Association Between Graft Choice and 6-Year Outcomes of Revision Anterior Cruciate Ligament Reconstruction in the MARS Cohort

MARS Group*
Investigation performed at Vanderbilt University Medical Center, Nashville, Tennessee, USA

Background: Although graft choice may be limited in the revision setting based on previously used grafts, most surgeons believe that graft choice for anterior cruciate ligament (ACL) reconstruction is an important factor related to outcome.

Hypothesis: In the ACL revision setting, there would be no difference between autograft and allograft in rerupture rate and patient-reported outcomes (PROs) at 6-year follow-up.

Study Design: Cohort study; Level of evidence, 2.

Methods: Patients who had revision surgery were identified and prospectively enrolled in this cohort study by 83 surgeons over 52 sites. Data collected included baseline characteristics, surgical technique and pathology, and a series of validated PRO measures. Patients were followed up at 6 years and asked to complete the identical set of PRO instruments. Incidence of additional surgery and reoperation because of graft failure were also recorded. Multivariable regression models were used to determine the predictors (risk factors) of PROs, graft rerupture, and reoperation at 6 years after revision surgery.

Results: A total of 1234 patients including 716 (58%) men were enrolled. A total of 325 (26%) underwent revision using a bone-patellar tendon-bone (BTB) autograft; 251 (20%), soft tissue autograft; 289 (23%), BTB allograft; 302 (25%), soft tissue allograft; and 67 (5%), other graft. Questionnaires and telephone follow-up for subsequent surgery information were obtained for 809 (66%) patients, while telephone follow-up was only obtained for an additional 128 patients for the total follow-up on 949 (77%) patients. Graft choice was a significant predictor of 6-year Marx Activity Rating Scale scores (P = .024). Specifically, patients who received a BTB autograft for revision reconstruction had higher activity levels than did patients who received a BTB allograft (odds ratio [OR], 1.92; 95% CI, 1.25-2.94). Graft rerupture was reported in 5.8% (55/949) of patients by their 6-year follow-up: 3.5% (16/455) of patients with autografts and 8.4% (37/441) of patients with allografts. Use of a BTB autograft for revision resulted in patients being 4.2 times less likely to sustain a subsequent graft rupture than if a BTB allograft were utilized (P = .011; 95% CI, 1.56-11.27). No significant differences were found in graft rerupture rates between BTB autograft and soft tissue autografts (P = .87) or between BTB autografts and soft tissue allografts (P = .36). Use of an autograft was found to be a significant predictor of having fewer reoperations within 6 years compared with using an allograft (P = .010; OR, 0.56; 95% CI, 0.36-0.87).

Conclusion: BTB and soft tissue autografts had a decreased risk in graft rerupture compared with BTB allografts. BTB autografts were associated with higher activity level than were BTB allografts at 6 years after revision reconstruction. Surgeons and patients should consider this information when choosing a graft for revision ACL reconstruction.

Keywords: anterior cruciate ligament; ACL reconstruction; revision; outcomes; graft failure

Revision anterior cruciate ligament (ACL) reconstruction remains a clinical management challenge for patients and physicians. Consistently worse clinical outcomes as compared with outcomes after primary ACL reconstructions have been demonstrated,[1,3,5,12,21,23] and despite an improving level of research in this area, sports orthopaedic surgeons continue to struggle to dramatically improve the care and counseling of these patients. The Multicenter ACL Revision Study (MARS) Group has been able to explore predictors of improved and worse outcomes with the challenge that many predictors may be nonmodifiable by the patient or the surgeon. One critical area of treatment decision making that may offer some ability for modification is the graft chosen for the revision reconstruction.

Previously, in the MARS Group cohort, patient-reported outcomes (PROs) and rerupture rates were reported to have been improved at 2-year follow-up when an autograft was chosen for a revision reconstruction versus an allograft.[13] Specifically, the rerupture rate favored autograft (odds ratio [OR], 2.78; P = .047). The number of failures at 2 years did

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not demonstrate a difference between soft tissue and bone-patellar tendon-bone (BTB) autografts or allografts: only broadly between autograft and allograft. These findings raised the question of whether graft choice truly existed in the revision ACL reconstruction setting given factors limiting graft choice, such as previous graft choice and patient desires. A propensity analysis of graft choice was subsequently performed to address this question.[14] This analysis demonstrated that, despite concerns that surgeons lacked control, surgeon preference was by far the strongest predictor of autograft versus allograft choice. In fact, the influence of surgeon preference was 5 times greater than was any other factor, including previous graft, sex, activity, and age. Thus, educating surgeons to utilize an autograft for ACL revision surgery could decrease the incidence of rerupture and improve PROs at least in the early follow-up time of 2 years after revision surgery.

The patients with revision ACL reconstruction enrolled in this MARS cohort were older and less active than were typical cohorts with primary ACL reconstruction. This led us to question whether findings noted at 2-year follow-up might be dampened with further follow-up, with graft choice becoming less important with longer follow-up (ie, much of the cohort having decreased their activity to the point any graft survives). With this in mind, the MARS Group undertook an analysis of the cohort at a minimum 6-year follow-up. Little evidence exists regarding ≥5-year follow-up in the revision setting.[23] In total, 4 studies have reported follow-up in 116 patients with a minimum 5-year follow-up.[7,11,16,18] Therefore, it was important that the MARS Group address this question by analyzing this unique cohort. We hypothesized that in the revision setting, there would be no difference between autograft and allograft in rerupture rate and PROs at longer (6-year) follow-up.

METHODS

Study Design and Setting

The MARS Group was established to address the clinical challenges found in the revision ACL reconstruction setting. Its formation has been described previously.[22] Briefly, we enrolled a prospective cohort of patients who underwent revision ACL reconstruction between 2006 and 2011 (Figure 1). The surgeon group consisted of fellowship-trained sports medicine specialists who were members of the American Orthopaedic Society for Sports Medicine. All surgeons participated in planning and study design sessions, agreed to inclusion and exclusion criteria, participated in articular cartilage and meniscal pathology agreement studies, and reviewed the surgeon and patient enrollment questionnaires before beginning patient enrollment. Patients were enrolled in the study if they had ACL deficiency secondary to failed previous ACL reconstruction, were between the ages of 12 and 65 years, and were scheduled to have a revision ACL reconstruction performed by a participating (MARS Group) surgeon. Patients with concomitant injuries to the medial and lateral collateral ligaments, posterior cruciate ligament, or posterolateral complex were included. Patients were excluded if they had graft failure secondary to previous intra-articular infection, arthrofibrosis, or complex regional pain syndrome. If an allograft was used, it was obtained from the Musculoskeletal Transplant Foundation (MTF; MTF Biologics). Currently, 83 surgeons are participating in 52 institutional review board-approved sites. It is approximately a 50/50 mix of private practice and academic centers and surgeons.

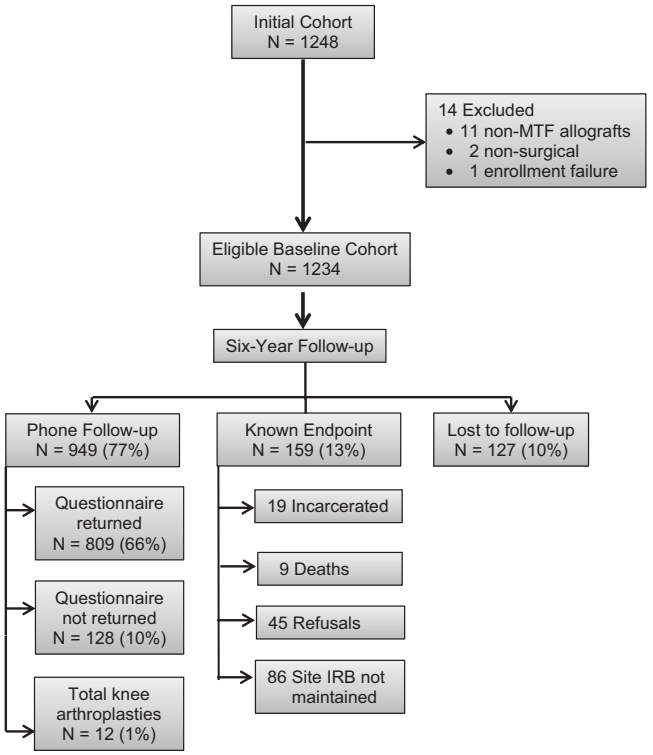

Figure 1. Patient enrollment flow diagram.
IRB, institutional review board; MTF, Musculoskeletal Transplant Foundation (MTF Biologics).

Data Sources

After providing informed consent, each patient completed a self-reported questionnaire examining patient characteristics, injury characteristics, sports participation history, and

*Address correspondence to Rick W. Wright, MD, Department of Orthopaedic Surgery, Vanderbilt University Medical Center, Medical Center East, South Tower, Suite 4200, Nashville, TN 37232-8774, USA (email: rick.w.wright@vumc.org).

All authors are listed in the Authors section at the end of this article.

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health status before their revision ACL reconstruction surgery. Within this questionnaire, each participant completed a series of validated general and knee-specific outcome instruments, including the Knee Injury and Osteoarthritis Outcome Score (KOOS), the International Knee Documentation Committee (IKDC) Subjective form, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and the Marx Activity Rating Scale. Surgeons completed a questionnaire that included physical examination findings, surgical technique utilized, intra-articular findings, and surgical management of meniscal and chondral damage.

Completed data forms were mailed from each participating site to our data coordinating center. Data from both the patient and surgeon questionnaires were scanned using Teleform software (OpenText) utilizing optical character recognition, and the scanned data were verified and exported to a master database. A series of custom logical error and quality control checks were subsequently performed before data analyses.

Patient Follow-up

At 6 years after their revision ACL reconstruction, patients completed the same questionnaire that had been used both at baseline and at 2-year follow-up. This included descriptive data, validated patient-reported outcome measures (IKDC, KOOS, WOMAC, and Marx Activity Rating Scale), and reinjury and reoperation queries. Patients were contacted via telephone or email to establish current location and, at a minimum, address the reinjury and reoperation questions, if they were unwilling to complete the entire questionnaire. Information on subsequent graft failures was obtained and documented using physicians' clinical examination notes, KT-1000 arthrometer, or magnetic resonance imaging verification and/or using subsequent operative reports.

Statistical Analysis

Descriptive statistics of each of the baseline patient and surgical characteristics were examined and reported (Table 1). The effect of the independent (risk factor) variables on the (1) continuous outcome measures of the IKDC, the KOOS, the WOMAC, and the Marx Activity Rating Scale were modeled using proportional odds logistic regression, binary outcomes of graft failure (yes/no, as determined via physical examination, magnetic resonance imaging, or KT-1000), and reoperation (yes/no) were modeled using a logistic multivariable regression. The odds ratio (OR) and 95% confidence interval (CI) were obtained by exponentiating the parameter estimates. Patient- and surgical-related covariates were included in the models. Patient-related covariates included sex (male/female), age at the time of revision ACL reconstruction, body mass index, smoking status (nonsmoker, quit, or current), education level (in years), baseline Marx activity level, and baseline outcome measures (IKDC, KOOS, and WOMAC). Covariates related to previous surgical information (if known) included previous ACL reconstruction on the contralateral knee (yes/no), previous meniscal surgery (medial and lateral; yes/no), previous articular cartilage surgeries (yes/no), previous graft type (autograft vs allograft), and previous graft source (BTB vs soft tissue). Covariates related to current surgical information included time (in years) since the patient's last ACL reconstruction, number of revisions, the surgeon's opinion of failure (traumatic, technical, biological, other, or combination), the surgeon's revision of his of her own failure (yes/no), the surgeon's years of experience, mechanism of injury (nontraumatic: gradual or sudden onset traumatic: contact or noncontact), surgical technique (1 incision transtibial, 1 incision anteromedial portal, 2 incisions, or arthrotomy), graft type (autograft, allograft, or both), graft source (BTB, soft tissue, or other), femoral tunnel aperture position and fixation, tibial tunnel aperture position and fixation, meniscal and articular cartilage pathology and treatment, and biologic enhancement used (yes/no). Of primary interest was the independent variable created by crossing current revision graft type (autograft vs allograft) and graft source (BTB vs soft tissue), resulting in a 4-level variable of BTB autograft, soft tissue autograft, BTB allograft, and soft tissue allograft. Three-knot restricted cubic splines were used for all continuous covariates to allow for nonlinear relationships with the outcomes.

The changes in outcome scores between baseline and 6 years were assessed by comparing medians and interquartile ranges at each time point and analyzed using the Kruskal-Wallis test. In addition, minimal clinically important differences (MCID) were examined between time points. MCID for the IKDC was 11 points,[9] 8 to 10 points for each of the 5 KOOS subscales and the WOMAC,[17] and 2 points for the Marx Activity Rating Scale. Alpha was set at .05 for all statistical tests. A multiple imputation using predictive mean matching was used to address missing data. The Hmisc and rms packages of the open-source R statistical software (R Core Team) was used for statistical analysis.

RESULTS

Study Population and Follow-up

Baseline descriptive statistics of the study population at the time of the revision ACL reconstruction are listed in Table 1. A total of 1234 patients, with 716 (58%) men, were successfully enrolled. The median age was 26 years. In 87% of patients, this was their first revision. In addition, 367 (30%) patients were undergoing revision by the surgeon who had performed the previous ACL reconstruction. A total of 598 (48%) patients underwent revision reconstruction using an autograft; 599 (49%), an allograft; and 37 (3%), both autograft and allograft. The median time since their last ACL reconstruction was 3.3 years. A 6-year follow-up questionnaire was obtained from 809 patients (66%), while telephone follow-up for subsequent surgery information was obtained for 949 (77%). The median age of the cohort at the time of 6-year follow-up was 32 years (range, 18-69 years).

TABLE 1
Baseline Cohort Characteristics at the Time of Revision ACL Reconstruction[a]

Patient Characteristics	Baseline Cohort (n = 1234), n (%)
Sex	
Men	716 (58)
Women	518 (42)
Age, y	26 (20, 34)
BMI	25.1 (22.6, 28.6)
Smoking status	
Nonsmoker	949 (77)
Quit	157 (13)
Current	109 (9)
Blank/missing	19 (2)
Education level, y	14 (12-16)
Activity level (Marx Activity Rating Scale, 0-16 points)	11 (4-16)
Previous surgery information	
Previous ACL reconstruction on the contralateral knee	
No	1110 (90)
Yes	124 (10)
Previous medial meniscal surgery	
No	765 (62)
Yes, repair healed/stable	32 (3)
Yes, repair not healed/unstable	69 (6)
Yes, excision	368 (30)
Previous lateral meniscal surgery	
No	979 (79)
Yes, repair healed/stable	30 (2)
Yes, repair not healed/unstable	23 (2)
Yes, excision	198 (16)
Blank/missing	4 (<1)
Previous articular cartilage surgeries	
No	1086 (88)
Yes	148 (12)
Previous graft type (most recent only)	
Autograft	834 (68)
Allograft	354 (29)
Both autograft and allograft	34 (3)
Unknown/missing	12 (<1)
Previous graft source	
BTB	642 (52)
Soft tissue	473 (38)
Both BTB and soft tissue	11 (<1)
Unknown/missing	108 (9)
Current surgical information at the time of revision surgery enrollment	
Time since last ACL reconstruction, y	3.3 (1.4, 8)
No. of revisions	
1	1077 (87)
2	131 (11)
≥3	26 (2)
Surgeon's opinion of failure	
Traumatic	429 (35)
Technical	266 (22)
Biological	101 (8)
Other	10 (<1)
Combination	426 (35)
Blank/missing	10 (<1)
Surgeon's revision of their own failure	
No	862 (70)
Yes	367 (30)
Blank/missing	5 (<1)
Surgeon experience, y	13 (8, 18)
Mechanism of injury	
Nontraumatic, gradual onset	340 (28)
Nontraumatic, sudden onset	84 (7)
Traumatic, noncontact	658 (53)
Traumatic, contact	150 (12)
Blank/missing	2 (<1)
Surgical technique	
1 incision (transtibial)	427 (35)
1 incision (AM portal)	575 (47)
2 incisions	220 (18)
Arthrotomy/other	12 (1)
Graft type	
Autograft	598 (48)
Allograft	599 (49)
Both autograft and allograft	37 (3)
Graft source	
BTB	616 (50)
Soft tissue	580 (47)
Other (eg, both BTB and soft tissue, quadriceps-bone)	37 (3)
Graft type x source	
BTB autograft	325 (26)
Soft tissue autograft	251 (20)
Semitendinosis (n = 21)	
Semitendinosis and gracilis (n = 230)	
BTB allograft	289 (23)
Soft tissue allograft	302 (25)
Achilles tendon (n = 83)	
Hamstring (n = 21)	
Tibialis anterior/posterior (n = 193)	
Combination (n = 5)	
Other (eg, both autograft and allograft, both BTB and soft tissue, quadriceps-bone)	67 (5)
Femoral fixation	
Interference screw	691 (56)
Suture and button/Endobutton[b]	265 (21)
Cross-pin	144 (12)
Other	54 (4)
Combination	77 (6)
Blank/missing	3 (<1)
Tibial fixation	
Interference screw	707 (57)
Intrafix[c]	107 (9)
Suture and post or button	65 (5)
Other	67 (5)
Combination	285 (23)
Blank/missing	3 (<1)
Medial meniscal pathology/treatment	
Normal (no tear)	680 (55)
No treatment for tear	29 (2)
Repair	166 (13)
Excision	336 (27)
Other	23 (2)
Lateral meniscal pathology/treatment	
Normal (no tear)	790 (64)
No treatment for tear	58 (5)
Repair	63 (5)
Excision	316 (26)
Other	7 (<1)
LFC articular cartilage pathology	
Normal/grade 1	881 (71)
Grade 2	189 (15)
Grade 3	99 (8)
Grade 4	65 (5)
MFC articular cartilage pathology	
Normal/grade 1	699 (57)
Grade 2	295 (24)
Grade 3	166 (13)
Grade 4	72 (6)
Blank/missing	2 (<1)

(continued)

TABLE 1
(continued)

Patient Characteristics	Baseline Cohort (n = 1234), n (%)
LTP articular cartilage pathology	
Normal/grade 1	1019 (83)
Grade 2	162 (13)
Grade 3	46 (4)
Grade 4	7 (<1)
MTP articular cartilage pathology	
Normal/grade 1	1098 (89)
Grade 2	94 (8)
Grade 3	21 (2)
Grade 4	16 (1)
Patella articular cartilage pathology	
Normal/grade 1	867 (70)
Grade 2	239 (19)
Grade 3	119 (10)
Grade 4	9 (<1)
Trochlea articular cartilage pathology	
Normal/grade 1	979 (79)
Grade 2	105 (9)
Grade 3	94 (8)
Grade 4	55 (4)
Biologic enhancement used	
No	1117 (91)
Yes	112 (9)
Blank/missing	5 (<1)

[a]Continuous variables are reported as median (25% quartile, 75% quartile); categorical variables are reported as percentage (frequency). ACL, anterior cruciate ligament; AM, anteromedial; BMI, body mass index; BTB, bone-patellar tendon-bone; LFC, lateral femoral condyle; LTP, lateral tibial plateau; MFC, medial femoral condyle; MTP, medial tibial plateau.
[b]Smith and Nephew, Andover, MA.
[c]DePuy Mitek, Raynham, MA.

Patient-Reported Outcomes

The IKDC, KOOS, and WOMAC scores (with the exception of the WOMAC stiffness subscale) all significantly improved at the 6-year follow-up time point as compared with the baseline ($P < .001$; Table 2). Conversely, the 6-year Marx Activity Rating Scale results demonstrated a significant decrease compared with both the baseline score at the time of enrollment and the 2-year follow-up score ($P < .001$).

Influence of Graft Choice on PROs at 6 Years

Graft choice proved to be a significant predictor of 6-year Marx Activity Rating Scale scores ($P = .024$). Activity level at 6 years was found to be significantly better when an autograft was chosen (OR, 1.49; 95% CI, 1.11-2.01; P = .009), or more specifically, when a BTB autograft was chosen compared with patients who received a BTB allograft (OR, 1.92; 95% CI, 1.25-2.94; $P = .003$), after controlling for the baseline activity level. Patients who had soft tissue autografts (OR, 1.2; 95% CI, 0.74-1.96; $P = .45$) or soft tissue allografts (OR, 1.41; 95% CI, 0.88-2.27; $P = .15$) had no significant differences in 6-year activity levels compared with patients who had BTB autografts. There was no difference in 6-year Marx activity levels between soft tissue autografts and soft tissue allografts (median Marx Activity Rating Scale score, 5 for both groups; Table 3). For the IKDC, and the KOOS and WOMAC subscales, graft choice was an insignificant factor in predicting 6-year outcome scores (Table 3).

Influence of Graft Choice on Predicting Graft Rerupture and Reoperation at 6 Years

Graft rerupture was reported in 5.8% (55/949) of patients by their 6-year follow-up: 3.5% (16/455) of patients with autografts; 8.4% (37/441), allografts; and 3.8% (2/53), other grafts (eg, autograft and allografts). There was a significant difference in graft rerupture rates among graft types: soft tissue autografts (3.1%), BTB autografts (3.8%), other grafts (3.8%), soft tissue allografts (6.2%), and BTB allografts (10.6%) ($P = .007$; Table 4). Both BTB and soft tissue autografts failed at a significantly lower rate compared with BTB allografts ($P = .016$ for both). There were no significant differences found in graft rerupture rates between BTB autografts and soft tissue autografts ($P = .87$), BTB autografts and soft tissue allografts ($P = .36$), soft tissue autografts and soft tissue allografts ($P = .28$), or BTB allografts and soft tissue allografts ($P = .28$; Table 4).

A logistic regression model was utilized to determine the significant predictors of graft rerupture at 6 years, controlling for the patient's age, sex, baseline activity level, and graft choice. Use of an allograft for revision resulted in patients being 3.9 times more likely to sustain a subsequent graft failure than did use of an autograft ($P = .001$; 95% CI, 1.69-8.33). Use of a BTB allograft for revision resulted in patients being 4.2 times more likely to sustain a subsequent graft rupture than did use of a BTB autograft ($P = .011$; 95% CI, 1.6-11.3; Figure 2). When controlling for age, sex, and baseline activity levels, no significant differences were found in graft rerupture rates between BTB autografts and soft tissue autografts ($P = .51$) or between BTB autografts and soft tissue allografts ($P = .36$; Figure 2). Similarly, sex ($P = .10$), age ($P = .18$), and baseline activity level ($P = .34$) were not significant predictors of subsequent graft failure in our logistic regression model (Figure 2).

The incidence of ipsilateral reoperation within 6 years of the index revision surgery was documented in 16% (154/949) of our cohort. Use of an autograft was found to be a significant predictor of having fewer reoperations within 6 years compared with using an allograft ($P = .01$; OR, 0.56 [95% CI, 0.36-0.87]). However, there was no significant difference among specific graft types (BTB autograft, soft tissue autograft, BTB allograft, and soft tissue allograft).

DISCUSSION

The purpose of this study was to determine if graft choice at the time of revision ACL reconstruction influenced PROs at 6 years. Previous studies evaluating 5-year results of revision ACL reconstruction have been limited, encompassing only 4 previous studies totaling 116 patients.[7,11,16,18] Our current study of 949 revision

TABLE 2
PROs Over Time[a]

	Score Range	Baseline (n = 1234)	2 Years (n = 989)	6 Years (n = 809)
IKDC	0-100	52 (38, 63)	77 (60, 86)	75 (59, 87)
KOOS				
Symptoms	0-100	68 (54, 82)	79 (64, 89)	79 (64, 89)
Pain	0-100	75 (58, 86)	89 (75, 94)	89 (75, 97)
Activities of daily living	0-100	87 (69, 96)	97 (88, 100)	96 (87, 100)
Sports & recreation	0-100	45 (25, 65)	75 (55, 90)	75 (50, 90)
Quality of life	0-100	31 (19, 44)	56 (38, 75)	62 (44, 75)
WOMAC				
Stiffness	0-100	75 (50, 88)	75 (62, 100)	75 (62, 100)
Pain	0-100	85 (70, 95)	95 (80, 100)	95 (80, 100)
Activities of daily living	0-100	87 (69, 96)	97 (88, 100)	96 (87, 100)
Marx Activity Rating Scale	0-16	11 (4, 16)	7 (2, 12)	5 (1, 9)

[a]Data are reported as median (interquartile range [25%, 75%]). IKDC, International Knee Documentation Committee; IQR, interquartile range; KOOS, Knee Injury and Osteoarthritis Outcome Score; PROs, patient-reported outcomes; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

TABLE 3
PROs at 6 Years, Stratified by Graft Type[a]

	BTB Autograft	Soft Tissue Autograft	BTB Allograft	Soft Tissue Allograft	Other
IKDC	76 (61, 89)	78 (59, 87)	74 (58, 85)	74 (58, 85)	77 (62, 88)
KOOS					
Symptoms	79 (68, 89)	79 (63, 89)	82 (68, 89)	82 (64, 93)	82 (69, 93)
Pain	89 (78, 97)	89 (75, 97)	89 (75, 97)	89 (75, 97)	89 (79, 97)
Activities of daily living	97 (88, 100)	96 (87, 100)	97 (87, 100)	97 (85, 100)	97 (84, 100)
Sports & recreation	70 (55, 90)	75 (50, 90)	75 (50, 90)	70 (50, 90)	75 (55, 90)
Quality of life	63 (44, 75)	63 (44, 75)	63 (44, 75)	56 (38, 75)	63 (44, 81)
WOMAC					
Stiffness	81 (63, 100)	75 (63, 100)	75 (63, 100)	75 (63, 100)	75 (63, 97)
Pain	90 (80, 100)	95 (80, 100)	95 (80, 100)	95 (80, 100)	95 (81, 100)
Activities of daily living	97 (88, 100)	96 (87, 100)	97 (87, 100)	97 (85, 100)	97 (84, 100)
Marx Activity Rating Scale	6 (3, 10)	5 (1, 10)	4 (0, 8)	5 (0, 9)	7.5 (3, 11)

[a]Data are reported as median (interquartile range [25%, 75%]). BTB, bone-patellar tendon-bone; IKDC, International Knee Documentation Committee; IQR, interquartile range; KOOS, Knee Injury and Osteoarthritis Outcome Score; PROs, patient-reported outcomes; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

TABLE 4
Incidence of Graft Rerupture at 6 Years[a]

	Follow-up, N	Graft Rerupture, n (%)	Overall significance[b]	Pairwise Comparisons[c]			
				BTB Autograft	ST Autograft	BTB Allograft	ST Allograft
Revision graft choice	949	55 (5.8)	$P = .007$				
BTB autograft	263	10 (3.8)		–	$P = .87$	**$P = .016$**	$P = .36$
Soft tissue autograft	192	6 (3.1)			–	**$P = .016$**	$P = .28$
BTB allograft	216	23 (10.6)				–	$P = .28$
Soft tissue allograft	225	14 (6.2)					–
Other[d]	53	2 (3.8)		–	–	–	–

[a]Bolded values represent significant findings (at $p < 0.05$). Dashes indicate no pairwise comparison test was performed between these groups. BTB, bone-patellar tendon-bone; ST, soft tissue.
[b]The chi-square test of association was used to assess significance ($\chi^2 = 14.21$).
[c]Pairwise differences were tested using Z-tests of 2 proportions with Benjamini and Hochberg adjusted P values.
[d]No adjusted pairwise P values are reported for comparisons using cell size <5.

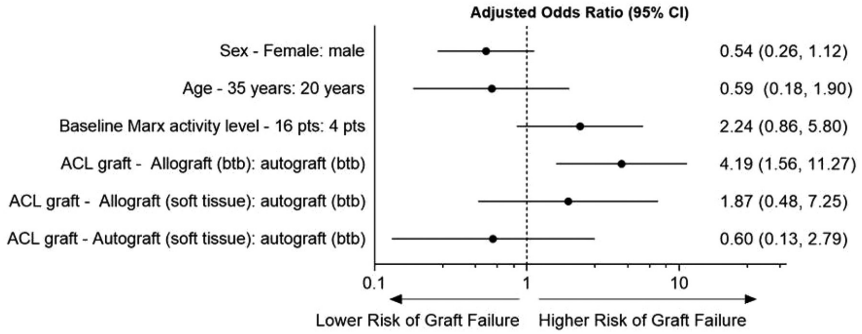

Figure 2. Plot of effects of predictors in the model on subsequent graft failure. The independent covariates in this model are listed along the y-axis, with the comparisons listed afterward. The second variable within each line is considered the reference value. The adjusted OR for each variable is listed along the right side, with the 95% CI listed in parentheses. For example, for sex, a woman was 54% less likely to sustain a graft rerupture at 6 years compared with a man. For age, a 35-year-old person was 59% less likely to sustain a graft rerupture at 6 years as compared with a 20-year-old person. For baseline Marx Activity Rating Scale Score, a person with a high activity level of 16 points was 2.24 times more likely to sustain a graft rerupture at 6 years as compared with a person with very low activity level of 4 points. For ACL graft, a person with a BTB allograft was 4.19 more likely to sustain a graft rerupture at 6 years as compared with a person with a BTB autograft. A person with a soft tissue allograft was 1.87 times more likely to sustain a graft rerupture at 6 years compared with a person with a BTB autograft. A person with a soft tissue autograft was 60% less likely to sustain a graft rerupture at 6 years compared with a person with a BTB autograft. Any line that crosses 1 on the x-axis is not significant. ACL, anterior cruciate ligament; BTB, bone-patellar tendon-bone, OR, odds ratio; pts, patients.

ACL reconstructions with a 77% 6-year follow-up represents the largest cohort reported to date. Our hypothesis that with time, the differences between autograft and allograft would become less evident as the cohort aged and activity decreased was not demonstrated by our findings, as the rerupture risk continued to increase in patients who had a revision ACL reconstruction using an allograft. Specifically, we found that using a BTB allograft resulted in a 4.2 times increased risk of graft rerupture compared with using a BTB autograft (OR, 4.19; 95% CI, 1.56-11.27; $P = .011$).

The 2-year graft failure rate in this cohort was 3.3%, with an increased risk of failure if an allograft was utilized (OR, 2.78; 95% CI, 1.01-7.69; $P = .047$).[13] In the current 6-year findings, the incidence of graft failure increased to 5.8%, and the failure risk for allograft increased to 3.9 times that of autograft. While the investigators thought this difference might be mitigated by increased length of follow-up in a cohort already older and less active than typical cohorts with primary ACL reconstruction, this was not demonstrated by our analysis. As inclusion criteria for the study, surgeons were required to use MTF grafts if an allograft were chosen for the patient's revision ACL reconstruction. This ensured knowledge of sterilization processes and that all grafts received either no irradiation or 1.8 mrad at most to the entire body specimen. All grafts were fresh frozen. No differences were noted in the rerupture rate between grafts with or without light irradiation.

While we were able to identify statistically significant differences between autograft and allograft rerupture risk, we could not demonstrate a statistical difference between BTB autograft and soft tissue autograft. Although it appears the soft tissue autografts were failing 60% less than were BTB autografts (Figure 2), this difference did not reach statistical significance ($P = .51$). This will be an issue we continue to monitor at our further follow-up at 10 years.

The risk of graft rerupture in our cohort was not significantly affected by age, sex, or baseline activity level (Figure 2). Previous studies of cohorts with primary ACL reconstruction have demonstrated that younger age and higher baseline activity levels are predictors for increased failure rate.[2,6,10,19,20] While we intuitively assume this may be true, the findings from our current study did not demonstrate this in the revision setting. We do note, however, that our allograft subgroup with an increased failure rate was in general older and less active, which is why we included and adjusted for these factors (age, activity level) in our regression model. Of note in this cohort with revision ACL reconstruction, the baseline activity levels between the patients receiving autografts and allografts did not significantly differ (10 points vs 9 points on the Marx Activity Rating Scale). As such, we believe that there was not a selection bias on the part of the surgeons or patients who may have been more inclined to select an autograft if the patients were more active and wanted to remain more active after the revision ACL reconstruction.

This study did not demonstrate a significant failure rate difference between BTB autografts and soft tissue allografts. It is uncertain what factors may be affecting this finding at 6 years. BTB allograft failed at a higher rate than did soft tissue allograft (10.6% vs 6.2% [Table 4]). We cannot discern a reason for this and do not know of a processing difference that could explain this.

The 16% reoperation rate of our cohort at 6 years is higher than what has been reported at 2 years (11%).[15] The 16% reoperation rate is consistent with the incidence of reoperations after ACL reconstruction with similar follow-up,[8] where Hettrich et al[8] reported a reoperation rate of 18.9% at 6 years after primary and revision ACL reconstructions. Our study

found that use of an autograft was a significant predictor of having fewer reoperations within 6 years compared with use of an allograft (OR, 0.56; 95% CI, 0.36-0.87; $P = .010$). However, there was no significant difference among graft types (BTB autograft, soft tissue autograft, BTB allograft, and soft tissue allograft). These findings were also consistent with those of Hettrich et al,[8] who reported that use of allografts was a predictor of subsequent surgeries.

PROs have become common in orthopaedics because they represent a validated assessment of the knee from the patient's perspective. At baseline (before the patients' revision ACL reconstruction), we obtained several validated PROs (IKDC Subjective form, KOOS, WOMAC, and Marx Activity Rating Scale), and we have followed patients for 2 and 6 years after surgery. Graft choice demonstrated limited predictive effect on 6-year PROs. Marx Activity Rating Scale scores at 6 years were found to be significantly better when an autograft was chosen (OR, 1.49; 95% CI, 1.11-2.01; $P = .009$), or more specifically, when a BTB autograft was chosen (OR, 1.92; 95% CI, 1.25-2.94; $P = .003$), even after controlling for the patient's age and baseline activity level. The higher 6-year activity levels seen in the patients with autografts is in contradistinction to the results seen in this cohort at 2 years, where receiving a hybrid combination autograft and allograft was predictive of improved 2-year Marx Activing Rating Scale scores. In comparison to the the Multicenter Orthopaedic Outcomes Network (MOON) primary ACL reconstruction cohort, graft choice did not affect activity level at 6-year follow-up.[4]

Interestingly, the IKDC and the KOOS and WOMAC subscales were not affected by graft choice at 6 years in this study. This is in contradistinction to previous results.[4,13] At 2 years, the use of autograft predicted improved IKDC scores (OR, 1.31; 95% CI, 1.01-1.70; $P = .045$).[13] In the primary ACL reconstruction setting at 6 years in the MOON cohort, the use of allograft predicted worse IKDC scores ($P = .008$).[4] Similarly, at 2 years, autograft use in our cohort predicted significantly improved KOOS subscale scores for both the KOOS sports and recreation and quality of life subscales (OR, 1.33).[13] At 6 years in our cohort, decreasing activity may reflect that patients are decreasing activity to the point that a leveling of scores has occurred. In the primary ACL reconstruction setting at 6 years in the MOON cohort, the use of allograft predicted worse KOOS sports and recreation ($P = .021$) and KOOS quality of life ($P = .014$) subscales.[4]

Our study has many strengths but admittedly some limitations. Our strengths include the size of the cohort and the prospective nature of the data collection. The multiple sites and the mix of private and academic surgeons using a variety of surgical techniques and grafts makes our findings generalizable to the sports medicine-trained community. We controlled for this variation in our regression analysis. Study limitations include lack of onsite follow-up to obtain structural measures for graft integrity and radiographic assessment of osteoarthritis. If an allograft were chosen for the revision, the study limited the surgeons to using MTF grafts to account for variation in tissue processing. In addition, we were only able to obtain questionnaire follow-up for PROs for 66% of patients. The focus of this study was graft rerupture, and telephone follow-up for 77% regarding rerupture and reoperation mitigated some of this concern. Telephone follow-up can be flawed, but we believe that the combination of patient recall for graft rupture and reoperation and obtaining the corresponding operative and clinic notes for verification was reasonable.

CONCLUSION

This is the first study to analyze the effect of graft choice on outcome, including graft rerupture, reoperation, and PROs in a large cohort of patients with revision ACL reconstruction at a minimum 6-year follow-up. Autografts have a decreased risk of graft rerupture compared with allografts. There was no significant difference in risk of graft rerupture at 6 years among BTB autograft, soft tissue autograft, and soft tissue allograft. This was noted in the direct comparison statistical analysis and the logistic regression modeling. Uncontrolled factors may be affecting these results and may be able to be better detected via additional graft ruptures and longer follow-up. BTB autografts were found to have 4.2 times decreased risk of graft rerupture at 6 years follow-up compared with BTB allografts. Use of BTB autograft was associated with significantly higher activity levels at 6-year follow-up compared with use of BTB allografts. Use of an autograft was found to be a significant predictor of having fewer reoperations within 6 years compared with use of an allograft. Surgeons and patients should consider this information when choosing a graft for revision ACL reconstruction.

AUTHORS

Rick W. Wright, MD (Vanderbilt University, Nashville, Tennessee, USA); Laura J. Huston, MS (Vanderbilt University, Nashville, Tennessee, USA); Amanda K. Haas, MA (Washington University in Saint Louis, Saint Louis, Missouri, USA); Jacquelyn S. Pennings, PhD (Vanderbilt University, Nashville, Tennessee, USA); Christina R. Allen, MD (Yale University, New Haven, Connecticut, USA); Daniel E. Cooper, MD (W.B. Carrell Memorial Clinic, Dallas, Texas, USA); Thomas M. DeBerardino, MD (The San Antonio Orthopaedic Group, San Antonio, Texas, USA); Warren R. Dunn, MD, MPH (Texas Orthopedic Hospital, Houston, Texas, USA); Brett (Brick) A. Lantz, MD (Slocum Research and Education Foundation, Eugene, Oregon, USA); Kurt P. Spindler, MD (Cleveland Clinic, Cleveland, Ohio, USA); Michael J. Stuart, MD (Mayo Clinic, Rochester, Minnesota, USA); John P. Albright, MD (University of Iowa Hospitals and Clinics, Iowa City, Iowa, USA); Annunziato (Ned) Amendola, MD (Duke University, Durham, North Carolina, USA); Jack T. Andrish, MD (Cleveland Clinic, Cleveland, Ohio, USA); Christopher C. Annunziata, MD (Commonwealth Orthopaedics & Rehabilitation, Arlington, Virginia, USA); Robert A. Arciero, MD (University of Connecticut Health Center, Farmington, Connecticut, USA); Bernard R. Bach Jr, MD (Rush University Medical Center, Chicago, Illinois, USA); Champ L. Baker III, MD (The Hughston Clinic, Columbus, Georgia, USA); Arthur R. Bartolozzi, MD (3B Orthopaedics, University of Pennsylvania Health System, Philadelphia, Pennsylvania, USA); Keith M. Baumgarten, MD (Orthopedic Institute, Sioux Falls, South Dakota, USA); Jeffery R. Bechler, MD (University

Orthopaedic Associates LLC, Princeton, New Jersey, USA); Jeffrey H. Berg, MD (Town Center Orthopaedic Associates, Reston, Virginia, USA); Geoffrey A. Bernas, MD (State University of New York at Buffalo, Buffalo, New York, USA); Stephen F. Brockmeier, MD (University of Virginia, Charlottesville, Virginia, USA); Robert H. Brophy, MD (Washington University in Saint Louis, Saint Louis, Missouri, USA); Charles A. Bush-Joseph, MD (Rush University Medical Center, Chicago, Illinois, USA); J. Brad Butler V, MD (Orthopedic and Fracture Clinic, Portland, Oregon, USA); John D. Campbell, MD (Bridger Orthopedic and Sports Medicine, Bozeman, Montana, USA); James L. Carey, MD, MPH (University of Pennsylvania, Philadelphia, Pennsylvania, USA); James E. Carpenter, MD (University of Michigan, Ann Arbor, Michigan, USA); Brian J. Cole, MD (Rush University Medical Center, Chicago, Illinois, USA); Jonathan M. Cooper, DO (HealthPartners Specialty Center, Saint Paul, Minnesota, USA); Charles L. Cox, MD, MPH (Vanderbilt University, Nashville, Tennessee, USA); R. Alexander Creighton, MD (University of North Carolina Medical Center, Chapel Hill, North Carolina, USA); Diane L. Dahm, MD (Mayo Clinic, Rochester, Minnesota, USA); Tal S. David, MD (Synergy Specialists Medical Group, San Diego, California, USA); David C. Flanigan, MD (The Ohio State University, Columbus, Ohio, USA); Robert W. Frederick, MD (The Rothman Institute/Thomas Jefferson University, Philadelphia, Pennsylvania, USA); Theodore J. Ganley, MD (Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, USA); Elizabeth A. Garofoli (Washington University in Saint Louis, Saint Louis, Missouri, USA); Charles J. Gatt, Jr, MD (University Orthopaedic Associates LLC, Princeton, New Jersey, USA); Steven R. Gecha, MD (Princeton Orthopaedic Associates, Princeton, New Jersey, USA); James Robert Giffin, MD (Fowler Kennedy Sport Medicine Clinic, University of Western Ontario, London, Ontario, Canada); Sharon L. Hame, MD (David Geffen School of Medicine at UCLA, Los Angeles, California, USA); Jo A. Hannafin, MD, PhD (Hospital for Special Surgery, New York, New York, USA); Christopher D. Harner, MD (University of Texas Health Center, Houston, Texas, USA); Norman Lindsay Harris Jr, MD (Grand River Health, Rifle, Colorado, USA); Keith S. Hechtman, MD (UHZ Sports Medicine Institute, Coral Gables, Florida, USA); Elliott B. Hershman, MD (Lenox Hill Hospital, New York, New York, USA); Rudolf G. Hoellrich, MD (Slocum Research and Education Foundation, Eugene, Oregon, USA); David C. Johnson, MD, (National Sports Medicine Institute, Leesburg, Virginia, USA); Timothy S. Johnson, MD (National Sports Medicine Institute, Leesburg, Virginia, USA); Morgan H. Jones, MD (Cleveland Clinic, Cleveland, Ohio, USA); Christopher C. Kaeding, MD (The Ohio State University, Columbus, Ohio, USA); Ganesh V. Kamath, MD (University of North Carolina Medical Center, Chapel Hill, North Carolina, USA); Thomas E. Klootwyk, MD (Methodist Sports Medicine, Indianapolis, Indiana, USA); Bruce A. Levy, MD (Mayo Clinic, Rochester, Minnesota, USA); C. Benjamin Ma, MD (University of California, San Francisco, California, USA); G. Peter Maiers II, MD (Methodist Sports Medicine Center, Indianapolis, Indiana, USA); Robert G. Marx, MD (Hospital for Special Surgery, New York, New York, USA); Matthew J. Matava, MD (Washington University in Saint Louis, Saint Louis, Missouri, USA); Gregory M. Mathien, MD (Knoxville Orthopaedic Clinic, Knoxville, Tennessee, USA); David R. McAllister, MD (David Geffen School of Medicine at UCLA, Los Angeles, California, USA); Eric C. McCarty, MD (University of Colorado Denver School of Medicine, Denver, Colorado, USA); Robert G. McCormack, MD (University of British Columbia/Fraser Health Authority, New Westminster, British Columbia, Canada); Bruce S. Miller, MD, MS (University of Michigan, Ann Arbor, Michigan, USA); Carl W. Nissen, MD (Connecticut Children's Medical Center, Hartford, Connecticut, USA); Daniel F. O'Neill, MD, EdD (Littleton Regional Healthcare, Littleton, New Hampshire, USA); Brett D. Owens, MD (Warren Alpert Medical School, Brown University, Providence, Rhode Island, USA); Richard D. Parker, MD (Cleveland Clinic, Cleveland, Ohio, USA); Mark L. Purnell, MD (Aspen Orthopedic Associates, Aspen, Colorado, USA); Arun J. Ramappa, MD (Beth Israel Deaconess Medical Center, Boston, Massachusetts, USA); Michael A. Rauh, MD (State University of New York at Buffalo, Buffalo, New York, USA); Arthur C. Rettig, MD (Methodist Sports Medicine, Indianapolis, Indiana, USA); Jon K. Sekiya, MD (University of Michigan, Ann Arbor, Michigan, USA); Kevin G. Shea, MD (Intermountain Orthopaedics, Boise, Idaho, USA); Orrin H. Sherman, MD (NYU Hospital for Joint Diseases, New York, New York, USA); James R. Slauterbeck, MD (University of South Alabama, Mobile, Alabama, USA); Matthew V. Smith, MD (Washington University in Saint Louis, Saint Louis, Missouri, USA); Jeffrey T. Spang, MD (University of North Carolina Medical Center, Chapel Hill, North Carolina, USA); LTC Steven J. Svoboda, MD (Keller Army Community Hospital, United States Military Academy, West Point, New York, USA); Timothy N. Taft, MD (University of North Carolina Medical Center, Chapel Hill, North Carolina, USA); Joachim J. Tenuta, MD (Albany Medical Center, Albany, New York, USA); Edwin M. Tingstad, MD (Inland Orthopaedic Surgery and Sports Medicine Clinic, Pullman, Washington, USA); Armando F. Vidal, MD (University of Colorado Denver School of Medicine, Denver, Colorado, USA); Darius G. Viskontas, MD (Royal Columbian Hospital, New Westminster, British Columbia, Canada); Richard A. White, MD (Fitzgibbon's Hospital, Marshall, Missouri, USA); James S. Williams Jr, MD (Cleveland Clinic, Euclid, Ohio, USA); Michelle L. Wolcott, MD (University of Colorado Denver School of Medicine, Denver, Colorado, USA); Brian R. Wolf, MD (University of Iowa Hospitals and Clinics, Iowa City, Iowa, USA); James J. York, MD (Orthopaedic and Sports Medicine Center, LLC, Pasadena, Maryland, USA).

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