 1.2% (95% CI, 0.1%-11.4%). The rate of ipsilateral non-ACL injuries was similar (1.2%; 95% CI, 0.2%-7.6%). Contralateral ACL and non-ACL injuries requiring surgical intervention were documented in 9.8% (95% CI, 4.9%-19.5%). The median Pedi-IKDC score was 94 (interquartile range, 89-98). The median Lysholm score was 99.5 (interquartile range, 89.0-100.0). At 36 months after surgery, 87.9% (95% CI, 81.4%-94.9%) of individuals had returned to play.

Conclusion: The quadriceps tendon–patellar autograft is a novel graft that demonstrates excellent stability and favorable patient-reported outcomes. Based on these results, the QPA is a reliable choice for primary ACL reconstruction in adolescent patients.

Keywords: quadriceps tendon–patellar autograft; ACL reconstruction; pediatrics; anterior cruciate ligament

Anterior cruciate ligament (ACL) rupture is a common injury in the pediatric and adolescent population.[3,12,16,24,31,36] Historically, ACL ruptures in skeletally immature patients have been managed nonoperatively with physical therapy, bracing, and activity modification.[4,25,27,30] Improved physeal-sparing and physeal-saving techniques have made ACL reconstruction with autograft the standard for treating ACL rupture in adolescent patients.[1,2,11,20,26]

The quadriceps tendon is a novel graft choice for ACL reconstruction in adolescent and adult patients.[6,21,22,32-34] The quadriceps tendon, either as an isolated soft tissue graft or with a patellar bone block, has been shown to provide favorable outcomes among adult and adolescent patients.[21,23,32] The quadriceps tendon graft is associated with decreased incidence of postoperative anterior knee pain and better extensor strength recovery as compared with the bone–patellar tendon–bone graft.[23] The

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quadriceps tendon graft also leads to similar, if not superior, graft survival and patient-reported outcomes as compared with the hamstring tendon graft in adults and adolescents.[6,21,32]

The purpose of this study was to report the outcomes of primary ACL reconstruction with the quadriceps tendon–patellar bone autograft (QPA) in a consecutive adolescent patient population of a single surgeon. We hypothesized high graft survival, patient-reported outcomes, and ability to return to sport. We also hypothesized good outcomes in terms of few subsequent knee injuries at >2 years postoperatively.

METHODS

Patient Selection and Data Collection

After institutional review board approval, we queried an existing database of patients who underwent QPA reconstruction at our institution (n = 214). The database included patients of a single surgeon who underwent ACL reconstruction performed at our current institution, a children's hospital, between the years of 2014 and 2018. We selected a time frame to include approximately the first 100 patients who underwent QPA ACL reconstruction with the current fixation system at our institution (January 2014 to July 2015; n = 104). Individuals who were followed for <2 years (n = 16), underwent revision surgery for a failed primary ACL reconstruction performed at an outside hospital (n = 2), had a concomitant ligament repair procedure other than a meniscal procedure (n = 2), were >18 or <10 years of age at the initial surgery (n = 1), or were missing a functional knee score (n = 2) were excluded. Follow-up was obtained for 84% of all eligible participants (n = 81 of 97).

The existing ACL database included retrospectively and prospectively collected measures. The Pediatric International Knee Documentation Committee (Pedi-IKDC) and Lysholm questionnaires were prospectively collected during a clinic visit and/or per telephone interview conducted >2 years postoperatively. The retrospectively collected data from medical records included graft failure, reinjury to the ipsilateral knee, injury to the contralateral knee, return to sport, manual Lachman examination, and demographic information. The Lachman examination was performed by either a physician assistant or an orthopaedic surgeon (J.C.A.) and recorded in the clinic visit note. Reinjury was defined as any new injury to the surgically reconstructed knee that required operative intervention. Subsequent surgery performed on the contralateral leg was also documented. Ability to return to sport was defined as an individual who passed the physical therapist–supervised return-to-sport test, was cleared to returned to sport per clinic notes, or was orally confirmed to return to sport during the research visit/telephone call.

Surgical Technique

All patients underwent standard anesthesia in conjunction with a combined sciatic nerve block and either femoral nerve block or continuous femoral nerve catheter.[8] Arthroscopy was performed to assess the presence and location of the ACL rupture. If the rupture was not amenable to ACL repair, the surgeon continued with ACL reconstruction surgery. A single orthopaedic surgeon (J.C.A.) performed all ACL reconstructions with an all-inside technique using the QPA with an all-epiphyseal, hybrid, or transphyseal technique according to the patient's level of skeletal maturity (Figure 1). A transphyseal technique was used for patients who were within 6 months of skeletal maturity or were completely skeletally mature at the time of the surgery. For this technique, a femoral drill coronal plane angle of 110° was chosen, which would violate the physis if still present. For patients who were within 3 years to 6 months of skeletal maturity—based on standard assessment of skeletal maturity per the bone age of the hand or femoral physis—an 85° coronal plane drill angle (all epiphyseal) was chosen on the femur and controlled fluoroscopically to prevent injury to the femoral growth plate.[15,19] A tibial drill tunnel angle crossing the physis of 55° to 60° in the sagittal/coronal plane was employed, creating the hybrid technique. An all-epiphyseal technique was chosen for patients with >3 years of growth remaining. An all-epiphyseal femoral tunnel was performed as described with an all-epiphyseal tibial socket technique. The surgical technique has been described in detail.[1]

A 2.5- to 3.5-cm longitudinal incision was made over the superior aspect of the patella. A 15-blade was used to create longitudinal incisions separating the central portion of the quadriceps tendon (approximately 10 mm in width) until reaching the superior pole of the patella. At this point, a 1 × 1.5–cm trapezoidal bone block was cut with a sagittal saw and then loosened and removed with a curved 3/8th-inch osteotome. The bone block was elevated, and the graft was separated from the remaining quadriceps fibers until reaching approximately 65 mm in length. The graft was cut proximally and prepared using adjustable-loop suspensory fixation devices (BTB/RT TightRope; Arthrex, Inc) and a whipstitch to secure the loop to the tendon side of the graft, as previously described.

After standard arthroscopic evaluation of the knee joint, any necessary meniscal procedures and preparation of the notch (with possible notchplasty) were performed. The native ACL was trimmed down without being fully removed. The pediatric femoral drill guide (Pediatric Drill Guide Set; Arthrex, Inc) was positioned approximately 43% from the proximal to distal aspects of the intercondylar notch, measuring at the footprint of the femoral origin of the ACL and 1 to 2 mm anterior to the articular margin of the posterior aspect of the condyle. For skeletally immature patients, the femoral drill angle was set at 85° to allow for all-epiphyseal placement and checked intraoperatively with a mini C-arm to ensure protection of the physis. For skeletally mature patients, the transphyseal technique was used, and the femoral socket was positioned at 110°. The femoral socket was drilled in an inside-out fashion to a depth that was 5 mm greater than the length of the patellar bone block. Attention was then turned to positioning the tibial socket. Tibial guide pins were placed in the

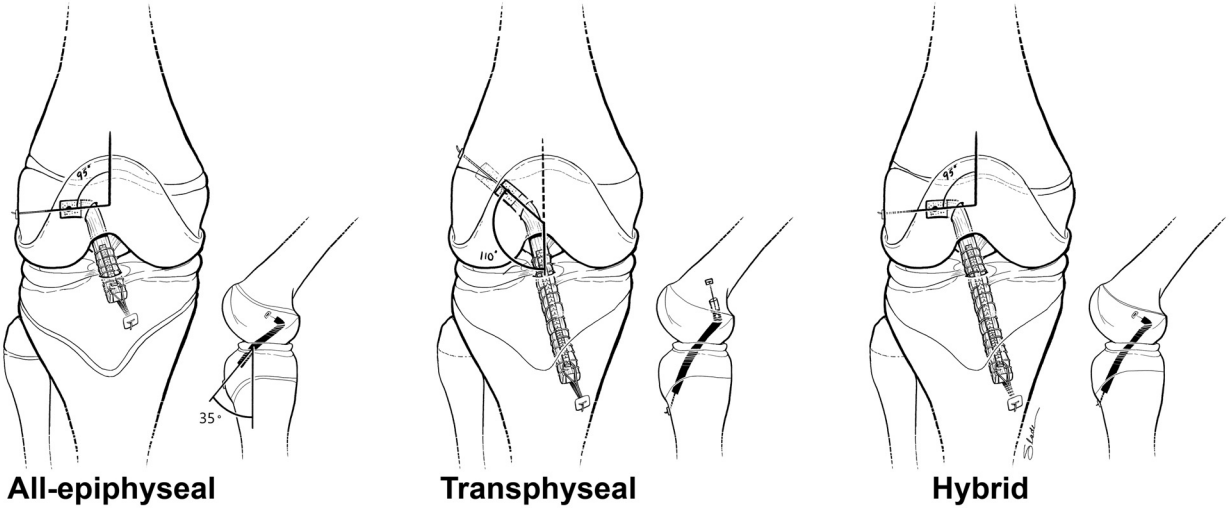

Figure 1. Graft and tunnel placement for each surgical technique.

posterior one-third of the tibial footprint, in line with the posterior aspect of the anterior root of the lateral meniscus. For the all-epiphyseal technique, the depth of the tibial socket was positioned at 35°, and the depth did not exceed the height of the epiphysis. Position was confirmed intraoperatively with a mini C-arm. For the transphyseal or hybrid technique, the socket was positioned at 55° to 60° with a depth of approximately 27 mm.

The bone block was guided into the femoral socket and firmly seated with the adjustable suspensory device. The tendon end of the graft was inserted into the tibial socket until completely seated into the tunnel by way of pulling the suture tails through the tibial socket and out of the tibial incision. The tibial-side adjustable loop was then tightened with the knee in 15° of flexion. The knee was cycled through full range of motion to ensure there was no graft impingement, particularly in full extension. The knee was cycled 25 to 30 times to condition the graft and retensioned as necessary. The cinching sutures and the whipstitch suture were tied over the buttons on the femoral and tibial sides.

Postoperative Protocol and Rehabilitation

Postoperatively, the surgical limb was immobilized in extension. Patients who underwent concomitant meniscal repair were instructed to use crutches and bracing for up to 6 weeks postoperatively. All patients were encouraged to complete physical therapy at our institution, where an adapted Multicenter Orthopaedics Outcomes Network (MOON) group rehabilitation protocol is in place.[37] Patients were also encouraged to pass a rigorous physical therapist–administered return-to-sport test. The return-to-sport test required >90% leg symmetry on single-leg functional tests of endurance, jumping, strength, and agility for clearance to fully return to athletic competition.

Statistical Analysis

Descriptive statistics were used to summarize the demographics, clinical characteristics, and outcomes among patients included in the cohort. Cox proportional hazards regression analyses were used to estimate the cumulative incidence of graft failure, non-ACL reinjuries affecting the ipsilateral knee, injuries to the contralateral knee, and return to play. When cumulative incidence was estimated, ipsilateral and contralateral knee injuries were modeled as competing risks through the subdistribution hazard function.[10] We recognize the potential for bias introduced by our patient selection mechanism. By selectively enrolling approximately the first 100 patients with complete data, the patients included in the study may not be representative of all patients who underwent QPA reconstruction at our institution. We compared differences in preoperative characteristics between patients who met inclusion criteria and those who were included in the database but did not meet the inclusion criterion time frame or were missing required data points (n = 128) (Appendix Table A1, available in the online version of this article). Inverse probability of selection weights were then used to re-estimate the cumulative incidence rates of interest. SAS software (Version 9.4; SAS Institute Inc) was used for all statistical analyses.

RESULTS

A total of 97 patients met the inclusion criteria, and 16 were lost to follow-up before postoperative 2 years (Table 1). Manual Lachman test measurements were available for 80 patients. The median manual Lachman measurement was 3 mm (interquartile range [IQR], 2-3 mm) of increased laxity (with a strong endpoint) of the involved

TABLE 1
Patient Characteristics[a]

	n	%
Concomitant medial meniscectomy	3	3.7
Female patients	39	48.1
Graft failure sex distribution		
Male	1	1.2
Female	0	0.0
Surgical technique		
All epiphyseal	2	2.5
Transphyseal	41	50.6
Hybrid	38	46.9
Mechanism of injury		
Sport	78	96.3
Accident/other	3	3.7
Skeletally maturity level at time of surgery		
Skeletally mature	46	56.8
Skeletally immature	35	43.2
Age at surgery,[b] y	15.9	1.7
Body mass index *Z* score[b,c]	1.1	0.9
Time from injury to surgery, mo[d]	1.3	0.9-2.2
Follow-up after surgery, y[d]	3.1	2.7-3.6

[a]Total included patients, n = 81.
[b]Mean (SD).
[c]Age- and sex-specific *Z* score.
[d]Median (interquartile range).

TABLE 2
Injuries Sustained During the Entire Follow-up Period[a]

	n	%
Contralateral knee injuries		
ACL	8	9.9
Lateral meniscus	3	3.7
Medial meniscus	0	0.0
Ipsilateral knee injuries		
ACL (graft failure)	1	1.2
Lateral meniscus	1	1.2
Medial meniscus	2	2.5

[a]ACL, anterior cruciate ligament.

joint as compared with the noninvolved joint. The median Pedi-IKDC score was 94 (IQR, 89-98). The median Lysholm score was 99.5 (IQR, 89.0-100.0).

The cumulative incidence of graft failure during the follow-up period was 1.2% (n = 1; 95% CI, 0.1%-11.4%). The cumulative incidence of ipsilateral injuries (non-ACL related) was also 1.2% (n = 1; 95% CI, 0.2%-7.6%). Contralateral ACL injuries requiring surgical intervention (cumulative incidence, 9.9%; n = 8; 95% CI, 4.9%-19.5%) were more common than injuries to the ipsilateral knee. All injuries requiring surgery during the entire follow-up period are summarized in Table 2. Within 36 months after surgery, 87.9% (95% CI, 81.4%-94.9%) of individuals demonstrated an ability to return to sport per the study definition.

We also explored whether patients selected for the cohort were comparable with patients who were excluded because of missing data and/or the timing of surgery (surgery occurred before or after the observation period). Differences in preoperative characteristics among patients who were included versus patients who were not included in the study are summarized in Appendix Table A1 (available online). Incidence estimates adjusted per the inverse probability of selection weights (Appendix Table A2, available online) reflected the unadjusted estimates presented earlier.

DISCUSSION

The most significant finding of this study was the low failure rate in our cohort (1.2%, n = 1 of 81). The increase in the number of adolescent patients undergoing ACL reconstruction underscores the importance of determining the optimal graft choice and technique for successful surgery.[5] The higher failure rates reported in this age group with the hamstring tendon and the postoperative anterior knee pain associated with the bone–patellar tendon–bone graft call for consideration of other graft options.[35,38] The quadriceps tendon is an effective graft choice for ACL reconstruction in young patients. Only 1 previous study reported outcomes of quadriceps tendon ACL reconstruction in adolescent patients; however, the sample size was limited to 15 participants.[21] Our study included a larger patient population of a single surgeon with >2-year follow-up. Our results suggest that the quadriceps tendon provides similar, if not better, results as compared with other graft types.

Limitations

There are a number of limitations to the present study. The small cohort (n = 81) and lack of objective joint laxity measurements may have led to a biased representation of graft survival and knee stability. This study is also limited by the lack of a control group, which was not possible for us to include, as only the quadriceps tendon technique is used at our institution except in rare cases. Another limitation is the lack of preoperative patient-reported outcomes and joint laxity measurements for comparison. Finally, the inclusion of patients who had all-epiphyseal, hybrid, or transphyseal ACL reconstruction increased the heterogeneity of our population and is important to bear in mind.

Graft Failure

We identified 1 graft failure within 36 months postoperatively. Our rate parallels that of Kohl et al,[21] who reported graft survival in all 15 patients (mean ± SD age, 12.8 ± 2.6 years; range, 6.2-15.8 years). QPA failure in the adult population ranges from 0% to 6%.[6,13,21-23,32] The range of the QPA failure rate is slightly lower than that of the hamstring and patellar tendon autografts, which range from 2.5% to 20% and 2.3% to 6.7%, respectively.[7,9,14,35] While we were unable to include a comparison group in the present study, previous research from our institution reported

4 graft failures (11.43%) among 35 patients aged 11 to 18 years (mean ± SD 15.60 ± 1.57 years) who underwent primary hamstring tendon autograft reconstruction.[9] Although definitive conclusions cannot be drawn without studies conducting a direct comparison of these autografts, the higher probability of graft survival for the quadriceps tendon relative to other graft options is promising.

Other Knee Injury Requiring Subsequent Surgery

In our study, there was a low rate of non–ACL related ipsilateral injury and non-ACL contralateral injury. However, the rate of contralateral ACL ruptures (n = 8; 9.9%) as compared with graft failures (n = 1; 1.2%) was increased. This suggested that the QPA provides excellent joint stability and return of lower extremity strength and biomechanics of the surgical limb. These findings are consistent with previous reports in the literature. Webster and Feller[35] reported contralateral ACL ruptures in 18.9% of female participants and 18.8% of male participants <18 years old. Paterno et al[28] reported that 20.5% of patients aged 10 to 25 years (mean ± SD 17.1 ± 3.1 years) experienced a contralateral ACL rupture. The increased incidence of contralateral ACL rupture may be due to multiple factors. There may be a combination of increased reliance on the contralateral leg after the index surgery and a predisposition of movement patterns, neuromuscular timing, body mechanics, and morphology, of which only a certain amount can be modified through proven training programs.[17,18,29] Favoring the nonoperative limb likely subjects the joint to increased force, weightbearing, and pivoting during activity. The lower incidence of rerupture as compared with contralateral rupture may also be explained by superior tensile strength and joint stability provided by the quadriceps tendon graft when compared with the patient's native ACL.

Patient-Reported Outcomes and Return to Sport

Our findings demonstrated normal knee function at postoperative 2 to 3 years. The median Pedi-IKDC score was 94 (IQR, 89-98), and the median Lysholm score was 99.5 (IQR, 89.0-100.0). The present patient-reported outcomes are comparable with those of Kohl et al,[21] who reported 13 of 15 patients had an A or B grade IKDC 2000 score and all patients, a mean Lysholm score of 94.0 (range, 68-100). The majority of index injuries in our cohort occurred during athletic participation, and 87.9% (95% CI, 81.4%-94.9%) of patients demonstrated the ability to return to sport after surgery. In this study, the ability to return to sport was confirmed by documentation in the medical records or self-report. Rigorous physical therapy may have contributed to the high functional outcome measures and return-to-sport rate in this study. Patients who completed in-house physical therapy were required to reach at least 90% movement quality and strength symmetry between the operative and nonoperative limbs before clearance for return to sport. The high rate of ability to return to sport despite this strict requirement suggests sufficient recovery of the quadriceps strength and neuromuscular control after graft harvest.

CONCLUSION

The present findings are consistent with previous reports in predominately adult patients. The QPA is a reliable graft choice that is relatively simple to perform. Our results demonstrated that ACL reconstruction with a QPA in adolescent patients leads to excellent stability and good patient outcomes. Although our cohort was not large enough to determine the failure rate of the QPA with statistical certainty, we believe that our results remain noteworthy given the higher failure rates reported of other graft types.[7,9,14,35] Further research is necessary to directly compare the QPA with other graft choices and determine the longevity of these outcomes.

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