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Meniscal and Articular Cartilage Predictors of Outcome after Revision ACL Reconstruction: A 6-Year Follow-up Cohort Study

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Abstract

Background: Meniscal and chondral damage is common in the revision anterior cruciate ligament (ACL) reconstruction patient.

Hypothesis/Purpose: The purpose of this study was to determine if either meniscal and/or articular cartilage (AC) pathology at the time of revision ACL surgery significantly influences a patient's outcome at 6-year follow-up.

Study Design: Cohort study

Methods: Revision ACL reconstruction patients were prospectively enrolled between 2006–2011. Baseline demographics, surgical technique, pathology, and treatment, and four validated patient-reported outcome instruments (IKDC, KOOS, WOMAC, Marx activity rating score) were collected. Patients were followed up at 6 years and asked to complete the identical set of outcome instruments. Regression analysis assessed the meniscal and AC pathology risk factors for clinical outcomes 6 years after revision ACL reconstruction.

Results: 1234 patients were enrolled (716 [58%] males; median age of 26 years). Surgeons reported pathology at the time of revision surgery in the medial meniscus (45%), lateral meniscus (36%), medial femoral condyle (MFC; 43%), lateral femoral condyle (LFC; 29%), medial tibial plateau (MTP; 11%), lateral tibial plateau (LTP; 17%), patella (30%), and trochlea (21%). Six-year follow-up was obtained on 79% (980/1234). Meniscal pathology as well as AC pathology (in the MFC, LFC, LTP, trochlea, and patella) were found to be significant drivers of poorer outcomes at 6 years. The most consistent factors driving outcome were having a medial meniscus excision (either prior to revision surgery or at the time of revision surgery) and patellofemoral AC pathology. Six-year Marx activity levels were negatively impacted by having either a repair/excision of the medial meniscus (odds ratio [OR] range =1.45–1.72; $p < 0.04$) or having grade 3–4 patellar chondrosis (OR=1.72; $p=0.04$). Meniscal pathology occurring prior to the index revision surgery negatively affected all KOOS subscales except for sports/recreation ($p < 0.05$). Articular cartilage pathology significantly impaired all KOOS subscales ($p < 0.05$). Lower baseline outcome scores, **higher BMI**, being a smoker, and incurring a subsequent surgery all significantly increased the odds of reporting poorer clinical outcomes at 6 years.

Conclusion: Meniscal and chondral pathology at the time of revision ACL reconstruction have continued significant detrimental effects on patient-reported outcomes 6 years after revision surgery.

INTRODUCTION

Revision anterior cruciate ligament (ACL) reconstruction remains a difficult clinical problem. Orthopaedic surgeons continue to be challenged not only by the technical aspects of returning ligamentous stability to the knee, but also the difficulty of optimizing clinical results to meet the expectations of the patients. Results of revision ACL reconstructions rarely match the clinical results of primary ACL reconstructions. Revision ACL patient cohorts commonly report outcomes inferior with regards to reoperations, graft failure and patient-reported outcomes as compared to primary ACL reconstructions.^{1,3,5,9,14,19,21}

The Multicenter ACL Revision Study (MARS) was developed to try to identify both the modifiable and non-modifiable factors that contribute to results following revision ACL reconstruction. A better understanding of this complex clinical issue would allow us to potentially change our technical approach and better counsel patients as to appropriate expectations following these surgeries. This prospective multi-surgeon and multicenter group has assembled a large cohort of patients which allows us to critically assess results and predictors. One area of significant concern amongst our group was the level of meniscal and chondral damage noted at the time of revision ACL reconstruction in these patients. Previous analysis of these patients at the time of enrollment and revision reconstruction noted that ~90% had sustained either meniscal or chondral (modified Outerbridge Grade 2 or greater) damage.¹⁰ Both meniscal and chondral damage was noted in 59% of these patients. Only 9% had neither meniscal nor chondral damage. These patients underwent previous analysis at 2-year follow-up and findings demonstrated that the strongest predictors of outcome were the presence of trochlear groove chondral damage and the history of a previous lateral meniscectomy.¹⁰ The current study was undertaken to evaluate this same cohort of patients at minimum 6 years after revision ACL reconstruction to determine if later follow-up showed broader, more significant impact on outcome as the articular cartilage potentially deteriorated further with time. We hypothesized that additional meniscal and chondral factors would impact the outcomes of these patients 6 years following their revision ACL reconstruction.

METHODS

Study Design

The MARS Group was assembled in cooperation with the American Orthopaedic Society for Sports Medicine as a collection of 83 sports medicine fellowship-trained surgeons working at 52 sites. The surgeons are a mix of academic and private practitioners. Surgeon inclusion criteria included maintaining an active institutional review board (IRB) approval, completing a training session that integrated articular cartilage and meniscus agreement studies, reviewing the study design and patient inclusion criteria, and reviewing the surgeon questionnaire. Surgeons could perform the ACL revision surgery according to their own practice preferences. If an allograft was chosen for reconstruction the surgeon was required

to utilize a Musculoskeletal Transplant Foundation graft to standardize and record allograft preparation methods.

The objective of this consortium has been to assess both the short- and long-term outcomes following revision ACL reconstruction, and to determine how the initial factors at the time of revision surgery may influence and predict disease progression. This study design involves a longitudinal prospective cohort for whom we currently have baseline, 2-year, and 6-year follow-up.

Setting and Participants

After Institutional Review Board approval from each institution, 1234 patients with documented ACL reconstruction failure that underwent revision ACL reconstruction surgery qualified for and were consented to be in this study (Figure 1). This multicenter consortium began patient enrollment in 2006 and ended in 2011. Study inclusion criteria were revision ACL reconstructions performed by a MARS surgeon on ACL deficient patients that had failed a previous ACL reconstruction as identified by either magnetic resonance imaging, physical exam (positive pivot shift and Lachman test), KT-1000 testing demonstrating > 5mm side-to-side difference, functional instability or arthroscopic confirmation.

Data Sources

After informed consent was obtained, 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. Chondral damage was described using the modified Outerbridge system,⁶ with worse grade defined in this study as being a grade 2 or higher. Meniscal injuries were classified by location (i.e. medial, lateral; anterior, posterior, anterior + posterior) and partial versus complete tears, while treatment was recorded as no treatment, repair, resection, or other (i.e., abrade and trephine, meniscal transplant, etc.). For the purposes of this study, “previous” or “prior” refers to meniscal or articular cartilage injuries sustained and documented before the time of the ACL revision surgery. This was determined either by previous operative reports or by noting surgical changes consistent with previous meniscal resection. “Current” refers to meniscal or articular cartilage damage noted for the first time at the time of ACL revision surgery.

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 6 years, the same questionnaire was administered as at baseline and at 2-year follow-up. Patients were also contacted by phone or email to determine if subsequent graft failure and/or any additional knee surgery had occurred.

Variables and Statistical Analysis

Descriptive statistics of each of the baseline patient and surgical characteristics were examined and reported. The effect of the independent (risk factor) variables on the, 1) outcome measures of IKDC, KOOS, WOMAC, and the Marx activity scale were modeled with proportional odds logistic regression, and 2) binary outcome of subsequent surgery (yes/no) was modeled with logistic multivariable regression. Odds ratios (OR) and 95% confidence intervals (CI) were obtained by exponentiation the parameter estimates. Both patient and previous and current surgical-related covariates were included and controlled for 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, Marx). Covariates related to previous surgical information included time (in years) since the patient's last ACL reconstruction, number of revisions, 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), prior graft source (bone-patellar tendon-bone [BTB] vs. soft tissue), surgeon's opinion of failure (traumatic, technical, biologic, other, combination), and surgeon's revision of his/her own failure (yes/no). Covariates related to current surgical information included surgeon years of experience, mechanism of injury (non-traumatic, traumatic, contact, non-contact), surgical technique (1 incision transtibial, 1 incision anteromedial portal, 2 incision), graft type (BTB autograft, soft tissue autograft, BTB allograft, soft tissue allograft), meniscal pathology and treatment (medial, lateral; normal/no tear, no treatment for tear, repair, excision), articular cartilage pathology (normal/grade 1, grade 2, grade 3, grade 4 in each of the six compartments – medial femoral condyle [MFC], lateral femoral condyle [LFC], medial tibial plateau [MTP], lateral tibial plateau [LTP], patella, and trochlea), articular cartilage treatment (none, chondroplasty, other), and biological enhancement used (yes/no). Due to the low frequency counts of grade 4 chondral lesions in the MTP, LTP, patella, and trochlear compartments, these grades were combined with their respective grade 3 compartment lesion to form a combined “grade 3 to 4” variable for each of these 4 compartments for analysis purposes. 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, 8–10 points for each of the 5 KOOS subscales, 8–10 points for the WOMAC, 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 **baseline** data. **Specifically, the “smoking status” and “time**

since the patient's last ACL reconstruction" variables were missing in 14 cases and were imputed. The six-year data was not imputed. The Hmisc and rms packages of the open source R statistical software (<https://www.r-project.org>) was used for statistical analysis.

RESULTS

The study cohort included 1234 patients who met the inclusion criteria, with 716 (58%) males and a median cohort age of 26 years (Appendix 1). Surgeons noted previous pathology (prior to the revision ACL reconstruction) in the medial meniscus (38%), lateral meniscus (21%), and articular surfaces (12%) at the time of revision surgery. Surgeons reported current pathology (defined as the time of the revision ACL reconstruction) in the medial meniscus (45%), lateral meniscus (36%), medial femoral condyle (MFC; 43%), lateral femoral condyle (LFC; 29%), medial tibial plateau (MTP; 11%), lateral tibial plateau (LTP; 17%), patella (30%), and trochlea (21%).

Six-year follow-up was obtained on 79% (980/1234; Figure 1). Previous (prior to revision ACL reconstruction) and current (at the time of revision ACL reconstruction) meniscal pathology, as well as current AC pathology (in the MFC, LFC, LTP, trochlea, and patella) were found to be significant drivers of poorer outcomes at six years. The most consistent factors driving outcome in revision patients at 6 years were either a previous or current excision of the medial meniscus and patellofemoral AC pathology.

Marx Activity Levels

Six-year Marx activity levels were negatively impacted by having either a repair or an excision of the medial meniscus (odds ratio [OR] range=1.45–1.72; 95% CI=1.02, 2.70; $p < 0.04$; Table 1) or having grade 3–4 patellar chondrosis at the time of the revision ACL reconstruction (OR=1.72; 95% CI= 1.02, 2.94; $p=0.04$; Table 1). Conversely, 6-year activity levels were significantly higher if a patient had either a lateral meniscus repair or excision at the time of their revision ACL reconstruction (OR=1.44–2.13; 95% CI=1.02, 3.88; $p < 0.04$; Table 1).

IKDC

Six-year IKDC scores were negatively impacted in patients who had previous medial meniscus surgery prior to the index revision ACL reconstruction, as well as having patellar chondrosis documented at the time of the index revision ACL reconstruction (Table 1). Specifically, a medial meniscal repair or excision performed prior to their revision ACL reconstruction was an independent predictor of having a poorer 6-year IKDC score (OR range=1.56–2.07; 95% CI=1.09, 3.90; $p < 0.03$). Grade 2 patellar chondrosis documented at the time of the index revision ACL reconstruction was also a significant predictor of lower 6-year IKDC scores (OR=1.52; 95% CI: 1.05, 2.22; $p=0.026$).

KOOS

Meniscal pathology negatively affected all KOOS subscales except for sports/recreation ($p < 0.05$; Table 1). Specifically, having a medial meniscectomy (performed either prior to

the index revision ACL reconstruction or at the time of the revision ACL surgery) resulted in significantly lower KOOS symptom (OR range=1.45–1.59; 95% CI: 1.05, 2.22; $p = 0.03$), pain (OR range=1.63–1.67; 95% CI: 1.16, 2.33; $p < 0.01$), ADL (OR=1.41; 95% CI: 1.01, 2.00; $p = 0.046$), and quality-of-life (OR range=1.41–1.62; 95% CI: 1.0, 2.27; $p = 0.05$) scores at 6 years. Patients who had a previous lateral meniscal repair prior to the index revision ACL reconstruction resulted in significantly lower KOOS symptom (OR=2.78; 95% CI: 1.12, 6.67; $p = 0.027$), pain (OR=2.70; 95% CI: 1.11, 6.67; $p = 0.029$), and quality-of-life (OR=3.85; 95% CI: 1.52, 9.09; $p = 0.004$) scores at 6 years.

Articular cartilage pathology significantly impaired all KOOS subscales ($p < 0.05$; Table 1). The 6-year KOOS symptoms subscale was negatively impacted by MFC (OR=1.61; 95% CI: 1.12, 2.27; $p = 0.009$) and trochlear (OR=1.89; 95% CI: 1.18, 3.03; $p = 0.009$) chondrosis. The KOOS pain subscale was negatively impacted by LFC (OR=1.56; 95% CI: 1.05, 2.33; $p = 0.027$) and patellar (OR=1.69; 95% CI: 1.02, 2.86; $p = 0.042$) chondrosis. The KOOS ADL subscale was significantly affected by LFC (OR=1.92; 95% CI: 1.00, 3.66; $p = 0.005$) chondrosis. The KOOS sports/recreation subscale was significantly affected by LFC (OR=2.41; 95% CI: 1.27, 4.57; $p = 0.007$), LTP (OR=2.22; 95% CI: 1.12, 4.55; $p = 0.022$) and trochlear (OR=2.0; 95% CI: 1.25, 3.23; $p = 0.004$) chondrosis. The 6-year KOOS quality-of-life subscale was negatively impacted by LFC (OR=1.88; 95% CI: 1.05, 3.39; $p = 0.035$), and patellar chondrosis (OR=1.54; 95% CI: 1.06, 2.22; $p = 0.021$).

WOMAC

Six-year WOMAC scores were negatively impacted by having a previous medial meniscal excision (prior to the index revision ACL reconstruction), and MFC, LFC, patellar and trochlear chondrosis documented at the time of the index revision ACL reconstruction (Table 1). Previous medial meniscectomies (OR=1.41; 95% CI: 1.01, 2.00; $p = 0.046$) and grade 4 LFC chondrosis (OR=1.91; 95% CI: 1.00, 3.66; $p = 0.05$) were predictive of significantly lower six-year WOMAC ADL scores. Previous medial meniscectomies (OR=1.59; 95% CI: 1.12, 2.22; $p = 0.008$), previous lateral meniscal repairs (OR=2.86; 95% CI: 1.12, 7.14; $p = 0.028$), and grades 3–4 patellar chondrosis (OR=2.17; 95% CI: 1.30, 3.70; $p = 0.003$) were predictive of significantly lower six-year WOMAC pain scores. Grade 4 MFC chondrosis (OR=1.92; 95% CI: 1.06, 3.45; $p = 0.032$) and grades 3–4 trochlear chondrosis (OR=2.22; 95% CI: 1.35, 3.70; $p = 0.002$) and were predictive of significantly lower WOMAC stiffness scores.

Subsequent Surgeries

Predictors of having a subsequent surgery by 6 years included patients who had a medial meniscal repair done at the time of their index revision ACL reconstruction (OR=2.2; 95% CI: 1.27, 3.88; $p = 0.005$), compared with patients who had no medial meniscal pathology at the time of their revision surgery. Similarly, patients who had either grade 2 MFC chondrosis (OR=1.7; 95% CI: 1.04, 2.82; $p = 0.035$), or grade 3–4 MTP chondrosis (OR=3.0; 95% CI: 1.07, 8.54; $p = 0.037$) at the time of the index revision ACL reconstruction were 1.7 to 3 times more likely to have a subsequent surgery by their 6-year follow-up.

Secondary Covariates

Lower baseline outcome scores, **higher BMI**, and being a smoker at the time of the revision surgery significantly increased the odds of reporting consistently poorer clinical outcomes at 6 years (Table 2).

DISCUSSION

Meniscal and chondral damage, both prior to the time of the revision ACL surgery, as well as at the time of revision ACL surgery, have a significant detrimental impact upon patient-reported outcomes six years later. Previous (prior to revision ACL reconstruction) and current (at the time of revision ACL reconstruction) meniscal pathology, as well as current articular cartilage pathology (in the MFC, LFC, LTP, trochlea, and patella) were found to be significant drivers of poorer patient-reported outcomes (Marx, IKDC, KOOS and WOMAC), as well as subsequent surgery outcomes at 6 years follow-up. This was a broader, but different pattern than seen at two years follow-up in this cohort.¹⁰

This **longitudinal** cohort study design allows us to **analyze how various baseline factors impact outcomes over time**. There is little comparative data from the literature as only 5 previous studies with 159 patients have a minimum 5-year follow-up to revision ACL reconstruction,^{4,7,8,11,12} so the most relevant comparison is to our previously published 2-year results¹⁰. Meniscal and/or chondral damage did not predict Marx activity level at 2-year follow-up. At six years, Marx activity levels were significantly lower in patients who underwent repair or excision of the medial meniscus and in patients with grade 3 or 4 patella chondrosis. Conversely, 6-year activity levels were higher in patients who underwent a lateral meniscus repair or excision. The latter was counterintuitive as lateral meniscus excision might be expected to promote articular cartilage deterioration and decreased activity after 6 years. We are uncertain as to why the intuitively expected deterioration of Marx activity level results with lateral meniscus excision did not occur by 6 years and in fact predicted higher activity levels. Less surprising is the fact that repair of a lateral meniscus tear had reasonable results at 6 years. Planned follow-up at 10 years will investigate this relationship further.

Lateral meniscus injury prior to the index revision ACL reconstruction, but not previous medial meniscus injury had been shown to impact 2-year outcomes (IKDC, all KOOS and WOMAC subscales).¹⁰ New meniscal pathology found at the time of revision reconstruction was not found to be a significant risk factor for KOOS, IKDC, or WOMAC scores at 2 years. However, at 6-year follow-up, both medial and lateral meniscal pathology prior to the index revision ACL reconstruction negatively affected all KOOS subscales in this cohort. These findings are consistent with previous literature reporting that meniscal pathology negatively impacts outcome scores in the revision ACL reconstruction setting.^{2,4,15,17,18} Anand et al. reported on 136 patients with mean 5-year follow-up.² Patients with an intact medial meniscus had significantly higher KOOS-QOL scores at follow-up compared with the patients with medial meniscal pathology. Return to sport was not impacted by meniscal status. Webster et al. collected IKDC, KOOS-QOL, Marx, and SANE scores in 180 revision ACL patients with a mean follow-up of 4.6 years (range, 2–8 years).¹⁷ They reported that patients with medial meniscal pathology at the time of revision surgery had

significantly lower functional and quality of life scores than patients without pathology. No difference was found in any outcome score between patients with and without lateral meniscal pathology.

In a separate study, Webster et al. investigated the outcomes of re-revisions in 128 young patients aged less than 25 years.¹⁸ In this study, the mean follow-up was 4.5 years (range, 2–9 years). Twenty-seven percent (35/128) of the patients had a third ACL injury by 2 years. Of the group who had graft re-ruptures, 70% had medial meniscal pathology (i.e. tear or previous repair/resection). They found a significant association between having medial meniscal pathology and sustaining a graft re-rupture ($p=0.02$). There was no association with graft re-rupture and lateral meniscal pathology or chondral pathology. They concluded that medial meniscal pathology and returning to high-risk sports are factors associated with re-revisions.

Our study found that meniscal and chondral pathology documented at the time of revision surgery are risk factors for incurring a subsequent surgery within 6 years. Specifically, patients who had a medial meniscal repair were over 2 times more likely to have a subsequent surgery occur when compared to patients who had no medial meniscal pathology at the time of their revision surgery. Similarly, patients who had grade 2 chondrosis in the MFC or grades 3–4 chondrosis in the MTP at the time of revision surgery were 1.7 to 3 times more likely to incur a subsequent surgery by their 6-year follow-up. These results are consistent with our previous work at two-year follow-up²⁰ and are in concordance to published results from both primary as well as revision ACL reconstruction cohorts.^{13,16} Sullivan et al. reported on the predictors of subsequent surgery after primary ACL reconstruction.¹³ This cohort consisted of 3276 patients (56.3% male) with a median age of 23 years and a six-year follow-up rate of 91.5%. They found that having a medial meniscal repair at the time of index primary ACL surgery was an independent significant risk factor for incurring a subsequent meniscus-related surgery within six years. Similarly, Vindfeld et al. investigated the patient-related risks of inferior outcomes leading to revision surgery after ACL reconstruction.¹⁶ A total of 100 revision cases and 100 matched controls, with a median follow-up time of 11 years were included in the study. They demonstrated that a failed meniscal repair was among the significant factors which were associated with primary ACL reconstruction failure and was found to affect the risk of undergoing revision ACL surgery.

Chondral pathology has also been found to negatively impact patient outcomes in the mid-term follow-up revision setting.^{2,4,17} Anand et al. reported significantly lower 5-year Marx activity, KOOS-QOL, and IKDC scores for patients with initial grade 3 or 4 chondral damage at the time of revision surgery, compared to those with grade 0, 1, or 2 changes.² Similarly, Webster et al. reported significantly reduced functional scores (IKDC, KOOS-QOL, Marx activity and SANE scores) and lower rates of return to sport after 5 years in revision ACL patients who had grade 3 or 4 chondral damage noted at the time of their revision surgery.¹⁷ Boyle et al. followed 43 revision ACL patients over a mean follow-up of 9 years (range, 5–15 years), and found a statistically significant correlation between increasing age and worse functional outcome scores in the Lysholm in those who had

grade 3 or 4 chondral damage.⁴ Patients who had grade 3 or 4 chondral damage showed a reduction of about 25 points in the Lysholm score for every 10 years increase in age.

In our previous 2-year analysis, having grade 3 or 4 articular cartilage chondrosis of the trochlea at the time of revision ACL reconstruction consistently resulted in significantly poorer outcomes across all outcome measures (IKDC, KOOS, and WOMAC subscales), except for activity level (which was not affected).¹⁰ In the current 6-year study, chondral pathology continued to negatively impact 6-year outcome measures, with the addition of activity level (Table 1). This negative impact spanned across all AC regions, except for the MTP region. Because overall activity levels continue to trend downwards for this cohort, patients may be decreasing their activity to control their pain level.

There are strengths and limitations to this study. Patients were not brought back to each clinic to have a physician's assessment of the knee performed, nor were follow-up x-rays or MRI images taken as part of the study protocol. As such, we cannot verify the integrity of the ACL in those that did not undergo subsequent MRI, physician, or surgical verification. Similarly, we can only report on the meniscal and chondral findings at the time of the revision ACL reconstruction, and not at the time of 6-year follow-up. It is likely that the meniscal and/or chondral pathology worsened over the course of follow-up in a subset of these patients, and this study could not determine this progression. Strengths include the prospective enrollment and size of the cohort which is the largest ever followed at six years after revision reconstruction. The retained follow-up at six years strengthens our conclusions. The multiple sites and surgeons make the findings generalizable to the sports medicine surgeon and the revision ACL patient.

CONCLUSIONS

Meniscal and chondral pathology in the knee at the time of revision ACL reconstruction have significant detrimental effects on patient-reported outcomes 6 years after surgery. The impact is more wide-ranging at 6 years following revision ACL surgery compared to 2-year follow-up. Medial meniscal repair/excision and patellofemoral chondrosis predict a lower activity level at 6 years, although lateral meniscal repair/excision predicts a higher activity level at 6 years. Independent predictors of lower IKDC, KOOS and WOMAS scores at 6-year follow-up include chondrosis and a history of medial meniscus repair prior to the revision ACL reconstruction. Longer term follow-up of this cohort will further characterize the role of meniscal and articular cartilage pathology in predicting outcomes of this procedure.

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Appendix 1.: Baseline Cohort Characteristics at the Time of Revision ACL Reconstruction

Patient Characteristics	Cohort (n=1234)
Sex <ul style="list-style-type: none"> • Males • Females 	58% (716) 42% (518)
Age, years	26 (20, 34)
Body Mass Index (BMI)	25.1 (22.6, 28.6)
Smoking Status <ul style="list-style-type: none"> • Non-smoker • Quit • Current • Blank/missing 	77% (949) 13% (157) 9% (109) 2% (19)
Education Level, years	14 (12, 16)
Activity Level (Marx, 0–16 points)	11 (4, 16)
Previous Surgery Information (prior to the revision ACL reconstruction)	
Time since last ACL reconstruction, years	3.3 (1.4, 8.0)
Number of Revisions <ul style="list-style-type: none"> • 1 • 2 • 3 or more 	87% (1077) 11% (131) 2% (26)
Previous ACL reconstruction on the contralateral knee <ul style="list-style-type: none"> • No • Yes 	90% (1110) 10% (124)
Previous Medial Meniscal Surgery <ul style="list-style-type: none"> • No • Yes, repair healed/stable • Yes, repair not healed/unstable • Yes, excision 	62% (765) 3% (32) 6% (69) 30% (368)
Previous Lateral Meniscal Surgery <ul style="list-style-type: none"> • No • Yes, repair healed/stable • Yes, repair not healed/unstable • Yes, excision • Blank/missing 	79% (979) 2% (30) 2% (23) 16% (198) <1% (4)
Previous Articular Cartilage Surgeries <ul style="list-style-type: none"> • No • Yes 	88% (1086) 12% (148)
Prior Graft Type <ul style="list-style-type: none"> • Autograft • Allograft • Both autograft + allograft • Unknown/missing 	68% (834) 29% (354) 3% (34) <1% (12)
Prior Graft Source <ul style="list-style-type: none"> • BTB • Soft tissue • BTB + soft tissue • Unknown/missing 	52% (642) 38% (473) <1% (11) 9% (108)
Current Surgical Information (at the time of the revision ACL reconstruction)	
Surgeon Experience, years	13 (8, 18)

Patient Characteristics	Cohort (n=1234)
Graft Type <ul style="list-style-type: none"> Autograft Allograft Both autograft + allograft 	48% (598) 49% (599) 3% (37)
Graft Source <ul style="list-style-type: none"> BTB Soft tissue Other (i.e. both, quadriceps-bone, etc) 	50% (616) 47% (580) 3% (37)
Graft Type x Source <ul style="list-style-type: none"> BTB autograft Soft tissue autograft BTB allograft Soft tissue allograft Other (i.e. both autograft + allograft, both BTB + soft tissue, quad-bone grafts, etc) 	26% (325) 20% (251) 23% (289) 25% (302) 5% (67)
Medial Meniscus Pathology/Treatment <ul style="list-style-type: none"> Normal (no tear) No treatment for tear Repair Excision Other 	55% (680) 2% (29) 13% (166) 27% (336) 2% (23)
Lateral Meniscus Pathology/Treatment <ul style="list-style-type: none"> Normal (no tear) No treatment for tear Repair Excision Other 	64% (790) 5% (58) 5% (63) 26% (316) <1% (7)
LFC Articular Cartilage Pathology <ul style="list-style-type: none"> Normal/grade 1 Grade 2 Grade 3 Grade 4 	71% (881) 15% (189) 8% (99) 5% (65)
MFC Articular Cartilage Pathology	
Normal/grade 1 <ul style="list-style-type: none"> Grade 2 Grade 3 Grade 4 Blank/missing 	57% (699) 24% (295) 13% (166) 6% (72) <1% (2)
LTP Articular Cartilage Pathology <ul style="list-style-type: none"> Normal/grade 1 Grade 2 Grade 3 Grade 4 	83% (1019) 13% (162) 4% (46) <1% (7)
MTP Articular Cartilage Pathology <ul style="list-style-type: none"> Normal/grade 1 Grade 2 Grade 3 Grade 4 	89% (1098) 8% (94) 2% (21) 1% (16)
Patella Articular Cartilage Pathology <ul style="list-style-type: none"> Normal/grade 1 Grade 2 Grade 3 Grade 4 	70% (867) 19% (239) 10% (119) <1% (9)
Trochlea Articular Cartilage Pathology <ul style="list-style-type: none"> Normal/grade 1 Grade 2 Grade 3 Grade 4 	79% (979) 9% (105) 8% (94) 4% (55)
Biologic Enhancement Used <ul style="list-style-type: none"> No Yes Blank/missing 	91% (1117) 9% (112) <1% (5)

Key: continuous variables are listed as median (25% quartile, 75% quartile); categorical variables are listed as percentage (frequency); ACL = anterior cruciate ligament; 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.

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What is known about the subject:

Both meniscal and articular cartilage pathology is common in the revision ACL setting and more common than that found in primary ACL reconstructions. Both pathologies independently contribute to worse significantly outcomes at 2 years following a revision ACL reconstruction.

What this study adds to existing knowledge:

This study provides evidence from a prospective cohort that meniscal pathology, particularly medial meniscectomies, as well as articular cartilage damage noted at the time of the revision surgery predict significantly worse outcomes 6 years following revision ACL reconstruction, as measured by patient reported outcome measures.

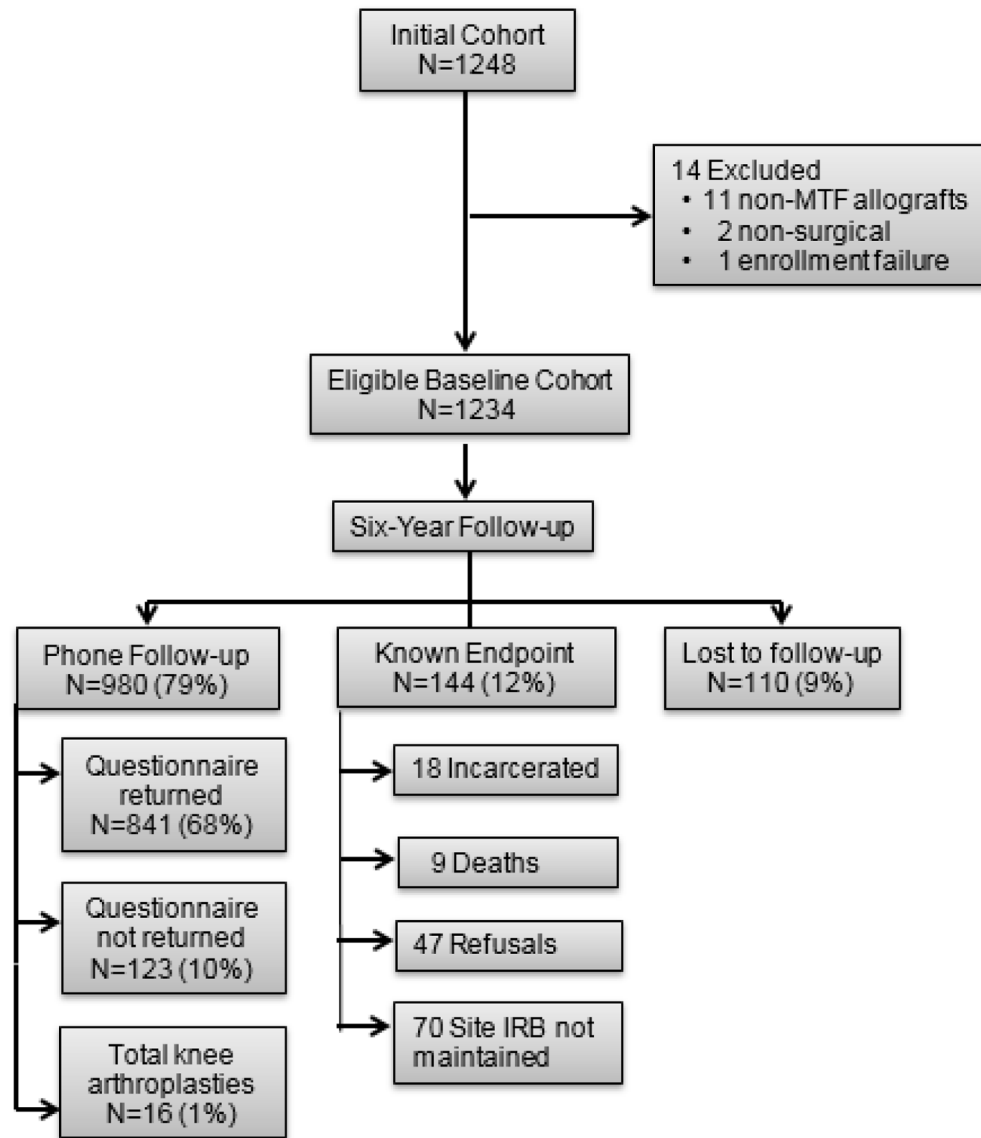


Figure 1.
Patient Enrollment Flow Diagram

Table 1. Significant Odds Ratios (95% CI) for Individual Meniscus and Articular Cartilage Variables

Structure	Comparison	Worse Outcome	Marx	KOOS					WOMAC			
				Symptoms	Pain	ADL	Sports/ Rec	QoL	IKDC	Stiffness	Pain	ADL
MENISCAL STATUS (Previous pathology prior to enrollment)	No tear vs. excised	excised		1.45 (1.05, 2.04) p=0.025	1.67 (1.19, 2.33) p=0.003	1.41 (1.01, 2.00) p=0.046		1.41 (1.00, 1.96) p=0.047	1.56 (1.12, 2.17) p=0.009		1.59 (1.12, 2.22) p=0.008	1.41 (1.01, 2.00) p=0.046
	No tear vs. unstable, not healed repair	no tear		2.07 (1.05, 4.06) p=0.035		2.04 (1.03, 4.05) p=0.042			2.07 (1.09, 3.90) p=0.025	2.06 (1.04, 4.10) p=0.039		2.04 (1.03, 4.05) p=0.042
MENISCAL STATUS (at time of revision ACLR)	No tear vs. stable/healed repair	excised			2.78 (1.12, 6.67) p=0.027	2.70 (1.11, 6.67) p=0.029						
	normal vs. repair	repair	1.72 (1.12, 2.70) p=0.013									
ARTICULAR CARTILAGE STATUS (Previous)	normal vs. excision	excision		1.59 (1.13, 2.22) p=0.007	1.63 (1.16, 2.30) p=0.005			1.62 (1.16, 2.27) p=0.005				
	normal vs. repair	normal	2.13 (1.17, 3.88) p=0.028									
ARTICULAR CARTILAGE STATUS (at time of revision ACLR)	normal vs. excision	normal										
	yes vs. no	normal	1.44 (1.02, 2.03) p=0.039									
MFC	Normal/G1 vs. G2	G2		1.61 (1.12, 2.27) p=0.009								
	Normal/G1 vs. G4	G4									1.92 (1.06,	

Structure	Comparison	Worse Outcome	Marx	KOOS					WOMAC					
				Symptoms	Pain	ADL	Sports/Rec	QoL	IKDC	Stiffness	Pain	ADL		
LFC	Normal/G1 vs. G2	G2		1.56 (1.05, 2.33) p=0.027								3.45 p=0.032		
	Normal/G1 vs. G4	G4			1.92 (1.00, 3.66) p=0.050	2.41 (1.27, 4.57) p=0.007	1.88 (1.05, 3.39) p=0.035							1.91 (1.00, 3.66) p=0.050
MTP	Normal/G1 vs. G3/4	G3/4												
LTP	Normal/G1 vs. G3/4	G3/4				2.22 (1.12, 4.55) p=0.022								
Patella	Normal/G1 vs. G2	G2						1.54 (1.06, 2.22) p=0.021		1.52 (1.05, 2.22) p=0.026				
	Normal/G1 vs. G3/4	G3/4	1.72 (1.02, 2.94) p=0.042	1.69 (1.02, 2.86) p=0.042									2.17 (1.30, 3.70) p=0.003	
Trochlea	Normal/G1 vs. G3/4	G3/4		1.89 (1.18, 3.03) p=0.009		2.00 (1.25, 3.23) p=0.004						2.22 (1.35, 3.70) p=0.002		

Key: Cells are populated as Odd Ratios (95% confidence intervals) and p-values where significant
 An empty cell indicates that the particular knee rating at the top of the column was not significantly affected by meniscal and articular surface conditions. Light shaded cells indicate result was counter-intuitive to initial hypothesis.

ADL=activities of daily living; G1=grade 1; G2=Grade 2; G3=grade 3; G4=grade 4; G3/4=grades 3-4
 LFC=lateral femoral condyle; LTP=lateral tibial plateau; MFC=medial femoral condyle; MTP=medial tibial plateau; Sports/Rec=sports and recreation; QoL=quality of life

Table 2.

Significant Odds Ratios (95% CI) for Secondary Variables in Model

	Comparison	Worse Outcome	Marx	KOOS					WOMAC				
				Symptoms	Pain	ADL	Sports/Recreation	QoL	IKDC	Stiffness	Pain	ADL	
Baseline Patient-Reported Outcome Score		lower baseline score	2.54 (1.69, 3.80) p<0.0001	2.98 (2.34, 3.79) p<0.0001	3.17 (2.49, 4.04) p<0.0001	5.09 (3.67, 7.06) p<0.0001	2.43 (1.94, 3.03) p<0.0001	2.23 (1.80, 2.77) p<0.0001	2.62 (2.11, 3.25) p<0.0001	2.53 (1.93, 3.31) p<0.0001	3.27 (2.40, 4.47) p<0.0001	5.09 (3.67, 7.07) p<0.0001	
Patient Demographics													
Age (years)		older age	3.03 (1.89, 5.00) p<0.0001										
Sex	male vs. female	females	2.22 (1.64, 2.94) p<0.0001	1.35 (1.01, 1.79) p=0.044									
Smoking status	never vs. current	current smoker	2.08 (1.16, 3.70) p=0.013	3.13 (1.82, 5.56) p<0.001	3.45 (2.00, 5.88) p<0.001	3.85 (2.27, 6.67) p<0.001	3.13 (1.79, 5.26) p<0.001	4.17 (2.44, 7.14) p<0.001	3.33 (1.96, 5.88) p<0.001	3.23 (1.89, 5.56) p<0.001	3.85 (2.27, 6.67) p<0.001		
Body mass index (BMI)		higher BMI		1.04 (1.01-1.07) p=0.014	1.04 (1.01-1.07) p=0.008	1.06 (1.03-1.10) p<0.001	1.04 (1.01-1.07) p=0.003	1.06 (1.03-1.09) p<0.001		1.05 (1.02-1.09) p=0.001	1.06 (1.03-1.10) p<0.001		
Baseline Marx Activity Level		lower baseline Marx score	2.54 (1.69, 3.80) p<0.0001					1.65 (1.09, 2.50) p=0.003					
Previous Surgical Information													
Time since last ACLR (years)		less time since last ACLR		1.87 (1.23, 2.86) p=0.037									
Previous ACLR on contra. knee	no vs. yes	yes			1.61 (1.03, 2.56) p=0.035					1.60 (1.02, 2.51) p=0.021			

Key: An empty cell indicates that the particular knee rating at the top of the column was not significantly affected by meniscal and articular surface conditions. ACLR= anterior cruciate ligament reconstruction; ADL = activities of daily living; contra = contralateral; QoL = quality of life; sports/rec = sports and recreation