Original Research

Anterior Cruciate Ligament Injury—Who Succeeds Without Reconstructive Surgery?

The Delaware-Oslo ACL Cohort Study

Hege Grindem,[*†] PT, PhD, Elizabeth Wellsandt,[‡§] DPT, PhD, Mathew Failla,[‡||] PT, PhD, Lynn Snyder-Mackler,[¶] PT, ScD, SCS, ATC, FAPTA, and May Arna Risberg,[†#] PT, PhD

Investigation performed at the Norwegian Research Center for Active Rehabilitation, Oslo, Norway, and the University of Delaware, Newark, Delaware, USA

Background: More than 50% of highly active patients with an anterior cruciate ligament (ACL) injury who choose nonsurgical treatment (active rehabilitation alone) have successful 2-year outcomes and comparable knee function to an uninjured population. Early predictive factors for a successful outcome may aid treatment decision making in this population.

Purpose: To identify early predictors of a successful 2-year outcome in those who choose nonsurgical treatment of an ACL injury.

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

Methods: This prospective cohort study consisted of ACL-injured athletes who were consecutively screened for inclusion. A total of 300 patients were included from 2 sites (Oslo, Norway, and Delaware, USA), and the 118 patients who initially chose not to undergo ACL reconstruction were included. All patients participated in pivoting sports before the injury, and none had significant concomitant injuries. A successful 2-year outcome was defined as having 2-year International Knee Documentation Committee (IKDC) scores $\geq$15th normative percentile and not undergoing ACL reconstruction. Multivariable logistic regression models were built using demographic and knee function data (quadriceps muscle strength, 4 single-leg hop tests, IKDC score, and Knee Outcome Survey–Activities of Daily Living Scale [KOS-ADLS] score) collected at baseline or after a 5-week neuromuscular and strength training (NMST) rehabilitation program.

Results: After 2 years, 52 of 97 (53.6%) patients had a successful outcome. In the multivariable baseline model, older age, female sex, better performance on the single-leg hop test, and a higher KOS-ADLS score were significantly associated with successful 2-year outcomes. After the 5-week NMST rehabilitation program, older age, female sex, and a higher IKDC score increased the odds of a successful 2-year outcome. The 2 models had comparable predictive accuracy (post-NMST area under the curve [AUC], 0.78 [95% CI, 0.68-0.88]; baseline AUC, 0.81 [95% CI, 0.72-0.89]).

Conclusion: Clinicians and patients can be more confident in a nonsurgical treatment choice (active rehabilitation alone) in athletes who are female, are older in age, and have good knee function, as measured by single-leg hop tests and patient-reported outcome measures, early after an ACL injury. Prediction models that include measures of knee function, assessed either before or after rehabilitation, can estimate 2-year prognoses for nonsurgical treatment and thereby assist shared treatment decision making.

Keywords: anterior cruciate ligament; nonsurgical treatment; knee function; prognosis

There are 2 treatment options after an anterior cruciate ligament (ACL) injury, surgical and nonsurgical treatment, and both require extensive rehabilitation.[11-13] In highly active patients who initially choose nonsurgical treatment (rehabilitation alone), 33% to 37% undergo late ACL reconstruction (ACLR) within 2 years.[11,13] An additional 11% remain nonsurgically treated and report poorer knee function than the general population,[13] leaving 52% to 56% with successful 2-year outcomes.

Shared treatment decision making requires knowledge on criteria that may predict a successful outcome in the individual patient with an ACL injury. In surgically treated patients, previously identified predictors include patient age,[20,36,37] activity level,[20,31] education level,[21,33] preoperative knee self-efficacy,[34] and concomitant meniscal and cartilage injuries.[5,8,22] There is markedly less knowledge on predictive factors in the nonsurgical population. Older age,[3,32] lower activity level,[3] absence of a medial meniscal

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tear,[32] and having a more pyramid-shaped intercondylar notch[4] may predict better outcomes in nonsurgically treated patients. Measures of knee function, such as single-leg hop tests, quadriceps muscle strength, and patient-reported outcome measures (PROMs), predict outcomes in both nonsurgically treated patients[7,15] and those who undergo ACLR.[5,24,25] These measures of knee function change significantly after only 5 weeks of rehabilitation,[6,26] and some measures may have ceiling effects that could limit predictive ability. As some patients will improve more with rehabilitation than others, the patient who has good knee function early after an injury is not identical to the patient who has good knee function after rehabilitation. We therefore need to identify predictors both before and after a 5-week period of rehabilitation.

The primary aim of this study was to identify early predictors of a successful 2-year outcome in nonsurgically treated patients with an ACL injury. A secondary aim was to assess if prediction models would be different before and after a 5-week rehabilitation program.

METHODS

Patients

This study included all patients in the Delaware-Oslo ACL Cohort Study (N = 300) who had not undergone ACLR by the 6-month follow-up time point (n = 118; Oslo: n = 69; Delaware: n = 49). The other 182 patients made an early decision to undergo ACLR and did not pursue nonsurgical treatment. In the main cohort, patients were consecutively screened for inclusion between 2006 and 2012; 150 patients were included from the Norwegian Sports Medicine Clinic in Oslo, Norway, and 150 patients included from the University of Delaware in Newark, Delaware, USA. We included patients who had a unilateral ACL rupture (verified by magnetic resonance imaging and a ≥3-mm side-to-side difference in anterior laxity measured by KT-1000 arthrometer). Other inclusion criteria were age between 13 and 60 years and preinjury participation in level I or II sports[17] (Table 1) for ≥50 hours per year. Patients were excluded if they had current or previous contralateral knee injuries, other ipsilateral grade III knee ligament injuries, fractures, or full-thickness cartilage defects. Patients were also excluded from participation in the study if they had a concomitant injury (eg, a symptomatic meniscal tear) that prevented them from completing a 5-week neuromuscular and strength training (NMST) rehabilitation program. Approvals from the Regional Committee for Medical and Health Research Ethics of Norway and the University of Delaware Institutional Review Board were obtained, and written informed consent was acquired before inclusion.

TABLE 1
Sports Activity Classification[14,17] With Examples of Sports

Level	Sports Activity	Examples of Sports
I	Jumping, cutting, pivoting	Soccer, football, handball, basketball, floorball
II	Lateral movements, less pivoting than level I	Tennis, squash, alpine skiing, snowboarding, gymnastics, baseball, softball
III	Straight-ahead activities, no jumping or pivoting	Running, cross-country skiing, weight lifting
IV	Sedentary	

Treatment Algorithm

Before study inclusion, all patients underwent rehabilitation to resolve effusion and range of motion deficits. After baseline testing, rehabilitation continued for 5 additional weeks. This rehabilitation program consisted of progressive NMST exercises, including 10 sessions of perturbation training. The program has been previously described in detail.[6] The primary aim of rehabilitation was to restore muscle strength and appropriate neuromuscular responses. Strength training followed the principles of resistance training for healthy adults as outlined in the American College of Sports Medicine position stand.[30] The program consisted of single- and multiple-joint exercises; open and closed kinetic chain exercises; and concentric, eccentric, and isometric exercises with 3 to 4 sets and 6 to 8 repetitions per exercise. Plyometric exercises were gradually progressed. These exercises focused on the quality of movement and were tailored to individual patient needs based on that patient's specific goals. Perturbation training was performed according to our previously published protocol[10] and consisted of dynamic stability exercises on a roller board, rocker board, and platform.

After the 5-week NMST rehabilitation program, testing was repeated and surgical or nonsurgical treatment decided. The treatment decision-making process was shared between the patient, the physical therapist, and the surgeon. At both sites, patients were more likely to be

*Address correspondence to Hege Grindem, PT, PhD, Norwegian Research Center for Active Rehabilitation, Department of Sports Medicine, Norwegian School of Sport Sciences, Pb 4014, Ullevål Stadion, 0806 Oslo, Norway (email: hege.grindem@nih.no) (Twitter: @hegegrindem).

†Norwegian Research Center for Active Rehabilitation, Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway.

‡Biomechanics and Movement Science Program, University of Delaware, Newark, Delaware, USA.

§Division of Physical Therapy Education, University of Nebraska Medical Center, Omaha, Nebraska, USA.

||Department of Rehabilitation and Movement Science, University of Vermont, Burlington, Vermont, USA.

¶Department of Physical Therapy, College of Health Sciences, University of Delaware, Newark, Delaware, USA.

#Department of Orthopaedic Surgery, Oslo University Hospital, Oslo, Norway.

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Ethical approval for this study was obtained from the University of Delaware Institutional Review Board and the Regional Committee for Medical and Health Research Ethics of Norway.

recommended to ACLR if they experienced instability after rehabilitation or were highly active in, and intended to return to, level I sports. In Oslo, the main patient-reported reason for making a nonsurgical treatment choice was that he or she had achieved good knee function after rehabilitation.[13] Additionally, although patients who intended to return to level I sports were advised to undergo ACLR, 34% of those who made a nonsurgical treatment choice reported that they intended to return to level I sports.[13] Late ACLR was performed in patients who developed dynamic knee instability. In Delaware, those with good knee function (classified as potential copers with a screening test battery[9]) were given the opportunity to continue nonsurgical management and return to their respective sport in the short term. Comparable with the patients in Oslo, these athletes were recommended to undergo ACLR after the conclusion of a short-term return to sport if they wanted to maintain a highly active lifestyle in level I sports.

Data Collection

A battery of tests was performed at baseline (mean, 2.1 ± 0.9 months after injury) and repeated after the 5-week rehabilitation program (mean, 3.4 ± 1.1 months after injury). Patients returned for follow-up testing 2 years later. Baseline testing was performed as soon as the patient had full range of motion, little to no knee effusion, and ≥70% quadriceps muscle strength and was able to hop on 1 leg. In Oslo, concentric quadriceps muscle strength was measured at 60 deg/s with an isokinetic dynamometer (Biodex 6000; Biodex Medical Systems). Four submaximal practice trials were followed by a 1-minute rest, after which 5 maximum-effort repetitions were recorded. In Delaware, maximal voluntary isometric quadriceps contraction was recorded using an isometric dynamometer (Kin-Com; DJO Global). The patient was positioned with the hips and knees in 90° of flexion and performed 3 submaximal practice trials, followed by 3 maximum-effort trials. The uninvolved leg was tested first at both sites.

After strength testing, single-leg hop tests were performed in the following order: single hop for distance, crossover hop for distance, triple hop for distance, and 6-m timed hop.[15,24] The uninvolved leg was always tested first. Following the respective clinical guidelines, all patients in Delaware wore a brace (DonJoy Defiance; DJO Global), while none of the patients in Oslo wore a brace while hopping.

After single-leg hop testing, patients completed the Knee Outcome Survey–Activities of Daily Living Scale (KOS-ADLS)[19] and the International Knee Documentation Committee subjective knee form (IKDC).[18] The KOS-ADLS assesses symptoms and function in activities of daily living, while the IKDC assesses symptoms and knee function in sports. Both are scored from 0 (worst) to 100 (best).

Data Management

The quadriceps limb symmetry index (LSI) was defined as the peak torque (Oslo) or force (Delaware) of the involved leg as a percentage of the uninvolved leg. For all single-leg hop tests, except the 6-m timed hop, LSIs were expressed in percentages as the average hop distance of the involved limb versus the average hop distance of the uninvolved limb. The LSI for the 6-m timed hop was expressed in percentages as the average time of the uninvolved limb versus the average time of the involved limb. Categorical variables were created for all hop and strength tests, with a cut-off point at 90% LSI. These variables were dichotomized to enable the inclusion of patients who could not perform a test because of problems with the index knee (n = 7). The patients who could not perform a test because of knee problems were classified with patients who had an LSI <90%. For single-leg hop tests, cutoff points around 90% LSI have previously been shown to have the highest sensitivity and specificity for predicting self-reported knee function.[15,24]

Patients who did not undergo ACLR within 2 years and had a 2-year IKDC score higher than or equal to the age- and sex-specific 15th normative percentile were classified as having a successful outcome. The normative data represent a US general population with no prior knee problems, knee treatments, or knee surgery.[1] This cutoff point has been used in previous research.[13,15,23,24] An IKDC score below the 15th normative percentile can predict failure to meet functional criteria for return to sports[23] and provides a high degree of certainty that the patient's knee function differs from normal.

Statistical Analysis

The main analysis was performed with multivariable logistic regression. The dependent variable was a successful outcome as defined above. To identify candidate predictor variables, logistic regression was performed for each variable in a predetermined order. Site was added as a covariate in all analyses. The candidate predictors were grouped by category: demographics, single-leg hop tests, PROMs, and quadriceps muscle strength. The testing order within each category was based on previous studies and expert opinion, giving priority to variables with the highest empirical support.[15,26] Single-leg hop tests that had shown a stronger association with 1-year self-reported outcomes in nonsurgically treated patients with an ACL injury were prioritized over single-leg hop tests with weaker associations with the 1-year outcome.[15] The IKDC was prioritized over the KOS-ADLS because it is a more sensitive outcome measure in the early phase after an ACL injury.[26] In successive rounds, 1 candidate variable in each category was tested. Variables with $P < .25$ qualified for multivariable analysis. To avoid redundancy and high intercorrelations, it was decided a priori not to include more than 1 candidate predictor from the single-leg hop tests (either categorical or continuous) or the PROMs. If a candidate predictor was already identified from these categories, that category was skipped in the next round. If both a categorical and continuous variable of the same measure qualified for multivariable analysis, the variable with the lowest P value would be chosen.

The number of variables in the multivariable model was limited to 4 to ensure high statistical power. From an initial site-adjusted model with 4 candidate predictors, the variable with the highest P value was excluded in a step-wise process. To avoid excluding meaningful confounding variables, we decided a priori to keep variables that were significant at the .25 level if the exclusion of that variable led to a >20% change in the beta value of another predictor.[2] If more than 4 candidate predictors were identified by univariable analysis, a new predictor variable was added to the multivariable model once it contained ≤3 variables. The inclusion order of new variables was predetermined by the testing order as described above. This process was repeated until all variables in the model were either statistically significant at $P < .05$ or defined as a meaningful confounder. Goodness of fit was assessed with the Hosmer-Lemeshow chi-square test. The predicted probabilities from the final model were calculated and used in a receiver operating characteristic analysis to estimate predictive accuracy (area under the curve [AUC]).

For the postrehabilitation model, the predictors included data from single-leg hop tests, strength measurements, and PROMs collected after rehabilitation. A baseline model was built using the same variables collected at baseline. Demographic variables were identical for the 2 models. The procedure described above was performed for both models, and the correlations between predictors in the final models were <0.229. The interaction between site and knee functional measures was assessed with logistic regression, with successful outcome as the dependent variable. No statistically significant interactions were found, and the 2 sites were merged. Multiple imputation by fully conditional specification[35] was performed with 10 imputations, and the final models were rerun. All predictors remained statistically significant in the imputed data set, and changes in beta values were negligible. Results from the original data set were therefore presented.

Any other analyses were performed using chi-square tests for categorical data and independent t tests for continuous data in which the assumption of normality was met. The significance level was set to .05. SPSS v24 was used for all analyses (IBM Corp).

RESULTS

Of the 300 patients, 118 (39.3%) remained nonsurgically treated at the 6-month follow-up point (Figure 1): 49 (41.5%) from Delaware and 69 (58.5%) from Oslo. The mean age at baseline was 28.6 ± 10.5 years, 58 (49.2%) were male and 60 (50.8%) female, and 68 (57.6%) patients had participated in level I sports while 50 (42.4%) participated in level II sports before the injury. There were no significant differences in age, sex, or preinjury activity level between the 2 sites (all $P > .276$), but the patients in Delaware had a higher body mass index (mean, 25.8 ± 4.1 kg/m^2) than the patients in Oslo (mean, 23.6 ± 3.1 kg/m^2) ($P = .002$).

Data on late ACLR and 2-year IKDC scores were available for 97 patients (82.2%) (Figure 1). After 2 years, 52 of these 97 patients (53.6%) were classified as having a successful outcome. Of the 45 who were classified as having an unsuccessful outcome, 12 remained nonsurgically treated but had 2-year IKDC scores <15th normative percentile, and 33 patients underwent late ACLR (Delaware: n = 10; Oslo: n = 23). The proportion of patients who were classified as having a successful outcome was not significantly different between the 2 sites ($P = .714$). Patients who scored ≥15th normative percentile had mean 2-year IKDC scores of 94.2 ± 4.4, and those who scored <15th normative percentile scored a mean of 73.2 ± 12.7 at the 2-year follow-up. The mean time from injury to late ACLR was 14.9 ± 4.3 months. Of 63 patients who had not undergone late ACLR and attended the 2-year follow-up, 17 (27.0%) participated in level I sports, 21 (33.3%) participated in level II sports, 24 (38.1%) participated in level III sports, and 1 patient (1.6%) was not active in any sport. Demographics and functional outcomes of those who were classified as having a successful versus an unsuccessful 2-year outcome can be found in Table 2.

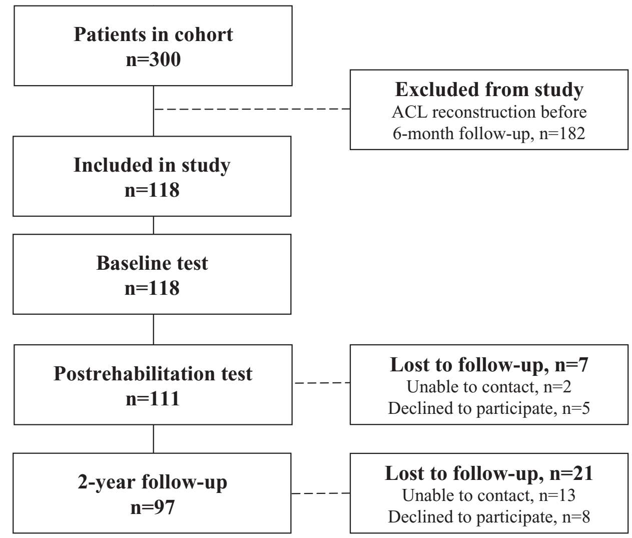

Figure 1. Flowchart of patient participation in the study. ACL, anterior cruciate ligament.

Baseline Prediction Model

Age, preinjury sport level, sex, single hop test LSI ≥90%, quadriceps LSI ≥90%, and KOS-ADLS score at baseline met the criteria for inclusion (Table 3). In the final baseline model, a higher KOS-ADLS score, single hop test LSI ≥90%, older age, and female sex increased the odds of a successful outcome (Table 4). The AUC of the model was 0.81 (95% CI, 0.72-0.89), and the P value for the Hosmer-Lemeshow test was .27.

Post-NMST Rehabilitation Prediction Model

Age, preinjury sport level, sex, and IKDC score after rehabilitation met the criteria for inclusion in the multivariable model (Table 5). In the final postrehabilitation model, a higher IKDC score after rehabilitation, older age, and female sex increased the odds of a successful outcome (Table 6). The AUC of the model was 0.78 (95% CI, 0.68-0.88). The P value for the Hosmer-Lemeshow goodness-of-fit test was .176.

DISCUSSION

Clinicians and patients can be more confident of a good prognosis with nonsurgical treatment (active rehabilitation

TABLE 2
Demographics and Functional Outcomes[a]

	Successful 2-y Outcome (n = 52)	Unsuccessful 2-y Outcome (n = 45)	*P* Value
Demographics			
Preinjury sport level, I/II, n (%)	25 (48.1)/27 (51.9)	31 (68.9)/14 (31.1)	.039
Age, y	32.0 ± 10.8	25.2 ± 10.1	.002
Body mass index, kg/m^2	23.9 ± 3.5	24.6 ± 4.2	.380
Sex, female/male, n (%)	30 (57.7)/22 (42.3)	19 (42.2)/26 (57.8)	.129
Baseline functional outcomes[b]			
Quadriceps			
LSI ≥90%, yes/no, n (%)	30 (57.7)/22 (42.3)	17 (37.8)/28 (62.2)	.050
LSI	91.2 ± 9.5	90.1 ± 12.7	.622
Single hop			
LSI ≥90%, yes/no, n (%)	30 (57.7)/22 (42.3)	20 (44.4)/25 (55.6)	.193
LSI	90.2 ± 9.1	89.0 ± 8.7	.514
Crossover hop			
LSI ≥90%, yes/no, n (%)	29 (55.8)/23 (44.2)	28 (63.6)/16 (36.4)	.434
LSI	90.0 ± 11.6	91.4 ± 9.3	.550
Triple hop			
LSI ≥90%, yes/no, n (%)	30 (57.7)/22 (42.3)	23 (53.5)/20 (46.5)	.681
LSI	91.2 ± 9.1	90.8 ± 8.8	.832
6-m timed hop			
LSI ≥90%, yes/no, n (%)	35 (68.6)/16 (31.4)	30 (66.7)/15 (33.3)	.838
LSI	93.7 ± 9.3	93.3 ± 10.1	.852
IKDC score (0-100)	72.2 ± 11.6	71.2 ± 12.1	.682
KOS-ADLS score (0-100)	85.2 ± 10.8	80.9 ± 12.3	.073
Postrehabilitation functional outcomes[c]			
Quadriceps			
LSI ≥90%, yes/no, n (%)	31 (60.8)/20 (39.2)	28 (63.6)/16 (36.4)	.775
LSI	92.9 ± 9.7	93.1 ± 10.8	.941
Single hop			
LSI ≥90%, yes/no, n (%)	39 (75.0)/13 (25.0)	31 (70.5)/13 (29.5)	.618
LSI	94.7 ± 6.7	94.5 ± 9.6	.886
Crossover hop			
LSI ≥90%, yes/no, n (%)	41 (78.8)/11 (21.2)	35 (79.5)/9 (20.5)	.933
LSI	96.7 ± 6.4	95.6 ± 7.4	.449
Triple hop			
LSI ≥90%, yes/no, n (%)	45 (86.5)/7 (13.5)	35 (79.5)/9 (20.5)	.360
LSI	96.3 ± 5.5	95.1 ± 7.9	.422
6-m timed hop			
LSI ≥90%, yes/no, n (%)	42 (80.8)/10 (19.2)	37 (84.1)/7 (15.9)	.671
LSI	96.2 ± 5.1	95.6 ± 7.5	.683
IKDC score (0-100)	83.3 ± 9.5	79.3 ± 11.5	.064
KOS-ADLS score (0-100)	92.0 ± 7.1	88.9 ± 9.3	.080

[a]Data are reported as mean ± SD unless otherwise indicated. IKDC, International Knee Documentation Committee; KOS-ADLS, Knee Outcome Survey–Activities of Daily Living Scale; LSI, limb symmetry index.
[b]Missing data for crossover hop (n = 1), triple hop (n = 2), and 6-m timed hop (n = 1).
[c]Missing data for quadriceps (n = 2), single hop (n = 1), crossover hop (n = 1), triple hop (n = 1), and 6-m timed hop (n = 1).

alone) for an ACL injury if the patient is female, is older, and has better knee function early after the injury. Knee function can be assessed either before or after a period of rehabilitation, but different measures are needed to quantify knee function at the 2 time points.

Clinical Applicability

The models developed in this study (see equations 1 and 2 in the Appendix) can easily be applied in clinical practice to estimate the 2-year prognosis in sports-active patients who choose nonsurgical treatment for an ACL injury. The time and effort needed to record the required information are minimal. For example, a 30-year-old woman who, early after an injury, scores 90 on the KOS-ADLS and has an LSI ≥90% on the single hop test would have 85% probability of a successful 2-year outcome without ACLR. In contrast, the same woman would only have 29% probability of a successful outcome if she scored 65 on the KOS-ADLS and was unable to hop within 90% of the distance of the uninjured leg. These differences in prognoses provide a powerful argument for

TABLE 3
Site-Adjusted Univariable Predictors of a Successful 2-Year Outcome With Variables at Baseline Included[a]

Category	Independent Variable	Odds Ratio (95% CI)	*P* Value	Candidate Predictor
Testing round 1				
Demographics	Preinjury sport level I/II	2.376 (1.028-5.491)	.043	Yes
Hop tests	Single hop LSI ≥90%	1.712 (0.764-3.835)	.191	Yes
Hop tests	Single hop LSI	1.016 (0.970-1.064)	.494	No
PROMs	IKDC score	1.007 (0.972-1.043)	.693	No
Muscle strength	Quadriceps LSI ≥90%	2.250 (0.979-5.173)	.056	Yes
Muscle strength	Quadriceps LSI	1.008 (0.971-1.047)	.671	No
Testing round 2				
Demographics	Age	1.065 (1.021-1.111)	.004	Yes
Hop tests	Skipped[b]			
PROMs	KOS-ADLS score	1.034 (0.996-1.074)	.077	Yes
Muscle strength	Skipped[b]			
Testing round 3				
Demographics	Body mass index	0.944 (0.844-1.055)	.307	No
Hop tests	Skipped[b]			
PROMs	Skipped[b]			
Muscle strength	Skipped[b]			
Testing round 4				
Demographics	Sex	0.517 (0.228-1.173)	.114	Yes
Hop tests	Skipped[b]			
PROMs	Skipped[b]			
Muscle strength	Skipped[b]			

[a]Level I was the reference category for preinjury sport level, LSI <90% was the reference category for all dichotomous functional outcomes, and female was the reference category for sex. IKDC, International Knee Documentation Committee; KOS-ADLS, Knee Outcome Survey–Activities of Daily Living Scale; LSI, limb symmetry index; PROM, patient-reported outcome measure.
[b]A candidate predictor in this category was identified in a previous round.

TABLE 4
Multivariable Predictors of a Successful 2-Year Outcome After Nonsurgical Treatment of ACL Injuries With Variables at Baseline Included[a]

	β	Standard Error	Odds Ratio[b] (95% CI)	*P* Value
Constant	–8.626	2.584		
Age	0.121	0.030	1.129 (1.065-1.196)	<.001
Sex (female = 0, male = 1)	–1.323	0.531	0.266 (0.094-0.754)	.013
KOS-ADLS score (0-100)	0.063	0.024	1.065 (1.016 -1.118)	.009
Single hop LSI ≥90%	1.053	0.510	2.866 (1.056-7.781)	.039

[a]LSI <90% was the reference category for all dichotomous functional outcomes. Site was included as an adjustment factor. ACL, anterior cruciate ligament; KOS-ADLS, Knee Outcome Survey–Activities of Daily Living Scale; LSI, limb symmetry index.
[b]The odds ratio represents the increase in odds of a successful 2-year outcome for a 1-unit increase in the predictor variable.

why clinicians should routinely assess the patient's knee function after an injury.

Role in Treatment Decision

Estimates of prognosis provide valuable information, but treatment decisions still need to be tailored to the specific patient. Realistic expectations of treatment outcomes are paramount, and before suggesting ACLR for everyone with a suboptimal prognosis after nonsurgical treatment, it is important to recognize that results after ACLR are not perfect. Two years after ACLR, 22% of patients report poorer knee function than the general population,[13] and 24% of patients will have sustained knee reinjuries.[16] Muller et al[28] suggested an IKDC score of 75.9 as a threshold for an acceptable symptom state after ACLR. The IKDC score thresholds for a successful outcome were higher in our study, especially for the youngest patients. Only 5 patients in this study were nonsurgically treated and had 2-year IKDC scores below the acceptable symptom state after ACLR.

Two nonmodifiable factors, younger age and being male, were associated with worse outcomes with nonsurgical treatment. Compared with older patients, young patients also have poorer outcomes after ACLR.[20,36,37] ACLR should therefore not be assumed to be superior to nonsurgical treatment in young patients. Instead, our results in nonsurgically treated patients, as well as previous studies on surgically treated patients,[29,37] support the growing concern that our current treatment methods are not successful enough for the youngest and most active patient group. For those who have good prognoses with nonsurgical treatment, however, our results can help clinicians and patients to have more confidence in a nonsurgical treatment choice (active rehabilitation).

Further, 182 of the 300 patients included in the total cohort were not part of this study because they made an early decision to undergo ACLR. We have previously shown

TABLE 5
Site-Adjusted Univariable Predictors of a Successful 2-Year Outcome With Variables After Rehabilitation Included[a]

Category	Independent Variable	Odds Ratio (95% CI)	*P* Value	Candidate Predictor
Testing round 1				
Demographics	Preinjury sport level I/II	2.376 (1.028-5.491)	.043	Yes
Hop tests	Single hop LSI ≥90%	1.239 (0.501-3.062)	.643	No
Hop tests	Single hop LSI	1.004 (0.954-1.056)	.883	No
PROMs	IKDC score	1.037 (0.996-1.080)	.076	Yes
Muscle strength	Quadriceps LSI ≥90%	0.890 (0.387-2.048)	.784	No
Muscle strength	Quadriceps LSI	0.998 (0.959-1.040)	.937	No
Testing round 2				
Demographics	Age	1.065 (1.021-1.111)	.004	Yes
Hop tests	6-m timed hop LSI ≥90%	0.825 (0.282-2.415)	.725	No
Hop tests	6-m timed hop LSI	1.014 (0.950-1.083)	.671	No
PROMs	Skipped[b]			
Muscle strength	Skipped[c]			
Testing round 3				
Demographics	Body mass index	0.944 (0.844-1.055)	.307	No
Hop tests	Triple hop LSI ≥90%	1.651 (0.559-4.878)	.365	No
Hop tests	Triple hop LSI	1.025 (0.963-1.090)	.436	No
PROMs	Skipped[b]			
Muscle strength	Skipped[c]			
Testing round 4				
Demographics	Sex	0.517 (0.228-1.173)	.114	Yes
Hop tests	Crossover hop LSI ≥90%	0.980 (0.362-2.650)	.968	No
Hop tests	Crossover hop LSI	1.025 (0.965-1.090)	.421	No
PROMs	Skipped[b]			
Muscle strength	Skipped[c]			

[a]Level I was the reference category for preinjury sport level, LSI <90% was the reference category for all dichotomous functional outcomes, and female was the reference category for sex. IKDC, International Knee Documentation Committee; LSI, limb symmetry index; PROM, patient-reported outcome measure.
[b]A candidate predictor in this category was identified in a previous round.
[c]All candidate predictors in this category had been tested in previous rounds.

TABLE 6
Multivariable Predictors of a Successful 2-year Outcome After Nonsurgical Treatment of ACL Injuries With Variables After Rehabilitation Included[a]

	β	Standard Error	Odds Ratio[b] (95% CI)	*P* Value
Constant	–6.075	2.177		
Age	0.084	0.025	1.088 (1.035-1.142)	.001
Sex (female = 0, male = 1)	–1.421	0.519	0.241 (0.087-0.667)	.006
IKDC score (0-100)	0.058	0.024	1.060 (1.012-1.110)	.015

[a]Site was included as an adjustment factor. ACL, anterior cruciate ligament; IKDC, International Knee Documentation Committee.
[b]The odds ratio represents the increase in odds of a successful 2-year outcome for a 1-unit increase in the predictor variable.

that only 6% of those who make an early decision to undergo ACLR do so because of instability; the main patient-reported reasons are intention to return to level I pivoting sports and patient preference.[13] It is therefore unknown how many of these patients could have had a successful outcome with nonsurgical treatment.

Timing of Assessment

Patients who fail a functional screening examination early after an injury have great potential for improvement with rehabilitation and can achieve 1-year outcomes comparable with those who pass.[27] We therefore assessed 2 different sets of predictors: one with measures of knee function at baseline (mean, 2.1 months after injury) and another in which knee function was assessed after 5 weeks of rehabilitation (mean, 3.4 months after injury). The predictive accuracy of the 2 models indicated that they were equally useful. Interestingly, the IKDC score was only a significant predictor after rehabilitation. However, the KOS-ADLS score was a significant predictor at baseline. The IKDC was developed partly on the basis of the KOS-ADLS, and these questionnaires include several of the same items.[18] Still, the IKDC includes items related to knee function during sports activities, while the KOS-ADLS measures knee function during activities of daily living. Baseline testing was conducted as soon as the patient had full range of motion, little to no knee effusion, and ≥70% quadriceps muscle strength and was able to hop on 1 leg. None of our patients participated in pivoting sports at the time of baseline testing.

One explanation for our findings could be that the KOS-ADLS score is more relevant at baseline, while the IKDC score is more relevant after rehabilitation.[26] When conducting testing early after an injury, this study found that the single hop test (LSI) was associated with 1-year outcomes[15] and 2-year outcomes. Although quadriceps muscle strength measured at baseline was not statistically significant in the multivariable model, it was identified as a candidate predictor in the univariable analysis. Neither quadriceps muscle strength nor any of the single-leg hop tests were identified as candidate predictors after rehabilitation. It is possible that when knee function improves with rehabilitation, the measures of knee function lose the variance that is required for predictive ability.

Definition of a Successful Outcome

A successful 2-year outcome was defined as not having undergone ACLR within 2 years and having IKDC scores higher than or equal to the sex- and age-specific 15th normative percentile. The use of late surgery as part of an outcome is not without limitations, as surgical rates may be influenced by clinical treatment patterns. The patient samples at the 2 sites were similar, but a higher proportion of patients were nonsurgically treated in Oslo. The rate of late surgery was slightly higher in Oslo than in Delaware, signifying a higher propensity for a wait-and-see approach. Those who underwent late surgery did not have inferior 2-year outcomes compared with the patients who underwent ACLR as their primary treatment choice.[13] Treatment goals and expectations of outcomes will differ between patients, and our results cannot be generalized to other definitions of a successful outcome than the one used in our study.

Strengths and Limitations

The main strength of this study is the high external validity gained by including patients from 2 different continents. To our knowledge, this is the largest prospective cohort study in which knee function was investigated as a predictor for outcomes in nonsurgically treated ACL-injured patients. Our sample consisted of 118 pivoting-sport athletes who had chosen nonsurgical treatment, and continued validation, including validation in the patient who traditionally elects early surgery, is needed. While also increasing the generalizability of the findings, one limitation was the differences in functional testing between the 2 sites. We did not have access to identical dynamometers, and our clinical guidelines with regard to bracing during single-leg hop testing were different. However, these differences are unlikely to have affected the results, as there was no significant interaction between site and muscle strength or hop test measures. Further studies are needed to assess whether prediction can be improved by the inclusion of other potential predictors (eg, anatomic factors, associated injuries, laxity, and psychological factors) or by allowing a longer period of rehabilitation before testing. Last, these results should not be generalized to patients who have significant concomitant injuries.

CONCLUSION

Clinicians and patients can have more confidence in a nonsurgical treatment choice (active rehabilitation alone) in athletes who are female, are older, and have good knee function early after an ACL injury. Only 5 patients in this study were nonsurgically treated and had 2-year IKDC scores below the acceptable symptom state after ACLR. A simple set of measures, assessed either before or after a short period of rehabilitation, can provide 2-year prognoses and thereby aid shared treatment decision making.

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APPENDIX

The B coefficients in Tables 4 and 6 are used to compute functions that are exponentiated to estimate the 2-year probability of a successful outcome. Equation 1 is used as soon as the patient has regained full range of motion, little to no knee effusion, and $\geq$70% quadriceps strength and is able to hop on 1 leg. Equation 2 is used when knee function is assessed after an additional 5-week period of rehabilitation.

$$\text{Equation 1}: \exp(-8.626 + 0.121 \times \text{age} - 1.323 \times \text{sex} + 0.063 \times \text{KOS-ADLS} + 1.053 \times \text{single hop}) / (1 + \exp(-8.626 + 0.121 \times \text{age} - 1.323 \times \text{sex} + 0.063 \times \text{KOS-ADLS} + 1.053 \times \text{single hop})) \times 100.$$

$$\text{Equation 2}: \exp(-6.075 + 0.084 \times \text{age} - 1.421 \times \text{sex} + 0.058 \times \text{IKDC}) / (1 + \exp(-6.075 + 0.084 \times \text{age} - 1.421 \times \text{sex} + 0.058 \times \text{IKDC})) \times 100.$$

Age, age at the time of injury in years (range, 13-55 years); sex, 0 = female and 1 = male; KOS-ADLS, Knee Outcome Survey–Activities of Daily Living Scale score at baseline (range, 50-100); single hop, 0 = single hop test limb symmetry index (LSI) $<$90% and 1 = single hop test LSI $\geq$90%; IKDC, International Knee Documentation Committee score after rehabilitation (range, 55-100).