All-Soft Tissue Quadriceps Tendon Autograft in Revision Anterior Cruciate Ligament Reconstruction in Athletes

Comparison to Bone-Patellar Tendon-Bone Autograft With at Least a 2-Year Follow-up

Joseph C. Brinkman,*† MD, Sailesh V. Tummala,† MD, Michael L. Moore,‡ BS, MBA, and Kostas J. Economopoulos,† MD
Investigation performed at Mayo Clinic, Phoenix, Arizona, USA

Background: Revision anterior cruciate ligament (ACL) reconstruction is being performed at an increasing rate. Previous literature has suggested that autograft ACL reconstruction is a better option than allograft in revision surgery, although the optimal autograft choice remains unknown. The all–soft tissue quadriceps tendon (ASTQT) autograft has been found to be an effective option for primary ACL reconstruction. However, few studies have evaluated ASTQT autograft in revision ACL reconstruction.

Purpose/Hypothesis: The purpose of this study was to evaluate the ASTQT autograft in revision ACL reconstruction in athletes compared with bone–patellar tendon–bone (BTB) autograft. We hypothesized that the ASTQT autograft would lead to similar return to play, time to return to play, retear rate, and patient-reported outcomes compared with BTB autograft.

Study Design: Cohort study; Level of evidence, 3.

Methods: A retrospective study was performed on all athletes undergoing revision ACL reconstruction between August 2013 and December 2019 at a single institution. Patients participating in high school or college athletics undergoing first-time revision with either ASTQT or BTB autograft with ≥2 years of follow-up were included. Demographic variables, complications, return to sports, and outcome scores including the International Knee Documentation Committee (IKDC) and Lysholm were collected and compared between the 2 cohorts.

Results: A total of 58 revision ACL reconstructions were included, with 32 in the ASTQT cohort and 26 in the BTB cohort. Return to sports at the same level occurred in 62.5% of the ASTQT group and 53.8% of the BTB group. The ASTQT group returned to sports significantly faster than the BTB group (8.9 vs 10.3 months; $P = .020$). There was no difference in retear rates (3.1%, ASTQT; 7.7%, BTB) or other complications between the 2 groups. The IKDC scores were significantly higher at the 6- and 12-month follow-up for the ASTQT autograft group compared with the BTB group (6 months: ASTQT, 71.3; BTB, 61.7, $P = .001$; 12 months: ASTQT, 82.7; BTB, 78.6; $P = .021$). Lysholm scores were also greater in the ASTQT cohort at these time points (6 months: ASTQT, 75.1; BTB, 63.6; $P < .001$; 12 months: ASTQT, 82.0; BTB, 74.5; $P < .001$). However, IKDC and Lysholm scores were similar between both groups at final follow-up (IKDC: ASTQT, 82.9; BTB, 81.7; $P = .344$; Lysholm: ASTQT, 83.0; BTB, 81.0; $P = .104$) There was no significant clinical difference in the absolute difference in scores or rate of achieving clinical thresholds between the 2 cohorts.

Conclusion: ASTQT autograft for revision ACL in athletes has similar outcomes compared with BTB autograft. However, the ASTQT may possibly afford quicker return to sports and better early improvements in patient-reported outcomes that normalize by 1 year. The soft tissue quadriceps autograft should be considered a viable graft option in revision ACL reconstruction in athletes.

Keywords: anterior cruciate ligament; ACL; ACL reconstruction; revision ACL reconstruction; quadriceps tendon; patellar tendon; autograft; outcomes

Anterior cruciate ligament (ACL) injuries are one of the most common and debilitating knee injuries sustained in sports, with increasing rates of surgical management.[13,14] Reconstruction can be complicated by graft rupture and structural failure, indicating a need for repeat surgical

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intervention. Specifically, revision ACL reconstruction rates have been noted to be as high as 10.4% after a primary ACL reconstruction.[7,30] Despite evidence indicating inferior clinical results after revision surgery compared with primary reconstruction, a large proportion of patients will opt for a repeat intervention to improve stability of their knee.[15]

Revision surgery is more technically demanding than primary cases, with factors such as previous autograft use, existing hardware, tunnel position, bone loss, and muscle weakness complicating this procedure.[22] Notably, choice of graft type has been a source of controversy in these cases and largely determined based on factors such as primary graft type, quality of autogenous tissue, and surgeon or patient preference.[2] It has previously been established that autograft performs in a superior manner in subjective and clinical outcomes for revision cases compared with irradiated allograft, with lower rerupture and complication rates,[8,19,29] but the optimal autograft type remains unclear.

Bone–patellar tendon–bone (BTB) autografts are commonly used in revision cases,[1] but recent evidence has suggested that soft tissue autografts, particularly hamstring tendon (HT), may perform similarly or with improved clinical outcomes.[8,29] Recently, all–soft tissue quadriceps tendon (ASTQT) autografts have become a more popular graft type secondary to their favorable biomechanical properties and comparable clinical and functional outcomes and graft survival compared with HT autografts in primary ACL reconstruction.[5,6,11,22-27] Interest has further grown in ASTQT autograft use in revision cases; however, data are limited, and authors have expressed concern about the patients' ability to tolerate a secondary insult to the extensor mechanism after a primary BTB autograft.[22]

The purpose of this study was to evaluate the ASTQT autograft in revision ACL reconstruction in athletes compared with BTB autograft with a minimum 2-year follow-up. We hypothesized that use of ASTQT autografts would lead to similar return to play, time to return to play, retear rate, and patient reported outcomes (PROs) compared with BTB autografts.

METHODS

Patients and Outcome Measures

A retrospective study was performed on all athletes undergoing revision ACL reconstruction between August 2013 and December 2019 by a single fellowship-trained sports medicine surgeon (K.E.). Included were patients participating in high school or college athletics undergoing first-time revision with either ASTQT or BTB autograft with $\geq$2 years of follow-up. Exclusion criteria included multiple ACL reconstruction revisions, associated procedures other than meniscectomy or meniscal repair, multiligamentous injury, osteotomy, grade 3 to 4 chondromalacia, and the presence of previous infection.

Patient charts were retrospectively reviewed for patient demographics, reoperation, graft retears, return to sports, time to return to sports, level of sports returned to, and complications. Other PROs included International Knee Documentation Committee (IKDC) and Lysholm scores, which were obtained electronically preoperatively and at 6 months, 12 months, and annual follow-up. If patients did not fill out their PRO forms or missed their appointment, they were contacted by email and telephone to complete the forms virtually.

Clinical outcomes were compared between patients with ASTQT and BTB autografts using descriptive statistics and Student t test with a P value $<.05$ considered significant. Rates of achieving previously reported substantial clinical benefit (SCB)[4] and minimal clinically important difference (MCID)[21] thresholds were compared between the 2 groups using χ^2 test. A power analysis was calculated to determine the minimum number of patients in each cohort needed to show statistical validity using MCID values and previously reported patient outcomes after revision ACL reconstruction.[20,21] Statistical analysis was performed using Microsoft Excel (Version 16.65, Microsoft Corp).

Graft Selection

The graft choice was made before surgery after a detailed discussion with the patient and family. If the patient had a previous BTB or ASTQT autograft, then the same graft was not offered. Graft options for the revision included BTB autograft, ASTQT autograft, and allograft. In this young population, the senior surgeon (K.E.) tended to avoid allografts in these athletes, and his opinion was made clear to the patient. The benefits and risks of both the BTB and the ASTQT autografts were discussed with the patient and his or her family. Previous graft use or sport type did not influence revision graft choice except as noted above. It was explained to the patient that the senior surgeon was equally comfortable with both autograft options. Ultimate graft decision was made solely by the patient and family. The need for bone grafting and staging was determined using preoperative computed tomography or magnetic resonance imaging scans that demonstrated tunnel widening $\geq$13 mm. Also, if hardware removal was performed and a large bone defect was left, then the senior surgeon used his discretion to perform bone grafting and stage the procedure. Tunnels were placed in what the senior surgeon deemed anatomic

*Address correspondence to Joseph C. Brinkman, MD, Department of Orthopedic Surgery, Mayo Clinic, 5777 E. Mayo Blvd, Phoenix, AZ 85054, USA (email: brinkman.joseph@mayo.edu).
†Department of Orthopedic Surgery, Mayo Clinic, Phoenix, Arizona, USA.
‡Mayo Clinic Alix School of Medicine, Scottsdale, Arizona, USA.
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positioning, with bone grafting used where necessary to achieve proper placement.

Surgical Procedure

The procedure was performed with the patient in the supine position and with a nonsterile tourniquet around the proximal thigh, with use of general anesthesia and a femoral nerve block. A diagnostic arthroscopy was initially performed through typical anteromedial and anterolateral portals to confirm ACL graft rupture, followed by graft harvesting as described below.

Quadriceps Tendon Harvesting and Preparation

A 3-cm transverse incision was made 1 cm above the superior pole of the patella with dissection carried down to the quadriceps tendon. A double-bladed knife (Arthrex) was used to make an incision in the central third of the quadriceps tendon. The distal end of the tendon was dissected off the proximal pole of the patella and a whipstitch placed on the distal end of the graft. A cigar cutter was used to transect the full-thickness graft at the appropriate length. Graft length depended on patient height. Patients 5′5′′ (165cm) or shorter had graft lengths of 60 mm. A 65-mm graft was used in patients 5′6′′ (168cm) to 6′1′′ (185cm). Those patients 6′2′′ (188cm) to 6′6′′ (198cm) had grafts 70 mm in length, and those taller than 6′6′′ had 75-mm grafts. A TightRope (Arthrex) was sutured to the femoral end of the graft and an Attachable Button System (ABS; Arthrex) sutured to the tibial side. The graft was left on tension on the back table.

BTB Graft Harvesting and Preparation

The BTB autograft was harvested through a midline incision from the inferior pole of the patella to the tibial tubercle. Dissection was carried down until the paratenon was identified and opened sharply. A patellar retractor was placed over the top of the patella. A 20 × 10–mm bone plug on the centroinferior pole of the patella was marked using a cautery. A saw was then used to cut the 20 × 10 × 10–mm bone plug out in trapezoidal fashion. A 10 mm–wide strip of the central patellar tendon was then cut down to the tibial tubercle. Next, a 20 × 10–mm area was marked using the cautery. A saw was then used to cut the bone graft and a curved osteotome used to extract the bone plugs, which were subsequently trimmed down to 20 × 10 mm. A tight rope was attached to the femoral bone plug, and 2 passing sutures were placed on the tibial side. The graft diameter was then measured, and the graft was placed on tension on the back table.

For the femoral tunnel, a 7-mm over-the-top guide was placed over the posterior lateral condyle with the knee in a hyperflexed position through an accessory anteromedial portal. A spade-tip guide pin was then placed through the femoral footprint and out the lateral cortex of the lateral condyle. An appropriately sized low-profile reamer was then used to create a 25-mm femoral socket. A passing suture was then placed in the femoral socket for future graft passing. Attention was then placed on the tibial tunnel. Previous hardware was removed from the anterior tibia as needed. A tibial guide set at 55° was then placed over the anatomic tibial footprint of the ACL. When the quadriceps tendon was used as the graft, a FlipCutter (Arthrex) was drilled up through the center of the tibial footprint. The FlipCutter was then deployed to the appropriate size and drilled, creating a 25-mm tibial socket. A passing suture was then passed up through the tibial socket. For the BTB graft, a guide pin was placed through the center of the tibial footprint and a fully fluted reamer was used to create a complete tunnel of appropriate size.

The ASTQT graft was brought into the knee through the anteromedial portal and passed up first through the femoral tunnel and then down through the tibial tunnel using an all-inside technique. The knee was then placed in full extension, and the TightRope (Arthrex) and ABS (20-mm) buttons were deployed with a posterior drawer force on the knee. For the BTB graft, the graft was brought up through the tibial tunnel and up the femoral tunnel. The TightRope was then deployed until the bone plug was completely in the tunnel. With the knee in full extension and a posterior drawer force on the knee, an interference screw was used in the tibial tunnel, stabilizing the graft. A 4.75-mm SwivelLock (Arthrex) was used to back up the graft on the tibial side for all cases.

Postoperative Care

Postoperatively, patients wore a brace locked in extension and remained 50% weightbearing for 2 weeks. All patients were then able to bear weight as tolerated regardless of meniscal repair status. The brace was discontinued at 6 weeks. Physical therapy protocols focused initially on range of motion and quadriceps strengthening. The rehabilitation programs of both groups were identical regardless of the graft type used. Athletes went through several tests before being cleared for return to sports, with identical protocols between groups. In addition to full range of motion and lack of an effusion, quadriceps and hamstring strength had to be 90% that of the nonoperated side. In addition, the single-hop and triple-crossover hop for distance tests had to be within 10% of the noninjured leg. Finally, the athlete completed the lower extremity functional test with his or her physical therapist. Once these were passed, the athlete progressed from sport-specific activities to full contact sports under the supervision of the athletic trainer. Final clearance came from the senior surgeon when the athlete practiced fully and displayed no hesitancy or compensation strategies during cutting drills, especially during deceleration when performing at 100% speed.

RESULTS

A total of 80 revision ACLs were performed on athletes during the study period. Excluded cases included 8 with concomitant lateral extra-articular tenodesis due to residual pivot shift after reconstruction, 4 with multiligamentous reconstructions, and 6 because allograft or HT

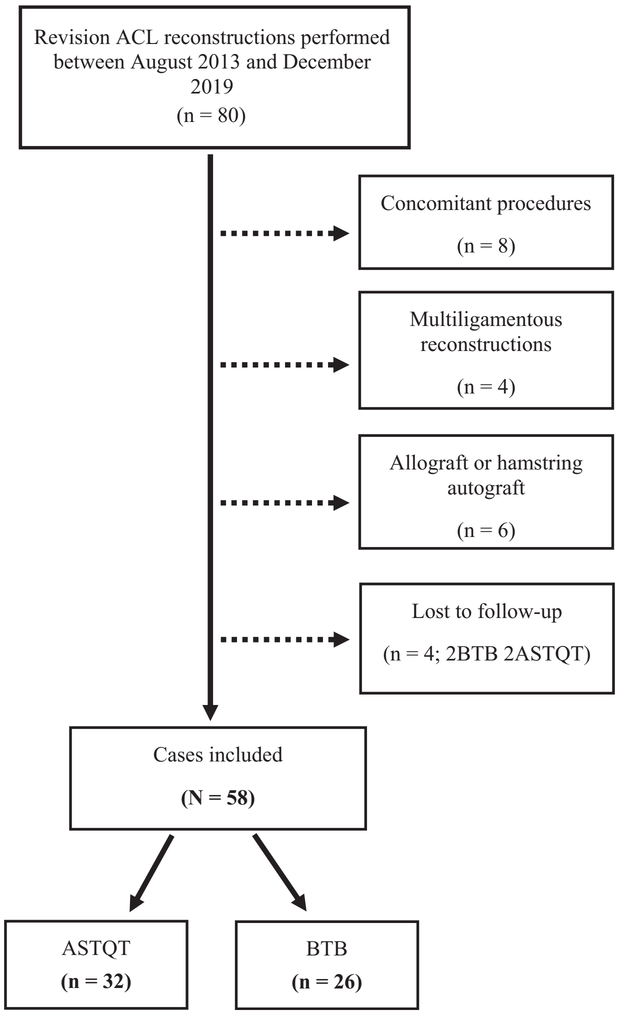

Figure 1. Patient inclusion flowchart. ACL, anterior cruciate ligament; ASTQT, all–soft tissue quadriceps tendon; BTB, bone–patellar tendon–bone.

autograft was used for the revision. This left a total 62 athletes who had undergone revision ACL reconstruction with either BTB or ASTQT autograft. A total of 4 patients were lost to follow-up, leaving 58 patients (93.5%) with ≥2 years of follow-up. Of these, 32 had ASTQT autograft and 26 had BTB autograft (Figure 1). Power analysis confirmed these cohorts were of adequate size to determine statistical significance, as a minimum of 23 patients in each cohort was calculated from previously published Lysholm score outcomes and MCID for revision ACL reconstruction.[20,21]

The mean follow-up of the ASTQT and BTB groups was 31.2 months and 33.8 months, respectively (P = .292). The ages were similar between the 2 groups (ASTQT, 18.3 years; BTB, 18.2 years; P = .937). Patient body mass index was 24.3 in the ASTQT group and 25.2 in the BTB cohort (P = .343). Sex breakdown did not significantly differ between the 2 groups (ASTQT, 62.5% female; BTB, 53.8% female; P = .514) Collegiate athletes made up 37.5% of the ASTQT group and 42.3% of the BTB group (P = .716). Graft sizes were similar between the groups

TABLE 1
Group Characteristics[a]

Characteristic	ASTQT (n = 32)	BTB (n = 26)	P Value
Follow-up, mo	31.2 ± 8.1	33.8 ± 10.4	.292
Age, y	18.3 ± 2.7	18.2 ± 2.8	.937
BMI	24.3 ± 3.5	25.2 ± 3.1	.343
Sex, female, %	62.5	53.8	.514
Laterality, right, %	65.4	59.4	.646
Graft size, mm	9.8 ± 0.7	9.6 ± 0.6	.392
Meniscectomy, %	12.5	11.5	.913
Meniscal repair, %	43.8	42.3	.914
Sport, No. (%)			
Baseball	1 (3.1)	2 (7.7)	.435
Basketball	3 (9.4)	2 (7.7)	.820
Football	9 (28.1)	9 (34.6)	.595
Gymnastics	1 (3.1)	0 (0)	—
Hockey	1 (3.1)	0 (0)	—
Lacrosse	2 (6.2)	3 (11.5)	.475
Soccer	11 (34.4)	8 (30.8)	.771
Softball	2 (6.2)	2 (7.7)	.829
Volleyball	2 (6.2)	0 (0)	—

[a]Data presented as mean ± SD unless otherwise indicated. Comparison performed using the Student t test or χ^2 test. ASTQT, all–soft tissue quadriceps tendon; BMI, body mass index; BTB, bone–patellar tendon–bone; —, unable to perform statistical analysis due to 0 value.

(9.8 mm in the ASTQT group and 9.6 mm in the BTB group; P = .392). Similarly, the rate of meniscal repair and meniscectomy did not differ between the 2 groups (meniscectomy: ASTQT, 12.5%; BTB, 11.5%; P = .913; meniscal repair: ASTQT, 43.8%; BTB, 42.3%; P = .914) (Table 1).

Overall, time to revision from retear was 9.3 weeks in the ASTQT group and 7.8 weeks in the BTB group (P = .591) (Table 2). In the patients who did not have grafting, the time from retear to surgery was 4.5 weeks in the BTB group and 6.9 weeks in the ASTQT group. In the group requiring bone grafting, the time to revision was 43.5 weeks after retear in the BTB group and 31.3 weeks in the ASTQT group. Rates of hardware removal (P = .437) and bone grafting (P = .820) were not significantly different between the 2 groups. There were no significant differences detected between primary graft choice between the 2 cohorts, although the BTB autograft was used primarily in 34.4% of the ASTQT cohort and none of the BTB cohort. The HT was the most commonly used primary graft in both the ASTQT (59.4%) and the BTB (80.8%) cohorts (P = .079). Quadriceps tendon was used primarily in 1 patient in the BTB cohort, and allografts were used in 6.3% of the ASTQT cohort and 15.4% of the BTB cohort (P = .256).

Return to sports occurred in 81.3% of the ASTQT group; however, only 62.5% were able to return to the same level of play. In the BTB group, 69.2% returned to play but only 53.8% at the same level as before injury. While the group differences in return to sports and level of sports returned to were not significant (P = .296 and P = .514, respectively), the ASTQT group returned to sports significantly faster than the BTB group (8.9 vs 10.3 months, respectively; P

TABLE 2
Group Surgical Factors[a]

Factor	ASTQT (n = 32)	BTB (n = 26)	*P* Value
Mean time to surgery, wk	9.3	7.8	.591
Hardware removal	13 (40.6)	8 (30.7)	.437
Bone grafting	3 (9.4)	2 (7.7)	.820
Primary graft			
BTB	11 (34.4)	0 (0)	—
HT	19 (59.4)	21 (80.8)	.079
ASTQT	0 (0)	1 (3.8)	—
Allograft	2 (6.3)	4 (15.4)	.256

[a]Data presented as number (%) unless otherwise indicated. Comparison performed using the Student *t* test or χ^2 test. ASTQT, all–soft tissue quadriceps tendon; BTB, bone–patellar tendon–bone; HT, hamstring tendon; QT, quadriceps tendon; —, unable to perform statistical analysis.

TABLE 3
Return to Sports Outcomes[a]

Outcome	ASTQT (n = 32)	BTB (n = 26)	*P* Value
Overall return	81.3	69.2	.296
Cutting-pivoting	80.0	78.6	.919
Collision	83.3	58.3	.178
Return to same level	62.5	53.8	.514
Cutting-pivoting	60	71.4	.493
Collision	66.7	33.3	.102
Time to return	8.9 ± 1.6	10.3 ± 2.5	**.020**
Cutting-pivoting	9.2 ± 1.8	10.3 ± 1.9	.141
Collision	8.4 ± 1.0	10.4 ± 3.4	.085

[a]Data presented as percentage or mean ± SD. Time to return reported in months. Comparison performed using the Student *t* test or χ^2 test. Bold denotes statistical significance. ASTQT, all–soft tissue quadriceps tendon; BTB, bone–patellar tendon–bone.

TABLE 4
Postoperative Outcome Scores[a]

Score	ASTQT (n = 32)	BTB (n = 26)	*P* Value
IKDC			
Preoperative	49.8 ± 9.3	50.3 ± 9.1	.828
6-mo postoperative	71.3 ± 11.9	61.7 ± 9.4	**.001**
1-y postoperative	82.7 ± 6.0	78.6 ± 7.0	**.021**
Final	82.9 ± 4.5	81.7 ± 5.5	.344
Lysholm			
Preoperative	52.7 ± 8.9	52.8 ± 9.9	.939
6-mo postoperative	75.1 ± 6.2	63.6 ± 8.8	**<.001**
1-y postoperative	82.0 ± 5.7	74.5 ± 4.9	**<.001**
Final	83.0 ± 4.4	81.0 ± 4.7	.104

[a]Data presented as mean ± SD. Comparison performed using the Student *t* test. Final outcome as per last follow-up. Bold denotes statistical significance. ASTQT, all–soft tissue quadriceps tendon; BTB, bone–patellar tendon–bone; IKDC, International Knee Documentation Committee.

= .020). These return metrics did not demonstrate any significant differences when comparisons were made between cutting and pivoting athletes versus collision and contact athletes (Table 3).

Preoperative IKDC scores were not significantly different between the ASTQT and BTB groups (*P* = .828). Similarly, preoperative Lysholm scores were not significantly different between the 2 groups (*P* = .939). Both the IKDC and the Lysholm scores were significantly higher for the ASTQT autograft group at the 6-month (IKDC, *P* = .001; Lysholm, *P* < .001) and 12-month (IKDC, *P* = .021; Lysholm, *P* < .001) follow-up compared with the BTB group. However, these scores were similar between groups at final follow-up (IKDC, *P* = .344; Lysholm, *P* = .104) (Table 4, Figure 2). The rate of clinical achievement in the Lysholm score was not statistically significant at 2 years postoperatively, although the ASTQT cohort had slightly higher achievement (*P* = .435) (Table 5). Similarly, at 1 year postoperatively, there were nonsignificant higher achievement rates of SCB (*P* = .475) and MCID (*P* = .0981) in the ASTQT cohort for the IKDC. Both cohorts demonstrated 100% achievement in the IKDC MCID at 2 years.

There was no detected difference in the rate of complications between the 2 groups. Retears occurred in 1 (3.1%) of the ASTQT group and 2 (7.7%) of the BTB group (*P* = .444). There was 1 infection in the BTB group (3.8%) and 0 (0%) infections in the ASTQT group (*P* = .271). Arthrofibrosis affected 2 (7.7%) of the BTB group and 4 (12.5%) of the ASTQT group (*P* = .558).

DISCUSSION

In our series, athletes undergoing ASTQT autograft revision ACL reconstruction returned to sports at similar rates and to a similar level of competition compared with patients receiving BTB autografts. However, patients receiving an ASTQT autograft were found to return to sports significantly faster than patients with BTB autograft (8.9 vs 10.3 months, respectively). In addition, our results revealed significantly greater IKDC and Lysholm scores in the ASTQT group at 6 and 12 months postoperatively, but this difference was not present at 2 years or final follow-up. There were no clinically significant differences detected between the absolute outcome scores or rate of achieving MCID or SCB. Differences in complication rates, retears, and graft size between these 2 groups were not significantly different. Our results support that the ASTQT autograft is a viable option for athletes receiving revision ACL reconstruction surgery and at least may temporarily outperform BTB autograft on certain metrics in short-term follow-up.

Previous investigations have sought to examine graft choice and outcomes in revision ACL reconstruction. In a large cohort study with >1200 patients, the Multicenter ACL Revision Study group found that revision ACL reconstruction with autograft outperformed allograft in terms of sports function, PRO scores, and risk of rerupture.[19] However, limited analysis was performed on the difference between the various grafts in the study. Previous studies

TABLE 5
Postoperative Outcome Threshold Achievement[a]

Outcome	Δ 1 y	MCID 1 y, %	*P* Value	SCB 1 y, %	*P* Value	Δ 2 y	MCID 2 y, %	*P* Value
IKDC								
BTB	28.3 (7.0, 14-43)	84.6	.0981	50	.475	31.3 (8.9, 14-49)	100	
ASTQT	32.9 (8.8, 18-51)	96.9		59.4		33.1 (10.3, 16-56)	100	
Lysholm								
BTB	21.6 (8.8, 6-45)					28.2 (10.5, 8-50)	92.3	.435
ASTQT	29.3 (9.9, 14-51)					30.4 (9.4, 9-49)	96.9	

[a]The 1-year and 2-year data presented as mean score (SD, range). MCID and SCB reported as percentage of cohort that achieved minimum values. MCID values: IKDC 1 year (18.9), IKDC SCB 1 year (29.6), IKDC 2 years (9.5), and Lysholm 2 years (10.6).[4,21] Comparison performed using χ^2 test. ASTQT, all–soft tissue quadriceps tendon; BTB, bone–patellar tendon–bone; IKDC, International Knee Documentation Committee; MCID, minimal clinically important difference; SCB, substantial clinical benefit.

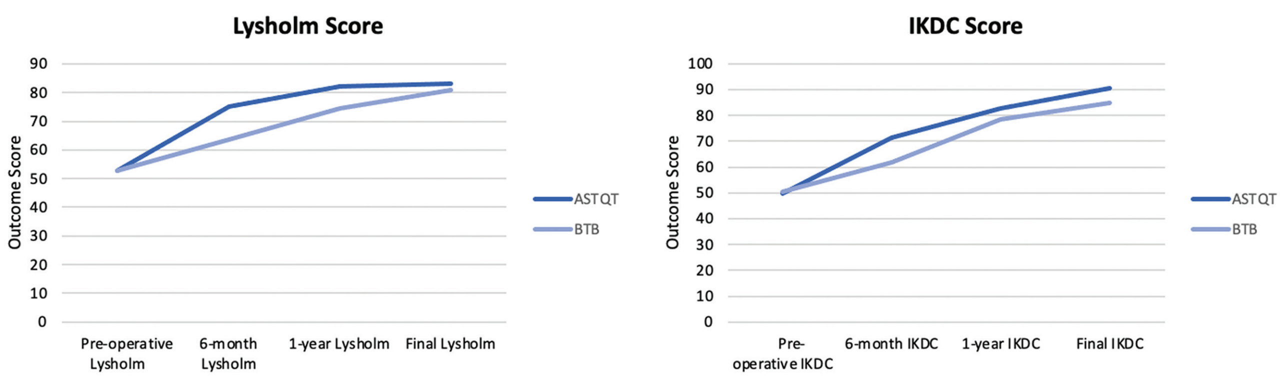

Figure 2. Graphical display of postoperative outcome scores over time. ASTQT, all–soft tissue quadriceps tendon; BTB, bone–patellar tendon–bone; IKDC, International Knee Documentation Committee.

examining the use of BTB autografts in primary as well as revision ACL reconstruction have found that BTB autografts provide excellent clinical and functional outcomes and are associated with low measured laxity, rapid graft incorporation, low complication and failure rates, favorable biomechanical properties, faster return to sports and/or activity, and high PRO measures (PROMs) postoperatively.[3,12,16,26] Fewer data exist regarding the use of ASTQT autografts in revision ACL reconstruction. However, a study by Hunnicutt et al[17] found that ASTQT autograft for revision ACL reconstruction exhibited acceptable early and intermediate-term clinical and functional outcomes. In that series, IKDC scores significantly improved over the study period, and the mean score at 2 years after operation was 82.8, which is comparable with the 82.9 two-year mean IKDC score observed in our cohort. Overall, it appears that both ASTQT and BTB autografts for primary and revision ACL reconstruction are viable options with reliable clinical and functional improvement in the short and intermediate term. Our data offer additional evidence that ASTQT autograft is an effective graft type and may offer superior functional outcomes in the short term via improved PROMs compared with BTB autograft.

Although the ASTQT cohort exhibited improved PROMs during the early study period, the clinical implications of this difference remain unclear. Although the MCID for the Lysholm score has not yet been reported in the setting of ACL reconstruction at the 6- or 12-month postoperative time points, it has been reported to be 10.6 at 2 years postoperatively.[21] This threshold was reached by 92.3% and 96.9% of the BTB and ASTQT cohorts, respectively. In terms of the IKDC outcome score, the thresholds for SCB and MCID have been reported at 1 year postoperatively.[4] The SCB threshold was achieved in 50% of the BTB group and 59.4% of the ASTQT group, while the MCID was met by 84.6% and 96.9%, respectively. At 2 years, each cohort demonstrated 100% achievement of the IKDC MCID. Taken together, at early follow-up, the ASTQT cohort did demonstrate a higher yet nonsignificant percentage achievement of the SCB and MCID thresholds in each metric analyzed. These detected differences and the absolute difference in outcome scores between the cohorts do not appear to be clinically important.

There is a paucity of research regarding the use of ASTQT graft and return to sports, particularly in the revision setting. In our analysis, the 2 cohorts demonstrated similar rates of overall return (ASTQT, 81.3%; BTB, 69.2%) and return to the same level of competition (ASTQT, 62.5%; BTB, 53.8%). This is consistent with other findings reported in the literature. A study by

Shelbourne et al[24] found that 62% of school-aged athletes undergoing revision ACL reconstruction with BTB graft returned to the same level of sports, while 43% of collegiate athletes and 73% of recreational athletes returned to the same level of sports. Interestingly, this study found that the reported time for return to sports ranged from 6.4 months in school-aged athletes to 7.1 months in collegiate athletes, which was substantially sooner than what was observed in our analysis. It has also been demonstrated that patients undergoing revision ACL reconstruction return to preinjury level at a significantly lower rate compared with those who had primary reconstructions.[18] Specifically, a meta-analysis by Grassi et al[9] reported that an average of 53.4% of individuals returned to preinjury level of activity after revision reconstruction. In our series, return to same level was 53.8% for the BTB group and 62.5% for the ASTQT group.

However, our results also suggest that use of ASTQT autograft in revision ACL reconstruction is associated with a significantly earlier return to sports compared with BTB autograft. In our series, this difference in return was 1.4 months, on average. Reasons for this expedited return are speculative but may relate to increased collagen in the ASTQT autograft, higher tensile strength, or reduced pain that may have afforded quicker progression in early rehabilitation phases.[10,23] Together with the improved short-term PROMs at 6 and 12 months, ASTQT autograft may demonstrate better earlier improvement compared with BTB autograft. As previously noted, the clinical consequences of these differences remain unknown, and additional studies are needed to fully elucidate these findings. However, our analysis provides preliminary insight on the potential benefits of choosing an ASTQT autograft and supports the increasing popularity of using the quadriceps tendon in revision ACL reconstruction.[28]

Limitations

The presented study has several limitations. First, it is inherently limited due to a retrospective design. Although this cohort of patients represents a consecutive series, the study is accordingly prone to selection bias between the groups as they were not formally randomized. However, our comparison between the 2 cohorts did not identify any significant differences in characteristics and thus affords reasonable external validity. Our sample size is also relatively small and thus increases the likelihood of a type II error. Second, all procedures were performed by a single high-volume surgeon. Although this provides consistency, it may limit generalizability to other surgeons and centers. Last, our data analysis did not include biomechanical data regarding physician examination or compare rates between those with and without concomitant meniscal pathology or treatment. Although our PROs may serve as a surrogate for clinical stability, our results do not provide objective information regarding measures, including anterior tibial translation or quadriceps strength. Longer-term follow-up is also needed to compare durability of the surgery and the progression of degeneration, if present.

CONCLUSION

ASTQT autograft for revision ACL in athletes had similar outcomes compared with BTB autograft. However, the ASTQT autograft may possibly afford quicker return to sports and better early improvements in PROs that normalize by 1 year. The soft tissue quadriceps autograft should be considered a viable graft option in revision ACL reconstruction in athletes.

REFERENCES

1. Akhtar MA, Bhattacharya R, Ohly N, Keating JF. Revision ACL reconstruction—causes of failure and graft choices. *Br J Sports Med*. 2011;45(15):A15-A16.
2. Ann JH, Lee YS, Ha HC. Comparison of revision surgery with primary anterior cruciate ligament reconstruction and outcome of revision surgery between different graft materials. *Am J Sports Med*. 2008;36(10):1889-1895.
3. Barrett G, Stokes D, White M. Anterior cruciate ligament reconstruction in patients older than 40 years: allograft versus autograft patellar tendon. *Am J Sports Med*. 2005;33(10):1505-1512.
4. Beletsky A, Naami E, Lu Y, et al. The minimally clinically important difference and substantial clinical benefit in anterior cruciate ligament reconstruction: a time-to-achievement analysis. *Orthopedics*. 2021;44(5):299-305.
5. Belk JW, Kraeutler MJ, Marshall HA, Goodrich JA, McCarty EC. Quadriceps tendon autograft for primary anterior cruciate ligament reconstruction: a systematic review of comparative studies with minimum 2-year follow-up. *Arthroscopy*. 2018;34(5):1699-1707.
6. Cavaignac E, Coulin B, Tscholl P, Nik Mohd Fatmy N, Duthon V, Menetrey J. Is quadriceps tendon autograft a better choice than hamstring autograft for anterior cruciate ligament reconstruction? A comparative study with a mean follow-up of 3.6 years. *Am J Sports Med*. 2017;45(6):1326-1332.
7. Drogset JO, Grøntvedt T. Anterior cruciate ligament reconstruction with and without a ligament augmentation device: results at 8-year follow-up. *Am J Sports Med*. 2002;30(6):851-856.
8. Grassi A, Nitri M, Moulton SG, et al. Does the type of graft affect the outcome of revision anterior cruciate ligament reconstruction? *Bone Joint J*. 2017;99(6):714-723.
9. Grassi A, Zaffagnini S, Muccioli GMM, Neri MP, Villa SD, Marcacci M. After revision anterior cruciate ligament reconstruction, who returns to sport? A systematic review and meta-analysis. *Br J Sports Med*. 2015;49(20):1295-1304.
10. Hadjicostas PT, Soucacos PN, Berger I, Koleganova N, Paessler HH. Comparative analysis of the morphologic structure of quadriceps and patellar tendon: a descriptive laboratory study. *Arthroscopy*. 2007;23(7):744-750.
11. Heffron WM, Hunnicutt JL, Xerogeanes JW, Woolf SK, Slone HS. Systematic review of publications regarding quadriceps tendon autograft use in anterior cruciate ligament reconstruction. *Arthrosc Sports Med Rehabil*. 2019;1(1):e93-e99.
12. Hertel P, Behrend H, Cierpinski T, Musahl V, Widjaja G. ACL reconstruction using bone-patellar tendon-bone press-fit fixation: 10-year clinical results. *Knee Surg Sports Traumatol Arthrosc*. 2005;13(4):248-255.
13. Herzog MM, Marshall SW, Lund JL, Pate V, Mack CD, Spang JT. Trends in incidence of ACL reconstruction and concomitant procedures among commercially insured individuals in the United States, 2002-2014. *Sports Health*. 2018;10(6):523-531.
14. Hewett TE, Di Stasi SL, Myer GD. Current concepts for injury prevention in athletes after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2013;41(1):216-224.
15. Horvath A, Senorski EH, Westin O, Karlsson J, Samuelsson K, Svantesson E. Outcome after anterior cruciate ligament revision. *Curr Rev Musculoskelet Med*. 2019;12(3):397-405.

16. Hospodar MSJ, Miller MD. Controversies in ACL reconstruction: bone-patellar tendon-bone anterior cruciate ligament reconstruction remains the gold standard. *Sports Med Arthrosc Rev*. 2009;17(4): 242-246.
17. Hunnicutt JL, Haynes WB, Slone HS, Prince JA, Boden SA, Xerogeanes JW. Revision anterior cruciate ligament reconstruction with the all-soft tissue quadriceps tendon autograft has acceptable early and intermediate-term outcomes. *Arthroscopy*. 2021;37(9):2848-2857.
18. Lefevre N, Klouche S, Mirouse G, Herman S, Gerometta A, Bohu Y. Return to sport after primary and revision anterior cruciate ligament reconstruction: a prospective comparative study of 552 patients from the FAST Cohort. *Am J Sports Med*. 2017;45(1):34-41.
19. MARS Group. Effect of graft choice on the outcome of revision anterior cruciate ligament reconstruction in the Multicenter ACL Revision Study (MARS) cohort. *Am J Sports Med*. 2014;42(10):2301-2310.
20. Mohan R, Webster KE, Johnson NR, Stuart MJ, Hewett TE, Krych AJ. Clinical outcomes in revision anterior cruciate ligament reconstruction: a meta-analysis. *Arthroscopy*. 2018;34(1):289-300.
21. Nwachukwu BU, Sullivan SW, Rauck RC, et al. Patient-reported outcomes and factors associated with achieving the minimal clinically important difference after ACL reconstruction: results at a mean 7.7-year follow-up. *JBJS Open Access*. 2021;6(4):e21.00056.
22. Shah SS. Editorial commentary: revision anterior cruciate ligament using soft tissue autograft quadriceps is effective but not recommended for all comers. *Arthroscopy*. 2021;37(9):2858-2859.
23. Shani RH, Umpierez E, Nasert M, Hiza EA, Xerogeanes J. Biomechanical comparison of quadriceps and patellar tendon grafts in anterior cruciate ligament reconstruction. *Arthroscopy*. 2016;32(1): 71-75.
24. Shelbourne KD, Benner RW, Gray T. Return to sports and subsequent injury rates after revision anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sports Med*. 2014;42(6): 1395-1400.
25. Slone HS, Romine SE, Premkumar A, Xerogeanes JW. Quadriceps tendon autograft for anterior cruciate ligament reconstruction: a comprehensive review of current literature and systematic review of clinical results. *Arthroscopy*. 2015;31(3):541-554.
26. Tan TK, Subramaniam AG, Ebert JR, Radic R. Quadriceps tendon versus hamstring tendon autografts for anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Published online September 2, 2021. *Am J Sports Med*. doi:10.1177/03635465211033995
27. Todor A, Nistor DV, Caterev S. Clinical outcomes after ACL reconstruction with free quadriceps tendon autograft versus hamstring tendons autograft: a retrospective study with a minimal follow-up two years. *Acta Orthop Traumatol Turc*. 2019;53(3):180-183.
28. Winkler PW, Vivacqua T, Thomassen S, et al. Quadriceps tendon autograft is becoming increasingly popular in revision ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2022;30(1):149-160.
29. Wright RW, Huston LJ, Haas AK, et al. Association between graft choice and 6-year outcomes of revision anterior cruciate ligament reconstruction in the MARS Cohort. *Am J Sports Med*. 2021;49(10):2589-2598.
30. Wright RW, Magnussen RA, Dunn WR, Spindler KP. Ipsilateral graft and contralateral ACL rupture at five years or more following ACL reconstruction. *J Bone Joint Surg Am*. 2011;93(12):1159-1165.