Winner of the O'Donoghue Award

Ten-Year Outcomes and Risk Factors After Anterior Cruciate Ligament Reconstruction

A MOON Longitudinal Prospective Cohort Study

The MOON Knee Group*‡
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Background: The long-term prognosis and risk factors for quality of life and disability after anterior cruciate ligament (ACL) reconstruction remain unknown.

Hypothesis/Purpose: Our objective was to identify patient-reported outcomes and patient-specific risk factors from a large prospective cohort at a minimum 10-year follow-up after ACL reconstruction. We hypothesized that meniscus and articular cartilage injuries, revision ACL reconstruction, subsequent knee surgery, and certain demographic characteristics would be significant risk factors for inferior outcomes at 10 years.

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

Methods: Unilateral ACL reconstruction procedures were identified and prospectively enrolled between 2002 and 2004 from 7 sites in the Multicenter Orthopaedic Outcomes Network (MOON). Patients preoperatively completed a series of validated outcome instruments, including the International Knee Documentation Committee (IKDC), Knee injury and Osteoarthritis Outcome Score (KOOS), and Marx activity rating scale. At the time of surgery, physicians documented all intra-articular abnormalities, treatment, and surgical techniques utilized. Patients were followed at 2, 6, and 10 years postoperatively and asked to complete the same outcome instruments that they completed at baseline. The incidence and details of any subsequent knee surgeries were also obtained. Multivariable regression analysis was used to identify significant predictors of the outcome.

Results: A total of 1592 patients were enrolled (57% male; median age, 24 years). Ten-year follow-up was obtained on 83% (n = 1320) of the cohort. Both IKDC and KOOS scores significantly improved at 2 years and were maintained at 6 and 10 years. Conversely, Marx scores dropped markedly over time, from a median score of 12 points at baseline to 9 points at 2 years, 7 points at 6 years, and 6 points at 10 years. The patient-specific risk factors for inferior 10-year outcomes were lower baseline scores; higher body mass index; being a smoker at baseline; having a medial or lateral meniscus procedure performed before index ACL reconstruction; undergoing revision ACL reconstruction; undergoing lateral meniscectomy; grade 3 to 4 articular cartilage lesions in the medial, lateral, or patellofemoral compartments; and undergoing any subsequent ipsilateral knee surgery after index ACL reconstruction.

Conclusion: Patients were able to perform sports-related functions and maintain a relatively high knee-related quality of life 10 years after ACL reconstruction, although activity levels significantly declined over time. Multivariable analysis identified several key modifiable risk factors that significantly influence the outcome.

Keywords: anterior cruciate ligament; ACL reconstruction; follow-up; outcomes; IKDC; KOOS; Marx; revision ACL reconstruction; meniscus; articular cartilage; subsequent surgery

Numerous studies have reported on the short- and intermediate-term successful results of anterior cruciate ligament (ACL) reconstruction.[3,10,32,54,56] However, while researchers have documented the long-term risks of osteoarthritis after ACL reconstruction[§] and the incidence of subsequent surgeries and ACL graft tears,[7,10] there has been less discussion of patient-specific risk factors and patient-reported outcome measures after ACL reconstruction.[36] Patient-reported outcome measures offer a complementary set of diagnostic tools with which to quantify "outcomes." A subset of these patient-reported outcome measures have been validated, defined as having undergone testing for the instrument's reliability, responsiveness, and validity (ie, content validity, face validity, construct validity, and/or criterion validity). During the last decade, validated patient-reported outcome measures have become more popular, as these measures have provided invaluable information to researchers about the

[§]References 1, 2, 4, 6, 11, 13, 19, 20, 25, 27-29, 31, 33, 40-42, 45, 52, 55, 57.

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relative success of orthopaedic interventions.[5,30,46,49] These instruments document information about knee function, symptoms, and quality of life (QOL) from the patient's point of view and have been reported to be strong proxies for on-site assessments.[58] Because patient-reported outcome instruments have come to play an increasingly large role in the assessment of outcomes after treatment, they have become a recommended component of all clinical trials.[9] Additionally, a unique advantage of questionnaire-based, validated patient-reported outcome measures is the ability to follow hundreds or thousands of patients at a fraction of the cost and with improved follow-up compared with the logistic difficulties of having patients return for on-site evaluations (clinical examinations, radiographs, etc).

Ten-year patient-reported outcomes (eg, the International Knee Documentation Committee [IKDC][50] form, the Knee injury and Osteoarthritis Outcome Score [KOOS],[49] and the Marx activity rating scale[38]) as well as the modifiable risk factors for an individual patient's worse outcomes have not yet been determined in a large prospective cohort with a high (>80%) follow-up. In a systematic review[36] on 10-year patient-reported outcomes, only 3 studies reported using the IKDC: Lebel et al[27] (n = 154; 67% follow-up), Bourke et al[8] (n = 755; 79% follow-up), and Shelbourne and Gray[52] (n = 1276; 72% follow-up), with both the larger studies excluding long-term graft failure or contralateral ACL tears. The KOOS has been reported in 2 studies by Barenius et al[4] and Moller et al,[39] with a total sample size of 226 and both with a greater than 80% follow-up. The Marx activity rating scale has not been reported at 10 years.[36] In a 2014 systematic review on the long-term natural history of ACL injuries, Chalmers et al[10] identified 27 studies that reported outcomes after surgical reconstruction (incidence of subsequent surgeries and Tegner activity level). Unfortunately, the mean sample size of the 27 operative cohorts was 59 (range, 22-181), with a cumulative sample size of 1585 patients. As such, the ability to control for confounding factors that may influence outcomes has been extremely limited.

The Multicenter Orthopaedic Outcomes Network (MOON) project was designed in 2002 to prospectively determine which variables at the time of an ACL injury (including surgical history of the knee, patient demographics, mechanism of the current injury, surgical technique/choices at the time of index ACL surgery, concomitant meniscus and/or articular cartilage abnormalities and treatment, among other potential modifiable and nonmodifiable variables) would influence and predict both short- and long-term outcomes after ACL reconstruction. This consortium has a proven ability to maintain 80% follow-up at 2 and 6 years as well as capture important time-dependent risk factors such as activity level and additional surgery.[12,15,18,53] Utilizing this infrastructure, the objective of the current study was to identify both patient-specific risk factors as well as sports-specific patient-reported outcomes (IKDC, KOOS, and Marx activity rating scale) 10 years after ACL reconstruction in a prospective longitudinal cohort. We hypothesized that meniscus and articular cartilage injuries noted at the time of index ACL reconstruction, revision ACL reconstruction, any subsequent knee surgeries occurring after index ACL reconstruction, and certain demographic characteristics would be significant risk factors for inferior 10-year patient-reported outcomes.

METHODS

Setting and Study Population

After obtaining approval from each site's respective institutional review boards, the multicenter consortium began enrolling patients in 2002. This consortium consisted of 7 sites (Vanderbilt University, Nashville, Tennessee; Cleveland Clinic, Cleveland, Ohio; The Ohio State University, Columbus, Ohio; University of Iowa, Iowa City, Iowa; Washington University in St Louis, St Louis, Missouri; Hospital for Special Surgery, New York, New York; and University of Colorado, Denver, Colorado), with 12 surgeons over a 3-year enrollment period (2002-2004). One university functioned as the data processing center for the study and was responsible for entering baseline data and collecting follow-up data on all patients. The trial is registered at ClinicalTrials.gov (NCT00463099). The details of enrollment, capturing patient-reported outcomes, surgical documentation at ACL reconstruction, and method of follow-up have been described previously.[12]

All patients who underwent unilateral primary or revision ACL reconstruction surgery between January 1, 2002 and December 31, 2004 were eligible for enrollment. During this time frame, sites identified 1678 patients who were slated to undergo ACL reconstruction. A total of 1592 patients met the study's inclusion criteria and were enrolled in the study (Figure 1).

Data Sources and Measurement

After informed consent was obtained, each participant was asked to complete a 13-page questionnaire encompassing baseline demographics; injury descriptors; sports participation level; comorbidities; knee surgical history; and

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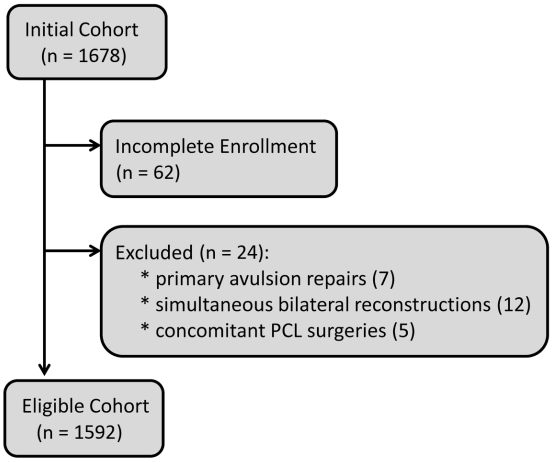

Figure 1. Enrollment flow diagram. PCL, posterior cruciate ligament.

patient-reported outcomes that included the IKDC,[22,23] 5 KOOS subscales (symptoms, pain, activities of daily living, sports and recreation, and knee-related QOL),[49] and Marx activity rating scale scores.[38] The questions related to the IKDC and KOOS pertain to the patient's pain and function level within the past week, while the Marx activity rating scale queries the patient's activity level from the past year. As such, the baseline IKDC and KOOS scores represent the ACL-deficient postinjury/presurgery state, while the baseline Marx score likely reflects the patient's preinjury state. The validity, reliability, responsiveness to clinical change, and minimal clinically meaningful difference of these instruments have been previously documented (IKDC,[22-24] KOOS,[44,48,49] and Marx[38]). Each surgeon completed a detailed form that documented the results of the examination under anesthesia, surgical technique, arthroscopic findings, and treatment of concomitant meniscus and cartilage injuries. Surgeon documentation of articular cartilage injuries was recorded based on the modified Outerbridge classification.[14,37,43] The presence of linear cracks/fracture lines on articular cartilage surfaces were also noted (if applicable). Meniscus injuries were classified by size, location, and partial versus complete tears, while treatment was recorded as not treated, repair, or extent of resection.[16] After surgery, the patients were given a uniform set of standardized, evidence-based rehabilitation guidelines.[59-61] Completed data forms were mailed from each participating site to the data coordinating center. Data from both the patient and surgeon questionnaires were scanned with TeleForm software (Cardiff Software) using 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. Cases that failed these checks were tagged and verified against the source documents to resolve before data analysis.

Follow-up

Two-, 6-, and 10-year follow-ups were completed by mail with readministration of the same questionnaire that the patients completed at baseline (defined as the time of index ACL surgery). In addition, patients were also contacted to determine whether any underwent additional surgical knee procedures since baseline (eg, revision ACL reconstruction on the ipsilateral knee, primary ACL reconstruction on the contralateral knee, and/or any arthroscopic procedures on either knee). Every effort was made to obtain the operative notes on these additional surgical procedures. Follow-up was managed at a central coordinating site but also required surgeon investigators and/or their respective sites to aid in contacting patents to achieve a high level of follow-up.

Statistical Analyses

To determine the association between independent (risk factor) variables and 10-year patient-reported outcomes, multivariable regression models were utilized. Multivariable analysis was used to determine which baseline variables measured at the time of index ACL surgery were significant predictors (risk factors) of the IKDC, KOOS, and Marx scores at 2, 6, and 10 years after surgery. Longitudinal analysis was performed using proportional odds ordinal logistic regression in lieu of linear regression models because the assumption of normal linear residuals was violated.[51]

The dependent variables (IKDC, KOOS, and Marx) were treated as continuous and consisted of the 10-year IKDC (scored 0 [worst] to 100 [best]), 5 KOOS subscales (scored 0 [worst] to 100 [best]), and Marx (scored 0 [lowest activity] to 16 [highest activity]) scores. Independent patient covariates (risk factors) in the model included age at the time of surgery, sex, ethnicity, education level, body mass index (BMI), smoking status, sport played at the time of injury, competition level, baseline activity level as assessed using the Marx activity rating scale, and baseline outcome measure (IKDC, KOOS, or Marx).

Independent surgical risk factors included surgeon, history of meniscus surgery (medial and/or lateral) at the time of index ACL reconstruction (yes/no), history of ACL reconstruction on the contralateral knee (yes/no), primary versus revision surgery, graft type (autograft bone–patellar tendon–bone [BPTB], autograft soft tissue, allograft BPTB, allograft soft tissue), and concomitant medial collateral ligament or lateral collateral ligament lesions. Meniscus injuries noted at the time of index ACL reconstruction were classified by location (medial, lateral), size, and treatment (categorized as not treated, repaired, or percentage excised). Excision options were categorized as none, 33%, 67%, or 100% excision for each segment (anterior and/or posterior). For this study, we used the largest excision in either segment. Articular cartilage variables noted at the time of index ACL reconstruction were grouped by location to include the medial compartment (medial femoral condyle, medial tibial plateau), lateral compartment (lateral femoral condyle, lateral tibial plateau), and patellofemoral compartment (patella, trochlea). The severity of articular cartilage degeneration in each location was categorized according to the modified Outerbridge classification[14] and

included normal, grade 1 (softening), grade 2 (fraying or fissures), grade 3 (partial-thickness loss with fibrillation), or grade 4 (full-thickness loss with exposed subchondral bone). If a lesion was present in both locations within a compartment (eg, lateral femoral condyle and lateral tibial plateau for the lateral compartment), the highest grade from either location was selected and extracted for analyses. The presence of linear cracks (fracture lines) on articular cartilage surfaces were also noted (yes/no) and grouped in the same way as articular cartilage degeneration: medial compartment, lateral compartment, and patellofemoral compartment. An articular cartilage fracture was noted as a "yes" if any surface within a compartment had these linear cracks/fracture lines at the time of index ACL reconstruction.

An additional independent surgical risk factor included in the model was preoperative laxity of the knee (defined as "high-grade" laxity = yes or no). "High-grade" laxity was determined by having either a Lachman or anterior drawer examination finding greater than a 10-mm difference from the contralateral side or a $\geq$3 pivot shift during the examination under anesthesia. Previous literature has shown this definition to be predictive of increased odds of undergoing subsequent revision ACL surgery.[34,35]

Details of the cohort were described using counts and percentages for categorical data and medians and interquartile ranges (IQRs) for continuous data. Each of the 7 outcomes was recorded at 10 years, and risk factors were recorded at the time of surgery. The risk factors, baseline outcome scores, BMI, smoking status, and subsequent surgery to the ipsilateral knee and contralateral knee were recorded at 2 years after surgery and 6 years after surgery. Therefore, a model at baseline, 2 years after surgery, and 6 years after surgery was created to predict 10-year outcome scores with updated risk factors. Because the amount of missing information was small, only complete cases were used in the modeling, and no imputation was used. All models were constructed using a proportional odds regression model because this method has been reported to produce better predictive models.[51] The baseline model was created using all risk factors available at baseline and reduced using a step-down reduction process in which the removal of each variable was evaluated by determining which had the smallest effect on the R^2 value and was stopped when the adjusted R^2 was maximized and the Bayesian information criterion was minimized. The models at 2 and 6 years were created using the same variables in the baseline model, while updating BMI, smoking status, and baseline outcome scores if they were included within the baseline model, and added subsequent surgeries. The performance of each model was measured using bootstrap correction to the adjusted R^2. Each model was then programmed into an online calculator for an easier assessment of a patient's risk at the time of surgery, 2 years after surgery, or 6 years after surgery.

Regarding the clinically meaningful change in scores, we utilized 11 points for the IKDC,[21] 8 points for the KOOS,[47] and 2 points for the Marx activity rating scale. All statistical analyses were performed using R open-source statistical software (https://www.R-project.org/).

RESULTS

Study Population

A total of 1592 patients fit the inclusion criteria and were enrolled. Ten-year follow-up was obtained on 83% (n = 1320; 87% [n = 1379] at 2 years and 86% [n = 1375] at 6 years), while subsequent surgery information (performed after index ACL surgery, if applicable) was obtained on over 90% of the cohort.

Baseline demographic and clinical characteristics of the analyzed cohort are provided in Table 1. The study population was 57% male, with a median age of 24 years (IQR, 17-35 years) at the time of their ACL reconstruction. Ninety percent underwent primary ACL reconstruction, while the remaining 10% underwent revision ACL reconstruction. Graft choice at the time of surgery was 42% autograft BPTB, 31% autograft soft tissue, and 27% allograft. Thirty-seven percent had documented medial meniscus lesions at the time of their surgery, while 45% had documented lateral meniscus lesions. Articular cartilage abnormalities (grades 2-4) at the time of ACL surgery were less prevalent in this cohort: 24% in the medial compartment, 21% in the lateral compartment, and 22% in the patellofemoral compartment. Interestingly, 37% of patients in this cohort were classified as having "high-grade" knee laxity preoperatively.

10-Year Outcomes

Both IKDC and KOOS scores for the entire cohort significantly improved after 2 years and were maintained at 6 and 10 years (Table 2 and Figure 2, A and B). Interestingly, Marx scores for the cohort dropped markedly over time (Figure 2C), from a median score of 12 points at baseline to 9 points at 2 years, 7 points at 6 years, and 6 points at 10 years (Table 2).

Patient-Specific Risk Factors

The patient-specific risk factors for inferior 10-year outcomes are reported in Table A1 (see the Appendix, available in the online version of this article) and summarized in Table 3. The consistent risk factors for inferior 10-year outcomes across all outcome measures were lower baseline scores, higher BMI, and having a medial meniscus procedure performed before index ACL reconstruction (Tables 3 and 4). Other significant risk factors shown in the majority of our outcome measures (but not all) were female sex; older age; being a smoker at baseline; lower baseline activity level; lower educational level; undergoing revision ACL reconstruction; having grade 3 to 4 articular cartilage abnormalities in the medial, lateral, or patellofemoral compartments at the time of index ACL surgery; and undergoing any subsequent ipsilateral surgery after index ACL surgery (Tables 3 and 4). Having either a lateral meniscus procedure performed before index ACL reconstruction or undergoing lateral meniscectomy at the time of index ACL reconstruction were significant risk factors for poorer 10-year KOOS QOL subscores, while having high-grade

TABLE 1
Baseline and Intermediate Patient and Surgical Characteristics of the Study Cohort[a]

	Value
Age, median (IQR), y	24 (17-35)
Sex	
Male	902 (57)
Female	690 (43)
Ethnicity/race	
White	1333 (84)
Black	135 (8)
Other	114 (7)
Missing	10 (1)
Baseline BMI, median (IQR), kg/m^2	25 (22.4-28.1)
Missing	35 (2)
Baseline smoking status	
Never	1248 (78)
Quit	158 (10)
Current	170 (11)
Missing	16 (1)
Education level, median (IQR), y	14 (11-16)
Missing	11 (1)
Main sport	
None	123 (8)
Baseball/softball	141 (9)
Basketball	358 (22)
Football	174 (11)
Soccer	212 (13)
Other	577 (36)
Missing	7 (0)
Competition level	
None	205 (13)
Recreational	527 (33)
Amateur	222 (14)
High school	440 (28)
College	159 (10)
Semiprofessional/professional	30 (2)
Missing	9 (1)
Surgeon volume	
No. 1	75 (5)
No. 2	14 (1)
No. 3	459 (29)
No. 4	86 (5)
No. 5	27 (2)
No. 6	95 (6)
No. 7	301 (19)
No. 8	7 (0)
No. 9	72 (5)
No. 10	304 (19)
No. 11	147 (9)
No. 12	5 (0)
Reconstruction type	
Primary	1439 (90)
Revision	153 (10)
Graft type	
Autograft BPTB	674 (42)
Autograft soft tissue	496 (31)
Allograft BPTB	122 (8)
Allograft soft tissue	300 (19)
Previous ACL reconstruction on contralateral knee	
Yes	138 (9)
No	1454 (91)
Previous medial meniscus surgery	
Yes	151 (9)
No	1441 (91)
Previous lateral meniscus surgery	
Yes	67 (4)
No	1525 (96)
Medial collateral ligament lesion	
Normal/grade 1	1497 (94)
Grades 2/3	95 (6)
Lateral collateral ligament lesion	
Normal/grade 1	1554 (98)
Grades 2/3	38 (2)
Medial meniscus lesion	
No tear	999 (63)
No treatment for tear	87 (5)
Repair	199 (13)
Excision of one-third	72 (5)
Excision of two-thirds	193 (12)
Excision of all	32 (2)
Other	10 (1)
Lateral meniscus lesion	
No tear	880 (55)
No treatment for tear	167 (10)
Repair	99 (6)
Excision of one-third	260 (16)
Excision of two-thirds	155 (10)
Excision of all	24 (2)
Other	7 (0)
AC lesion in medial compartment	
Normal/grade 1	1207 (76)
Grade 2	229 (14)
Grades 3-4	156 (10)
AC lesion in lateral compartment	
Normal/grade 1	1252 (79)
Grade 2	231 (15)
Grades 3-4	109 (7)
AC lesion in patellofemoral compartment	
Normal/grade 1	1241 (78)
Grade 2	202 (13)
Grades 3-4	149 (9)
AC lesion (linear cracks/fracture lines) in medial compartment	
Yes	119 (7)
No	1473 (93)
AC lesion (linear cracks/fracture lines) in lateral compartment	
Yes	176 (11)
No	1416 (89)
AC lesion (linear cracks/fracture lines) in patellofemoral compartment	
Yes	31 (2)
No	1561 (98)
Surgical exposure	
1 incision	1103 (69)
2 incision	488 (31)
Missing	1 (0)
Notchplasty	
Yes	1545 (97)
No	47 (3)

(continued)

TABLE 1
(continued)

	Value
High-grade laxity	
Yes	587 (37)
No	1005 (63)
2-year BMI, median (IQR), kg/m^2	25.1 (22.6-28.1)
Missing	237 (15)
6-year BMI, median (IQR), kg/m^2	25.8 (23.0-28.7)
Missing	224 (14)
2-year smoking status	
Current	127 (8)
Quit	201 (13)
Never	1013 (64)
Missing	251 (16)
6-year smoking status	
Current	156 (10)
Quit	238 (15)
Never	965 (61)
Missing	233 (15)
Subsequent surgery in ipsilateral knee	
None	1223 (77)
Scope	221 (14)
Revision ACL reconstruction	132 (8)
Total knee arthroplasty	16 (1)
Subsequent surgery in contralateral knee	
None	1310 (82)
Scope	78 (5)
ACL reconstruction	140 (9)
Total knee arthroplasty	3 (0)
Missing	61 (4)

[a]Values are expressed as n (%) unless otherwise indicated. AC, articular cartilage; ACL, anterior cruciate ligament; BMI, body mass index; BPTB, bone–patellar tendon–bone; IQR, interquartile range.

preoperative knee laxity was a significant independent risk factor for worse 10-year Marx scores.

Sport or level of competition, graft type (autograft BPTB, autograft soft tissue, allograft), medial collateral ligament or lateral collateral ligament lesions, medial meniscus lesions at the time of ACL reconstruction, and surgeon were not found to be significant risk factors.

Relative Strength of Association Between Predictor Variables and Outcomes

The relative strength of associations between predictor variables and IKDC, KOOS, and Marx scores at 10 years is shown in Figure A1 (available online). This figure shows the independent variables on the vertical axis and the relative portion of the variation in the outcome accounted for the given variable on the horizontal axis. This importance is measured by Wald chi-square statistics minus the degrees of freedom. The overarching result, regardless of

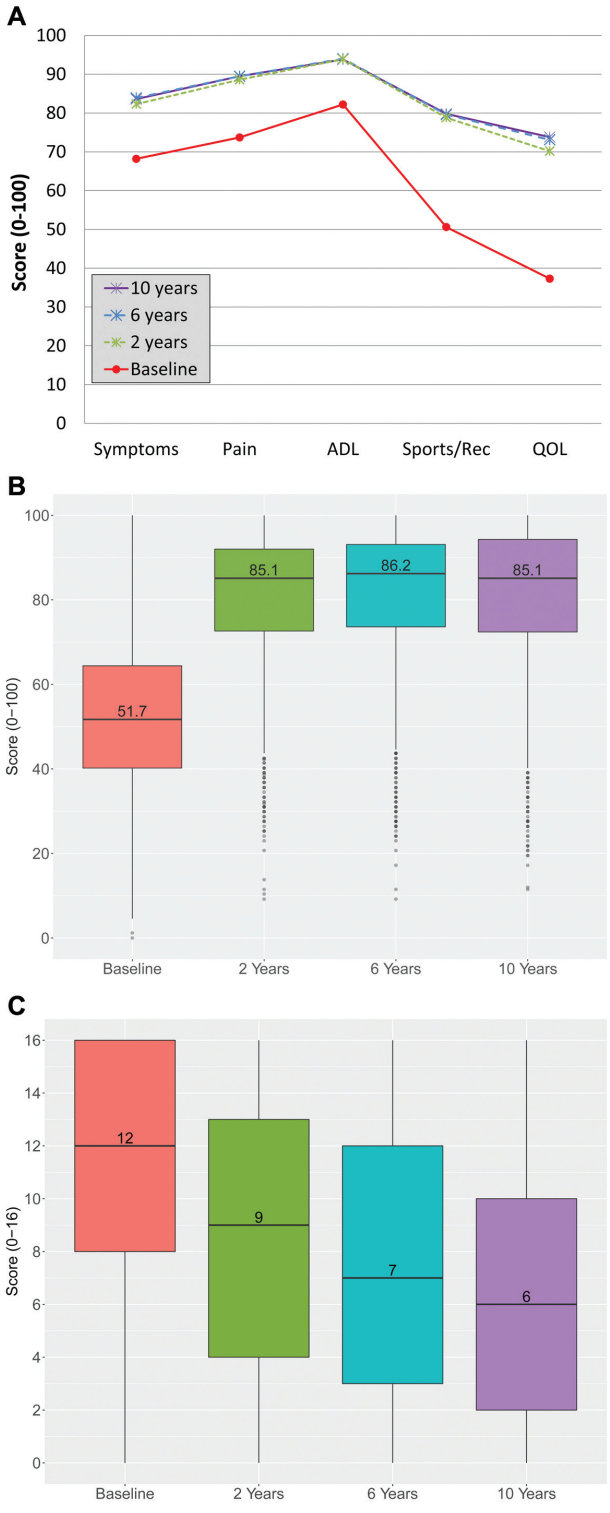

Figure 2. Ten-year patient-reported outcomes over time (population means): (A) Knee injury and Osteoarthritis Outcome Score (KOOS), (B) International Knee Documentation Committee (IKDC), and (C) Marx activity rating scale.

TABLE 2
KOOS, IKDC, and Marx Scores Over Time[a]

	Baseline	2 Years	6 Years	10 Years
KOOS symptoms	71 (57-82)	86 (75-93)	89 (75-96)	89 (75-96)
KOOS pain	75 (61-89)	92 (83-97)	94 (86-100)	94 (86-100)
KOOS activities of daily living	88 (72-96)	99 (93-100)	99 (93-100)	99 (93-100)
KOOS sports and recreation	50 (25-75)	85 (70-95)	85 (70-100)	90 (70-100)
KOOS QOL	38 (25-50)	75 (56-88)	75 (63-94)	75 (63-94)
IKDC	52 (40-64)	85 (72-92)	86 (74-93)	85 (72-94)
Marx	12 (8-16)	9 (4-13)	7 (3-12)	6 (2-10)

[a]Values are expressed as median (interquartile range). Scores range from 0 to 100, except for the Marx score, which ranges from 0 to 16. IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QOL, quality of life.

TABLE 3
Significant Predictors for Worse Outcomes 10 Years After ACL Reconstruction[a]

IKDC	KOOS Sports and Recreation	KOOS QOL	Marx
Low baseline IKDC score	Low baseline KOOS sports and recreation score	Low baseline KOOS QOL score	Low baseline Marx score (low baseline activity level)
Low baseline activity level		Low baseline activity level	
	Higher age	Higher age	Higher age
Female sex	Female sex		Female sex
Higher BMI	Higher BMI	Higher BMI	Higher BMI
Smoker	Smoker		
Lower education level			Lower education level
Revision ACL reconstruction	Revision ACL reconstruction	Revision ACL reconstruction	
Medial meniscus procedure before index ACL reconstruction	Medial meniscus procedure before index ACL reconstruction	Medial meniscus procedure before index ACL reconstruction Lateral meniscus procedure before index ACL reconstruction Lateral meniscectomy at the time of index ACL reconstruction	Medial meniscus procedure before index ACL reconstruction
AC lesion (grades 3/4) in medial compartment	AC lesion (grades 3/4) in medial compartment	AC lesion (grades 2/3/4) in medial compartment	
AC lesion (grades 3/4) in lateral compartment	AC lesion (grades 3/4) in lateral compartment	AC lesion (linear cracks/fracture lines) in lateral compartment	
AC lesion (grades 3/4) in patellofemoral compartment	AC lesion (grades 3/4) in patellofemoral compartment	AC lesion (grades 3/4) in patellofemoral compartment	
			High-grade laxity
Subsequent surgery in ipsilateral knee	Subsequent surgery in ipsilateral knee	Subsequent surgery in ipsilateral knee	

[a]AC, articular cartilage; ACL, anterior cruciate ligament; BMI, body mass index; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QOL, quality of life.

the outcome measure, is that the score recorded at baseline has a dominating influence on the score at 10 years after surgery.

DISCUSSION

The major findings of this study are that both short- and long-term IKDC and KOOS scores significantly improved after ACL reconstruction and that these outcome scores were maintained through 10 years. However, Marx scores steadily declined over time. There are also patient-specific risk factors that significantly influenced 10-year patient-reported outcomes. The risk factors that were found to negatively affect 10-year IKDC, KOOS, and Marx scores included lower baseline scores; higher BMI; being a smoker at baseline; history of a medial or lateral meniscus

procedure performed before index ACL reconstruction; undergoing revision ACL reconstruction; lateral meniscectomy performed at the time of index ACL reconstruction; grade 3 to 4 articular cartilage abnormalities in the medial, lateral, or patellofemoral compartments at the time of index ACL reconstruction; and undergoing any subsequent ipsilateral surgery after index ACL reconstruction. Unfortunately, we still had an insufficient sample size to model the interaction of meniscus injuries and treatment with articular cartilage damage in the same compartment.

An unanticipated positive result was that the 10-year IKDC and KOOS scores were similar to the 2- and 6-year scores (Figure 2, A and B). However, Marx scores steadily declined over time. This finding, along with previous work from others,[17,26,38] highlights the complexity of activity levels. As we age, we may tend to be less active. However, unacceptable symptoms may accelerate this relative inactivity, and some treatments may improve symptoms so much that they allow for higher activity levels.

The 10-year IKDC and KOOS QOL subscale identified nearly the same risk factors for worse outcomes except for 3 variables: the IKDC uniquely identified lower education, and the KOOS QOL subscale uniquely identified higher age and previous lateral meniscectomy as risk factors for a worse outcome. In our previous work at 2 and 6 years, the KOOS QOL subscores tracked most closely with the IKDC scores.[12] Thus, risk factors consistent across 2 "independent" measures are more likely to be more clinically meaningful. These risk factors should be explored to improve ACL reconstruction outcomes. Potential modifications to risk factors are to lower BMI, encourage smoking cessation, prevent/minimize subsequent ACL failure (revision ACL reconstruction), and identify optimal interventions for grade 3 or 4 articular cartilage lesions. A consistent observation was that a grade 3 or 4 articular cartilage lesion in the medial, lateral, or patellofemoral compartments at the time of index ACL reconstruction predicted worse 10-year IKDC and KOOS scores. The majority of these lesions were treated with chondroplasty/debridement, which negated our ability to model treatment options, including no treatment, debridement, and all various cartilage restorative procedures. Regardless, these patients should be counseled about a worse long-term prognosis. In the future, a larger sample size may allow us to model a more diverse set of articular cartilage treatment options.

Surprisingly, meniscus lesions and treatment performed at the time of index ACL procedure were not risk factors for 10-year outcomes as they were at 6 years.[12] The exception to this was that patients who underwent lateral meniscectomy at the time of index ACL surgery were found to have significantly lower KOOS QOL subscores at 10 years. Meniscus repair performed at the time of index ACL surgery did not affect 10-year outcomes. However, undergoing a medial meniscus procedure before index ACL reconstruction was an independent predictor of having significantly poorer IKDC, KOOS, and Marx scores at 10 years.

The risk factors identified for poor 10-year Marx scores included lower baseline activity level, older age, female sex, higher BMI, lower education level, having a medial meniscus procedure performed before index ACL reconstruction, and having high-grade preoperative knee laxity. These factors are similar to previously reported risk factors at 6-year follow-up.[12]

To assess a patient's expected outcome, the entire spectrum of potential risk factors must be simultaneously evaluated either in a nomogram or risk calculator. An online risk calculator is available at the Cleveland Clinic's website (http://rcalc.ccf.org) for physicians and patients to evaluate their expected 10-year outcomes with baseline, 2-year, and 6-year data. The R^2 value provides a measure of the variability in the 10-year IKDC, KOOS, and Marx scores and was found to consistently improve from baseline to 2 years to 6 years. Thus, updating the baseline factors with current IKDC, KOOS, and Marx scores, along with a patient's current BMI, smoking status, and subsequent surgery information on either knee, would provide more accurate estimates.

The main limitations of this study are that we did not perform on-site measures (such as clinical examinations, imaging, or other instrumented-based measures), and our sample size was too small to model the interaction between meniscus and articular cartilage lesions within the same compartment. The effect of treatment on grade 3 or 4 articular cartilage lesions could also not be assessed, given that the majority of these lesions were treated via chondroplasty. The lack of structural imaging (radiology or magnetic resonance imaging) to confirm the status of the articular cartilage and meniscus at $\geq$10 years after surgery is an area of future interest. An additional study limitation is the acknowledgment that baseline Marx scores likely reflect a patient's preinjury state, whereas the baseline KOOS and IKDC scores represent the ACL-deficient postinjury/presurgery state. Regarding activity levels over time, it remains unclear whether patients modified their activity level to one that allowed for acceptable symptoms.

CONCLUSION

Patients were able to perform sports-related functions and maintain a relatively high knee-related QOL 10 years after ACL reconstruction, although activity levels markedly declined over time. Multivariable analysis identified several key modifiable risk factors that significantly influenced the outcome. This information can be helpful to physicians counseling patients' expectations of outcomes after ACL reconstruction. Finally, intervention strategies for the potentially modifiable risk factors reported in this study should be developed and studied to assess their potential to improve outcomes after ACL reconstruction.

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