Title

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

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Abstract

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 is no difference between autograft and allograft in rerupture rate and patient-reported outcomes at 6-year follow-up.

Study Design: Prospective cohort study; Level of evidence, 2.

Methods: Revision patients were identified and prospectively enrolled in this cohort study by 83 surgeons over 52 sites. Data collected included baseline demographics, surgical technique and pathology, and a series of validated patient-reported outcome (PRO) instruments. Patients were followed at 6 years and asked to complete the identical set of outcome instruments. Incidence of additional surgery and reoperation due to 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 following revision surgery.

Results: 1234 patients were enrolled with 716 (58%) males. 325 (26%) underwent revision utilizing 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. Questionnaires and phone follow-up for subsequent surgery information was obtained on 809 (66%) subjects, while phone follow-up only was obtained on an additional 128 subjects for total follow up on 949 (77%) subjects.

Graft choice was a significant predictor of 6-year Marx activity level scores (p=0.024). Specifically, patients who received a BTB autograft for revision reconstruction had higher activity levels than patients who received a BTB allograft [Odds Ratio (OR) = 1.92; 95% confidence intervals (CI) = 1.25, 2.94].

Graft rerupture was reported in 5.8% (55/949) by their 6-year follow-up: 3.5% (16/455) in autografts and 8.4% (37/441) in allografts. Use of a BTB autograft for revision resulted in patients 4.2 times less likely to sustain a subsequent graft rupture than if a BTB allograft was utilized (p=0.011; 95% CI=1.56, 11.27). No significant differences were found in graft re-rupture rates

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between BTB autograft and soft tissue autografts (p=0.87), nor between BTB autografts and soft tissue allografts (p=0.36). Use of an autograft was found to be a significant predictor of having fewer reoperations within 6 years, compared to an allograft (p=0.010; OR=0.56; 95% CI=0.36, 0.87).

Conclusions: BTB and soft tissue autografts have a decreased risk in graft rerupture compared with BTB allografts. BTB autografts are associated with higher activity level than BTB allografts at 6 years following 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

INTRODUCTION

Revision anterior cruciate ligament (ACL) reconstruction remains a clinical management challenge for patients and physicians. Consistently worse clinical outcomes as compared to 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 unfortunate patients. The Multicenter ACL Revision Study (MARS) Group has been able to explore predictors of improved and worse outcome with the challenge that many predictors may be nonmodifiable by the patient or surgeon. One critical area of treatment decision making that may offer some ability for surgeons to modify is the graft chosen for the revision reconstruction.

Previously, in this cohort patient-reported outcomes 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, rerupture rate favored autograft (odds ratio of 2.78; p=0.047). The number of failures at two years did not demonstrate a difference between soft tissue and BTB autografts or allografts: only broadly between autograft and allograft. These findings raised the question as to whether graft choice truly existed in the revision ACL reconstruction setting given factors limiting graft choice such as previous graft choice, patient desires, etc. 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 vs. allograft choice. In fact, surgeon preference influence was five times greater than any other factor including previous graft, gender, activity, age, etc. Thus, educating surgeons to utilize an autograft for ACL revision surgery could decrease the incidence of rerupture and improve patient-reported outcomes at least in the early follow-up time of two years following revision surgery.

The revision ACL reconstruction patients enrolled in this MARS cohort are older and less active than typical primary ACL reconstruction cohorts. This led to the question as to 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; i.e. much of the cohort having decreased their activity to the point any graft survives With this in mind, the MARS

Group undertook analysis of the cohort at minimum 6-year follow-up. Little evidence exists regarding 5-year or greater follow-up in the revision setting.[23] In total, 116 patients have had follow-up reported in 4 studies with minimum 5-year follow-up.[7, 11, 16, 18] Therefore, it was important that the MARS Group address this question using this unique cohort. We hypothesized that in the revision setting, there is no difference between autograft and allograft in rerupture rate and patient-reported outcomes 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, it is a prospective cohort of patients enrolled that underwent revision ACL reconstruction between 2006–2011 (Figure 1). The surgeon group consisted of fellowship trained sports medicine specialists that were members of the American Orthopaedic Society for Sports Medicine. All surgeons participated in planning and study design sessions, agreed to inclusion/exclusion criteria, participated in articular cartilage and meniscus pathology agreement studies and reviewed the surgeon and patient enrollment questionnaires prior to beginning patient enrollment. Inclusion criteria for patients enrolled in the study included all patients with ACL deficiency secondary to failed previous ACL reconstruction, who were between the ages of 12 and 65 years old and were scheduled to have a revision ACL reconstruction by a participating (MARS study group) surgeon. Patients with concomitant injuries to the medial and lateral collateral ligaments, posterior cruciate ligament, or posterolateral complex were included. Exclusion criteria were patients with graft failure secondary to prior intra-articular infection, arthrofibrosis, or complex regional pain syndrome. If utilizing an allograft, it was obtained from the Musculoskeletal Transplant Foundation (MTF Biologics; Edison, NJ). Currently 83 surgeons are participating in 52 IRB approved sites. It is approximately a 50/50 mix of private practice and academic centers and surgeons.

Data Sources

After obtaining informed consent, each patient completed a self-reported questionnaire examining demographics, injury characteristics, sports participation history, and health status prior to 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 filled out a questionnaire that included physical exam findings, surgical technique utilized and the 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 with Teleform™ software (OpenText; Waterloo, Ontario, Canada) utilizing optical character recognition, and the scanned data was verified and exported to a master database. A series of custom logical error and quality control checks were subsequently performed prior to data analyses.

Patient Follow-up

At six years following their revision ACL reconstruction, patients completed the same questionnaire that had been used both at baseline and 2-year follow-up. This included demographic data, validated patient-reported outcome measurements (IKDC, KOOS, WOMAC, Marx activity rating scale) and reinjury and reoperation queries. Patients were contacted by phone or email to establish current location and at a minimum address the reinjury and reoperation questions, if unwilling to fill out the entire questionnaire. Information on subsequent graft failures was obtained and documented through physician clinical exam notes, KT-1000 or MRI verification, and/or 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 IKDC, KOOS, WOMAC, and the Marx activity scale were modeled with proportional odds logistic regression, and 2) binary outcomes of graft failure (yes/no, as determined by physical exam, MRI, or KT-1000) and reoperation (yes/no) were modeled with logistic multivariable regression. Odds ratios (OR) and 95% confidence intervals (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 their revision ACL reconstruction, body mass index (BMI), smoking status (non-smoker, quit, current), education level (years), baseline Marx activity level, and baseline outcome measures (IKDC, KOOS, 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), prior graft type (autograft vs. allograft), and prior graft source (bone-patellar tendon-bone [BTB] vs. soft tissue).. Covariates related to current surgical information included time (in years) since the patient's last ACL reconstruction, number of revisions, surgeon's opinion of failure (traumatic, technical, biologic, other, combination), surgeon's revision of his/her own failure (yes/no), surgeon years of experience, mechanism of injury (non-traumatic, traumatic, contact, non-contact), surgical technique (1 incision transtibial, 1 incision anteromedial portal, 2 incision, arthrotomy), graft type (autograft, allograft, both), graft source (BTB, soft tissue, other), femoral tunnel aperture position and fixation, tibial tunnel aperture position and fixation, meniscal and articular cartilage pathology and treatment, and biological 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 four-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 through a comparison and medians and interquartile ranges (IQR) at each time point and tested with Kruskal-Wallis tests. Additionally, minimal clinically important differences (MCID) were examined between time points. MCID for IKDC was 11 points,[9] 8–10 points for each of the 5 KOOS subscales and the WOMAC,[17] and 2 points for Marx activity scale. Alpha was

set at 0.05 for all statistical tests. Multiple imputation using predictive mean matching was used to address missing data. The Hmisc and rms packages of the open source R statistical software (https://www.r-project.org) was used for statistical analysis.

RESULTS

Study Population and Follow-up

Descriptive statistics of the baseline study population at the time of their revision ACL surgery are listed in Table 1. 1234 patients were successfully enrolled with 716 (58%) males. Median age was 26 years. In 87% this was their first revision. 367 (30%) were undergoing revision by the surgeon that had performed the previous ACL reconstruction. 598 (48%) underwent revision reconstruction utilizing an autograft, 599 (49%) allograft, and 37 (3%) both autograft and allograft. Median time since their last ACL reconstruction was 3.3 years. Six-year questionnaire follow-up was obtained on 841 subjects (68%), while phone follow-up for subsequent surgery information was obtained on 980 subjects (79%). The median age of the cohort at the time of 6-year follow-up was 32 years old (range, 18 to 69).

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 to baseline ($p<0.001$; Table 2). Conversely, the 6-year MARX activity scale demonstrated a significant decrease compared to both the baseline score at the time of enrollment as well as to 2-year follow-up ($p<0.001$).

Influence of Graft Choice on Patient-Reported Outcomes at 6 Years

Graft choice proved to be a significant predictor of 6-year Marx activity level scores ($p=0.024$). Specifically, patients who received a BTB autograft for revision reconstruction had higher activity levels at 6 years compared to patients who received a BTB allograft [Odds Ratio (OR) = 1.92; 95% confidence intervals (CI) = 1.25, 2.94; $p=0.003$], after controlling for baseline activity level. Patients who had soft tissue autografts (OR = 1.2; 95% CI = 0.74, 1.96; $p=0.45$) or soft tissue allografts (OR = 1.41; 95% CI = 0.88, 2.27; $p=0.15$) had no significant differences in six-year activity levels compared to 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 level = 5 for both groups; Table 3). For IKDC, 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) in autografts, 8.4% (37/441) in allografts, and 3.8% (2/53) in other grafts (i.e. autograft + allografts, etc). There was a significant difference between graft re-rupture rates between the 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%) ($p=0.007$; Table 4). Both BTB and soft tissue autografts failed at a significantly lower rate compared to

BTB allografts (p=0.016 for both). There were no significant differences found in graft re-rupture rates between BTB autografts and soft tissue autografts (p=0.87), BTB autografts and soft tissue allografts (p=0.36), soft tissue autografts and soft tissue allografts (p=0.28), or between BTB allografts and soft tissue allografts (p=0.28; Table 4).

A logistic regression model was utilized to determine the significant predictors of graft re-rupture 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 3.9 times more likely to sustain a subsequent graft failure than if an autograft was used (p=0.001; 95% CI=1.69, 8.33). Use of a BTB allograft for revision resulted in patients 4.2 times more likely to sustain a subsequent graft rupture than if a BTB autograft was utilized (p=0.004; 95% CI=1.6, 11.3; Figure 2). When controlling for age, sex, and baseline activity levels, no significant differences were found in graft re-rupture rates between BTB autografts and soft tissue autografts (p=0.51), nor between BTB autografts and soft tissue allografts (p=0.36; Figure 2). Similarly, sex (p=0.10), age (p=0.18), and baseline activity level (p=0.34) were not significant predictors of subsequent graft failure in our logistic regression model (Figure 2).

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 to an allograft (p=0.01; OR=0.56; 95% CI=0.36, 0.87). However, there was no significant difference between specific graft types (BTB autograft, soft tissue autograft, BTB allograft, soft tissue allograft).

DISCUSSION

The purpose of this study was to determine if graft choice at the time of revision ACL reconstruction influenced patient-reported outcomes at 6 years. Previous studies evaluating 5-year results of revision ACL reconstruction are limited, encompassing only four previous studies totaling 116 patients.[7, 11, 16, 18] Our current study of 980 revision ACL reconstruction with 79% 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 an allograft revision ACL reconstruction. Specifically, we found that using a BTB allograft had 4.2 times increased risk of graft rerupture, compared with using a BTB autograft (OR= 4.19; 95% CI: 1.56, 11.27; p=0.011).

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 = 0.047).[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 primary ACL reconstruction cohorts this was not demonstrated by our analysis. As inclusion criteria for the study, surgeons were required to use Musculoskeletal Transplant Foundation (MTF) grafts if an allograft was 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 rerupture rate between no or light irradiation grafts.

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. While it appears the soft tissue autografts were failing 60% less than BTB autograft (Figure 2), it did not reach statistical significance (p=0.51). 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 in primary ACL reconstruction cohorts 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 these factors (age, activity level) were included and adjusted for in our regression model. Of note in this revision cohort, the baseline activity levels between the patients receiving autografts and allografts did not significantly differ (10 vs. 9 points on the Marx scale). As such, we feel that there was not a selection bias on the part of the surgeon and/or patient who may have been more inclined to select autografts in patients who were more active and wished to remain more active following their 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 impacting this at six years. BTB allograft failed at a higher rate than 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 incidence of reoperations following ACL reconstruction with similar follow-up,[8] where Hettrich et al. reported a rate of 18.9% of reoperations at 6 years following 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 to an allograft (p=0.010; OR=0.56; 95% CI=0.36, 0.87). However, there was no significant difference between specific graft types (BTB autograft, soft tissue autograft, BTB allograft, soft tissue allograft). These findings were also consistent with Hettrich et al., who reported that use of allografts were predictors for subsequent surgeries.[8]

Patient reported outcomes (PROs) have become common in orthopaedics because they represent a validated assessment of the knee from the patient’s perspective. At baseline (prior to the patient’s revision ACL reconstruction) we obtained several validated PROs (IKDC subjective, KOOS, WOMAC, Marx activity level) and we have followed these at 2- and 6-years post-surgery. Graft choice demonstrated limited predictive impact on 6-year

PROs. Marx activity level scores at six years were found to be significantly better when an autograft was chosen (OR = 1.49; 95% CI = 1.11, 2.01; p = 0.009), or more specifically, when a BTB autograft was chosen (OR = 1.92; 95% CI = 1.25, 2.94; p = 0.024), even after controlling for the patient's age and baseline activity level. The higher 6-year activity levels seen in the autograft patients is in contradistinction to the results seen in this cohort at 2 years, where the patients receiving a hybrid combination autograft + allograft were predictive of improved 2-year Marx scores. In comparison to the MOON primary ACL reconstruction cohort, graft choice did not impact activity level at 6 years follow-up.[4]

Interestingly, the IKDC, KOOS and WOMAC subscales were not impacted by graft choice at six years in this study. This is in contradistinction to previous results.[4, 13] At two years, the use of autograft predicted improved IKDC scores (OR = 1.31; 95% CI: 1.01 – 1.70; p = 0.045). In the primary ACL reconstruction setting at six years in the MOON cohort the use of allograft predicted worse IKDC scores (p = 0.008).[4] Similarly, at two 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). At six years in this revision cohort, decreasing activity may reflect that subjects are decreasing activity to the point that a leveling of scores has occurred. In the primary ACL reconstruction setting at six years in the MOON cohort the use of allograft predicted worse KOOS sports and recreation (p = 0.021) and KOOS quality of life (p = 0.014) 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 chosen makes our findings generalizable to the sports medicine trained community. This variation was controlled for in our regression analysis. Study limitations include lack of onsite follow-up, in order to obtain structural measures for graft integrity and radiographic assessment of osteoarthritis. If an allograft was chosen for the revision, the study limited the surgeons to using MTF in order to account for variation in tissue processing. Additionally, we were only able to obtain questionnaire follow-up for patient-reported outcomes on 68%. The focus of this study is graft rerupture, and phone follow-up on 79% regarding rerupture and reoperation mitigates some of this concern. Phone follow-up can be flawed, but we believe that the combination of patient recall for graft rupture and reoperation along with obtaining the corresponding operative and clinic notes for verification are reasonable.

CONCLUSIONS

This is the first study to analyze the impact of graft choice on outcome, including graft rerupture, reoperation and PROs in a large cohort of ACL revision patients at 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 six years between BTB autograft, soft tissue autograft, or soft tissue allograft. This was noted in direct comparison statistical analysis and logistic regression modeling. Uncontrolled factors may be impacting these results and may be able to be better detected with additional graft ruptures and longer follow up. BTB autografts were found to have 4.2 times decreased risk of graft rerupture at six years follow-up compared to BTB allografts. Use of BTB autograft was associated

with significantly higher activity levels at 6-year follow-up compared to BTB allografts. Use of an autograft was found to be a significant predictor of having fewer reoperations within 6 years, compared to an allograft. Surgeons and patients should consider this information when choosing a graft for revision ACL reconstruction.

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What is known about the subject:

Revision ACL reconstructions have worse outcomes. Graft choice may contribute to these results. Results at two years for the MARS cohort demonstrated increased failure rate for allografts.

What this study adds to existing knowledge:

This represents the largest revision ACL cohort followed for 6 years in the orthopaedic literature. No previous objective evidence existed as to what graft choice for revision reconstruction resulted in best outcomes and lowest failures.

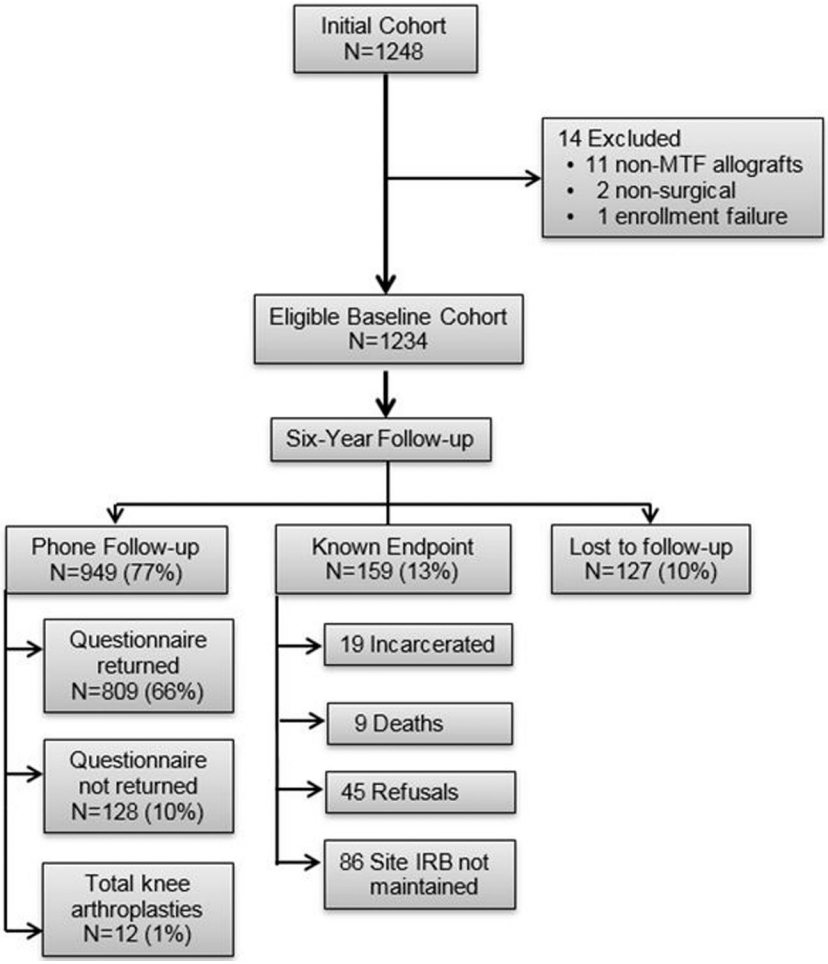

Figure 1.
Patient Enrollment Flow Diagram

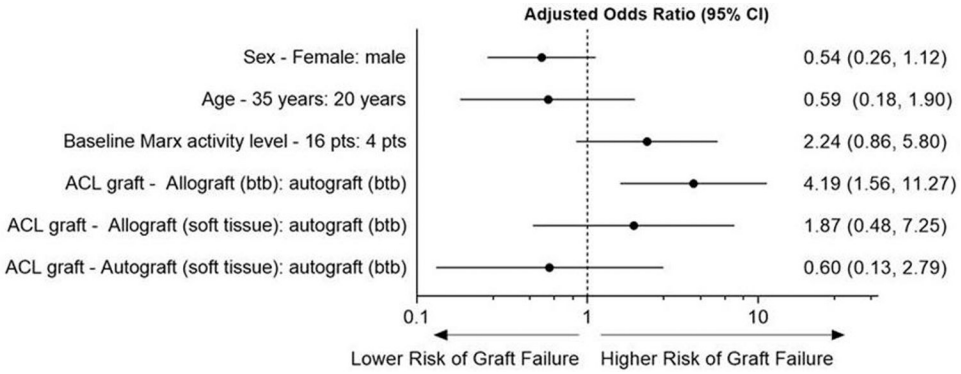

Figure 2.

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 afterwards. The second variable within each line is considered the reference value. The adjusted odds ratios for each variable are listed along the right side, with their 95% confidence intervals listed in parentheses. For example, for sex, a female is 54% less likely to sustain a graft re-rupture at 6 years as compared to a male. For age, a 35-year old is 59% less likely to sustain a graft re-rupture at 6 years as compared to a 20-year old. For baseline Marx activity level, a person with a high activity level of 16 points is 2.24 times more likely to sustain a graft re-rupture at 6 years as compared to a person with very low activity level (scoring 4 points on the Marx activity rating scale). For ACL graft, a person with a BTB allograft is 4.19 more likely to sustain a graft re-rupture at 6 years as compared to a person with a BTB autograft. A person with a soft tissue allograft is 1.87 times more likely to sustain a graft re-rupture at 6 years compared to a person with a BTB autograft. A person with a soft tissue autograft is 60% less likely to sustain a graft re-rupture at 6 years as compared to a person with a BTB autograft. Any line that crosses ‘1’ on the x-axis is not significant. Key: btb=bone-patellar tendon-bone.

Table 1.

Baseline Cohort Characteristics at the Time of Revision ACL Reconstruction

Patient Characteristics	**Baseline Cohort (n=1234)**
Sex	
• Males	58% (716)
• Females	42% (518)
Age, years	26 (20, 34)
Body Mass Index (BMI)	25.1 (22.6, 28.6)
Smoking Status	
• Non-smoker	77% (949)
• Quit	13% (157)
• Current	9% (109)
• Blank/missing	2% (19)
Education Level, years	14 (12, 16)
Activity Level (Marx, 0–16 points)	11 (4, 16)
Previous Surgery Information	
Previous ACL reconstruction on the contralateral knee	
• No	90% (1110)
• Yes	10% (124)
Previous Medial Meniscal Surgery	
• No	62% (765)
• Yes, repair healed/stable	3% (32)
• Yes, repair not healed/unstable	6% (69)
• Yes, excision	30% (368)
Previous Lateral Meniscal Surgery	
• No	79% (979)
• Yes, repair healed/stable	2% (30)
• Yes, repair not healed/unstable	2% (23)
• Yes, excision	16% (198)
• Blank/missing	<1% (4)
Previous Articular Cartilage Surgeries	
• No	88% (1086)
• Yes	12% (148)
Prior Graft Type (Most Recent only)	
• Autograft	68% (834)
• Allograft	29% (354)
• Both autograft + allograft	3% (34)
• Unknown/missing	<1% (12)
Prior Graft Source	
• BTB	52% (642)
• Soft tissue	38% (473)

Patient Characteristics	Baseline Cohort (n=1234)
• BTB + soft tissue	<1% (11)
• Unknown/missing	9% (108)
Current Surgical Information (at the time of enrollment revision surgery)	
Time since last ACL reconstruction, years	3.3 (1.4, 8.0)
Number of Revisions	
• 1	87% (1077)
• 2	11% (131)
• 3 or more	2% (26)
Surgeon's Opinion of Failure	
• Traumatic	35% (429)
• Technical	22% (266)
• Biological	8% (101)
• Other	<1% (10)
• Combination	35% (426)
• Blank/missing	<1% (10)
Surgeon's revision of his/her own failure	
• No	70% (862)
• Yes	30% (367)
• Blank/missing	<1% (5)
Surgeon Experience, years	13 (8, 18)
Mechanism of Injury	
• Non-traumatic, gradual onset	28% (340)
• Non-traumatic, sudden onset	7% (84)
• Traumatic; non-contact	53% (658)
• Traumatic; contact	12% (150)
• Blank/missing	<1% (2)
Surgical Technique	
• 1 incision (transtibial)	35% (427)
• 1 incision (AM portal)	47% (575)
• 2 incisions	18% (220)
• Arthrotomy/other	1% (12)
Graft Type	
• Autograft	48% (598)
• Allograft	49% (599)
• Both autograft + allograft	3% (37)
Graft Source	
• BTB	50% (616)
• Soft tissue	47% (580)
• Other (i.e. both, quadriceps-bone, etc)	3% (37)
Graft Type x Source	
• BTB autograft	26% (325)

Patient Characteristics	Baseline Cohort (n=1234)
• Soft tissue autograft	20% (251)
○ Semi-tendinosis (n=21)	
○ Semi-tendinosis+gracilis (n=230)	
• BTB allograft	23% (289)
• Soft tissue allograft	25% (302)
○ Achilles tendon (n=83)	
○ Hamstring (n=21)	
○ Tibialis anterior/posterior (n=193)	
○ Combination (n=5)	
• Other (i.e. both autograft + allograft, both BTB + soft tissue, quad-bone grafts, etc)	5% (67)
Femoral Fixation	
• Interference screw	56% (691)
• Suture + button/endobutton	21% (265)
• Cross-pin	12% (144)
• Other	4% (54)
• Combination	6% (77)
• Blank/missing	<1% (3)
Tibial Fixation	
• Interference screw	57% (707)
• Intrafix	9% (107)
• Suture + post or button	5% (65)
• Other	5% (67)
• Combination	23% (285)
• Blank/missing	<1% (3)
Medial Meniscus Pathology/Treatment	
• Normal (no tear)	55% (680)
• No treatment for tear	2% (29)
• Repair	13% (166)
• Excision	27% (336)
• Other	2% (23)
Lateral Meniscus Pathology/Treatment	
• Normal (no tear)	64% (790)
• No treatment for tear	5% (58)
• Repair	5% (63)
• Excision	26% (316)
• Other	<1% (7)
LFC Articular Cartilage Pathology	
• Normal/grade 1	71% (881)
• Grade 2	15% (189)
• Grade 3	8% (99)
• Grade 4	5% (65)
MFC Articular Cartilage Pathology	

Patient Characteristics	Baseline Cohort (n=1234)
• Normal/grade 1	57% (699)
• Grade 2	24% (295)
• Grade 3	13% (166)
• Grade 4	6% (72)
• Blank/missing	<1% (2)
LTP Articular Cartilage Pathology	
• Normal/grade 1	83% (1019)
• Grade 2	13% (162)
• Grade 3	4% (46)
• Grade 4	<1% (7)
MTP Articular Cartilage Pathology	
• Normal/grade 1	89% (1098)
• Grade 2	8% (94)
• Grade 3	2% (21)
• Grade 4	1% (16)
Patella Articular Cartilage Pathology	
• Normal/grade 1	70% (867)
• Grade 2	19% (239)
• Grade 3	10% (119)
• Grade 4	<1% (9)
Trochlea Articular Cartilage Pathology	
• Normal/grade 1	79% (979)
• Grade 2	9% (105)
• Grade 3	8% (94)
• Grade 4	4% (55)
Biologic Enhancement Used	
• No	91% (1117)
• Yes	9% (112)
• Blank/missing	<1% (5)

Key: continuous variables are listed as median (25% quartile, 75% quartile); categorical variables are listed as percentage (frequency); AM = anteromedial; BTB = bone-patellar tendon-bone; LFC = lateral femoral condyle; LTP = lateral tibial plateau; MFC = medial femoral condyle; MTP = medial tibial plateau.

Table 2.

Median (25%, 75% interquartiles) of Patient-Reported Outcomes over Time

	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 Level	0–16	11 (4, 16)	7 (2, 12)	5 (1, 9)

Table 3.

Median (25%, 75% quartile) Patient-Reported Outcome Scores at 6 Years, stratified by Graft Type

	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 Level	6 (3, 10)	5 (1, 10)	4 (0, 8)	5 (0, 9)	7.5 (3, 11)

Key: BTB = bone-patellar tendon-bone

Table 4.

Incidence of Graft Re-Rupture at Six Years

	Follow-up N	Graft Re-rupture N (%)	Overall significance[1]	Pairwise comparisons[2]			
				BTB Autograft	ST Autograft	BTB Allograft	ST Allograft
Revision Graft Choice	949	55 (5.8%)	p=0.007				
• BTB Autograft	263	10 (3.8%)		--	P=0.87	**P=0.016**	P=0.36
• Soft Tissue Autograft	192	6 (3.1%)			--	**P=0.016**	P=0.28
• BTB Allograft	216	23 (10.6%)				--	P=0.28
• Soft Tissue Allograft	225	14 (6.2%)					--
• Other[3]	53	2 (3.8%)		--	--	--	--

Key: BTB=bone-patellar tendon-bone; ST=soft tissue

[1] Chi-square test of association used to assess significance. $X^2 = 14.21$.

[2] Pairwise differences were tested using Z-tests of 2 proportions with Benjamini and Hochberg adjusted p-values.

[3] No adjusted pairwise p-values are reported for comparisons using cell size < 5.