

Predictors of Patient-Reported Outcomes at 2 Years After Revision Anterior Cruciate Ligament Reconstruction

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Background: Patient-reported outcomes (PROs) are a valid measure of results after revision anterior cruciate ligament (ACL) reconstruction. Revision ACL reconstruction has been documented to have worse outcomes when compared with primary ACL reconstruction. Understanding positive and negative predictors of PROs will allow surgeons to modify and potentially improve outcome for patients.

Purpose/Hypothesis: The purpose was to describe PROs after revision ACL reconstruction and test the hypothesis that patient- and technique-specific variables are associated with these outcomes.

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

Methods: Patients undergoing revision ACL reconstruction were identified and prospectively enrolled by 83 surgeons over 52 sites. Data included baseline demographics, surgical technique and pathology, and a series of validated PRO instruments: International Knee Documentation Committee (IKDC), Knee injury and Osteoarthritis Outcome Score (KOOS), Western Ontario and McMaster Universities Osteoarthritis Index, and Marx Activity Rating Scale. Patients were followed up at 2 years and asked to complete the identical set of outcome instruments. Multivariate regression models were used to control for a variety of demographic and surgical factors to determine the positive and negative predictors of PRO scores at 2 years after revision surgery.

Results: A total of 1205 patients met the inclusion criteria and were successfully enrolled: 697 (58%) were male, with a median cohort age of 26 years. The median time since their most recent previous ACL reconstruction was 3.4 years. Two-year questionnaire follow-up was obtained from 989 patients (82%). The most significant positive predictors of 2-year IKDC scores were a high baseline IKDC score, high baseline Marx activity level, male sex, and having a longer time since the most recent previous ACL reconstruction, while negative predictors included having a lateral meniscectomy before the revision ACL reconstruction or having grade 3/4 chondrosis in either the trochlear groove or the medial tibial plateau at the time of the revision surgery. For KOOS, having a high baseline score and having a longer time between the most recent previous ACL reconstruction and revision surgery were significant positive predictors for having a better (ie, higher) 2-year KOOS, while having a lateral meniscectomy before the revision ACL reconstruction was a consistent predictor for having a significantly worse (ie, lower) 2-year KOOS. Statistically significant positive predictors for 2-year Marx activity levels included higher baseline Marx activity levels, younger age, male sex, and being a nonsmoker. Negative 2-year activity level predictors included having an allograft or a biologic enhancement at the time of revision surgery.

Conclusion: PROs after revision ACL reconstruction are associated with a variety of patient- and surgeon-related variables. Understanding positive and negative predictors of PROs will allow surgeons to guide patient expectations as well as potentially improve outcomes.

Keywords: ACL reconstruction; revision; outcomes; IKDC; KOOS; Marx

Revision anterior cruciate ligament (ACL) reconstruction has been noted to have worse outcomes than primary ACL reconstructions by a variety of measures, including graft failure rates and patient-reported outcomes (PROs).^{7,8,26,27} The reasons for these worse outcomes have not been readily

apparent, and, unfortunately, the medical literature is replete with lower-level retrospective series and few level 1 or 2 studies. On the basis of this lack of understanding of this significant clinical problem, the Multicenter ACL Revision Study (MARS) consortium was developed to attempt to better understand the contributors and predictors for these worse outcomes.¹⁶

Previous analyses of this cohort by the MARS Group have been performed to assess the effect of graft choice, meniscal and chondral factors, rehabilitation variables, surgeon technical issues, and cross-cultural comparisons

that affect outcome, but no previous analysis has combined all available, practical variables into a common analysis to stratify the predictors.^{1-4,9-16} PROs have become accepted and popular in medicine and subsequently in orthopaedics.^{17,18,23-25} Identifying predictors of these measures after revision ACL reconstruction will identify opportunities for counseling and care for patients undergoing this procedure. The purpose of this study was to describe PROs after revision ACL reconstruction and test the hypothesis that patient- and technique-specific variables are associated with these outcomes.

METHODS

The MARS Group was assembled with the aim of determining what affects outcomes in an ACL revision setting and to identify potentially modifiable factors that could improve these outcomes. This collaboration consists of a group of 83 sports medicine fellowship-trained surgeons across 52 sites. Surgeons are a near equal mix of academic and private practitioners. After obtaining approval from institutional review boards, this multicenter consortium began patient enrollment in 2006 and ended in 2011, during which time 1205 patients undergoing revision ACL reconstruction were enrolled in this prospective longitudinal cohort. The study enrolled patients undergoing revision of a previously failed ACL reconstruction who agreed to participate, signed an informed consent, and completed a series of patient-reported outcome instruments. Indications for the revision ACL reconstruction included functional instability, abnormal laxity testing, or magnetic resonance imaging indicating graft tear. Multiligament reconstructions were excluded. Surgeon inclusion criteria included maintenance of an active institutional review board approval, completion of a training session that integrated articular cartilage and meniscal agreement studies, review of the study design and patient inclusion criteria, and a review of the surgeon questionnaire. Surgical technique was at the discretion of the treating surgeon. All allografts were obtained from a single allograft supplier (Musculoskeletal Transplant Foundation).

Data Sources and Measurement

After informed consent was obtained, the patient filled out a 13-page questionnaire that included questions regarding demographics, sports participation, injury mechanism, comorbidities, and knee injury history, as previously described.¹⁶ Within this questionnaire, each participant also 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, and the Marx Activity Rating Scale. Contained within the KOOS was the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Surgeons filled out a 42-page questionnaire that included the impression of the etiology (traumatic, technical, and/or biologic) of the previous failure, physical examination findings, surgical technique utilized, the intra-articular findings, and surgical management of meniscal and chondral damage.

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

Patient Follow-up

Two-year patient follow-up was completed by mail with readministration of the same questionnaire as the one completed at baseline. Patients were also contacted by phone to determine whether any subsequent surgery had occurred to either knee since their initial revision ACL reconstruction. If so, operative reports were obtained, whenever possible, to document pathology and treatment.

Statistical Analysis

To describe our patient sample, we summarized continuous variables as percentiles (ie, 25th, 50th, and 75th) and categorical variables with frequencies and percentages. Multivariable regression analyses were constructed to examine which baseline risk factors were independently associated with each outcome variable. The primary outcome variables of interest were the 2-year outcome scores of the IKDC, KOOS, WOMAC, and Marx activity level. These primary outcome variables were all treated as continuous. Regression analysis was used to control for age, sex, body mass index (BMI), activity level, smoking status, number of years of education, baseline outcome scores, surgeon, revision number, time from most recent previous ACL reconstruction, and a variety of previous and current surgical variables, to assess the demographic and surgical risk factors for clinical outcomes 2 years after revision surgery. To stay within the allowable degrees of freedom, each continuous variable was tested for a nonlinear relationship with a *P* value <.05 set as the significance level. Statistical analysis was performed with open source R statistical software (v 3.0.3).

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TABLE 1
Outcome Scores Over Time^a

	Scale	Baseline (T0) ^b	2-y Follow-up ^c
IKDC	0-100	52 (38, 63)	77 (61, 86)
KOOS	0-100		
Symptoms		68 (54, 82)	79 (64, 89)
Pain		75 (58, 86)	89 (75, 94)
ADL		87 (69, 96)	97 (88, 100)
Sports/Recreation		45 (25, 65)	75 (55, 90)
Quality of Life		31 (19, 44)	56 (38, 75)
WOMAC	0-100		
Stiffness		75 (50, 88)	75 (62, 100)
Pain		85 (70, 95)	95 (80, 100)
ADL		87 (69, 96)	97 (88, 100)
Marx activity level	0-16	11 (4, 16)	7 (2, 12)

^aValues are presented as median (25%, 75% quartile). ADL, Activities of Daily Living; IKDC, International Knee Documentation Committee subjective form; KOOS, Knee injury and Osteoarthritis Outcome Score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

^bTime at revision anterior cruciate ligament reconstruction surgery.

^cScores are all significantly changed as compared with baseline ($P < .001$), with the exception of the WOMAC stiffness scale.

RESULTS

Study Population and Follow-up

A total of 1205 patients (697 [58%] males) met the inclusion criteria and were successfully enrolled. The median age was 26 years, and the median time since the patients' most recent previous ACL reconstruction was 3.4 years. At 2 years, questionnaire follow-up was obtained on 82% (989 of 1205).

All outcome scores showed significant improvement from baseline to 2 years, with the exception of the WOMAC stiffness subscale ($P < .001$) (Table 1). The IKDC, KOOS, and WOMAC Pain and Activities of Daily Living (ADL) subscales all significantly improved at 2 years, while activity level significantly dropped at 2 years as compared with the baseline measure.

Positive and Negative Predictors of 2-Year Outcome Scores

International Knee Documentation Committee. The most significant drivers of 2-year IKDC scores were a patient's baseline IKDC score ($P < .001$), baseline Marx activity level ($P < .001$), sex ($P < .001$), and time since the most recent previous ACL reconstruction ($P = .003$). Specifically, having a high baseline IKDC score, high baseline Marx activity level, male sex, and a longer time since the most recent previous ACL reconstruction were significant positive predictors for having better (ie, higher) 2-year IKDC scores. A summary of all individual significant positive and negative predictors of 2-year IKDC scores are listed in Table 2.

Knee injury and Osteoarthritis Outcome Score. The variables that consistently influenced all 2-year KOOS were a patient's baseline score, the time since the last ACL

TABLE 2
Significant Predictors for 2-Year IKDC Scores^a

	Odds Ratio	95% CI	P Value
Positive predictors (improved scores)			
Baseline			
IKDC score	3.1	2.5-3.7	<.001
Marx activity level	2.2	1.6-3.2	<.001
Time since last ACLR, y	1.9	1.3-2.8	.003
Femoral fixation (interference screw)	1.8	1.0-3.1	.047
Male sex	1.6	1.3-2.1	<.001
Tibial fixation (interference screw)	1.6	1.1-2.2	.007
LFC chondrosis (grade 2)	1.5	1.1-2.2	.023
Current graft source: soft tissue	1.5	1.1-2.2	.025
Negative predictors (worse scores)			
Chondrosis (grades 3/4)			
MTP	0.45	0.21-0.97	.042
Trochlear	0.53	0.35-0.80	.003
Previous lateral meniscectomy	0.59	0.41-0.86	.005
Current graft type: allograft	0.76	0.59-0.99	.045

^aACLR, anterior cruciate ligament reconstruction; IKDC, International Knee Documentation Committee; LFC, lateral femoral condyle; MTP, medial tibial plateau.

reconstruction, and having a lateral meniscectomy before the revision ACL reconstruction. Specifically, having a high baseline score and having a longer time since a patient's last ACL reconstruction were significant positive predictors for having better (ie, higher) 2-year KOOS, while having a lateral meniscectomy before the revision ACL reconstruction was a consistent predictor for having significantly worse (ie, lower) 2-year KOOS across all subscales. Having a high baseline activity level significantly predicted higher 2-year KOOS ADL, Sports/Recreation, and Quality of Life (QOL) scores. Patients who had an interference screw for their tibial fixation also had significantly higher 2-year KOOS in 4 of the 5 subscales (Symptoms, Pain, ADL, and Sports/Recreation). Choosing an autograft for the revision ACL reconstruction predicted significantly higher KOOS Sports/Recreation and QOL scores at 2 years. Conversely, having grade 3-4 trochlear groove chondrosis predicted significantly lower 2-year KOOS in 4 of the 5 subscales (Symptoms, Pain, ADL, and Sports/Recreation). A summary of these significant positive and negative predictors of 2-year KOOS is listed in Table 3.

Western Ontario and McMaster Universities Osteoarthritis Index. The variables that consistently influenced all 2-year WOMAC scores were a patient's baseline WOMAC score, the time since the last ACL reconstruction, having an interference screw for tibial fixation, and having a lateral meniscectomy before the revision ACL reconstruction. Specifically, having a high baseline score, a longer time since the last ACL reconstruction, and having an interference screw for tibial fixation were the most consistent significant positive predictors for having better (ie, higher) 2-year WOMAC scores, while having a lateral meniscectomy before the revision ACL reconstruction was the most consistent predictor for having significantly worse (ie, lower) 2-year WOMAC scores.

TABLE 3
Significant Predictors for 2-Year KOOS^a

	Symptoms	Pain	ADL	Sports/Rec	QOL
Positive predictors					
Baseline score	3.9 (3.1-4.8), <.001	3.8 (3.1-4.8), <.001	5.1 (3.8-6.8), <.001	3.0 (2.4-3.6), <.001	2.1 (1.8-2.6), <.001
Time since last ACLR, y	1.7 (1.1-2.5), .001	1.9 (1.3-2.8), .001	1.9 (1.3-2.8), <.001	2.0 (1.4-3.0), .008	1.8 (1.3-2.7), .003
Baseline Marx activity level			1.6 (1.1-2.4), .007	1.8 (1.3-2.6), .001	2.0 (1.4-2.9), <.001
Lateral meniscal treatment: no treatment for tear			2.5 (1.3-4.7), .008		
Fixation (interference screw)					
Femoral					2.2 (1.3-4.0), .006
Tibial	1.5 (1.1-2.1), .013	1.6 (1.1-2.2), .007	2.0 (1.1-3.7), .024	1.5 (1.0-2.1), .033	
Current graft					
Autograft				1.3 (1.0-1.7), .037	1.3 (1.0-1.7), .031
Soft tissue		1.5 (1.1-2.3), .029			
Negative predictors					
Current smoker					0.6 (0.4-0.9), .012
Previous ACLR on the contralateral knee					0.7 (0.5-0.98), .037
Second revision ACLR					0.6 (0.4-0.9), .019
Meniscectomy before ACL revision					
Medial	0.7 (0.5-0.95), .022	0.7 (0.5-0.9), .006			
Lateral	0.6 (0.4-0.8), .002	0.7 (0.5-0.9), .019	0.6 (0.4-0.9), .024	0.7 (0.5-0.96), .029	0.5 (0.3-0.7), <.001
Chondrosis					
Trochlear groove (grades 3/4)	0.6 (0.4-0.9), .019	0.6 (0.4-0.9), .014	0.4 (0.2-0.6), <.001	0.5 (0.3-0.8), .003	
MTP (grades 3/4)				0.3 (0.2-0.7), .002	
LTP (grade 2)				0.7 (0.5-1.0), .046	
MFC (grade 4)					0.5 (0.3-0.9), .011
Surgeon's opinion on cause of failure:			0.4 (0.2-0.9), .037	0.3 (0.1-0.9), .026	
tibial tunnel malposition					

^aValues are presented as odds ratio (95% CI), *P* value. Numbers in cells are ones that were statistically significant. ACLR, anterior cruciate ligament reconstruction; ADL, Activities of Daily Living; KOOS, Knee injury and Osteoarthritis Outcome Score; LTP, lateral tibial plateau; MFC, medial femoral condyle; MTP, medial tibial plateau; QOL, Quality of Life; Sports/Rec, Sports/Recreation.

A summary of individual significant positive and negative predictors of 2-year WOMAC scores is listed in Table 4.

Marx Activity Level. The significant drivers of 2-year Marx activity levels were a patient's baseline Marx activity level, age, and sex (all *P* < .001) (Table 5). Specifically, having a high baseline Marx activity level, younger age, and male sex were the most significant positive predictors for having a higher 2-year Marx activity level. Another positive predictive variable for 2-year activity levels was being a nonsmoker, while negative predictors included having an allograft and a biologic enhancement (typically platelet-rich plasma).

A summary of individual significant positive and negative predictors of 2-year Marx activity level is listed in Table 5 and Figure 1.

DISCUSSION

Revision ACL reconstruction unfortunately does not always result in outcomes equivalent to a patient's results from the primary reconstruction. The current study reports 2-year PROs for a large prospective cohort of revision ACL reconstructions and identifies predictors for these outcomes. In general, PROs at 2 years were improved over baseline both statistically and clinically. Marx activity score was the real exception to improvement, with decreased activity at 2 years (see Table 1). Higher baseline scores were associated with higher 2-year outcome scores for all of the PROs included in this study. Longer time from most recent previous ACL reconstruction predicted higher IKDC, KOOS, and

WOMAC scores, while males were predicted to have higher IKDC and Marx scores. Previous lateral meniscectomy predicted lower WOMAC and KOOS scores at 2-year follow-up.

The predictors for better or worse results become invaluable for surgeons treating these patients, for 2 reasons: counseling patients on expected outcome and modifying the treatment plan when appropriate. These results allow improved care for both these reasons. Obvious preoperative factors that portend a good or poor result can be communicated to the patient, and technical factors identified can be incorporated into the surgical management to improve outcome.

The use of PROs for assessing patient outcome has become accepted in sports medicine as well as in the broader orthopaedic surgery community. This has not always been true. As recently as 2005, the use of PROs was editorialized as an invalidated assessment that was inferior to structural factors in determining outcome^{21,28}—this despite the surgeon's intuitive knowledge that asking a patient how she or he is functioning is as informative as measuring structural outcomes. As the use of PROs has become more mainstream, we have developed an increased understanding of their role and statistical integrity.^{17,18,23-25}

The use of PROs has facilitated the development of large patient cohorts, which creates the opportunity to assess a large number of variables that are involved in patient treatment. In revision ACL reconstruction, this has included as many as 80 variables in an analysis of >1000 patients. While it lacks ability to provide some of the data available from physical examinations and

TABLE 4
Significant Predictors for 2-Year WOMAC Scores^a

	Stiffness	Pain	ADL
Positive predictors (improved scores)			
Baseline score	4.3 (3.4-5.6), <.001	4.0 (3.0-5.3), <.001	5.1 (3.8-6.8), <.001
Time since last ACLR, y	1.8 (1.2-2.6), .003	1.7 (1.1-2.6), .001	1.9 (1.3-2.8), .050
Baseline Marx activity level			1.6 (1.1-2.4), .007
Lateral meniscal treatment: no treatment for tear			2.5 (1.3-4.7), .008
Fixation (interference screw)			
Femoral	1.8 (1.1-3.1), .032		
Tibial	1.7 (1.2-2.3), .029	1.4 (1.0-2.0), .040	2.0 (1.1-3.7), .024
Surgeon's years of experience		1.3 (1.0-1.6), .022	
Negative predictors (worse scores)			
Meniscectomy before ACL revision			
Medial	0.7 (0.5-0.9), .010		
Lateral	0.7 (0.4-0.9), .021	0.6 (0.4-0.9), .022	0.6 (0.4-0.9), .024
Chondrosis (grades 3/4)			
Trochlear groove	0.6 (0.4-0.96), .030		0.4 (0.2-0.6), <.001
Patellar		0.6 (0.4-0.9), .017	
Surgeon's opinion on cause of failure			
Traumatic	0.4 (0.1-0.96), .042		
Tibial tunnel malposition			0.4 (0.2-0.9), .037

^aValues are presented as odds ratio (95% CI), *P* value. ACLR, anterior cruciate ligament reconstruction; ADL, Activities of Daily Living; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

TABLE 5
Significant Predictors for 2-Year Marx Activity Level^a

	Odds Ratio	95% CI	<i>P</i> Value
Positive predictors (improved scores)			
Baseline Marx activity level	5.8	4.0-8.4	<.001
Younger age	2.2	1.4-3.2	<.001
Male sex	1.8	1.4-2.3	<.001
Nonsmoker	1.7	1.1-2.7	.018
Surgeon's own failure	1.5	1.1-2.2	.017
Negative predictors (worse scores)			
Current graft type: allograft	0.30	0.13-0.70	.005
Surgeon's opinion of failure: "traumatic"	0.33	0.12-0.92	.033
Biologic enhancement	0.55	0.33-0.90	.019
Having a previous ACLR on the contralateral knee	0.67	0.45-0.99	.047
Prior graft type: autograft	0.69	0.50-0.96	.027

^aACLR, anterior cruciate ligament reconstruction.

imaging, it serves a valuable role in assessing innumerable factors, and with modern sophisticated statistical methods, independent predictors can be determined for a variety of outcomes.

This study is unique in the field of revision ACL reconstruction. No previous studies have had the ability to assess outcome predictors, owing to the lack of adequate numbers of patients for analysis. Previous primary ACL reconstruction studies have looked at these predictors, but as health care professionals know, the revision setting is a different and more complex reconstruction scenario. Thus, comparing and contrasting our findings with other studies is difficult. To put our PRO results in perspective, an analysis of median PRO scores in Table 1 finds that the median KOOS subscale scores are at the definition of a "symptomatic knee" as described by Wasserstein et al²²

and defined by Englund et al⁶ as a QOL score ≤ 87.5 and ≥ 2 of the following: Pain ≤ 86.1 , Symptoms ≤ 85.7 , ADL ≤ 86.8 , and Sports/Recreation ≤ 85.0 . Our median scores would meet these criteria for the QOL (56), Symptoms (79), and Sports/Recreation (75) scores. Thus, at least 50% of our patients may meet the criteria for a symptomatic knee at 2-year follow-up.

Dunn and Spindler,⁵ in analyzing the predictors of activity level at 2 years in the Multicenter Orthopaedic Outcomes Network (MOON) cohort, found that higher baseline activity (Marx score) and lower baseline BMI predicted higher (more active) scores. Predictors for lower activity level scores included female sex, smoking, and, interestingly, revision ACL reconstruction. Similar to the findings in the current study were that meniscal and cartilage status did not predict 2-year activity level scores. In

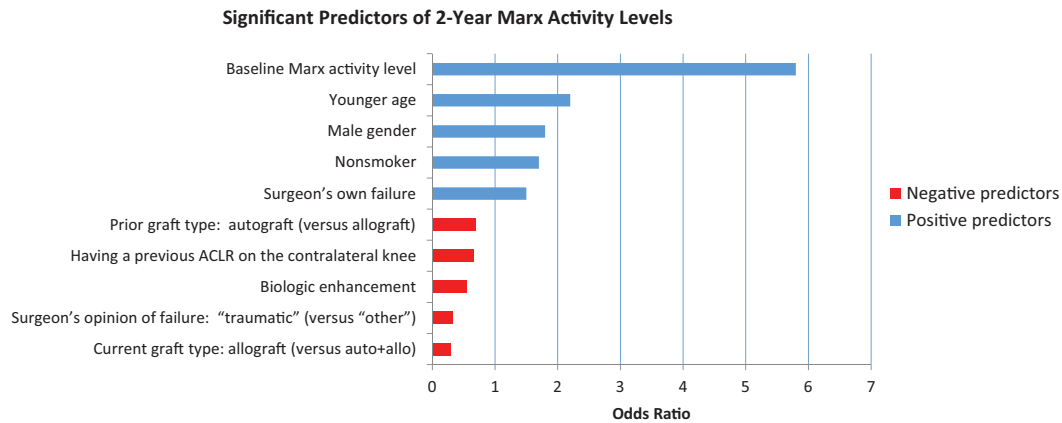


Figure 1. Significant predictors of 2-year Marx activity levels. ACLR, anterior cruciate ligament reconstruction.

the current revision cohort, male sex and being a non-smoker predicted increased activity level scores at 2 years. A variety of factors specific to the revision setting were impactful but would not be involved with a primary reconstruction.

Spindler et al,²⁰ in a MOON study analyzing predictors of activity and sports function at 6 years after ACL reconstruction, found that the use of an allograft predicted poorer IKDC, KOOS Sports/Recreation, and KOOS QOL scores.

Higher baseline BMI predicted poorer IKDC and KOOS Sports/Recreation scores at 6 years, and baseline smoking predicted poorer IKDC scores at 6 years. Lateral meniscal status predicted the KOOS Sports/Recreation and QOL scores. If the patient had undergone a revision ACL reconstruction, poorer IKDC, Marx, and all KOOS subscales were predicted. Early acknowledgment of the effect of revision ACL reconstruction in the MOON cohort was the impetus for the development of MARS.

Interestingly, when PROs were examined in that predominantly primary cohort at 6 years, the scores were no worse and typically improved as compared with the current MARS study findings at 2 years.¹⁹ The median IKDC score was identical at 77. The KOOS Sports/Recreation subscale score was 90 for MOON versus 75 at 2 years for MARS. The KOOS QOL subscale score was 81 for MOON and 56 for MARS. Thus, at 2 years, patients who underwent revision were doing significantly worse than those with primary ACL reconstruction at 6 years with some but not all measures. The caveat is that the comparison is not adjusted for confounding factors, such as patient age, sex, and so on.

Consistent with all cohort studies, there are limitations imposed by the study design. We do not have quantitative measures of laxity or arthritis at 2-year follow-up (eg, KT-1000, radiographs). This will be addressed by on-site follow-up at 10 years. The strengths are as follows: (1) this is the largest prospectively enrolled revision ACL reconstruction cohort reported to date; (2) validated PROs were collected at baseline and 2 years; and (3) the generalizability of our cohort was enhanced by including private and

academic fellowship-trained sports medicine physicians from a variety of geographic and practice settings.

CONCLUSION

This is the largest cohort to date reporting 2-year PROs for patients undergoing revision ACL reconstruction. Factors associated with 2-year PROs were identified, including baseline PRO scores, patient age and sex, time from most recent previous ACL reconstruction, and history of lateral meniscectomy. Understanding predictors of these scores helps surgeons guide patient expectations and optimize surgical technique.

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