Re-revision Anterior Cruciate Ligament Reconstruction: An Evaluation From the Norwegian Knee Ligament Registry

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Purpose: To identify the rate of re-revision anterior cruciate ligament reconstruction (ACLR) to estimate the influence of patient-related factors on the risk of re-revision ACLR. The secondary aim of the study was to report the intra-articular findings and patient-related factors at the time of revision ACLR and to compare these with the findings in a matched controlled group of primary ACLR. **Methods:** Patients with primary ACLR without a subsequent need of revision and patients with a revision ACLR identified in the Norwegian Knee Ligament Registry from June 2004 through September 2016 were included. Using age at operation, sex, activity at injury, and year of ACLR as covariates, a propensity score matched control group of primary ACLR patients for the revision ACLR patients was identified. For the revision ACLR patients, re-revision ACLR rates at 1, 2, 5, and 8 years were estimated with Kaplan-Meier analysis; the hazard ratio for a re-revision ACLR was estimated using a multivariable Cox regression model. **Results:** The cumulative estimated proportion of patients undergoing a re-revision ACLR at 1, 2, 5, and 8 years after the original revision ACLR was 0.4%, 3.0%, 6.5%, and 9.0% respectively. There was no significant difference between the control and revision ACLR groups regarding cartilage injury ($P = .72$) or associated ligament injury ($P = .17$). Revision ACLR patients did have fewer meniscal injuries ($P < .001$). There were no intraoperative findings or surgical techniques identified as a predictor for a higher risk of re-revision ACLR. **Conclusions:** Based on a review of a large ligament reconstruction registry,one can expect 9% of patients to undergo a re-revision ALCR at 8 years of follow up. Revision ACLR did not have an increase in cartilage injuries or associated ligament injuries and had significantly fewer meniscal injuries compared with a primary ACLR control group. **Level of Evidence:** Level III, retrospective comparative study.

Anterior cruciate ligament reconstruction (ACLR) is 1 of the most common orthopaedic procedures performed in the United States and Scandinavia.[1-5] Despite improved biomechanics with anatomically based ACLR techniques[6,7] graft re-rupture rates have been reported up to 25%, with cumulative re-rupture and objective clinical failure rate as high as 85%.[2,8-10] Subsequently, a significant patient population that undergoes ACLR will require a revision ACLR.[10,11]

In patients undergoing a revision ALCR, a higher prevalence of chondral injuries and lower patient-reported outcome scores at the time of surgery compared with primary ACLR have been reported.[12-19] Patient expectations regarding primary ACLR and revision ACLR are generally high and can subsequently contribute to postoperative dissatisfaction if patients are not appropriately counseled.[20] Although there has been an expansion in the literature regarding primary ACLR and first-time revision ACLR,[14,21] in particular with data from large multicenter and national study populations, there still remains an incomplete understanding of the risk factors for failures of revision ACLR.[22,23] Defining the risk of and outlining the

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patient-related and intraoperative factors associated with revision ACLR failure are important. The purpose was to identify the rate of re-revision ACLR to estimate the influence of patient-related factors on the risk of re-revision ACLR. The secondary aim of the study was to report the intra-articular findings and patient-related factors at the time of revision ACLR and to compare these to the findings in a matched controlled group of primary ACLR. We hypothesized an increased rate of re-revision ACLR compared with that previously reported for revision ACLR and expected a correlation between the cartilage and meniscus injuries and the rate of re-revision. We also hypothesized there would be a higher incidence of cartilage and meniscal injuries in patients that require revision ACLR compared with primary ACLR.

Methods

The Norwegian National Knee Ligament Registry (NKLR) was established in June 2004 to prospectively collect data on all cases of cruciate ligament reconstruction surgery in Norway.[3] Data from the start of the registry until September 30, 2016, were used to identify both a case and a control group of patients (Fig 1 and Fig 2). The case group had undergone at least 1 revision ACLR of the index knee following their primary ACLR. Patients with isolated ACL injury and those with concomitant meniscus or cartilage injury were included. Patients were excluded if they had undergone cartilage restoration surgery (osteochondral autograft transplantation, autologous chondrocyte implantation, or microfracture treatment), meniscal transplant, or if there had been an ipsilateral intra-articular fracture either at the time of primary ACLR or at the time of revision ACLR surgery. The control group of patients had undergone a primary ACLR without a subsequent revision ACLR and was identified through propensity score matching.

The following data were reviewed for this study: date of primary surgery, revision ALCR and date of any subsequent revision ACLR, surgery time, graft choice, activity at the time of injury, cause of ACLR revision, demographic profile (sex, age, body mass index [BMI]), and associated pathology; cartilage injuries (International Cartilage Repair Society [ICRS] grade 1-2 or 3-4); meniscal tears (medial, lateral, or both menisci); and other concomitant ligament injuries (posterior cruciate ligament, medial collateral ligament, fibular [lateral] collateral ligament or injury to the posterolateral corner).

Propensity Score Matching

The propensity score is the conditional probability of receiving a certain treatment given a specific set of covariates. We matched those patients considered treated and those untreated on their estimated probability of being treated. In our study, the treated were the revised patients and the untreated were the primary controls. To estimate the propensity scores, we used logistic regression, including the following covariates: age at operation, sex, activity at injury, and year of primary ACL reconstruction. We matched the data using a 1:5 ratio and set the scale parameter to 0.2 (default value). Based on the calculated propensity scores, we identified 5 controls for each case giving us a full dataset of 4704 patients.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics, version 23.0 (IBM Corporation, Armonk, NY), and the R computing environment R 3.4.1 (The R Foundation, Vienna, Austria)[24] using algorithms of the R

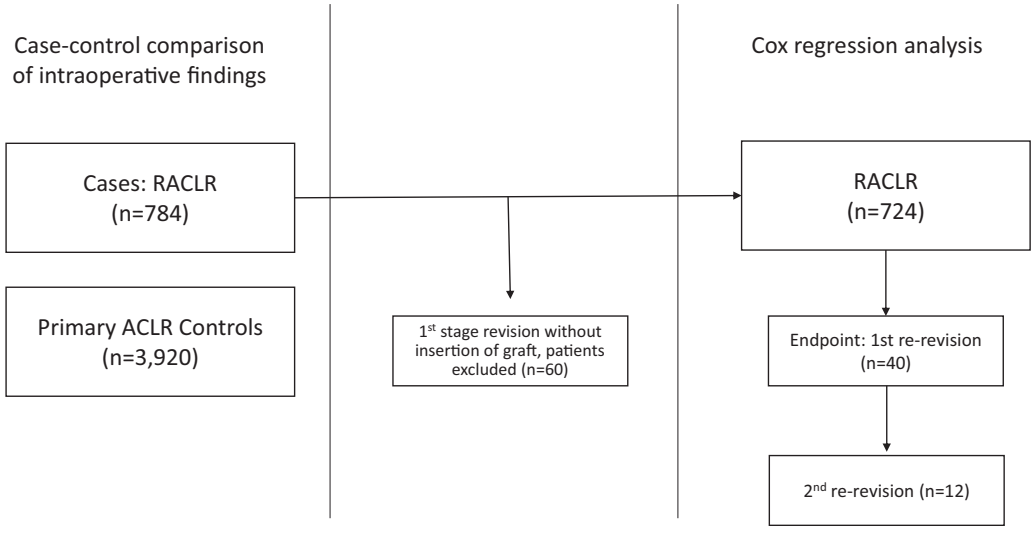

Fig 1. Study population for case control comparison and Cox regression. ACLR, anterior cruciate ligament reconstruction; RACLR, revision anterior cruciate ligament reconstruction.

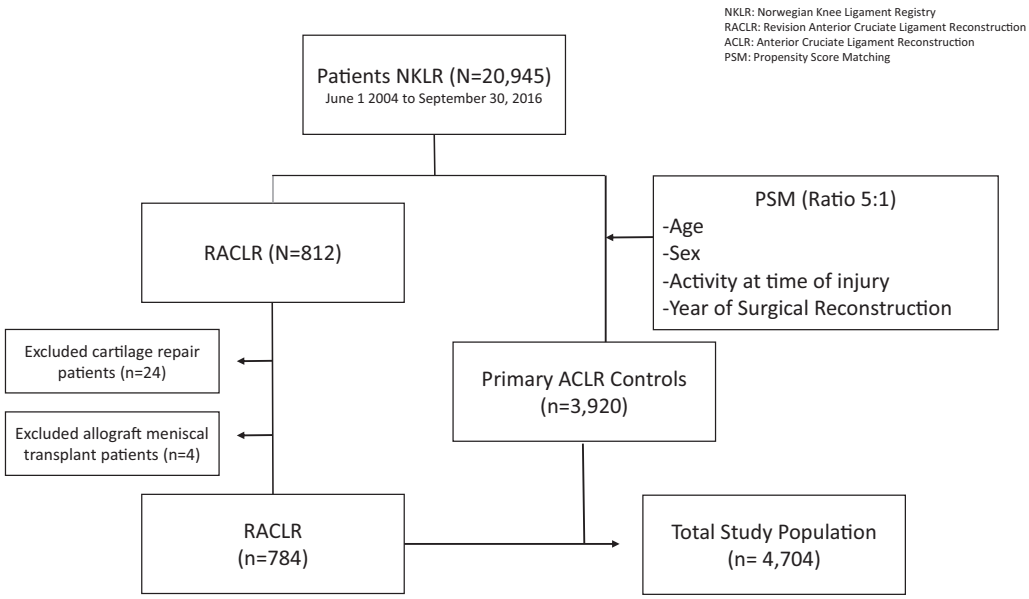

Fig 2. Patient inclusion/exclusion criteria. ACLR, anterior cruciate ligament reconstruction; NKLR, Norwegian Knee Ligament Registry; PSM, propensity score matching; RACLR, re-revision anterior cruciate ligament reconstruction.

"survival" and "nonrandom" packages to perform the survival analysis and propensity score matching.[25] All tests were 2-sided with a significance level set to .05. We used the χ-square test for categorical variables and Student's *t* test for continuous variables to test for group differences.

Estimated 1-, 2-, 5-, and 8-year re-revision rates with 95% confidence interval (CI) were calculated with Kaplan-Meier analysis. The hazard ratio for re-revision ACLR for the case group was analyzed with the first re-revision defined as the endpoint in the Cox multiple regression model. Patients who required a second re-revision met the endpoint at first revision, both in the Kaplan-Meier analysis and the Cox regression model (Fig 1). The proportional hazards assumption of the Cox regression models was evaluated by tests and inspection of Schoenfeld residuals[26] and found suitable.

Revision surgeries where no new graft was recorded (n = 60) were excluded from analysis calculating survivorship and risk estimates for re-revision because they were most likely the first stage in a staged revision surgery (Fig 1). Patients were followed and presumed at risk until the end of the study or until emigration (n = 10) or death (n = 4).

Confounding Factors

The following variables were considered as possible confounding factors and tested in the Cox regression models: age group (<20, 20 to 30, >30 years of age), graft choice, activity at injury (pivoting activities [soccer, handball, basketball] or nonpivoting activities), concomitant ligament injuries, cartilage injury, BMI, meniscal injuries, and sex. Multivariable analysis was tested with associated pathology and patient demographics as covariates (age at surgery, sex, activity at injury [pivoting/nonpivoting], chondral injuries [ICRS 1-2 or ICRS 3-4], and meniscal injury [medial, lateral, both menisci, or no injury]).

Results

Patient Demographics

A total of 812 patients were identified in the study period to have undergone at least 1 revision ACLR, of whom 24 patients had undergone cartilage restoration surgery and 4 had a meniscal allograft transplant and were therefore excluded. Based on the calculated propensity scores, we found 5 controls for each case, giving us a full dataset of 4,704 patients: 784 in the case group and 3,920 in the control group (Fig 2 and Table 1).

Patient characteristics, intraoperative findings, and associated injuries are presented in Table 1. The average patient age was 25.5 and 25.6 years for the case and control group, respectively, with 53% males in both groups. There was a significant difference in graft choice between the 2 groups, with a predominance of bone patellar bone in the case group (62.1%) and hamstring tendon autografts in the control group (64.9%) ($P < .001$). In the case group, reported new trauma (290) and graft failure (208) were the most common causes of revision ACLR (Table 2).

Revision ACLR patients had significantly less new meniscal pathology at time of surgery compared with the control group ($P < .001$). Surgery time was reported to be 11.7 minutes longer for the case group compared with the control group ($P < .001$).

Revision ACLR and Re-revision ACLR

At a mean follow up of 4.6 years (median 4.3 years), the rate of re-revision ACLR was 5.5%. Of those

Table 1. Patient Characteristics in the Revision ACLR Group and the Control (Primary ACLR) Group

	Primary Controls (n = 3,920)	Revised Patients (n = 784)	*P* Value
Age			
Mean (SD)	25.6 (8.8)	25.5 (8.7)	.74
Median (min-max)	23 (11-66)	23 (14-67)	
Sex	53% male	53% male	.85
Graft choice			
BPTB	1,334 (34.0%)	487 (62.1%)	<.001
Hamstring	2,546 (64.9%)	180 (23.0%)	
Allograft	10 (0.3%)	11 (1.4%)	
BQT	20 (0.5%)	46 (5.9%)	
Missing	10 (0.3%)	60 (7.7%)	
Meniscal injury			
Lateral	627 (16.0%)	79 (10.1%)	<.001
Medial	979 (25.0%)	154 (19.6)	
Both	386 (9.8%)	46 (5.9)	
ICRS			
Grades 1-2	566 (14.4%)	130 (16.6%)	.72
Grades 3-4	248 (6.3%)	65 (8.3%)	
Associated ligament injuries			.17
PCL	64 (1.6%)	5 (0.6%)	
MCL	268 (6.8%)	44 (5.6%)	
LCL	84 (2.1%)	8 (1.0%)	
PLC	44 (1.1%)	4 (0.5%)	
BMI kg/m^2	25.2 (7.3) (n = 2,519, 64%)	24.7 (3.8) (n = 521, 66%)	.15
Activity at injury			
Pivoting activities	1,931 (49.3%)	382 (48.7%)	.80
Nonpivoting	1,769 (45.1%)	350 (44.7%)	
Surgery time			
Mean (SD)	79.4 (38.8)	90.1 (38.1)	<.001
Median (min-max)	71 (26-350)	83 (30-320)	

NOTE: Pivoting activities included soccer, handball, and basketball.

BMI, body mass index; BPTB, bone patellar bone; BQT, bone quadriceps tendon; ICRS, International Cartilage Repair Society; LC, posterior lateral corner; LCL, lateral collateral ligament; max, maximum; min, minimum; PCL, posterior cruciate ligament; PMCL, medial collateral ligament; SD, standard deviation.

patients who underwent re-revision,12 (1.7%) required a second re-revision ACLR during the study period. The estimated 1-, 2-, 5-, and 8-year re-revision ACLR rates were 0.4% (95% CI, 0.0-0.8), 3.0% (95% CI, 1.6-4.4), 6.5% (95% CI, 4.3-8.7), and 9.0% (95% CI, 5.8-12.2), respectively (Fig 3). In a multivariable Cox regression analysis adjusted for sex, meniscal injury, age at revision surgery, graft choice, activity at time of injury, and cartilage injury, the hazard ratio for re-revision was 0.3 (95% CI, 0.2-0.7, $P = .002$) for patients reported to have participated in pivoting activity at the time of injury compared with nonpivoting activity.

Table 2. Cause of Revision Anterior Cruciate Ligament Reconstruction

Cause of Revision	N (%)
New trauma	290 (37.0)
Graft failure	208 (26.5)
Unknown	141 (18.0)
Graft failure and new trauma	73 (9.3)
Fixation failure	28 (3.6)
Other combinations	17 (2.2)
Tunnel position	14 (1.8)
Infection	8 (1.0)
Pain	3 (0.4)
Untreated other ligament laxity	2(0.3)

Discussion

The most important finding of this study was that the predicted rate of a subsequent re-revision for revision ACLR patients was 6.5% at 5 years and 9.0% at 8 years. The rates of re-revision ACLR after revision ACLR are higher than after primary ACLR, highlighting that this group of patients is at a higher risk of failure than from a primary ACLR. It is important to understand factors that increase this risk of re-revision to address them and also to counsel patients accordingly about anticipated outcomes. In the present study, we did not find any concomitant pathology (cartilage lesions, knee ligament tears) or demographic factors (age, gender, BMI, activity at time of injury) associated with the risk of a re-revision ACL. In the future, with a larger study population, we might be able to provide a definitive

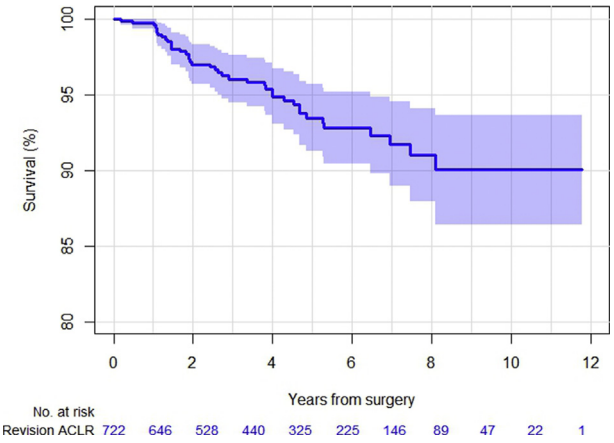

Fig 3. Kaplan-Meier survivorship curve for re-revision ACLR with 95% confidence interval. ACLR, anterior cruciate ligament reconstruction.

answer to these questions. This could also demonstrate the difficulty in predicting influencing factors on the rate of revision ACLR, and future studies should delve into other factors including tibial slope, alignment, ligament laxity, and rehabilitation protocols.

The rate of 5.5% re-revision ACLR after revision ACLR in the NKLR is higher than the 4.2% rate after primary ACLR previously reported from the same registry, highlighting that this group of patients is at a higher risk of failure than a primary ACLR.[27] The re-revision ACLR rate of 5.5% in our study was higher than the 2.0% to 5.4% reported in previous database and registry studies.[11,12,28,29] Lind et al[30] reported a revision ACLR rate of 4.1% from the Danish registry at 5 years. The time from a revision ACLR to a re-revision ACLR has previously been reported to range from 2.8 to 4.4 years.[31,32] A systematic review of the literature on revision ACLR by Liechti et al[33] found that, although re-revision ACLR could restore stability and improve functional outcomes compared with the preoperative state, outcomes were inferior when compared with primary ACLR regarding a patient's ability to return to his or her preinjury level of activity. Identifying patients who are at risk of re-revision ACLR, and adequate preoperative counseling are therefore important.

Patient demographics in our study for patient age, gender, and BMI were similar to those reported for other large revision ACLR registry database studies.[11,22,34,35] Schlumberger et al[28] reported that age (<25 years) was a risk for graft rupture after primary ACLR and revision ACLR; however, our results did not find that correlation. Just over one third of our patients had meniscal injury at the time of revision ACLR, which was lower than previously reported by Arianjam et al,[34] who reported more than half, and the Multicenter Orthopaedic Outcomes Network and the Multicenter ACL Revision Study (MARS) (close to 40% of new medial meniscal tears and 34% of new lateral meniscal tears).[35] This could be due to a different approach with a longer time to revision surgery from secondary injury, or a difference in data definition as to whether acute or chronic meniscal injuries are to be reported. Close to one quarter of patients in our study had cartilage injuries at time of revision ACLR, with two thirds having ICRS grades 1 and 2 cartilage changes, and one third having grades 3 and 4. This is similar to the findings of Lind et al (20%),[30] but lower than those reported by Arianjam et al (42%). The MARS and Multicenter Orthopaedic Outcomes Network studies only reported on grade 3 and 4 lesions, with the medial femoral condyle the most common location approximately 22% of the time.[35]

Autograft bone patellar bone or hamstrings were the predominant grafts used, with allografts used only 1.1% of the time. Regarding a difference between the type of autograft used, our results demonstrated no significant difference in survivorship based on the type of autograft used. This lack of difference between autografts is in line with previous work[36]; however, some studies on primary ACLR have reported higher risk of revision with hamstring tendon autograft than bone-patella tendon-bone autograft.[37,38] Previous revision ACLR studies have reported a higher use of allografts ranging from 21% to 76.7% of the time.[11,30,34] A recent systematic review of graft type and the outcomes of revision ACLR reported autografts to have better results than allografts with lower postoperative laxity, and lower rates of reoperation and complications.[9]

In the present study, patients who participated in pivoting activities at the time of injury before their first revision had a lower risk of re-revision compared with patients participating in nonpivoting activities, which is reflected by a hazard ratio of 0.3. The results for this category might therefore be caused by a reporting bias. Other explanations may be that these patients were able to regain a high level of quadriceps and hamstring strength that have been reported to be indicative of those able to cope with an ACL-deficient knee.[39-41]

Limitations

We recognize there are limitations to this study. Although the expected re-revision ACLR rate determined by this study is important, the unavailability of patient-reported outcomes measures limits the clinical insight of this study; subsequently, it is possible for there to be a difference regarding the subjective outcome scores for different groups of revised patients had those been available. Second is the acknowledgment that patients who do not undergo re-revision ACLR might still have had clinical failure but chose not to pursue re-revision surgery. Included in that group might be patients that sustained repeat failure, but through conservative management were able to return to a clinically functional state that did allow them to forgo re-revision.

We also do not have data on meniscal repair on resection at the time of the first revision, which potentially could affect the knee stability and risk of new injuries for further revision surgery.

Although this was review of large national registry. we still had a limited study population size. Although the Schoenfeld residuals were found suitable. it is possible that the Cox regression analysis was underpowered. In the group of patients included in the Cox regression analysis, 40 patients met the endpoint during the study period. With a larger study sample, we might have found other results, and it is possible that the analysis was underpowered.

Although surgical technique (transtibial, accessory medial, outside-in) has not been shown to play a role in ACLR failure, it would be beneficial to have that information regarding this patient population. In addition, the authors do not have data on the postoperative rehabilitation protocol used for the different groups of patients, surgeon experience, or patient activity levels, which could affect the results.

In conclusion, based on a review of a large ligament reconstruction registry, one can expect 9% of patients to undergo a re-revision ALCR at 8 years of follow up. Revision ACLR did not have an increase in cartilage injuries or associated ligament injuries and had significantly fewer meniscal injuries when compared with a primary ACLR control group.

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