Published in final edited form as:
Am J Sports Med. 2011 February ; 39(2): 348–359. doi:10.1177/0363546510383481.

The Prognosis and Predictors of Sports Function and Activity at Minimum Six Years after ACLR: A Population Cohort Study

Kurt P. Spindler, MD[1], **Laura J. Huston, MS**[1], **Rick W. Wright, MD**[2], **Christopher C. Kaeding, MD**[3], **Robert G. Marx, MD, MSc**[4], **Annunziato Amendola, MD**[5], **Richard D. Parker, MD**[6], **Jack T. Andrish, MD**[6], **Emily K. Reinke, PhD**[1], **Frank E. Harrell Jr, PhD**[7], **MOON Group***, and **Warren R. Dunn, MD, MPH**[1,8]

[1]Vanderbilt Orthopaedic Institute, Vanderbilt University Medical School, Nashville, TN

[2]Department of Orthopaedic Surgery, Washington University School of Medicine at Barnes-Jewish Hospital, St. Louis, MO

[3]Department of Orthopaedic Surgery, The Ohio State University School of Medicine, Columbus, OH

[4]Sports Medicine Division, Hospital for Special Surgery, New York, NY

[5]Department of Orthopaedic Surgery, University of Iowa School of Medicine, Iowa City, IA

[6]Department of Orthopaedic Surgery, Cleveland Clinic Foundation, Cleveland, OH

[7]Department of Biostatistics, Vanderbilt University Medical School, Nashville, TN

[8]Health Services Research Center, Vanderbilt University Medical School, Nashville, TN

[9]Department of Orthopaedic Surgery, University of Colorado School of Medicine, Denver, CO

Abstract

Background—The predictors of ACL reconstruction outcome at six years as measured by validated patient based outcomes instruments are unknown.

Hypothesis—We hypothesize that certain variables evaluated at the time of ACL reconstruction will predict return to sports function (as measured by the IKDC and KOOS Sports and Recreation subscale), knee-related quality of life (as measured by the KOOS Knee Related Quality of Life subscale), and activity level (as measured by the Marx scale). Potential predictor variables include demographics, surgical technique and graft choice for ACL reconstruction, and intra-articular injuries and treatment.

Study Design—Prospective cohort, Level 1

Methods—All unilateral ACL reconstructions from 2002 currently enrolled in the Multicenter Orthopaedic Outcomes Network (MOON) cohort were evaluated. Patients preoperatively completed a series of validated outcome instruments, including the IKDC, KOOS, and Marx activity level. Physicians documented intra-articular pathology, treatment, and surgical techniques utilized at the time of surgery. At 2 and 6 years postoperatively, patients completed the same validated outcome instruments.

Corresponding Author: Kurt P. Spindler, MD, Vanderbilt Sports Medicine, 4200 Medical Center East, South Tower, 1215 21st Ave South, Nashville, TN 37232-8774, P: (615) 343-1685, F: (615) 322-7126, kurt.spindler@vanderbilt.edu.
***MOON Group includes**: Angela Pedroza, MPH3, Angel Q. An, MS,7, Leah Schmitz, MPAS, PA-C,6, Eric C. McCarty, MD,9, Brian R. Wolf, MD, MS,5, Morgan H. Jones, MD, MPH,6, Matthew J. Matava, MD,2, David C. Flanigan, MD,3, Robert H. Brophy, MD,2, Armando F. Vidal, MD,9

Presented at the 2010 Annual Meeting of AOSSM

Results—Follow-up was obtained on 395/448 (88%) at 2 years and 378/448 (84%) at 6 years. The cohort was 57% male with median age of 23 at the time of enrollment. The ability to perform sports function was maintained at six years (IKDC T_2 = 75, T_6 = 77; $KOOS_{sports/rec}$ T_2 = 85, T_6 = 90). The Marx activity level continued to decline from baseline (T_0 = 12, T_2 = 9, T_6 = 7). Revision ACL reconstruction and use of allograft predicted worse outcomes on the IKDC and both KOOS subscales. Lateral meniscus treatment, smoking status, and BMI at T_0 were each predictors on two of three scales. The predictors of lower activity level were revision ACL reconstruction and female sex.

Conclusions—Six years after ACL reconstruction, patients are able to perform sports-related functions and maintain a high knee-related quality of life similar to their two year level, although their physical activity level (Marx) drops over time. Choosing autograft rather than allograft, not smoking, and having normal BMI are advised to improve long-term outcomes.

Keywords

ACL reconstruction; sports function; activity; KOOS; IKDC; Marx Activity Scale; six-year follow-up

INTRODUCTION

The prognosis and predictors of ACL reconstruction (ACLR) outcome at six years as measured by modern validated patient based outcomes instruments and assessed by multivariable analysis are unknown. Knowing prognostic information would be valuable in physician counseling of patients regarding likely results of ACLR. Identification of modifiable predictor(s) (i.e. risk factors) would provide future interventions to improve ACLR in those projected to have worse outcomes. The development of validated patient-reported outcome instruments for an athletically active population established methods of measuring and quantifying patient activity, symptoms, function, and quality of life. This MOON study is a consortium network established to follow a population cohort of sufficient size in order to perform multivariable analysis for identifying prognosis and modifiable predictors for both short and long-term outcomes following an ACLR.

Other groups and studies have looked at outcomes in ACLR patients at a minimum of 5 years after surgery. Eighteen[2, 3, 8, 9, 12, 19, 24, 25, 29, 34, 36, 41, 47, 48, 51, 52, 55, 56] level I or II studies provide the highest evidence for prognosis and predictors of greater than 5 years after ACLR. However, no previous study contained all of the following: 1) pre- and postoperative administration of outcome instruments, 2) modern validated sports-related instruments, 3) greater than 80% follow-up, and 4) multivariable analysis. Multivariable analysis is necessary in order to be able to see how factors affect outcome, and how important each is, in context together. In cohort studies, where variables cannot be randomly and equally distributed, this is the only way to account for uneven distributions of factors and potential confounders.[18] Risk factors that are likely to be relevant to outcomes of ACLR include age, gender, mechanism of injury, body mass index (BMI), concomitant medial and lateral meniscus tears and treatment, articular cartilage injuries and treatment, ACLR technique and graft choice. Large sample sizes with excellent follow-up are necessary for this type of analysis. The largest sample size of a previously reported randomized controlled trial had an enrollment of 225[34] which limits risk factor analysis. A previous cohort study using multivariable analysis had 69% follow-up and results weakened by no preoperative validated outcomes measured for each subject. [52]

Outcomes evaluation after ACLR can be broadly divided into two categories. Traditionally measurements that are performed onsite in a limited number of patients (usually around 100) are used to differentiate results between treatments based on physical examination, instrumented knee laxity, and imaging (primarily standard radiographs). Recently, partly as a result of an increasing focus on evidence-based medicine (EBM), patient-reported outcome questionnaires have been psychometrically designed and clinically validated. Several research studies have compared the validity of patient-reported outcome measures to clinician-based measures (i.e. clinical assessment) such as range of motion, knee laxity, and physical examination.[5, 10, 40, 50] These tools were designed to capture the impact of a knee injury and treatment on patients' activities and sports function. Included in our present study are the International Knee Documentation Committee (IKDC) questionnaire,[14] the Knee injury and Osteoarthritis Outcome Score (KOOS),[45] and the Marx Activity Level,[28] which are designed for self administration on an athletically active population. Their validity,[31] reliability,[30] responsiveness to clinical change,[45] and minimal clinically meaningful differences have been documented (IKDC[13-15, 46]; KOOS[26, 37, 42-45]; Marx[7, 28, 32]). The IKDC is designed as a tool to evaluate knee injuries.[14] The KOOS includes 5 subscales; of particular interest are the Sports and Recreation subscale ($KOOS_{sports/rec}$) and the Knee Related Quality of Life subscale ($KOOS_{krqol}$), as these are particularly aimed at evaluating relevance of functional disability of the knee in a younger (not elderly) population and are reported to change the most after surgery.[45] The Marx activity level is useful for differentiating those with high demands on their knees, usually due to participation in sports activities, from those people who are more sedentary and thus have less demand on their knees.[28]

Our multicenter group was initiated in 2002 to prospectively enroll sufficient sample size, be generalizable, and encompass a timeliness of ACLR treatments in order to identify prognosis and modifiable predictors of validated outcomes through multivariable analysis. The purpose of this prospective longitudinal cohort study was to investigate patient-reported outcomes and predictors for sports function, knee-related quality of life, and physical activity level at an intermediate term (6 years post ACL reconstruction).

We address three questions in the current study. (1) What are the predictors of sports function and activity as measured by the IKDC and $KOOS_{sports/rec}$ subscales? (2) What are the predictors of knee-related quality of life as measured by the $KOOS_{krqol}$ subscale? (3) What are the predictors of return to physical activity level, as measured by the Marx Activity Level? These results would aid physician counseling regarding an individual patient's prognosis after ACLR, provide highest level of evidence for physician decision making, and identify future modifiable risk factors to improve ACLR outcomes.

MATERIALS AND METHODS

Study Design and Setting

This MOON group began on January 1, 2002 as a consortium of six sites with eight physicians to conduct a multicenter population based cohort study following subjects after ACLR. One university serves as the data-coordinating center for the study, and is responsible for entering baseline data and for collecting follow-up data on all subjects. IRB approval was obtained from all participating centers.

Participants

All subjects having ACLR at participating sites in 2002 (from 01/01/02 to 12/31/02) were invited to enroll in the study (Figure 1 -- Flow Diagram of Study Cohort). There were 8% (39/496) enrollment failures and 9 simultaneous bilateral cases excluded, leaving a final baseline cohort of 448 unilateral ACLRs.

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Data Sources and Measurement

Following documentation of informed consent, participants complete a 13-page questionnaire previously described examining self-reported demographics, injury characteristics, sports participation history, and health status. Regarding the latter, the following validated instruments are included: the KOOS, which includes the Western Ontario and McMaster Universities Arthritis Index (WOMAC), the IKDC, and the Marx activity scale. This is typically completed the day of surgery; otherwise, it is completed within two weeks of the surgery date.

Surgeons complete a 49-page questionnaire which includes sections on past history of knee injury and/or surgery on both knees, the results of the general knee examination done under anesthesia, the grade of all intraarticular injuries and treatments to the meniscus and articular cartilage, and the surgical technique used for the ACLR. Classification of the general knee examination findings follows the recommendations of the updated 1999 IKDC guidelines.[14, 16] Surgeon documentation of articular cartilage injury is recorded on the modified Outerbridge classification.[1, 27] Meniscus injuries are classified by size, location and partial versus complete tears, and treatment is recorded as not treated, repair, or extent of resection.[4] Patients are given a standardized evidence-based rehabilitation protocol for ACLR rehabilitation.

Completed data forms are mailed from the participating sites to the data-coordinating center. Data from both the patient and surgeon questionnaires are scanned with Teleform™ software (Cardiff Software, Inc., Vista, CA) utilizing optical character recognition to avoid manual data entry, and the scanned data is verified and then exported to a database. A series of logical error checks is subsequently performed prior to data analysis.

Follow-up

Six-year patient follow-up was obtained by mail using the same outcome questionnaire completed at baseline. The questionnaire documented any additional surgeries subsequent to the index ACLR performed in 2002. Patient follow-up was initiated on 01/01/08 and completed on 10/01/09.

Quantitative Variables and Statistical Methods

Patient reported outcomes treated as continuous dependent variables were: 1) $KOOS_{krqol}$ subscale, 2) $KOOS_{sports/rec}$ subscale, 3) IKDC, and 4) Marx activity scale. The IKDC and KOOS subscales are transformed to a 0 to 100 score where 100 constitutes the best score, and 0 is the worst score. The Marx activity level is scored on a scale from 0-16, where 16 constitutes the highest activity level and 0 is the lowest.

Several categorical variables were reduced due to low prevalence categories. Articular cartilage variables were grouped by compartment (medial, lateral, anterior), and severity of chondromalacia was dichotomized into positive or negative, with grade II chondromalacia or higher (i.e. worse) being positive for chondrosis in that compartment. Lateral collateral ligament (LCL) injury and medial collateral ligament (MCL) injury were dichotomized from severity of grade into yes or no.

To evaluate the association of baseline predictors with knee function, multivariable linear multiple regression models were fit using the continuous scores of the KOOS subscales, IKDC score, and the Marx activity level as the dependent variables. Independent variables included in these models were current age, sex, race, baseline marital status, baseline smoking status, baseline body mass index (BMI) from self-reported height and weight, whether or not a “pop” was heard at the time of injury, medial and lateral meniscus status

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and treatment, collateral ligament injury, chondrosis in the medial, lateral, and anterior compartments, graft type, and type of reconstruction (see Table 3, column 1 [variables] and column 3 [comparison]). Therefore, in our multivariable analysis each of the independent variables studied (i.e. age, preoperative Marx activity, gender, etc.; see Table 1) were controlled for in order to identify variables that significantly determined the patient-reported outcome scale (KOOS, IKDC, Marx). Over time, as subjects age, other measured exposures may change as well such as smoking status and BMI. To that end, all regression models were fit using baseline (T_0) smoking and BMI as well as current (T_6) smoking and BMI. The former approach is to determine if a baseline exposure predicts an outcome regardless of whether a subject's exposure status has changed, while the later approach is a means of adjusting for the current exposure status which is the way age was handled in the models. The clinically meaningful effect based on their responsiveness is approximately 11 points for the IKDC and 8 points on the KOOS.[13, 42] The clinically meaningful effect of the Marx scale has not been determined, but consensus believes it is approximately 2 points. A nomogram was constructed to display the relationship of predictor variables and the outcomes. A nomogram can be used to estimate the mean response for individual patients as well as show the relationship between the different predictor variables and how this affects the response.

We did not assume linearity of covariate effects but only assumed smoothed relationships using restricted cubic regression splines. Missing values of predictor variables were imputed using multiple imputation incorporating predictive mean matching and flexible additive imputation models as implemented in the *aregImpute* function available in the Hmisc package in R. Data reduction methods used to preserve degrees of freedom in models included pooling of low prevalence categories, variable grouping, and hierarchical clustering (using squared Spearman rank correlation coefficients as the singularity matrix) to identify colinear variables that could be deleted from the model. Statistical analysis was performed with free open source R statistical software (www.r-project.org).

RESULTS

Participants

From 1/01/02 to 12/31/02, 448 subjects met the inclusion criteria of having a unilateral ACLR and are included in our final enrollment (Figure 1). Of the initial 448 subjects, repeat questionnaires were obtained on 395 subjects (88%) at two years (median = 2.08 yrs, 25^{th} percentile = 2.02 yrs, 75^{th} percentile = 2.19 yrs) and 378 subjects (84%) at 6 years (median = 6.7 yrs, 25^{th} percentile = 6.6 yrs, 75^{th} percentile = 6.8 yrs).

Baseline demographic and clinical characteristics of the cohort that were analyzed at six years are provided in Table 1. The median age of the female cohort at the time of their ACL reconstruction was 20 years, while in males it was 26 years (Table 1). Seventy-eight percent (290/372) reported that they were non-smokers at the time of their ACL reconstruction. The cohort was comprised of 92% primary reconstructions and 8% revision candidates. The participating surgeons opted for bone-patellar tendon-bone grafts 43% of the time and hamstring grafts 48% of the time (semi-tendinosis + gracilis=32%; semi-tendinosis only=16%), utilizing an arthroscopic, one-incision approach 72% of the time. The surgeons used autografts 84% of the time and allografts16%. When an allograft was used, they originated from one of four potential tissue banks. Just over half of the allografts were irradiated with less than 2.5 Mrad. Concomitant surgical pathology and treatments are summarized in Table 1. There were no drastic changes in smoking habits or BMI over the six-year follow-up period. Less than 9% of subjects changed smoking status from current to quit/never or vice versa, and the median change in BMI was only an increase of 3%.

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Changes in IKDC, KOOS, and MARX Scales over Time

The data was found to be non-normally distributed, and hence, medians and inter-quartile ranges are subsequently presented. The median with 25% and 75% quartiles for each of the outcome measures at baseline (T_0), 2 years (T_2), and 6 years (T_6) are shown in Table 2. The IKDC and KOOS at two years demonstrate a large improvement which is maintained at six-year follow-up. In contrast, the Marx activity level continues to decline over time.

Predictors of Outcome

Multivariable analysis was used to determine which baseline factors are significant predictors of patient-reported outcome six years after their ACL reconstruction. Additionally, this analysis was used to establish a patient-specific predictive model of the IKDC, KOOS, and Marx activity level scores. The candidate predictor variables, time of measurement, and levels of significance are listed in Table 3, and the significant predictors are summarized in the online appendix (Table A-1). For every model, the T_0 score was a significant predictor of the T_6 score. Revision ACLR was a significant predictor of poorer outcomes on all metrics (i.e., lower IKDC and KOOS subscale scores, and lower activity level). The use of an allograft was found to be a significant predictor of poorer IKDC and KOOS ($KOOS_{sports/rec}$, $KOOS_{krqol}$) outcomes. Baseline BMI was a significant predictor of the IKDC and $KOOS_{sports/rec}$ at six years, while baseline smoking status was a predictor of the IKDC at six years. When the IKDC and $KOOS_{sports/rec}$ models were repeated using the current (T_6) BMI and smoking status, the results were similar, i.e., current BMI and smoking status were associated with the outcome having significant p-values similar to those listed in Table 3 for baseline BMI and smoking status. There were only two slight differences in the results of the models when the current BMI and smoking status were used instead of the baseline variable, and these are denoted in Table 3. For example, for the $KOOS_{krqol}$ model baseline smoking status was not a significant predictor ($p = 0.102$) of outcome, however, there was a significant association between current smoking status and $KOOS_{krqol}$ scores ($p = 0.034$). Lateral meniscus status was significant on the two KOOS subscales ($KOOS_{sports/rec}$, $KOOS_{krqol}$). The Marx activity scores were lower for subjects who were female and had undergone revision ACL. To evaluate if these significant differences are clinically meaningful, the 95% confidence intervals for each value for each outcome measure are displayed in Figure 2 in the text and in Figures A-1, A-2, and A-3 in the online appendix. These figures display the comparison as negative (delineating a worse outcome score) or positive (better outcome score) with the mean (+/- 95% CI) for IKDC, two KOOS subscales, and activity level. The clinically meaningful difference is represented by a green line for better outcomes and a red line for worse outcomes on each graph.

For the IKDC, only revision ACLR reached a clinically meaningful difference (online appendix Figure A-1). For the $KOOS_{sports/rec}$ subscale, revision ACLR, use of allograft, and lateral meniscus status are both statistically significant and clinically relevant differences. For the $KOOS_{krqol}$ subscale, revision ACLR, use of allograft, lateral meniscus status, as well as smoking status are all individually meaningful (Figure 2). Using 2 points as an estimate of clinically relevant change in activity level, both being female and undergoing revision ACLR may portend a clinically meaningful decline in activity level.

The final models are presented as nomograms, IKDC (online appendix Figure A-4), KOOS (Figure 3 in the text and online appendix Figure A-5), and Marx (online appendix Figure A-6), can be used to predict outcomes on future subjects. To determine a specific patient outcome at six years, identify that patient's status for each individual predictor listed on the left hand column, then use the top line to get the corresponding points for each predictor, and sum them. Then, this total score for all the risk factor variables is transferred to the total points axis, and the patient's predicted outcome can be estimated by the direct vertical correspondence from total points axis to the bottom line on the nomogram. The number of points assigned for an individual predictor is proportional to strength of the association with the outcome. For example, a patient undergoing primary ACLR (~98 points) with an autograft (~55 points) who has never smoked (~52 points) and has a BMI of 15 (~100 points), letting the other predictors default to categories contributing 0 points, would have 305 total points, corresponding to a predicted $KOOS_{krqol}$ of 65. This is in contrast to a patient undergoing revision ACLR (0 points) with allograft (0 points) who also has never smoked (~52 points) and has a BMI of 15 (~100 points). This patient would have 152 total points, corresponding to a predicted $KOOS_{krqol}$ of 40. This represents a clinically relevant difference of 25 points.

DISCUSSION

This is the most comprehensive multivariable analysis of a prospective multicenter cohort of sufficient size and rate of follow-up to demonstrate that variables measured at the time of ACLR (revision ACLR, allograft, lateral meniscus status, BMI, smoking status) are predictors of six-year sports activity and function as measured by the IKDC, KOOS, and Marx activity level outcome instruments. Each of these predictors (variables) is modifiable except for revision ACLR. Thus, avoiding allograft as a graft choice, leaving "stable" partial and complete lateral meniscal tears alone, not smoking, and maintaining a relatively lower BMI could improve ACLR outcomes. In contrast to the modifiable predictors for IKDC and KOOS, the predictors of declining Marx activity (revision ACLR, and female sex) are not modifiable. However, despite the decline in activity level, the population medians of the cohort remain at the same two-year IKDC and KOOS subscale levels.

The maintenance of IKDC and KOOS outcomes at six years was an unexpected result. We anticipated a decline from the two-year outcomes in all three scales, which were clearly not observed. These results indicate that our present technique of ACLR is durable at the six-year mark. The potential role of declining Marx activity level to reducing knee-related stress and therefore preserving joint health, as would be measured in the future by IKDC and KOOS, is unknown. While it may take more time before declination of knee function is observed in this cohort, the similar group score at two and six years for the validated, patient-reported outcomes provide a good prognosis to be conveyed to our patients preoperatively.

A comprehensive systematic review by Oiestad *et al.* evaluated knee OA after ACL reconstruction and found that concomitant meniscus tears were associated with radiographic OA using univariate analysis. [35] Unfortunately, the authors were unable to perform a meta-analysis due to the heterogeneous classification systems defining OA, the lack of inter-rater agreement, and lack of multivariable analysis. [35] They concluded that future studies that define both the prognosis and predictors of OA after ACL reconstruction should be prospective with clearly defined aims and endpoints, include clear inclusion and exclusion criteria, utilize a common radiographic classification system with reliability data and independent blinded examiner, the rehabilitation protocol should be reported, and that regression analysis be used to evaluate risk factors.[35] We believe that the majority of these points characterize the current cohort. The strengths of this study include the application of multicenter prospective longitudinal assessment utilizing the same validated outcome measures over time and accruing greater than 85% follow-up, which is the preferred research design (level I) to evaluate prognosis and modifiable predictors through multivariable analysis.[35] In clinical practice, patients have many different combinations of potential predictors that can be independently scaled and then summed to yield a patient-specific result. This result can be obtained through use of an equation where individual values are entered or by the use of a nomogram. Patients present with an almost infinite combination of these variables and an individual's specific outcome now can be estimated. Alternatively, an individual surgeon can avoid allograft ACLR graft, counsel patients on smoking cessation and maintaining healthy weight, and leave stable lateral meniscal tears alone in an effort to improve the outcomes of his or her patients. The multicenter nature of this consortium lends the results to be generalizable to patients treated by fellowship-trained sports medicine physicians.

There are several weaknesses in this analysis. Despite being the largest prospective cohort utilizing multivariable analysis for ACLR outcomes, our sample size is still too small to provide a more detailed analysis to the injuries involving the articular cartilage and meniscus. Due to the relatively low frequency of chondromalacia grades II, III, and IV, these are grouped together in the current analysis. Ideally, as additional subjects are prospectively enrolled and evaluated at six years, our modeling can be divided into more clinically applicable chondromalacia grades (II vs. III vs. IV). Previous inter-rater agreement[27] has shown our ability to divide by individual grade. Likewise, meniscus excisions are currently all grouped together instead of by stratifying by one-third, two-thirds, or whole which has greater clinical meaning. Another weakness is the lack of important complimentary information gathered by clinician observation and testing of knee joint laxity, physical characteristics, and radiologic images of the ACL reconstructed knee. The logistical and financial requirements of onsite follow-up impede performing sufficiently powered multivariable analysis on equally important patient-reported outcomes (such as sports function, knee quality of life, and activity level) specifically designed to follow much larger cohorts. However, information regarding the principal outcomes that influence a surgeon's and patient's decision making -- clinical failure, restoration of functional stability, activity level and sports participation or function, pain, reoperation, and function in activities of daily living (ADL) can be gathered through the use of validated questionnaires and patient interview.

Several prospective and retrospective studies have explored predictors or risk factors for ACLR through a variety of statistical methods. Recently a randomized controlled trial (RCT) at ten-year follow-up showed no difference between autograft hamstring and patellar tendon in clinical assessment (laxity, hop, isokinetic strength), radiographic osteoarthritis or patient-reported outcomes (Cincinnati and Lysholm).[11] Likewise an RCT between neuromuscular versus traditional strength rehabilitation did not demonstrate a difference for Cincinnati or Lysholm at 2 years.[39] Similarly several studies failed to demonstrate a correlation between clinical assessments and validated patient-reported outcomes (KOOS, SF-36, IKDC).[21, 23, 33, 49] However, two studies found several clinical assessments significantly affected ACLR outcome.[38, 51] Decreased range of motion in knee extension, meniscectomy, presence of articular cartilage damage, and time from injury to surgery all led to significantly worse IKDC outcomes and radiologic OA.[51] However, a 7-10 year longitudinal cohort study on both patellar tendon and hamstring tendon ACLR did not find extension range of motion as a risk factor for radiologic OA.[38, 41] However, they did observe that patients undergoing a patellar tendon autograft ACLR had more radiologic OA. Analogous to our predictors of BMI and smoking, several prior studies have likewise demonstrated they are risk factors for patient-reported outcomes.[17, 22, 52] Also in agreement with our finding, age and gender were not risk factors for patient-reported outcomes.[33, 41] In our multivariable analysis, education level, prior meniscectomy, and medial meniscus status were not risk factors which have been previously shown by others.[6, 22, 23, 49, 52, 54] In addition, other factors not explored in our model that have been shown to be risk factors include preoperative quadriceps strength,[6] knee self-efficacy scale (KSES),[53] pivot shift,[21] and patient satisfaction.[20] We believe our study was underpowered to test the effect of meniscus and/or articular injury and treatment with a single year's cohort. When a second year is followed, we expect adequate sample size to evaluate.

The multivariable analysis most similar to our analysis found a pop at injury (KOOS, IKDC, Lysholm), no change in educational level (KOOS and IKDC), and weight gain greater than 15 pounds (IKDC) to be predictors of their respective outcomes.[52] Our analysis found high baseline BMI to be predictive of poorer IKDC and $KOOS_{sports/rec}$ subscale scores. However, just as in the prior study, the individual differences in outcome were below a clinically meaningful difference for each outcome measure. We did not find a pop heard at the time of injury to be significant in any outcome. The prior study did not evaluate smoking, allograft, or revisions, and the current study did not evaluate educational level. However, both studies found age and gender were not related to outcomes.

The major role that revision vs. primary ACLR has on every outcome measure clearly supports the role of additional research aimed at understanding and improving outcomes after revision ACLR. Thus, the importance of a multicenter study of revision ACL reconstructions is once again confirmed. Multivariable analysis of a large group of revision ACL reconstructions will be necessary to determine the predictors in revision surgery for these poor outcomes. Since revision ACLR has such a large negative effect on outcome even when controlling through multivariable analysis for articular cartilage and meniscus injuries and treatment, every effort should be made for secondary prevention of ACLR graft tear.

In conclusion, our MOON results found that choosing an autograft would significantly and in a clinically meaningful way improve sports function (IKDC, $KOOS_{sports/rec}$) and knee-related quality of life ($KOOS_{krqol}$), whilst not smoking is associated with better IKDC and $KOOS_{krqol}$ scores, and a lower BMI is predictive of better IKDC and $KOOS_{sports/rec}$ scores. The actual improvement in outcomes can be predicted for each outcome by use of the respective nomograms. Unfortunately, no modifiable predictors were identified for the declining Marx Activity scale. Since revision ACLR has the most powerful negative effect on outcome, secondary prevention strategies should be explored and tested.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

The project described was partially funded by Grant Number 5R01 AR053684 (KPS) and Number 5K23 AR052392-04 (WRD) from the National Institutes of Health/National Institute of Arthritis and Musculoskeletal and Skin Diseases, and by Grant Number 5 U18-HS016075 (RGM) from the Center for Education and Research on Therapeutics (Agency of Health Research and Quality). The project was also supported by the Vanderbilt Sports Medicine Research Fund. Vanderbilt Sports Medicine received unrestricted educational gifts from Smith & Nephew Endoscopy and DonJoy Orthopaedics.

The authors offer a special thanks to Robert S. Dittus, MD, MPH, Director of the Vanderbilt Health Services Research Center, for his continuing invaluable mentorship in establishing and guiding the MOON Group.

Additionally the authors thank the following Research Coordinators and Analysts from the MOON sites whose tireless efforts made this project possible: Lynn Borzi, Julia Brasfield, Lisa Hegemier (Cleveland Clinic Foundation); Carla Britton (University of Iowa); Paula Langner (University of Colorado); Linda Burnworth, Amanda Haas (Washington University in St. Louis); and Patrick Grimm (Hospital for Special Surgery); John Shaw, Suzet Galindo-Martinez, Zhouwen Liu, Thomas Dupont, and Erica Scaramuzza (Vanderbilt University); and Lynn S. Cain (Vanderbilt) for editorial assistance with this manuscript.

The authors acknowledge the original contributions in the development of MOON by John A. Bergfeld, MD, and Alexandra Kirkley, MD, FRCS (C), MSc.

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What is known about the subject? Univariate analysis from systematic reviews indicates meniscus loss is a risk factor for radiographic OA.

What does this study add to existing knowledge? Risk factors were identified through multivariable analysis of the IKDC, KOOS, and Marx at 6 years after ACL reconstruction.

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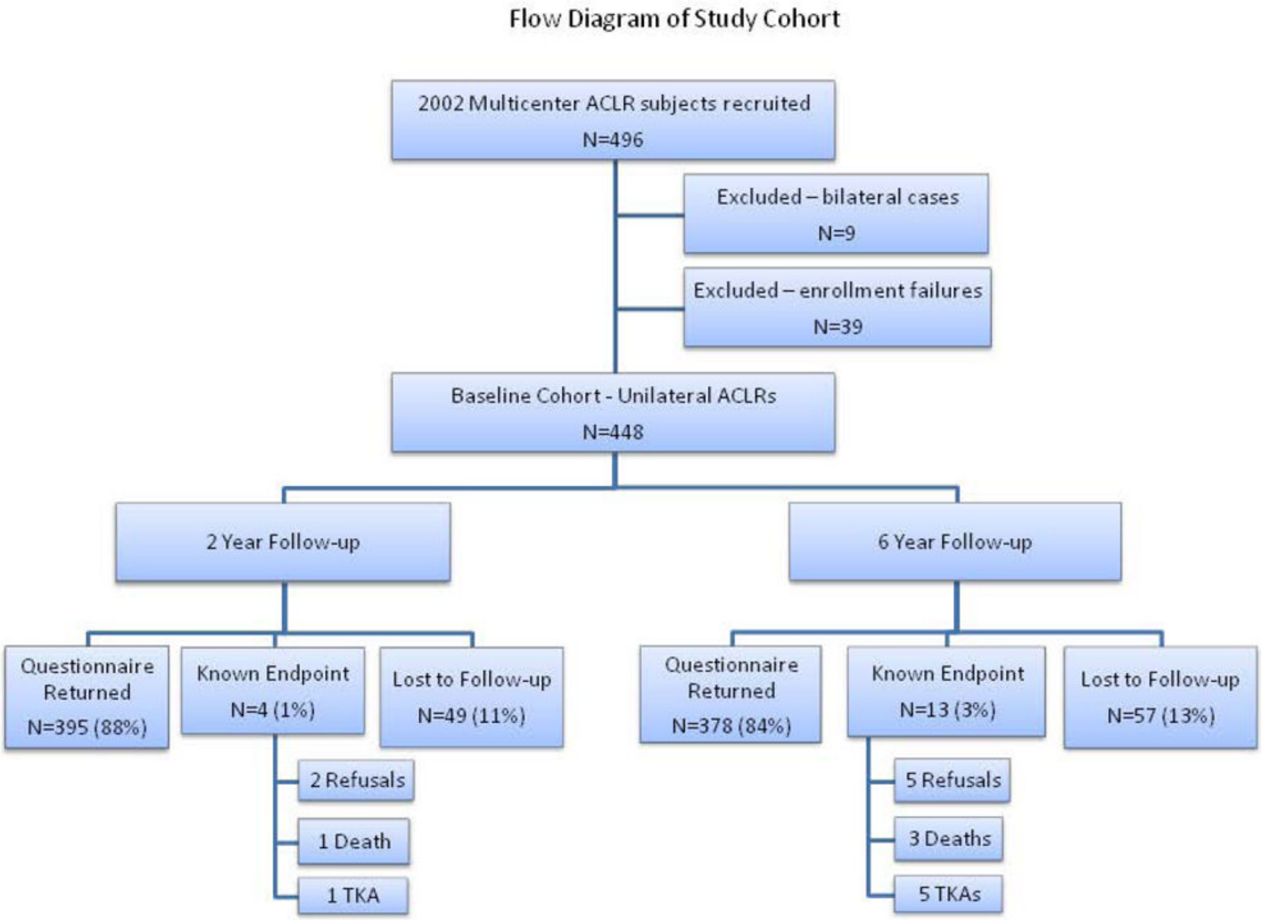

Figure 1.

Flow Diagram of Study Cohort. All ACL reconstruction patients were enrolled during calendar year 2002. The follow-up for each time interval, either minimum of two or six years, for the validated patient-reported outcome questionnaires is indicated as returned. In addition, the lost-to-follow-up patients with known results (i.e. end points) such as death, subsequent total knee arthroplasty (TKA), and refusals are shown.

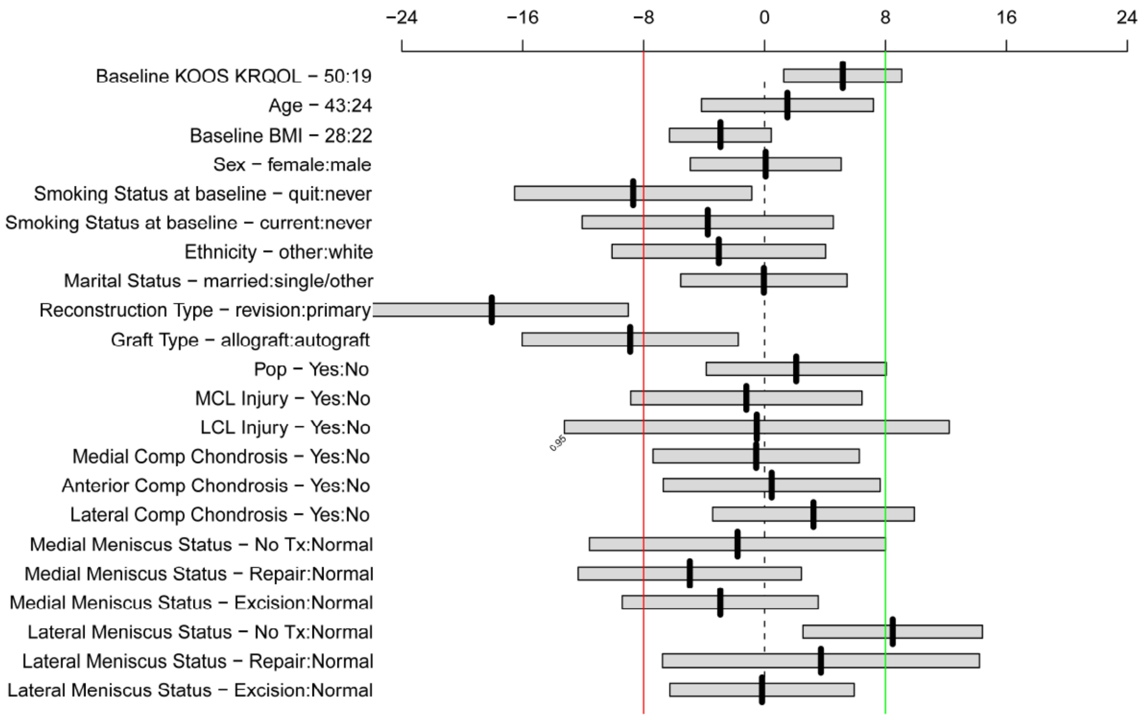

Figure 2.

KOOS: Knee Related Quality of Life Results of Potential Predictor Variables (mean +/- 95% CI). For each potential predictor variable listed and the comparison, the change either positive (better outcome) or negative (worse outcome), is shown. Each result is the mean plus or minus the 95% confidence interval. A result is statistically significant if the 95% CI does not cross the zero line. A result is felt to be clinically meaningful if the mean is outside the red and green lines. These lines represent the positive (green) and negative clinically meaningful difference based on development of outcome instruments.

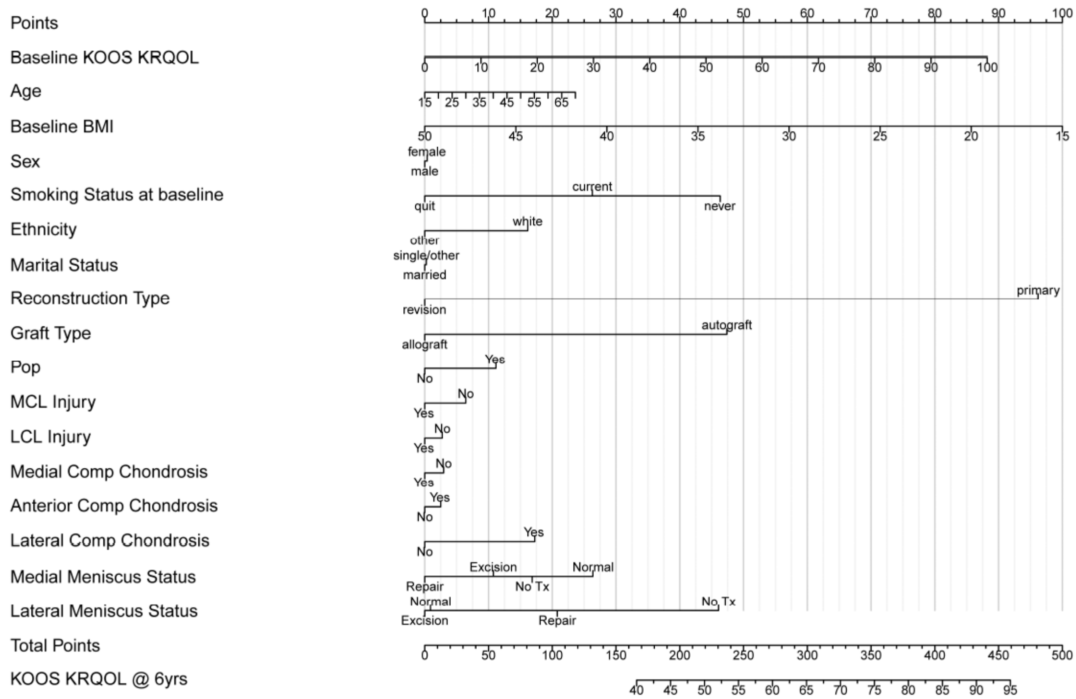

Figure 3.

KOOS: Knee Related Quality of Life Patient-Specific Results at Six Years. The nomogram is used to predict a patient-specific outcome score at six years based on summing the individual point total for each variable on the left. For each variable the patient's result is indicated and the points based on the top point scale are recorded. Then the sum of points is placed on the total points line on the bottom. After the total points are marked, you read the outcome score predicted at six years below.

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Table 1

Baseline patient and surgical characteristics

	N	Female N = 174	Male N = 201
Age (years)	375	$_{17.0}$ 20.0 $_{34.5}$ (25.4±11.4)	$_{19.0}$ 26.0 $_{36.0}$ (28.4±10.9)
BMI	368	$_{21.1}$ 22.8 $_{26.2}$ (24.1± 4.4)	$_{23.6}$ 25.8 $_{28.1}$ (26.1± 3.9)
Smoking Status	372		
never		82% (142)	75% (148)
quit		10% (17)	14% (28)
current		9% (15)	11% (22)
Ethnicity	371		
asian		2% (4)	6% (11)
black		8% (13)	2% (4)
hispanic		1% (1)	1% (1)
other		1% (1)	4% (7)
white		89% (154)	88% (175)
Marital Status	374		
single / other		61% (107)	45% (90)
married		39% (67)	55% (110)
“Pop” heard at time of injury	358		
no		21% (36)	22% (41)
yes		79% (133)	78% (148)
Reconstruction Type	375		
primary		95% (165)	89% (179)
revision		5% (9)	11% (22)
Graft Type	375		
allograft		13% (23)	18% (37)
autograft		87% (151)	82% (164)
Graft Source	374		
achilles tendon		1% (2)	<1% (1)
bone - patellar tendon - bone		40% (69)	45% (90)
hamstring (semi-tendinosis)		14% (25)	18% (35)
hamstring (semi-tendinosis+gracilis)		39% (67)	26% (53)
other		6% (11)	10% (21)
Surgical Exposure	375		
arthroscopic, one-incision		74% (129)	70% (140)
arthroscopic, two-incision		26% (45)	30% (61)
MCL Injury	375		
no		91% (159)	86% (173)
yes (grades 1,2 only)		9% (15)	14% (28)
LCL Injury	375		
no		98% (170)	95% (190)
yes (grades 1,2 only)		2% (4)	5% (11)

	N	Female N = 174	Male N = 201
Medial Compartment Chondrosis	375		
no		81% (141)	80% (160)
yes (grades II, III, or IV)		19% (33)	20% (41)
Lateral Compartment Chondrosis	375		
no		85% (148)	80% (161)
yes (grades II, III, or IV)		15% (26)	20% (40)
Anterior Compartment Chondrosis	375		
no		84% (147)	81% (163)
yes (grades II, III, or IV)		16% (27)	19% (38)
Medial Meniscus Status	375		
normal		67% (116)	57% (114)
no treatment		5% (9)	7% (15)
repair		11% (19)	13% (26)
excision		17% (30)	23% (46)
Lateral Meniscus Status	375		
normal		40% (69)	40% (80)
no treatment		32% (55)	23% (46)
repair		7% (12)	5% (11)
excision		22% (38)	32% (64)

a b c represent the lower quartile *a*, the median *b*, and the upper quartile c for continuous variables.

x±s represents X ± 1 SD.

N is the number of non–missing values.
Numbers after percents are frequencies.

Table 2

Median (25%, 75% quartile) Outcome Scores Over Time

	Scale	T0[a] – Baseline	2 Year	6 Year
IKDC[b]	0-100	45 (34,56)	75 (66,83)	77 (66,84)
$KOOS_{sports/rec}$	0-100	50 (25,75)	85 (70,95)	90 (70,100)
$KOOS_{krqol}$	0-100	38 (19,50)	75 (63,88)	81 (63,94)
Marx activity level	0-16	12 (8,16)	9 (4,13)	7 (3,11)

[a]T0 = at time of ACL reconstruction surgery (baseline)

[b]IKDC = International Knee Documentation Committee "subjective" form

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Table 3

Predictor Variables and Results

			Significance at T6 (p-values)			
Variable	**Timepoint**[a]	**Comparison**	**IKDC**	**$KOOS_{sports/rec}$**	**$KOOS_{krqol}$**	**Marx**
PRO[b]	T0		**<0.001**	**<0.001**	**0.011**	**<0.001**
Age (years)	T6	42:24	**0.031** (0.096) *	0.558	0.616	0.070
BMI	T0	28:23	**0.022**	**0.0497**	0.130	0.421
Sex	T0	female:male	0.587	0.983	0.694	**<0.001**
Smoking status[c]	T0	never:quit:current	**0.021**	0.448	0.102 (**0.034**) *	0.899
Ethnicity	T6	other:white	0.451	0.599	0.476	0.294
Marital status	T6	married:other	0.872	0.293	0.865	0.245
Reconstruction type	T0	revision:primary	**<0.001**	**0.008**	**<0.001**	**0.038**
ACL graft type	T0	allograft:autograft	**0.008**	**0.021**	**0.014**	0.405
"Pop" heard at time of injury	T0	no:yes	0.729	0.745	0.503	0.866
MCL injury[d]	T0	yes:no	0.668	0.136	0.962	0.899
LCL injury[d]	T0	yes:no	0.818	0.723	0.993	0.454
Medial compartment chondrosis[e]	T0	yes:no	0.399	0.550	0.938	0.226
Anterior compartment chondrosis[e]	T0	yes:no	0.858	0.334	0.911	0.548
Lateral compartment chondrosis[e]	T0	yes:no	0.718	0.678	0.395	0.710
Medial meniscus status[f]	T0	no tx, repair, excision: normal	0.742	0.713	0.714	0.145
Lateral meniscus status[f]	T0	no tx, repair, excision: normal	0.127	**0.017**	**0.027**	0.144

Key:

[a] measured either at baseline (T0) or at six year follow-up (T6)

[b] PRO = patient-reported outcomes for IKDC, $KOOS_{sports/rec}$, $KOOS_{krqol}$, and Marx outcome instruments

[c] comparison of never smoked, quit smoking, currently smokes

[d] yes is defined as Grade I or II only

[e] yes is any chondromalacia of Grades II, III, or IV

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[f] comparison of normal to no treatment of tear, repair and excision

[*] if there was a difference in the p-value when the models were repeated using T6 instead of T0 BMI and smoking status they are denoted in the parentheses. Only two variables changed from slightly above 0.05 to slightly below, or vice versa.