Factors influencing Return to Play and Second ACL Injury Rates in Level 1 Athletes after Primary ACL Reconstruction

Two-year follow-up on 1432 reconstructions at single centre

Abstract

Background

Despite the importance of return to play (RTP) rates, second Anterior Cruciate Ligament (ACL) injury rates and patient reported outcomes to athletes returning to sports after ACL Reconstruction (ACLR), these outcomes have not been evaluated together across a single cohort, nor the pre and intra-operative factors influencing outcomes explored.

Purpose

To prospectively report outcomes after ACLR relating to RTP, second ACL injury and International Knee Document Committee (IKDC) scores in a large cohort of athletes at a single centre to examine the influence of pre and intra-operative variables on these outcomes.

Design

Prospective longitudinal study

Methods

A consecutive cohort of 1432 athletes undergoing primary ACLR under two orthopaedic surgeons were followed up prospectively after 2 years post-surgery. Pre and intra-operative findings were reported along with outcomes at follow up relating to RTP, second ACL injury and IKDC. Between group differences for each outcome were reported and the predictive ability of pre and intra-operative variables relating to each of the outcomes assessed using a logistic regression.

Results

There was over 95% follow up 2 years post-surgery. The return to play rate was 81%, and of those who returned, 1.3% of patellar tendon grafts and 8.3% of hamstring grafts suffered ipsilateral re-rupture (Hazard Ratio 0.17). The contralateral ACL injury rate was 6.6% and the IKDC score at follow up was 86.8, a greater proportion of patellar tendon grafts scoring <80 on IKDC (Odds Ratio 1.56; 95% CI 1.15 to 3.12). There was no relationship between time to RTP and second ACL injury and a moderate correlation between ACL-RSI score and RTP at follow up ($p < 0.001$, rho = 0.46) . There were a number of differences in pre and intra-operative variables between groups for each outcome, but they demonstrated a poor ability to predict outcomes in Level 1 athletes at 2 year follow up.

Conclusions

Findings demonstrated high overall RTP rates, lower re-injury rates with patellar tendon graft after 2 years follow up in Level 1 athletes, and no influence of time from surgery on second ACL injury. Despite differences between groups there was poor predictive ability of pre and intra-operative variables. Results suggests pre and intra operative variables for consideration to optimise outcomes in Level 1 athletes after ACLR, but future research exploring other factors such as physical and psychological recovery may be needed to improve outcome prediction after ACLR.

Key Terms: Anterior Cruciate Ligament Reconstruction, Return to Play, Re-injury, Athletes

What is known on the subject?

Return to play, second ACL injury and patient reported outcomes are important indicators of success after ACL reconstruction. However, they have not all been reported on a single cohort. The influence of pre and intra-operative findings on these outcomes in Level 1 athletes has not been explored.

What this study adds to the existing knowledge:

Level 1 athletes have good outcomes relating to RTP and ACL re-injury using patellar tendon graft and a structured physical review pathway. Level 1 athletes undergoing ACLR with hamstring tendon were almost 7 times more likely to suffer re-injury. Pre and intra-operative variables have a poor ability to predict 2 year outcomes. Additional factors such as recovery of physical and psychological measures should be considered in addition to surgical data to identify those factors influencing positive outcome after ACLR.

Introduction

Anterior cruciate ligament (ACL) rupture is a common knee injury in sports involving landing, pivoting and change of direction. ACL reconstruction (ACLR) is the primary means of restoring structural stability to the knee to facilitate return to high demand activities and sports.[12] There are a number of outcomes used to assess the success of ACLR including return to play (RTP) rate, secondary ACL injury incidence (to either the ipsilateral ACLR limb or contralateral non ACLR-limb) and patient-reported outcomes such as the International Knee Document Committee (IKDC) questionnaire.[22] Despite the value of these outcomes, they have not been reported together on a single cohort of athletes post ACLR. Without reporting these outcomes concurrently it is difficult to interpret the results of previous research as, for example, low re-injury rate may be as a result of low RTP rate ; a high RTP rate but lower IKDC scores suggesting athletes RTP despite ongoing symptoms in knee. Therefore reporting all 3 main outcomes gives a more comprehensive overview of how the athlete fared after surgery and how the outcomes are interlinked. Differences in pre and intra-operative variables relating to better and worse outcomes (i.e. re-injury/no re-injury) have been investigated to explore factors that influence outcome. However, the ability of pre and intra-operative data to predict these outcomes, and thus inform surgeons' clinical decision making and prognosis setting prior to surgery, have not been investigated.

A resumption of pre-injury sporting participation (i.e. RTP), especially in high demand Level 1 sports (as defined by sports involving landing and pivoting and hard cutting)[15] is one of the primary indications for, and patient goals after, surgical reconstruction.[12, 27] However, RTP rates are not as high as one might expect with 55% of ACLR athletes reported to return to competitive sports.[5] When athletes do return to play following ACLR, it is often despite ongoing knee symptoms and low levels of patient reported knee function. The International Knee Document Committee (IKDC) questionnaire is a commonly used measure of patient perceived knee function and has been validated for use after ACLR.[3, 16] Lower IKDC scores have been reported in older populations, females, those with lower quadriceps strength and in individuals after ACLR compared to previously uninjured athletes.[4, 33, 35] Whether pre and intra-operative data can predict future low RTP rates and scores relating to IKDC at follow up has not been investigated.

Resumption of high-intensity Level 1 sport confers an increased risk of second ACL injury. There is a higher risk of subsequent ACL injury after ACLR than in healthy populations,[25] seen not only in the ipsilateral ACLR-limb, but also in the previously un-injured contralateral (non-ACLR) limb. A number of pre and intra-operative variables have been suggested to be associated with second ACL injury risk including age, gender, graft selection and level of sport played.[37-39] The predictive value of these measures in isolation, or combination, to identify those susceptible to second ACL injury is unknown.

Recovery of physical measures such as strength, power and movement during testing after ACLR have been suggested to influence outcomes especially relating to IKDC and subsequent injury to both the ACLR and non-ACLR knee.[15, 19, 30, 33, 35] In order to accurately assess the influence of pre and intra-operative variables on outcomes after ACLR and minimise heterogeneity in physical recovery after surgery, post-operative pathways which include assessment of physical function and give feedback on progress and remaining physical deficits may hold relevance. The consistency of these pathways may ensure those returning to high demand Level 1 sports are more physically prepared to do so but also allow for more accurate analysis of the role of pre and intra-operative variables than previous studies involving large registries with multiple surgeons, orthopaedic centres and potentially different rehabilitation and physical review pathways.

The aim of this study was to report a prospective in-depth follow up (RTP, second ACL injury and IKDC) on a consecutive cohort of athletes who underwent primary ACLR followed by a physical review pathway. A secondary aim was to identify association of pre-operative and intra-operative variables with each of the three outcomes and assess the ability of these variables to predict each of the outcomes after 2 years post-surgery.

Methods

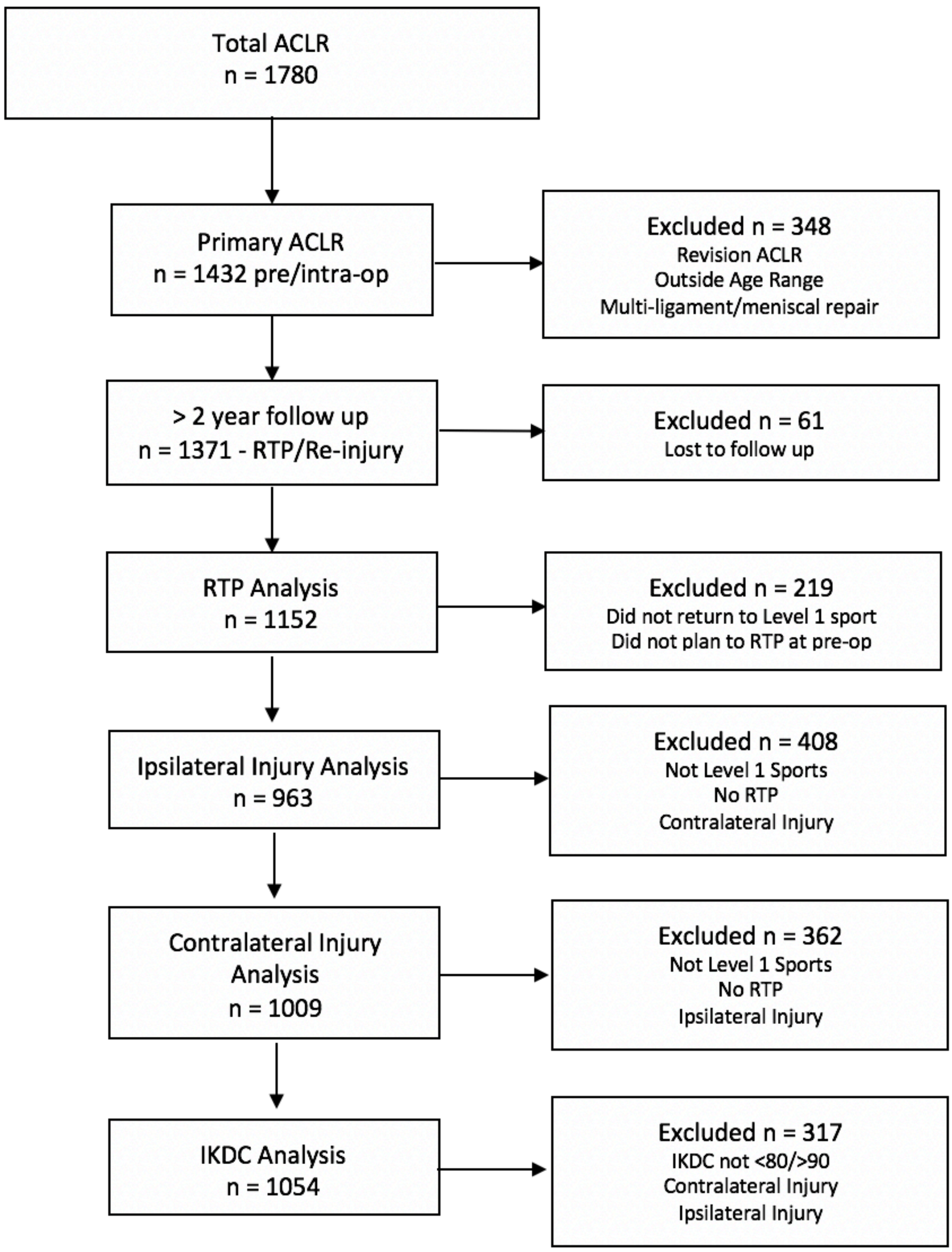
Participants were recruited prospectively at a at a single institution from the caseload of two orthopaedic surgeons, who specialise in knee surgery, between 1st January 2014 and 31st September 2016 and were consecutively recruited once diagnosis had been confirmed with MRI and orthopaedic review and surgery date had been set. All those undergoing primary ACL reconstruction, including those with previous contralateral injury, between the ages of 13 and 45, regardless of level or sport participation were included. Those with revision ACLR, those undergoing concurrent repair/reconstruction of other knee ligaments and those outside the age range were excluded. The study was registered at clinicaltrials.gov and all participants provided written informed consent prior to the collection of study data. Ethical approval for the study was received from the hospital ethics committee.

The study protocol was explained to subjects and after consent they completed a pre-operative questionnaire which captured demographic data relating to age, gender, sporting participation, intention to RTP after ACLR, primary mechanism of injury and Marx Activity Score at the time of injury. Surgery was carried out at the clinic by the two referring surgeons using equivalent arthroscopic and surgical techniques with bone-patellar tendon-bone (BPTB) or hamstring (HT) autografts with graft and tunnel placement within anatomical footprints with graft selection guided by case history and surgeon preference. No allografts surgical reconstructions were included in the current analysis. BPTB grafts were secured with metal interference screws (softsilk, Smith and Nephew). HT grafts were fixed using an endobutton (Endobutton CL Ultra, Smith and Nephew) for femoral fixation and a soft tissue screw (Biosure PK, Smith and Nephew) for tibial fixation. Routine arthroscopy was performed to address co-existing intra-articular pathology and treated accordingly. Extra-articular lateral tenodesis was carried out at the surgeons discretion on a small cohort of subjects.[26] Initial analysis revealed no difference in outcomes relating to this procedure and they were in included in overall analysis. All intra-operative data was recorded at the time of surgery in the ACL registry which was set up specifically for this study. Participants were instructed to weight-bear as tolerated with two elbow crutches for approximately two weeks after surgery and were reviewed by their surgeon at 2 weeks, 3 months and 6 to 9 months post-surgery. Due to the geographical spread of participants the majority were rehabilitated by clinicians/therapists local to their place of residence. As part of their review process they underwent a battery of physical tests to chart the progress of their rehabilitation. All participants were advised to achieve restoration of strength and power (>90% LSI) and not to RTP (defined as unrestricted resumption of their pre-injury sport) by their orthopaedic surgeon before at least the 6 month mark post-surgery. Participants were then followed up after 2 years post-surgery via e-mail and telephone by the ACL registry coordinator who was responsible for scheduling of review assessments and completion of 2 year follow up. At follow up, participants completed IKDC, ACL Return to Sport after Injury (ACL-RSI) and Marx Activity Scale questionnaires and a RTP questionnaire which recorded information regarding the ability and timing of return to sport and level of participation as well as any subsequent injury to the ACLR knee or non-ACLR knee. Participants who suffered a second ACL injury to either knee were identified at follow up or if they returned to the clinic for management prior to that time-point with a diagnosis of ipsilateral or contralateral ACL injury confirmed with MRI.

Statistical Analysis

The demographic, intra-operative and 2 year follow up data for the cohort were reported using descriptive statistics. Differences in survival (up to 36 months post-surgery) between ipsilateral and contralateral injury, BPTB and HT grafts and early (6 to <9 months post-surgery), middle (9-12 months) and late (13-16 months) RTP times were explored using a Kaplan Meier survival analysis. Additionally, a Cox proportional hazard regression was calculated for graft type and RTP class during the analysis. To test for differences in the resulting Kaplan-Meier estimate, a log-rank test (>2 classes) or a multivariate log-rank test was performed. If a significant difference was observed, the log-rank test was performed for different ranges of the data (up to 1 month, up to 2 months, continuing up to 36 months) to determine the month of onset of the differences. The relationship between the three main outcome measures - RTP, IKDC and second ACL injury (ipsilateral and contralateral separately) and pre-operative, intra-operative data and follow up data were explored. Given the potential influence of pre-operative intent to RTP and participation in Level 1 sports on outcomes, only those who intended to RTP prior to surgery and were involved in Level 1 sports were included in the analysis relating to RTP, ipsilateral and contralateral injury (Figure 1). For the IKDC analysis those who achieved a normal IKDC score (i.e. >90) and those who had a poor IKDC score (<80) were selected for analysis. The standard error of measure for IKDC is between 3.2 and 5.6 points so a minimum 10 point gap between groups was selected to offer clear differentiation between better and poorer scores.[10, 14] To examine relationships between measures a point biserial correlation coefficient (as the measures were binary) was used. To examine differences between groups for each of the variables (i.e. RTP/no RTP; ipsilateral ACL injury/no ipsilateral ACL injury; contralateral ACL injury/no contralateral ACL injury; IKDC <80/IKDC >90) a chi2 contingency table for nominal type features was used. Where significant results were observed within the chi^2 analysis, odds ratios were computed. Lastly, a logistic regression was fitted to a selection of pre-operative (gender, mechanism of injury, age, sport) and intra-operative variables (graft type, meniscal/chondral injury, extra-articular tenodesis; stepwise forward selection p = .01 in: p = .05 out) to predict each of the outcomes. The Marx Activity Scale was the only pre-operative data point not included in the regression analysis due to incomplete follow up. The regression generation and testing methodology is explained in detail in Appendix A.

Figure 1 Flowchart of participant inclusion in analysis



Results

Pre-operative Data

There were 1780 consecutive ACL reconstructions carried out by the two surgeons from January 2014 to September 2016 with 1432 of these primary ACL reconstructions and the majority of participants male (75%) (Table 1). Field sports were the most common activity at the time of primary injury, 90% of those undergoing surgery participated in Level 1 sports (involving landing and side-stepping). Most athletes (95%) planned resumption of similar or higher level of sport after surgery. Pivoting and sidestepping was the most common mechanism of primary injury (47%) and the average time from initial injury to surgery 4.5 months.

Table 1 Patient Demographic and Pre-Operative Data

Subject Demographic and Pre-Operative Data		
Total ACLR Surgeries	1780	
Primary ACL Reconstructions between 13-45 years	1432	80%
Gender		
Males	1068	75%
Females	364	25%
Age (years +/- STD)	24.3 (7.3)	
Sports Played at time of Injury		
Gaelic Football	569	40%
Football (Soccer)	266	19%
Hurling	209	15%
Rugby	158	11%
Snow Sports	74	5%
Basketball	29	2%
Racket Sports	6	<1%
Athletics	6	<1%
Other	115	8%
Pre-operative expected level of sport return		
Higher Level	329	23%
Same Level	1062	74%
Lower Level	15	1%
Other Sport	20	1%
No Return	5	<1%
Mechanism of Primary Injury		
Direct Contact	284	20%
Indirect Contact	219	15%
Non-Contact	929	65%
Pivoting/Sidestepping	670	47%
Jumping/Landing	293	20%
Being Tackled	252	18%
Tackling	105	7%
Other	116	8%
Pre-operative Marx Activity Quesionaire (74% Subjects)		
Mean (+/- STD)	10.9 (5.1)	
Time from Injury to Surgery (mean months +/STD; Range)		
Months (+/- STD); Range	4.5 (10.7)	1-147

ACLR - Anterior cruciate ligament reconstruction; STD - standard deviation;

Intra-Operative Data

The BPTB graft was the most commonly used graft (80%) for primary ACL reconstructions (Table 2). Medial meniscal injury was reported in 24% of surgeries and lateral meniscal injury in 38%. Injury to the medial and lateral femoral condylar surfaces was reported in 17% and 15% of cases respectively with low incidence of injury to tibial and patellofemoral surfaces reported (<1%).

Table 2 Intra-Operative Findings

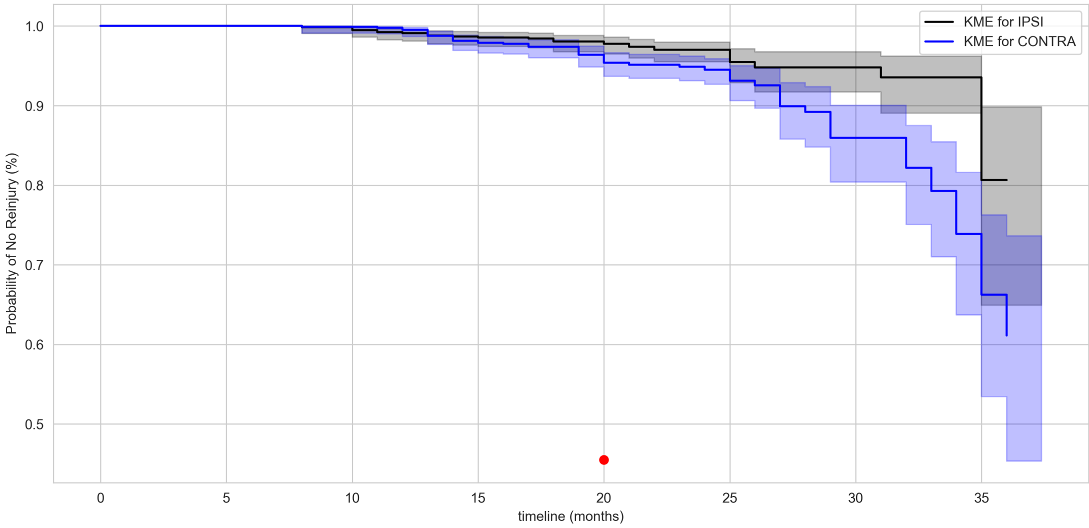
Intra-Operative Findings		
Graft Type		
Patellar	1142	80%
Hamstring	290	20%
Extra-articular tenodesis	32	2.2%
Medial Meniscal Injury		
Nil	1093	76%
Left in Situ	159	11%
Menisectomy	109	8%
Repair	71	5%
Lateral Meniscal Injury		
Nil	888	62%
Left in Situ	233	16%
Menisectomy	270	19%
Repair	41	3%
Medial Femoral Condyle		
Nil	1194	83%
Grade 1-2	171	12%
Grade 3-4	67	5%
Lateral Femoral Condyle		
Nil	1215	85%
Grade 1-2	196	14%
Grade 3-4	21	1%
Medial Tibial Condyle		
Nil	1420	99%
Grade 1-2	8	<1%
Grade 3-4	4	<1%
Lateral Tibial Condyle		
Nil	1421	99%
Grade 1-2	9	<1%
Grade 3-4	2	<1%
Patella		
Nil	1399	98%
Grade 1-2	28	1%
Grade 3-4	5	<1%
Trochlea		
Nil	1417	99%
Grade 1-2	9	<1%
Grade 3-4	6	<1%

Two Year Follow Up

There was 95.7% follow up greater than 2 years post-surgery (mean - 28.4 months; 24-55 months) on RTP and second ACL injury outcomes (Table 3). Return to sport was achieved by 81% of athletes across sports, on average 11.1 months ($\pm$ 5.1) post-surgery, with 82% of those participating in Level 1 sports returning to participation. Among the remaining patients who returned to Level 1 sports, the re-injury rate to the ACLR knee was 2.7% for all ACL reconstructions with 1.3% of BPTB and 8.3% of HT grafts suffering re-injury. The average time from surgery to ipsilateral injury was 21.4 months ($\pm$ 10.4) and 12.5 months ($\pm$ 9.6) from RTP to re-injury. The incidence of injury to the contralateral (non-ACLR) limb was 6.6% on average 24.6 months ($\pm$ 10.2) after surgery and 15.2 months ($\pm$ 10.1) after RTP. The average IKDC score at follow up for non-injured (no second ACL injury) was 86.8 ($\pm$ 10.1), Marx Activity Scale was 9.9 ($\pm$ 5.2) and ACL-RSI score was 74.8 ($\pm$ 22.6).

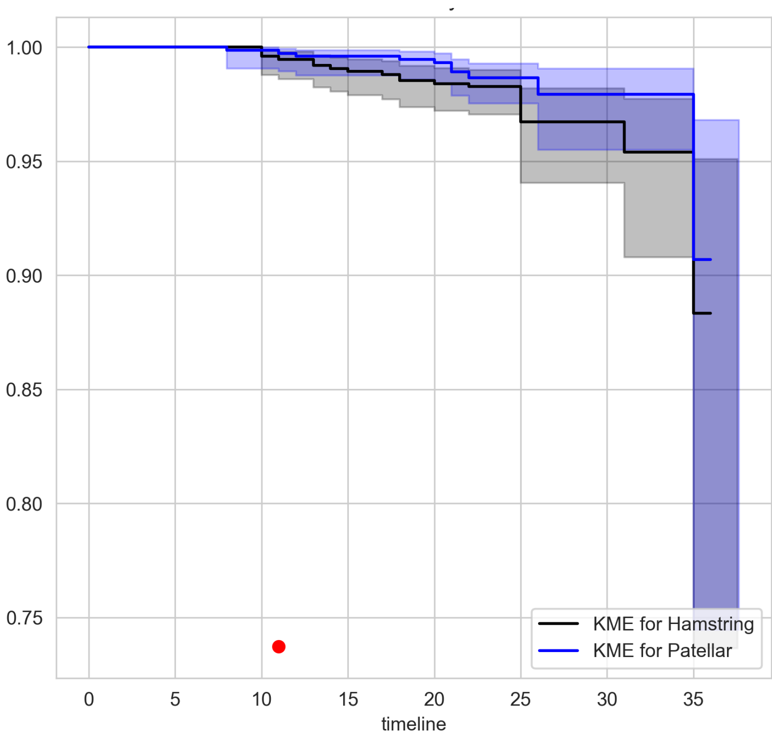
The Kaplan Meier Survival analysis reported a lower survival rate of the contralateral limb compared to the ipsilateral limb over time ($p < 0.001$; Figure 2) with differences in survival commencing from month 20 post-surgery. There was a superior survival rate of the BPTB graft relative to HT graft over time from month 11 post-surgery ($p < 0.001$, Figure 3). The BPTB graft had an 83% lower re-injury rate each month (Hazard Ratio 0.17; 95% CI 0.08 to 0.34). There was no difference in survival distribution between those who made an early (6 to < 9 month), middle (9 to 12 month) or later (13 to 16 month) return to sport after surgery when assessing ACL injury to either knee ($p = 0.234$) or the ACLR (ipsilateral) knee on its own ($p = 0.434$).

Figure 2 Kaplan Meier Survival Analysis For Ipsilateral vs Contralateral ACL



KME - Kaplan Meier Estimate; IPSI - Ipsilateral ACL Injury; CONTRA - Contralateral ACL Injury. The red dot indicates the first month a difference in survival was detected between groups.

Figure 3 Kaplan Meier Survival Analysis BPTB vs HT graft



KME - Kaplan Meier Estimate. The red dot indicates the first month a difference in survival was detected between groups.

Table 3 Two year follow up outcomes

2 Year Follow Up		
% Follow Up (total primary ACLR n = 1432)	1371	95.7%
Time to Follow Up (months +/- STD); Range	28.4 (7.9)	24-55
Return to Play (all sports) (n, %)		
Yes	1152	81%
No	219	15%
Unknown	61	4%
Time to RTP (months +/- STD); Range	11.1 (5.1)	3-32
Return to Play Level 1 sports (n = 1237); (n, %)	1012	82%
Second ACL Injury (n, %)		
Ipsilateral Total	39	2.7%
Ipsilateral BPTB Graft	15	1.3%
Ipsilateral HT Graft	24	8.3%
Contralateral	94	6.6%
Time to Second ACL Injury (months +/- STD); Range		
Ipsilateral Surgery to Injury	21.4 (10.4)	7 - 50
Hamstring Surgery to Injury	19.8 (9.9)	4 - 40
Patellar Surgery to Injury	23.9 (11.2)	8 - 50
Ipsilateral RTP to Injury	12.5 (9.6)	1 - 42
Contralateral Surgery to Injury	24.6 (10.2)	8 - 50
Contralateral RTP to Injury	15.2 (10.1)	1 - 45
IKDC (83% subjects); (n, %)		
Mean (+/-STD)	86.8 (10.1)	
IKDC >90	848	60%
IKDC <80	206	14%
Marx Activity Scale (72% subjects)		
Mean (+/-STD)	9.9 (5.2)	
ACL-RSI (48% subjects)		
Mean (+/- STD)	74.8 (22.6)	

STD - standard deviation; n = number; IKDC - international knee documentation committee

Differences RTP vs No RTP

The differences between athletes who achieved return to play and those that did not after 2 year follow up are reported in Table 4. Those athletes who pre-operatively determined they did not plan to return to the same level of activity (n = 28) and those who did not play Level 1 sports (n = 182) were removed from the analysis. There was a weak correlation between age (negative correlation) and pre-operative Marx Activity Scale and RTP with younger athletes and those with higher pre-operative Marx scores returning to sport ($p < 0.001$; rho -0.18 & 0.19 respectively). There was a moderate correlation with ACL-RSI score at follow up and RTP ($p < 0.001$, rho = 0.46) and a weak correlation between IKDC at follow up and RTP ($p < 0.001$; rho = 0.29). There was a significant difference in RTP between groups depending on the presence of injury to medial ($p = 0.017$) or lateral meniscus ($p = 0.041$) with higher rates of return in those with no medial meniscal tear or when left in situ and those with no lateral meniscal tear or meniscectomy. Similarly there was a difference in RTP depending on the presence of medial femoral condyle injury ($p = 0.008$) with those suffering a grade 3-4 injury having a lower rate of return (OR 3.03; 95% CI 1.58 to 5.55). When fitting pre and intra operative variables to RTP using a stepwise forward logistic regression, only age meet the inclusion criteria (older athletes less likely to RTP) and the generated logistic regression achieved an accuracy 64% (baseline 87%) with an AUC of 0.66 (sensitivity 0.66, specificity 0.65) indicating poor ability of pre-operative and intra-operative data to predict RTP after 2 year follow up.

Table 4 Differences between RTP and No RTP at Follow Up

		RTP	No RTP	p - value	Statistic	OR No RTP (95% CI)
Gender	Male	794 (86%)	124 (14%)	0.813	0.06†	
	Female	201 (86%)	33 (14%)			
Age		22.7 (±6.2)	26.1(±6.7)	<0.001*	-0.18‡	
Pre-Op Marx Score		11.8 (±4.8)	9.2 (±5.3)	<0.001*	0.17‡	
Injury Mechanism	Jumping/Landing	200 (89%)	24 (11%)	0.07	8.67†	
	Sidestep/Pivot	467 (86%)	79 (14%)			
	Tackling	78 (79%)	20 (21%)			
	Being Tackled	205 (89%)	24 (11%)			
	Other	45 (81%)	10 (19%)			
Injury Contact	Direct	207 (88%)	29 (12%)	0.473	1.5†	
	Indirect	160 (84%)	31 (16%)			
	Non-Contact	628 (86%)	97 (14%)			
Graft Type	BPTB	795 (86%)	129 (14%)	0.739	0.6†	
	HT	200 (88%)	28 (12%)			
Extra-articular Tenodesis	Yes	972 (87%)	150 (13%)	0.166	2.46†	
	No	23 (77%)	7 (23%)			
Medial Treatment	Nil	778 (88%)	111 (12%)	0.008*	11.91†	
	Left in Situ	123 (87%)	17 (13%)			0.97 (0.56 to 1.66)
	Menisectomy	52 (76%)	16 (24%)			2.17 (1.19 to 3.84)
	Repair	41 (74%)	13 (26%)			2.22 (1.14 to 4.34)
Lateral Treatment	Nil	599 (87%)	87 (13%)	0.041*	9.96†	
	Left in Situ	155 (79%)	39 (21%)			1.72 (1.13 to 2.63)
	Menisectomy	212 (84%)	39 (16%)			0.81 (0.51 to 1.29)
	Repair	28 (82%)	6 (18%)			1.47 (0.59 to 3.70)
Chondral Pathology MFC	Nil	858 (87%)	126 (13%)	0.002*	12.58†	
	Grade 1-2	103 (87%)	16 (13%)			1.05 (0.60 to 1.85)
	Grade 3-4	34 (69%)	15 (31%)			3.03 (1.58 to 5.55)
Chondral Pathology LFC	Nil	851 (87%)	124 (13%)	0.107	4.47†	
	Grade 1-2	131 (81%)	30 (19%)			
	Grade 3-4	13 (81%)	3 (19%)			
ACL RSI		79.4 (±19.5)	41.3 (±24.1)	<0.001*	0.56‡	
IKDC		88.5 (±8.8)	81.2 (±10.5)	<0.001*	0.29‡	

RTP - return to play, No RTP - no return to play, OR - odds ratio, CI - confidence interval, BPTB - bone patellar tendon bone, HT - hamstring tendon, MFC - medial femoral condyle, LFC - lateral femoral condyle, ACL RSI - anterior cruciate ligament return to sport after injury, IKDC - international knee documentation committee, † - Chi-Squared analysis, ‡ - point biserial correlation.

Differences in Ipsilateral re-injury and no ipsilateral re-injury

The differences between athletes who had suffered ipsilateral ACL injury and those who had not at follow up are reported in Table 5. For the comparisons of ipsilateral reinjury rates, there were 222 athletes who had not returned to play, 90 who suffered contralateral ACL injury and 156 who did not play Level 1 sports, or had a combination of the above, who were excluded from the analysis. There was a significant difference in ipsilateral injury depending of graft choice with 11.9% of HT suffering ipsilateral injury compared to 1.9% of BPTB grafts ($p < 0.001$, chi = 40.39; OR 6.80). There was a weak correlation between age and ipsilateral injury ($p < 0.001$; coefficient = 0.10) with those suffering ipsilateral injury younger than those who did not. The logistic regression model using pre and intra-operative data to predict ipsilateral ACL injury selected hamstring graft, male, age and side step primary injury mechanism to be included in the model. The logistic regression reported an accuracy of 76% (baseline 96%) with and ROC AUC of 0.73 (sensitivity 0.76, specificity 0.69) suggesting pre and intra-operative data has only fair accuracy in predicting ipsilateral ACL injury and the accuracy is well below the baseline.

Table 5 Differences between in ipsilateral ACL injury and no ipsilateral injury

		Ipsi	No Ipsi	p - value	Statistic	OR Ipsi (95% CI)
Gender	Male	32 (4%)	736 (96%)	0.485	0.49†	
	Female	6 (3%)	189 (97%)			
Age		20.3 (±5.1)	24.2 (±7.2)	0.003*	0.10‡	
Pre-op Marx Score		11.4 (4.9)	11.7 (5.1)	0.803	0.01‡	
Injury Mechanism	Jumping/Landing	7 (3%)	189 (97%)	0.992	0.27†	
	Sidestep/Pivot	19 (4%)	432 (96%)			
	Tackling	3 (4%)	73 (96%)			
	Being Tackled	7 (3%)	189 (97%)			
	Other	2 (5%)	42 (95%)			
Injury Contact	Direct	8 (4%)	199 (96%)	0.885	0.25†	
	Indirect	7 (4%)	143 (96%)			
	Non-Contact	23 (4%)	583 (96%)			
Graft Type	BPTB	15 (1.9%)	755 (98.1%)	<0.001*	40.39†	6.80 (3.48 to 13.31)
	HT	23 (11.9%)	170 (89.1%)			
Extra-articular Tenodesis	Yes	0 (0%)	24 (100%)	0.337	0.92†	
	No	38 (4%)	901 (96%)			
Medial Treatment	Nil	31 (4%)	721 (96%)	0.779	1.09†	
	Left in Situ	3 (2%)	112 (98%)			
	Menisectomy	3 (5%)	53 (95%)			
	Repair	1 (2%)	38 (98%)			
Lateral Treatment	Nil	25 (4%)	559 (96%)	0.504	3.33†	
	Left in Situ	8 (5%)	140 (95%)			
	Menisectomy	5 (2%)	198 (98%)			
	Repair	0 (0%)	28 (100%)			
Chondral Pathology MFC	Nil	34 (4%)	797 (96%)	0.427	1.7†	
	Grade 1-2	4 (4%)	95 (96%)			
	Grade 3-4	0 (0%)	33 (100%)			
Chondral Pathology LFC	Nil	31 (3%)	790 (97%)	0.786	0.48†	
	Grade 1-2	6 (5%)	123 (95%)			
	Grade 3-4	1 (7%)	12 (93%)			

Ipsi - ipsilateral; OR - odds ratio; BPTB - bone patellar tendon bone; HT - hamstring tendon; MFC - medial femoral condyle; LFC - lateral femoral condyle; † - Chi-Squared analysis, ‡ - point biserial correlation.

Differences in contralateral injury and no contralateral injury

The differences between athletes who had suffered contralateral ACL injury and those who had not at follow up are reported in Table 6. Those athletes who had not returned to play (n = 222), those who suffered ipsilateral ACL injury (n = 39) and those who did not play Level 1 sports (n=159) or had a combination of the above, were removed from the analysis. Of the variables examined, only age had a significant but weak relationship with contralateral ACL injury ($p < 0.001$; rho = 0.16) with those suffering contralateral injury younger than those who did not. The logistic regression using pre and intra-operative data to predict contralateral ACL injury selected age, male and non-contact injury mechanism to be included in the model. The logistic regression achieved an accuracy of 63% (baseline 96%) with an AUC of 0.71 (sensitivity 0.63, specificity 0.64; suggesting pre and intra-operative data has only fair accuracy in predicting contralateral ACL injury and the accuracy is well below the baseline.

Table 6 Differences between in contralateral ACL injury and no contralateral injury

		Contra	No Contra	p-value	Statistic	OR Contra (95% CI)
Gender	Male	66 (8%)	736 (92%)	0.829	0.05†	
	Female	18 (8%)	189 (92%)			
Age		19.7 (4.2)	24.2 (7.2)	<0.001*	-0.16‡	
Pre-op Marx Score		12.4 (4.3)	11.4 (5.0)	0.303	0.04‡	
Injury Mechanism	Jumping/Landing	17 (8%)	189 (92%)	0.671	2.36†	
	Sidestep/Pivot	40 (8%)	432 (92%)			
	Tackling	3 (4%)	73 (96%)			
	Being Tackled	20 (9%)	189 (91%)			
	Other	4 (9%)	42 (91%)			
Injury Contact	Direct	15 (7%)	199 (93%)	0.73	0.63†	
	Indirect	14 (9%)	143 (91%)			
	Non-Contact	55 (9%)	583 (91%)			
Graft Type	BPTB	66 (8%)	755 (92%)	0.495	0.47†	
	HT	18 (9%)	170 (91%)			
Extra-articular Tenodesis	Yes	0 (0%)	24 (100%)	0.135	2.23†	
	No	84 (9%)	901 (91%)			
Medial Treatment	Nil	67 (9%)	721 (91%)	0.975	0.22†	
	Left in Situ	10 (8%)	112 (92%)			
	Menisectomy	4 (7%)	53 (3%)			
	Repair	3 (7%)	38 (93%)			
Lateral Treatment	Nil	48 (8%)	559 (92%)	0.477	3.50†	
	Left in Situ	19 (12%)	140 (88%)			
	Menisectomy	15 (7%)	198 (93%)			
	Repair	2 (7%)	27 (93%)			
Chondral Pathology MFC	Nil	68 (8%)	797 (92%)	0.105	2.63†	
	Grade 1-2	14 (13%)	95 (87%)			
	Grade 3-4	2 (6%)	33 (94%)			
Chondral Pathology LFC	Nil	74 (9%)	790 (91%)	0.711	0.14†	
	Grade 1-2	10 (7%)	123 (93%)			
	Grade 3-4	0 (0%)	12 (100%)			

Contra - contralateral; OR - odds ratio; BPTB - bone patellar tendon bone; HT - hamstring tendon; MFC - medial femoral condyle; LFC - lateral femoral condyle; † - Chi-Squared analysis, ‡ - point biserial correlation.

Differences in IKDC <80 and >90

The differences between those with an IKDC score <80 and >90 at follow up are reported in Table 7. A gender disparity was seen, with a greater proportion of males achieving IKDC >90 (p < 0.001). There was a weak correlation between age and IKDC score with those >90 IKDC younger than those <80 (p < 0.001, coefficient = -0.18). In addition, there were differences between groups in relation to level of sport with those participating in Level 2 sports having a higher proportion of athletes with <80 IKDC (p <0.001, OR 2.26). There were differences in the intra-operative data, those with BPTB graft were more likely to have IKDC < 80 (OR 1.56). In addition, differences were also present in relation to medial meniscal injury (p < 0.001) with higher proportions of those with IKDC < 80 having undergone meniscectomy (OR 2.62) or meniscal repair (OR 2.15). Similarly injury to the medial femoral condyle was detrimental, with athletes with <80 IKDC having a higher proportion of grade 3-4 chondral injuries (p <0.001; OR 3.6). The logistic regression predicting IKDC >90 used age, gender and side stepping injury mechanism for inclusion in the regression and achieved an accuracy of 59% in the testing data (baseline 80%) with an AUC of 0.63 (sensitivity 0.71, specificity 0.57) suggesting a poor ability of pre and intra-operative data to predict who will achieve >90 IKDC at follow up.

Table 7 Differences between IKDC <80 and >90

IKDC		<80	>90	p-value	Statistic	OR <80 (95% CI)
Gender	Male	138 (17%)	664 (83%)	0.002*	9.91†	
	Female	68 (27%)	184 (73%)			1.72 (1.23 to 2.43)
Age		26.8 (7.5)	23.6 (6.7)	< 0.001*	-0.18‡	
Sports Played when injured	Level 1	163 (18%)	756 (82%)	< 0.001*	15.48†	
	Level 2	43 (32%)	92 (68%)			2.26 (1.65 to 3.45)
Marx Score		10.2 (5.4)	11.7 (4.8)	0.086	0.07‡	
Injury Mechanism	Jumping/Landing	42 (19%)	185 (81%)	0.098	7.82†	
	Sidestep/Pivot	99 (20%)	401 (80%)			
	Tackling	20 (26%)	56 (74%)			
	Being Tackled	26 (15%)	150 (85%)			
	Other	19 (26%)	56 (74%)			
Injury Contact	Direct	39 (19%)	167 (81%)	0.821	0.39†	
	Indirect	32 (21%)	123 (79%)			
	Non-Contact	135 (20%)	557 (80%)			
Graft Type	BPTB	176 (21%)	658 (79%)	0.039*	4.27†	1.56 (1.15 to 3.12)
	HT	30 (14%)	190 (86%)			
Extra-articular Tenodesis	Yes	5 (22%)	18 (78%)	0.773	0.08†	
	No	201 (19%)	830 (81%)			
Medial Treatment	Nil	141 (17%)	680 (83%)	< 0.001*	17.03†	
	Left in Situ	24 (21%)	88 (79%)			1.24 (0.75 to 2.06)
	Menisectomy	27 (35%)	51 (65%)			2.62 (1.54 to 4.45)
	Repair	14 (33%)	29 (67%)			2.15 (1.09 to 4.25)
Lateral Treatment	Nil	118 (18%)	527 (82%)	0.104	6.17†	
	Left in Situ	38 (23%)	128 (77%)			
	Menisectomy	38 (28%)	170 (82%)			
	Repair	12 (34%)	23 (66%)			
Chondral Pathology MFC	Nil	161 (18%)	723 (82%)	0.001*	17.97†	
	Grade 1-2	25 (22%)	93 (78%)			1.15 (0.70 to 1.89)
	Grade 3-4	20 (38%)	32 (62%)			3.60 (1.92 to 6.73)
Chondral Pathology LFC	Nil	168 (19%)	728 (81%)	0.192	3.3†	
	Grade 1-2	36 (25%)	110 (75%)			
	Grade 3-4	2 (17%)	10 (83%)			

IKDC - International Knee Documentation Committee; OR - odds ratio; CI - confidence interval; BPTB - bone patellar tendon bone; HT - hamstring tendon; MFC - medial femoral condyle; LFC - lateral femoral condyle. † - Chi-Squared analysis, ‡ - point biserial correlation.

Discussion

This prospective longitudinal study reports outcomes at a minimum of 2 years post-surgery from a large cohort ACLR athletes, 90% of whom were playing high demand Level 1 sports, who underwent ACLR with a post-operative physical review pathway at a single centre. The cohort was comprehensively characterised and followed-up (95%) and reports across a range of domains including RTP, IKDC and second ACL injury. The results demonstrate a lower re-injury rate for BPTB graft and high level of RTP for those returning to Level 1 sports at follow up, with a higher percentage of those returning to Level 1 sports achieving IKDC >90. In addition, time to RTP after 6 months post-surgery did not influence second ACL injury. The study identified differences in pre and intra-operative data between those who had better or worse outcomes. However the results highlighted the difficulty in using these data points to predict outcomes over 2 years post-surgery. The study demonstrates the success of this management pathway in athletes returning to high demand Level 1 sports and suggests other factors such as physical and psychological recovery after surgery may also need to be explored in conjunction with pre and intra-operative data to better predict positive outcomes after ACLR.

Return to Play

The return to play rates reported in this study of 82% for the entire cohort was comparable to the previous reviews in the literature[5, 21] and 81% for those involved in Level 1 sports was much higher than the 65% reported returning to pre-injury sport and 55% reported returning to competitive sport.[5] Differences between those who had and had not returned to Level 1 sports at follow up included age (greater RTP rate with weak correlation to younger age, rho = 0.18) in keeping with the previous literature.[5,7] In addition, there were lower percentage RTP rates in those with medial or lateral meniscal injury or grade 3-4 medial femoral chondral injuries present at the time of surgery. The influence of meniscal and chondral injury on RTP rates after primary ACLR has not been reported previously in the literature and may warrant further exploration. Its impact on RTP after revision ACLR has been investigated with no influence of meniscal injury but a negative impact of chondral injury on RTP rates.[1] The main reasons cited in the literature for non RTP after ACLR are fear of re-injury, ongoing knee symptoms and social factors.[6,11] This is supported in this study with lower IKDC scores (patient reported outcome relating to knee function) and ACL RSI scores (patient reported readiness to RTP) in those who had not returned to play. Given the main factors for non-RTP outlined above, it was intuitive that there would be an inability to predict RTP based on pre and intra-operative data with results reporting a poor prediction accuracy of 64% and AUC of 0.66. However, the follow up time for this study is relatively short and it is unknown if these factors, especially those relating to meniscal and chondral injury, had an impact on the ability to continue sporting participation with longer follow up.

Second ACL injury

This study reported an overall re-injury rate of 2.7% with a rate of 1.3% for BPTB and 8.3% for HT. When only those who returned to Level 1 sports are examined the re-injury rate for BPTB was 1.9% and for HT was 11.9%. The overall re-injury rate is favourable compared to other large cohorts with 2 year follow up at 4.4%[13,18] and Swedish registries which reported revision rate only (as opposed to all re-injuries) at 1.8%.[2] There was a clear difference in re-rupture rate between HT and BPTB grafts with a significant difference in graft survival (p <

0.001). BPTB had a 84% lower risk of injury every month (HR 0.17) and being almost 7 times less likely to re-rupture at over 2 year follow up. There is differing evidence on the influence of graft selection in re-injury in the literature. In a meta-analysis by Freedman et al, as well as in a systematic review of Scandinavian registries, lower re-rupture rates for BPTB grafts were reported.[13, 37] However, other systematic reviews reported no difference in re-rupture rates between graft selection albeit at longer follow up.[23, 36] Additional differences between those who suffered ipsilateral injury and those who did not in this study related to age, with younger athletes with higher ipsilateral injury rates although the correlation was weak (rho = 0.11; p<0.001). Younger athletes have been widely reported to be at higher risk of re-injury in the previous literature,[38, 40] principally through higher levels of RTP in high risk sports, as seen in our data above relating to RTP in Level 1 sports. The predictive ability of pre and intra-operative data to identify ipsilateral ACL injury was fair (76% accuracy, ROC 0.73) with hamstring graft selection the dominant factor. The accuracy was not superior to suggesting by default that no athlete would suffer re-injury however the low numbers relating to re-injury make more accurate prediction difficult. The influence of graft type may be a point for consideration during the clinical decision making of those managing Level 1 athletes who want to return to play.

The study also reported a higher overall contralateral injury rate than ipsilateral injury rate (6.6% vs 2.7% overall) and significant differences in survival (p < 0.001). The contralateral ACL injury rate in those returning to Level 1 sports was 9% with the only difference between those who went on to contralateral injury and those who did not relating to age (weak correlation (rho = 0.16; p<0.001) with higher injury rate in younger athletes) which is in agreement with the previous literature.[29, 38, 41] As there were few differences in pre and intra-operative data there was a low ability to predict who would suffer contralateral injury with a lower than baseline accuracy (63% vs 96%) and AUC of 0.71. Given the higher incidence of contralateral ACL injury, future work needs to prospectively identify those at higher risk so those factors can be addressed prior to RTP.

Of particular interest in this study was the absence of relationship between time to RTP and either contralateral or ipsilateral injury. Early return had been suggested to be a risk factor for re-rupture to the operated graft[19] and other injury to the operated knee,[15] with the risk of re-rupture highest in the first year after return with some recommending that return to sport should be delayed until 2 years after surgery.[28] This relationship with time from surgery has been suggested to be due to the time required for graft ligamentisation[8, 17, 31] and redevelopment of movement and physical qualities after surgery.[15, 19] However, our study reported an average time to injury after surgery of 21.4 months for ipsilateral injury and 24.6 months for contralateral injury. The time from RTP to injury at 12.5 months for ipsilateral injury and 15.2 months for contralateral injury. In addition, there was no difference in survival of contralateral or ipsilateral knee between those who returned from 6 to 9 months, between 9-12 months and those who returned between 12-16 months. Our results do not therefore support a timeline based restriction on RTP relating to second ACL injury after 6 months post-surgery.

IKDC

This study reported outcomes relating to IKDC scores after 2 years with results comparable to normative data of those with a previous history of knee injury and to other ACLR studies.[3, 20] In order to identify the relationship between pre and intra-operative findings and IKDC scores the cohort was split into those who had poorer outcome (IKDC < 80) and those who had a better outcome or return to normative levels (IKDC > 90). A number of factors were identified as different between groups with a higher percentage of younger athletes, males, those playing Level 1 sports and those with higher pre-operative Marx activity score having IKDC > 90, which is in agreement with previous literature.[3] There was a difference between groups relating to graft type with those having a HT more likely to have IKDC > 90. Graft site morbidity and additional quadriceps weakness after BPTB have been suggested to be an source of increased knee symptoms after ACLR compared to HT and this may be a contributor to the difference in scores.[4, 32] This is an often cited reason for selection of HT graft over BPTB for ACLR. However, given the primary indication for ACLR is to provide structural stability to the knee to participate in high demand activities and given the higher re-injury rate in HT reported in this study, pre and postoperative targeting of quadriceps strength and lower limb function after BPTB graft selection to offset the reported difference IKDC may be more appropriate than a change in graft selection. Those achieving IKDC >90 were younger than those <80. Higher self-reported knee function in younger athletes may contribute to the higher RTP rate and therefore and higher second ACL injury rate seen in younger athletes in the outcomes above. Injury to the medial compartment either to the meniscus or the medial femoral condyle was also different between groups with those with medial meniscectomy or medial meniscal repair as well as those with grade 3-4 changes in medial femoral condyle more likely to have IKDC < 80. This is in keeping with previous results where medial meniscus but not lateral meniscus tears at the time of surgery had a greater influence on IKDC score as well as grade 3-4 chondral changes.[9] It may also reflect that ACL injury is often a precursor to the early onset knee osteoarthritis.[24] The prediction model selected age, gender and side step injury mechanism as the key variables to predict >90 IKDC but the model demonstrated poor accuracy (59%; ROC 0.63). Given the short term follow up the influence of the intra-operative findings, in particular to the meniscus and chondral surfaces may have a more pronounced influence on IKDC at later follow up.

Limitations

There are a number of limitations to this study. Firstly, only two surgeons who specialise in knee surgery carried out the large number of reconstructions and this may reduce the generalisability of the results and comparison with registries with larger numbers of contributing surgeons. There was very high follow up rate (95%) after two years but there was a large spread in time to follow up 24-55 months. This may have influenced the results with potentially lower second ACL injury rates, lower RTP rates or recall bias and differences in IKDC scores if follow up had been completed over a shorter period around the two year mark. There was a larger number (80%) of BPTB grafts than HT grafts (20%) creating the potential for performance bias in favour of the more commonly used graft. However the two surgeons carried out 290 HT grafts reconstructions over the 20 month period between them, which would be more than most single graft surgeons would complete in the same time period and well in excess of the recommended 35 per year required to minimise the risk of future surgery on same knee.[34] A forward stepwise logistic regression model was used to assess the ability of pre and intra-operative data on outcomes after 2 years. The use of non-linear models may have enhanced the ability of those variables to predict outcomes but given the low accuracy and AUC in the receiver operating curve for all outcomes it is unlikely there would be a major change in the interpretation of the results. Given the challenges in predicting outcome using pre and intra-operative data alone, future research should look at the influence of other post-operative variables, such as biomechanical measures during RTP testing, as well as psychological and social factors on outcomes and combining pre and intra-operative data with biomechanical measures to improve predictive accuracy across outcomes.

Conclusion

This study prospectively reports across a range of outcomes including RTP, second ACL injury and IKDC in a large cohort with 95% follow up in athletes over 2 years post-surgery. There were high levels of RTP to Level 1 sports (81%) with low re-rupture rates in those athletes with BPTB graft (1.9%) who had a lower re-injury risk every month than those who underwent HT ACLR. There were a number of differences in pre and intra-operative data relating to each of the outcomes but these variables had poor ability to predict outcome after 2 years suggesting additional factors may also influence these outcome.

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