



Rates of revision and surgeon-reported graft rupture following ACL reconstruction: early results from the New Zealand ACL Registry

Richard Rahardja¹ · Mark Zhu^{1,3} · Hamish Love⁴ · Mark G. Clatworthy⁵ · Andrew Paul Monk^{1,3} · Simon W. Young^{1,2}

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Abstract

Purpose There remains a lack of consensus on the patient factors associated with graft rupture following anterior cruciate ligament (ACL) reconstruction. This study aimed to identify the rate of revision and surgeon-reported graft rupture and clarify the patient risk factors for failure.

Methods Analysis was conducted on prospective data captured by the New Zealand ACL registry. All primary isolated ACL reconstructions recorded between April 2014 and December 2018 were reviewed to identify the rate of revision and surgeon-reported graft rupture. Univariate and multivariate survival analysis was performed to identify patient factors associated with revision and graft rupture.

Results A total of 7402 primary isolated ACL reconstructions were reviewed and had a mean follow-up time of 23.1 (SD ± 13.9) months. There were 258 surgeon-reported graft ruptures (3.5%) of which 175 patients underwent subsequent revision ACL reconstruction (2.4%). Patients younger than 18 years had the highest risk of revision (adjusted HR = 7.29, $p < 0.001$) and graft rupture (adjusted HR = 4.26, $p < 0.001$) when compared to patients aged over 36 years. Male patients had a higher risk of revision (adjusted HR = 2.00, $p < 0.001$) and graft rupture (adjusted HR = 1.70, $p < 0.001$) when compared to their female counterparts. Patients who underwent ACL reconstruction within 6 months of their injury had a two times increased risk of revision compared to patients who had surgery after 12 months (adjusted HR = 2.15, $p = 0.016$).

Conclusion Younger age, male sex and a shorter injury-to-surgery time interval increased the risk of revision, while younger age and male sex increased the risk of surgeon-reported graft rupture.

Level of evidence II.

Keywords ACL reconstruction · National registry · Revision ACL · Graft rupture

Introduction

Rupture of the anterior cruciate ligament (ACL) is a common knee injury and is frequently managed with surgical reconstruction [1–5]. However, graft failure remains a major complication following ACL reconstruction, resulting in significant patient disability and economic cost. Various patient factors including age, gender, activity at the time of injury and concomitant injuries have been associated with repeat injury, but a lack of consensus remains [6–11]. Clarifying characteristics which may predispose patients to treatment failure may guide surgical and rehabilitation practice to prevent poor outcomes following ACL reconstruction.

The New Zealand ACL registry was recently implemented in 2014 following the success of the national and community ACL registries in Scandinavia, the United States, the United Kingdom and Luxembourg. In comparison to

✉ Richard Rahardja
rrah466@aucklanduni.ac.nz

¹ University of Auckland, 85 Park Road, Auckland 1023, New Zealand

² Department of Orthopaedic Surgery, North Shore Hospital, Auckland, New Zealand

³ Department of Orthopaedic Surgery, Auckland Hospital, Auckland, New Zealand

⁴ Forte Sports, Christchurch, New Zealand

⁵ Department of Orthopaedic Surgery, Middlemore Hospital, Auckland, New Zealand

traditional cohort studies and randomised controlled trials, registry studies allow for large population-specific analysis and cross-country comparisons where different patient demographics and surgical practice are observed [12–14].

Revision ACL reconstruction is a common primary outcome that is used to measure failure following primary ACL reconstruction as it is well defined and captured in a registry design. However, revision reconstruction underestimates the true rate of graft rupture as not all patients proceed to have a revision. As a result, current registry studies have reported difficulty with defining the true rate of failure associated with ACL reconstruction [15–20]. The New Zealand ACL registry is the only nation-wide registry to capture graft ruptures that are reported by surgeons following post-operative patient follow-up. This provides an alternative outcome measure that attempts to capture the true rate of treatment failure.

The aim of this study was to analyse prospective data captured by the New Zealand ACL registry to identify both the rates of ACL revision and surgeon-reported graft rupture, and the patient factors that increase the risk of treatment failure.

Materials and methods

A prospective cohort study was performed using data extracted from the New Zealand ACL registry. 7612 primary ACL reconstructions have been recorded by the registry since its inception in April 2014–December 2018. Patients undergoing multi-ligament reconstruction or any concurrent surgery such as osteotomy or unicompartmental knee replacement were excluded ($N=146$). Only the patient's first primary isolated ACL reconstruction recorded in the registry was eligible for analysis ($N=7402$) and was followed up until either a revision or surgeon-reported graft rupture was recorded, or to the end of the study period.

The New Zealand ACL Registry

The New Zealand ACL registry is a nation-wide registry that began in 2014 and prospectively captures patient, surgical and follow-up data. Since 2017, it is mandatory for all orthopaedic surgeons who perform ACL reconstructions to actively participate in the registry to achieve re-certification [21]. All patients recorded in the registry have signed consent forms to participate. In addition, this analysis has been approved by the Health and Disability Ethics Committee (HDEC) as an audit activity. As of 2018, based on comparisons to government healthcare data, it is estimated that approximately 85% of all ACL reconstructions performed in New Zealand are captured by the registry [22]. Patient demographic data are collected through a pre-operative

form. An operative data form detailing each reconstruction procedure is completed by the surgeon. In addition, surgeons can fill out a post-operative complication form that details any early and late complications relating to the procedure. Patient-reported complications are confirmed with the treating surgeon.

Outcome of interest and predictor variables

The primary outcome for this study was revision ACL reconstruction as recorded in the registry during the study period (April 2014–December 2018). The secondary outcome measure was surgeon-reported graft rupture as captured by the registry's post-operative complication form. Surgeon-reported graft rupture was defined as a patient who re-presented to the orthopaedic clinic for follow-up and was deemed to have sustained a graft rupture following clinical assessment and examination documenting knee laxity, with confirmation of graft injury on radiological imaging. Patients were included in this group regardless of whether they eventually proceeded to have a revision.

The predictor variables of interest included all patient demographic factors that are recorded by the registry using both a patient questionnaire that is completed prior to the operation and an intra-operative data form that is filled out by the surgeon. Variables analysed from the patient questionnaire included patient sex, age and activity at the time of injury. The activity at the time of injury was subcategorised into sporting versus non-sporting injuries, which included ACL injuries sustained during work, traffic or other non-sporting activities. Surgeon-reported variables analysed from the intra-operative data form included injury side, time from injury-to-surgery, previous history of surgery on the index knee, and the presence of meniscal and/or cartilage injury.

Statistical analyses

All statistical analyses were performed using IBM SPSS Statistics version 25 and results were considered statistically significant at $p < 0.05$. Age and injury-to-surgery time were analysed as both categorical and continuous variables following normality assessment with Q–Q plots and histograms. Kaplan–Meier survival analysis was performed to calculate the cumulative probability of graft survival following primary ACL reconstruction. Univariate analysis of categorical variables was performed via Chi-square test or Fisher's exact test, while continuous variables were analysed via Student's t tests. In addition, incidence densities per 100 observed person-years were calculated. Statistically significant factors on univariate analysis were entered into a multivariate Cox proportional hazards regression model to produce hazard ratios (HR) with 95% confidence intervals (CI). The validity and robustness of the subsequent model

was checked against forward and backward stepwise models. The assumption of proportional hazards was assessed via log(– log) plots.

Results

7402 primary isolated ACL reconstructions were performed during the study period (April 2014–December 2018) (Table 1). The mean time of follow-up was 23.1

(SD ± 13.9) months. The mean age of patients was 29.1 (SD ± 10.9) years. The median time from injury-to-surgery was 4.2 (IQR = 5.2) months. Fifty-eight percent of the patients were male. 50% of reconstructions were performed on the patient's right knee. Twenty-eight percent of patients had a concomitant meniscal injury reported by the surgeon. Fifty-seven percent of patients had a concomitant cartilage injury reported by the surgeon. Eighty-two percent of reconstructions were caused by a sporting injury.

Table 1 Baseline demographics

Demographic	<i>N</i>	%	Observed person-years	Per 100 person-years
Number of isolated ACL reconstructions	7402			
Number of revisions	175	2.4	13999.2	1.3
Number of reported ruptures	258	3.5	13839.5	1.9
Side				
Right	3717	50.2		
Left	3682	49.7		
NR	3	0.0		
Sex				
Male	4291	58.0		
Female	3111	42.0		
Age (years)				
Mean ± SD	29.1 ± 10.9			
< 18	1255	17.0		
19–24	1756	23.7		
25–30	1631	22.0		
31–36	970	13.1		
> 36	1790	24.2		
Months to surgery				
Median (IQR)	4.2 (5.2)			
< 6	4879	65.9		
6–12	1454	19.6		
> 12	1051	14.2		
NR	18	0.2		
Previous surgery				
Yes	273	3.7		
No	7129	96.3		
Meniscal injury				
Normal	2061	27.8		
Injury	4408	59.6		
NR	933	12.6		
Cartilage injury				
Normal	4229	57.1		
Injury	2943	39.8		
NR	230	3.1		
Sport vs non-sport injury				
Sport	6089	82.3		
Non sport	1197	16.2		
NR	116	1.6		

175 revision ACL reconstructions were performed out of 7402 primary isolated ACL reconstructions producing an overall revision rate of 2.4% over the study period. The number of revisions per 100 observed person-years was 1.3 (Table 1). The number at risk at 2 years was 3453 patients and the cumulative survival probability was 97.3% (95% CI, 96.8–97.7) (Fig. 1).

A total of 258 graft ruptures were reported by surgeons using the post-operative complication form producing a rate of 3.5%. As a result, there were 83 patients who had a graft rupture that did not proceed to have a revision (32.2%). The number of reported ruptures per 100 observed person-years was 1.9 (Table 1).

3558 patients had a minimum follow-up duration of 2 years. In these patients, the 2-year revision rate was 3.0% ($N=106$). The 2-year surgeon-reported graft rupture rate was 4.4% ($N=157$).

Revision ACL reconstruction

On univariate analysis, patient sex, age, time to surgery, concomitant cartilage injury and cause of injury (sporting vs non-sporting) had a statistically significant association with the rate of revision ACL reconstruction (Table 2). Injury side, history of previous surgery on the index knee and concomitant meniscal injury were not associated.

On multivariate analysis, patient sex, age and time from injury-to-surgery were statistically significant risk factors for revision ACL reconstruction (Table 3). Male patients

were two times more at risk of revision than female patients (HR = 2.00; 95% CI, 1.42–2.81; $p < 0.001$). Patients aged less than 18 years were the most at-risk age bracket with a seven times higher risk of revision compared to patients older than 36 years (HR = 7.29; 95% CI, 3.66–14.53; $p < 0.001$). Furthermore, patients aged 19–36 years also had a higher risk of revision compared to patients in the oldest age bracket (HR = 4.08; 95% CI, 2.05–8.15; $p < 0.001$, HR = 3.25; 95% CI, 1.60–6.61; $p = 0.001$ and HR = 2.32; 95% CI, 1.04–5.18; $p = 0.04$). Patients who underwent reconstruction within 6 months were two times more likely to undergo revision compared to patients who underwent delayed reconstruction 1 year from the initial injury date (HR = 2.15; 95% CI, 1.16–4.00; $p = 0.016$).

Concomitant cartilage injury and cause of injury (sporting versus non-sporting) were not risk factors for revision.

Surgeon-reported graft rupture

On univariate analysis, patient sex, age, concomitant cartilage injury and cause of injury (sporting versus non-sporting) had a statistically significant association with the rate of surgeon-reported graft rupture (Table 2). Injury side, time to surgery, previous history of surgery, concomitant meniscal injury were not associated.

On multivariate analysis, patient sex and age were statistically significant risk factors for surgeon-reported graft rupture (Table 3). Male patients had a 1.70 times higher risk of graft rupture compared to females (95% CI, 1.30–2.23; $p < 0.001$). All patients aged 36 years or

Fig. 1 Cumulative survival probability of revision following primary ACL reconstruction

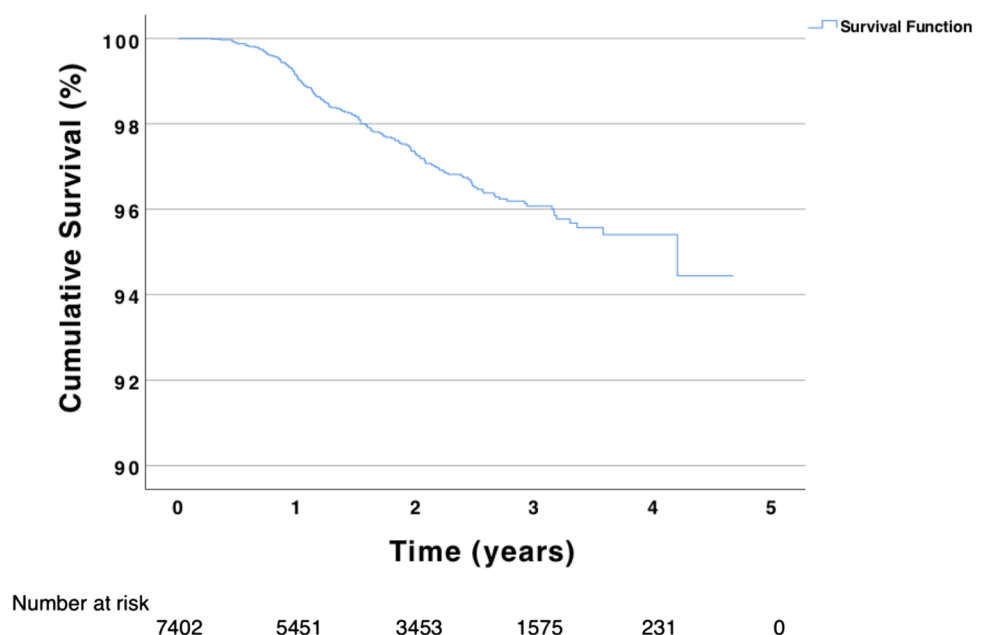


Table 2 Revision ACL reconstruction and surgeon-reported graft rupture

Demographic	N	Revision			Graft ruptures		
		Total revisions	% Revised	p value	Total ruptures	% Ruptured	p value
Side							
Right	3717	99	2.7	n.s	138	3.7	n.s
Left	3682	76	2.1		120	3.3	
NR	3	0	0.0		0	0.0	
Sex							
Male	4291	128	3.0	<0.001	180	4.2	<0.001
Female	3111	47	1.5		78	2.5	
Age (years)							
Continuous							
Mean ± SD	29.1 ± 10.9	23.5 ± 7.1		<0.001	24.3 ± 7.8		<0.001
Categorical							
< 18	1255	60	4.8	<0.001	71	5.7	<0.001
19–24	1756	53	3.0		78	4.4	
25–30	1631	36	2.2		59	3.6	
31–36	970	16	1.6		27	2.8	
> 36	1790	10	0.6		23	1.3	
Months to surgery							
Continuous							
Median (IQR)	4.2 (5.2)	3.7 (4.3)		<0.001	3.8 (5.0)		n.s
Categorical							
< 6	4879	129	2.6	0.014	179	3.7	n.s
6–12	1454	33	2.3		54	3.7	
> 12	1051	12	1.1		24	2.3	
NR	18	1	5.6		1	5.6	
Previous surgery							
Yes	273	3	1.1	n.s	9	3.3	n.s
No	7129	172	2.4		249	3.5	
Meniscal injury							
Normal	2061	48	2.3	n.s	71	3.4	n.s
Injury	4408	101	2.3		155	3.5	
NR	933	26	2.8		32	3.4	
Cartilage injury							
Normal	4229	123	2.9	0.001	167	3.9	0.025
Injury	2943	49	1.7		87	3.0	
NR	230	3	1.3		4	1.7	
Sport vs non-sport injury							
Sport	6089	159	2.6	0.008	230	3.8	0.014
Non-sport	1197	16	1.3		28	2.3	
NR	116	0	0.0		0	0.0	

younger had a higher risk of graft rupture compared to patients aged 37 or older. The highest risk of graft rupture was observed in patients younger than 18 years (HR = 4.26; 95% CI, 2.62–6.95; $p < 0.001$). There was no difference in the risk of graft rupture between sporting injuries and non-sporting injuries (n.s.).

Discussion

The most important finding of the present study was that patient age, sex and time from injury-to-surgery were associated with a higher risk of ACL revision, while age and sex were significant predictors for graft rupture.

Table 3 Cox regression analysis: patient predictors for revision and graft rupture

Patient factor	Revision		Graft rupture	
	HR (95% CI)	<i>p</i> value	HR (95% CI)	<i>p</i> value
Sex				
Male	2.00 (1.42–2.81)	<0.001	1.70 (1.30–2.23)	<0.001
Female	Reference		Reference	
Age (categorical)				
< 18	7.29 (3.66–14.53)	<0.001	4.26 (2.62–6.95)	<0.001
19–24	4.08 (2.05–8.15)	<0.001	3.07 (1.90–4.94)	<0.001
25–30	3.25 (1.60–6.61)	0.001	2.52 (1.54–4.12)	<0.001
31–36	2.32 (1.04–5.18)	0.04	1.84 (1.05–3.24)	0.034
> 36	Reference		Reference	
Months to surgery (categorical)				
< 6	2.15 (1.16–4.00)	0.016	–	–
6–12	1.77 (0.89–3.53)	n.s		
> 12	Reference			
Cartilage injury				
Normal	1.26 (0.90–1.78)	n.s	1.08 (0.83–1.41)	n.s
Injury	Reference		Reference	
Sport vs non sport injury				
Sport	1.22 (0.72–2.06)	n.s	1.19 (0.80–1.78)	n.s
Non sport	Reference		Reference	

Younger age has been a commonly reported risk factor for ACL revision [23–30]. In comparison to patients older than 36 years, we found patients aged less than 18 years had a seven times higher risk of revision ACL reconstruction (HR = 7.3). Amongst registry studies from the United States, Sweden and Norway, this is the highest reported risk of revision for the youngest age category in comparison to the oldest age category, however, different age brackets are reported by each registry [15, 16, 26, 31, 32]. Furthermore, patients aged 19–24, 25–30 and 31–36 had a 4.1, 3.3 and 2.3 times higher revision risk. The association between younger age and an increased risk of revision may be explained by various reasons. First, younger patients are more likely to return to high-contact pivoting sports which increases the risk of graft rupture [29, 30, 33–36]. Second, older patients may be less likely to undergo revision as they are more tolerant of reduced knee stability due to lower activity demands [32, 37]. Finally, younger patients may be under higher sporting expectations to return to sport following an ACL tear, and do so at an earlier stage in their recovery [38]. There may also be anatomical, biomechanical and neuromuscular factors that predispose them to injury at a younger age, which in turn may predispose them to reinjury [39].

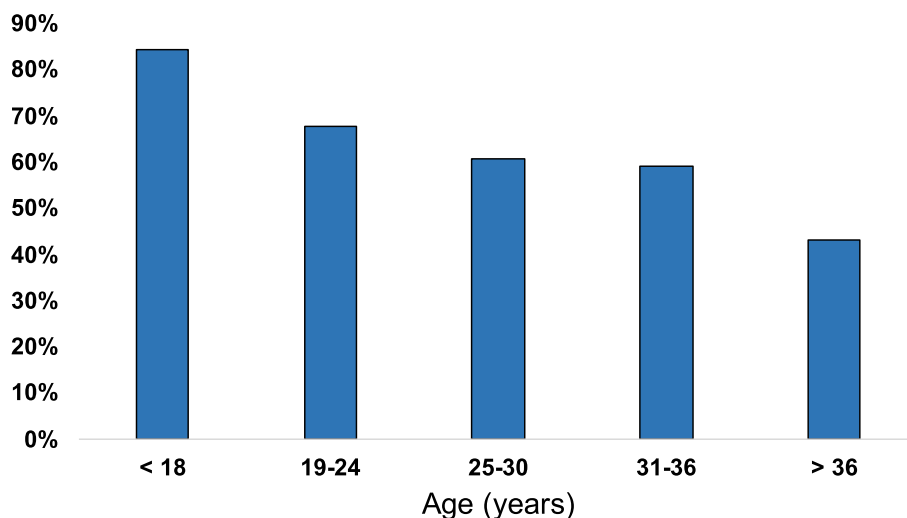
This study demonstrated that male patients were two times more likely than females to undergo revision ACL reconstruction. This is comparable to a study by Maletis et al. who found a 1.4 times higher risk of revision in males in the Kaiser

Permanente ACL registry [40]. The higher risk of revision observed in male patients may be explained by their tendency to return to sport earlier than females. Webster et al. investigated the return to sport following ACL reconstruction in 1440 patients and reported that males younger than 26 years had a 1.7 times higher odds of returning to sport within 1 year post-reconstruction compared to their female counterparts ($p < 0.001$), while males aged 26–35 years had 2.6 times higher odds of an early return to sport compared to females ($p < 0.001$) [35]. An earlier and higher rate of return to sport can be correlated to a higher risk of revision [30]. Despite these findings, the Scandinavian registries and a meta-analysis by Tan et al. did not find an association between patient gender and the risk of ACL revision [17, 23, 32, 41]. The lack of consensus between studies may be explained by different patient demographics, rates of return to sport and potentially different levels of participation in different high-risk sports, especially between males and females. Regardless, the conflicting results reported between countries demonstrate the benefits of implementing a nation-wide registry that can provide population-specific data and direct feedback to hospitals and surgeons.

A shorter injury-to-surgery time interval was associated with an increased risk of revision. This finding is comparable to Fältström et al. from the Swedish ACL registry who demonstrated that patients who underwent ACL reconstruction within 90 days of the initial ACL rupture were three times more likely to have a revision compared to patients who had surgery after 1 year from the initial injury (HR = 3.07, $p < 0.001$) [16]. Similarly, patients who had a reconstruction within 6 months of the initial ACL rupture had a two times higher risk of revision compared to patients who underwent primary reconstruction 1 year after the initial rupture (HR = 2.15, $p = 0.016$). It is possible this reflects a shorter time available for appropriate prehabilitation, however, it is more likely that higher level athletes who are more likely to return to play (and risk subsequent re-rupture) are also more likely to proceed to earlier surgical intervention following the initial ACL injury.

The New Zealand ACL registry is the only national registry that allows surgeons to report graft ruptures that require revision following appropriate clinical and radiological examinations. Using this method, 258 graft ruptures that were deemed to require revision (3.5%) were reported, with only 175 of these patients proceeding to undergo a revision ACL reconstruction. A similar rate of graft rupture has been reported by Kaeding et al. who analysed the multicentre orthopaedic outcomes network (MOON) cohort and reported a re-tear rate of 4.4% in 2684 patients after 2 years of follow-up [24]. We found patient age and gender were statistically significant risk factors for surgeon-reported graft rupture. Patients aged less than 18 years were 4.26 times more likely to have a graft rupture compared to patients aged over 36 years ($p < 0.001$). Furthermore, patients aged 19–36 years were between 3.1 and 1.8 times more likely to have a graft rupture ($p < 0.001$,

Fig. 2 Surgeon-reported graft failures proceeding to revision surgery



$p = 0.034$). In addition, males had a 1.7 times higher risk of graft rupture compared to females ($p < 0.001$). No other patient variables influenced the risk of surgeon-reported graft rupture. The rate of patients with a reported graft rupture proceeding to subsequent revision was higher with younger age (Fig. 2). Eighty-five percent of patients younger than 18 years who had a graft rupture proceeded to have a revision. In contrast, 43% of patients aged over 36 years who had a graft rupture proceeded to have a revision.

As the New Zealand ACL registry began in 2014, this study represents early follow-up following ACL reconstruction only. To adjust for differences in follow-up duration, the rate of revision and graft rupture was calculated per 100 observed person-years and a Cox regression survival analysis was performed. Furthermore, our findings were consistent when multivariate analysis was performed on only patients with a minimum follow-up of 2 years (Appendix 1).

Although revision ACL reconstruction is a well-defined primary endpoint, it is likely to underestimate the true rate of graft rupture. To mitigate against this, we investigated the rate of surgeon-reported graft rupture as captured by the registry. These data are a strength of this study and are a unique feature of the New Zealand ACL registry that is not utilised by any other national or community ligament registry. However, this process relies on patients re-presenting to the orthopaedic follow-up clinic and, therefore, not all graft ruptures would be recorded.

The registry does not currently record patients lost to emigration or death, therefore, there is a potential for bias in our analysis. However, we expect this number to be low and to not differ greatly between the patient populations compared. Additionally, large observational studies such as this are useful in identifying associations, however, they do not provide evidence of causation.

These findings allow clinicians to identify patients who may be more at-risk of reinjury following primary

ACL reconstruction. Clinicians should be aware of the higher rate of reinjury in younger patients, male patients and those with a shorter time from injury-to-surgery, especially when making rehabilitative decisions such as return-to-activity.

Conclusion

The rate of revision was 2.4% and the rate of surgeon-reported graft rupture was 3.5% in 7402 primary isolated ACL reconstructions. Younger age, male sex and a shorter injury-to-surgery time interval are risk factors for revision ACL reconstruction, while younger age and male sex increased the risk of a graft rupture proceeding to revision surgery.

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Compliance with ethical standards

Conflict of interest We, the authors, declare that we have no conflicts of interest with relation to this study. MGC reports that he does consulting for Johnson & Johnson, receives fellowship funding from Johnson & Johnson and Arthrex, and receives royalties from Arthrex, none of which are related to this study.

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Ethical approval Health and Disability Ethics Committee approval as an audit activity.

Appendix

See Table 4.

Table 4 Cox regression analysis: patients with minimum 2-year follow-up

Patient factor	N= 3558			
	Revision		Graft rupture	
	HR (95% CI)	p value	HR (95% CI)	p value
Sex				
Male	2.04 (1.40–2.97)	<0.001	2.00 (1.44–2.77)	<0.001
Female	Reference		Reference	
Age (categorical)				
< 18	7.65 (3.56–16.46)	<0.001	4.71 (2.65–8.39)	<0.001
19–24	4.31 (2.00–9.28)	<0.001	3.16 (1.79–5.57)	<0.001
25–30	2.90 (1.30–6.46)	0.009	2.39 (1.32–4.31)	0.004
31–36	2.68 (1.12–6.41)	0.027	1.88 (0.96–3.67)	n.s
> 36	Reference		Reference	
Months to surgery (categorical)				
< 6	2.24 (1.13–4.44)	0.021	–	–
6–12	1.86 (0.88–3.95)	n.s		
> 12	Reference			
Cartilage injury				
Normal	1.28 (0.88–1.86)	n.s	1.07 (0.79–1.46)	n.s
Injury	Reference		Reference	
Sport vs non-sport injury				
Sport	1.34 (0.74–2.43)	n.s	1.41 (0.85–2.33)	n.s
Non-sport	Reference		Reference	

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