The Knee 39 (2022) 29–37

Contents lists available at ScienceDirect

The Knee

journal homepage:

Variables associated with successful outcome after anterior cruciate ligament reconstruction in recreational athletes: A prospective cohort study

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ARTICLE INFO

Article history:
Received 28 March 2022
Revised 15 July 2022
Accepted 26 August 2022

Keywords:
Knee ligaments
ACL
Rehabilitation

ABSTRACT

Background: Anterior cruciate ligament (ACL) injury and subsequent reconstruction is common and has a profound effect on health-related quality of life. There is currently limited understanding as to which variables are associated with a successful outcome post-ACL reconstruction (ACLR) in recreational athletes.
Purpose: Explore the association between both patient-reported and performance-based measures, and successful outcome, post-ACLR in recreational athletes.
Procedures: We sought to recruit recreational athletes within one month of a primary-ACLR for a prospective cohort study. A dichotomised patient specific functional scale of ≥9 points determined a successful outcome at nine-months post-operative. Secondary patient-reported and performance-based data were collected at baseline, three-, six-, and nine-months post-operative. The association between secondary data and the primary outcome was determined using binomial logistic regression, expressed using odds ratio (OR) and 95% confidence intervals (CI).
Main results: 90 participants were recruited (males: 58, females: 32, mean age 32.8 years [±7.9], mean height 173.5 [±10.0], mean body mass 74.0 kg [±15.8]), 87 consented to baseline measures. 47 participants completed full data collection and 21 (45%) reported a successful outcome. Higher knee osteoarthritis outcome score (OR range 1.07–1.12) and anterior cruciate ligament quality of life (ACL-QoL) scores (OR range 1.06–1.10) were associated with a successful outcome post-ACLR at various timepoints.
Conclusions: Patient-reported, rather than performance-based, measures were associated with successful outcome nine-months post-ACLR in recreational athletes. Both patient-reported and performance-based characteristics are advocated to guide optimal return to function in clinical practice.
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https://doi.org/10.1016/j.knee.2022.08.017
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1. Introduction

The annual incidence of anterior cruciate ligament (ACL) rupture ranges from 0.03% to 1.62% in recreational athletes [15]. A total of 15,304 ACL ruptures were registered in the United Kingdom National Ligament Registry from January 2012 to December 2019 [4], an approximate prevalence of 0.3% of the adult population. ACL rupture (± surgical reconstruction) has a significant negative impact upon a person's overall health, with high rates of symptomatic tibiofemoral osteoarthritis [12] and impaired knee-related quality of life [3] reported more than five years post-injury. A high percentage (11,861/15,304; 78%) of people registered by the United Kingdom National Ligament Registry [4] are reported to undergo subsequent surgical anterior cruciate ligament reconstruction (ACLR), aiming to allow a return to full daily and sporting function. Despite well-defined surgical procedures, 40% of people who undergo ACLR fail to return to pre-injury levels of physical function [2].

Rehabilitation and return to function post-ACLR should be based on a combination of patient-reported and performance-based measures to reduce re-injury rates [6]. Kyritsis et al., [10] reported that the likelihood of re-rupture, or failed return to play (function), was four times greater in a cohort of professional footballers who did not achieve specific discharge criteria. These criteria were isokinetic strength testing of the quadriceps and hamstring muscles, single/triple hop tests, and the running t-test. A deficit in hamstring to quadriceps ratio had the strongest association with future graft failure from this test battery [10].

Poor health-related quality of life (HRQOL) is reported to be a common feature post-ACLR, especially in relation to both competitive sports participation and recreational activity [3]. A limitation of the work by Kyritsis et al., [10] is the absence of patient-reported outcome measures (PROMS) to reliably evaluate perceived readiness to return to function or health-related quality of life. Patient perceived readiness to return to function is the variable most strongly associated with a successful outcome, or return to pre-injury activity level, post-ACLR [1]. A return to function test battery that includes both performance-based and psychological elements is therefore advocated [5].

The association between specific components of a combined return to sport test battery and a successful outcome post-ACLR has not been investigated in a cohort of recreational athletes. The absence of evidence to inform clinical decision-making limits the ability of medical professionals to guide recreational athletes back to an adequate level of function post-ACLR. It is inappropriate to assume that a more heterogeneous recreational group will always seek to achieve a return to a pre-injury level of function comparable to a professional athlete. This also questions the use of return to play markers designed for professional athletes when attempting to determine a successful outcome in recreational athletes.

The overarching aim of this study was therefore to investigate the association between patient-reported and performance-based measures and a successful outcome post-ACLR in recreational athletes. It was hypothesised that high scores in both patient-reported and performance-based domains would be significantly associated with a successful outcome at nine months post-ACLR.

2. Materials and methods

Ethical approval was obtained from the Queen Mary Ethics of Research Committee (QMERC2014/24/127). All participants were provided with a participant information sheet and provided written informed consent prior to data collection.

2.1. Participants

An a priori sample size calculation for independent samples t-test was conducted, with hamstring to quadriceps ratio the primary dependent variable given its ability to differentiate those with a successful outcome post-ACLR. Using previously published data [10], (no ACL graft rupture 58 [±10], ACL graft rupture 53 [±11]), 70 participants were required to achieve α = 5% and β = 0.80 (calculated using G*Power 3.1.9.3, Heinrich-Heine University, Germany). 90 participants were sought to allow for a 20% attrition rate, at which point recruitment ceased.

90 consecutive patients presenting to one of four Pure Sports Medicine clinics (London, UK) within one month of primary surgical ACLR from 1st March 2017 were invited to participate. No age restriction was used to facilitate the recruitment of a heterogeneous group of recreational athletes (defined as desiring a return to non-competitive or competitive amateur sport). Patients presenting with revision procedures, ACL avulsion injuries, non-arthroscopic procedures (e.g., iliotibial tenodesis), previous contralateral ACLR, systemic hypermobility disorders (e.g., Ehlers Danlos syndrome), professional athletes (defined by earning a living from playing sport), and patients with a delay of more than one month in presenting for post-operative physiotherapy, were ineligible. Eligible participants subsequently completed a rehabilitation period with a physiotherapist at one of four Pure Sports Medicine clinics that was not standardized or controlled for. Any pre-surgery rehabilitation that may have been completed by eligible participants was also not standardised or controlled for. This was designed to reflect current clinical practice and the efficacy of component(s) of a rehabilitation programme that may/may not contribute positively to the variables associate with a successful recovery post-ACLR were not part of our research question.

2.2. Primary outcome

To measure patient-reported readiness to return to their chosen sport/function, the patient specific functional scale (PSFS) was used. PSFS is valid, reliable, and responsive to change in a range of patient populations [8], including people with knee dysfunction [9]. PSFS was chosen as a measure that could be applied to a heterogeneous group of recreational athletes with variable return to function demands. Participants were asked to describe up to three activities that they were unable to perform because of their ACL reconstruction, which formed subsequent return to function criteria. A score of one reflected complete inability to perform the tasks/activities, and a score of ten reflected normal function. Individual PSFS scores from up to three activities were mean pooled and collected at three, six- and nine-months post-operative. Scores from the study primary end point (nine months post-operative) were used as the primary outcome and dichotomised such that scores of nine or ten were deemed to reflect a successful return to function. This is consistent with previous studies where ordinal data (e.g., global rating of change scale) have subsequently been dichotomised and specific categories defined as reflecting a successful outcome, with all others reflecting an unsuccessful outcome [13].

2.3. Performance-based outcomes

Participants were informed that they would be required to present for follow up at three, six, and nine-months post-operative when providing informed consent. These follow up visits took place at the same Pure Sports Medicine clinic each time and commenced with the completion of PROMS, followed by performance-based measures. These data were collected by one of ten physiotherapists, all of whom were given extensive training from the primary investigator prior to the study commencing. For all testing sessions, data were initially collected from the non-operative limb, followed by the operative limb, with a single practice attempt per limb permitted for each task. All outcome data were collected in a sequential order to mitigate the potential for fatigue at three (PROMS, muscle strength), six (PROMS, muscle strength, single leg hop), and nine (PROMS, muscle strength, single leg hop, slalom run) months respectively.

2.3.1. Muscle strength

Isometric strength of both the quadriceps and hamstrings muscle groups was measured at three, six- and nine-months post-operative using a hand-held dynamometer (model 01165, Lafayette, Indiana, USA). To measure quadriceps strength, the dynamometer was externally secured with a belt 1 cm proximal to the anterior ankle joint in a 90° knee flexion position with the participant in sitting [7]. Participants were asked to cross their arms and sit upright, whilst 'pushing out' as hard as possible into the dynamometer (see Figure 1). To determine hamstrings strength, the dynamometer was placed 1 cm proximal to the Achilles mid-portion and was externally secured by a seatbelt in a 0° hip and knee flexion position with the participant in prone lying [20]. Both test positions have been previously reported to have excellent inter-rater reliability [7,20].

Figure 1. testing positions for quadriceps and hamstrings strength.

A non-slip matting was taped to the rear of the dynamometer to ensure contact with the seatbelt was maintained throughout each trial and was visually confirmed by the physiotherapist. Participants completed three separate attempts for both muscle groups, with their highest score recorded to reflect a maximum voluntary isometric contraction (MVIC). MVIC data were recorded in kg and normalized to body mass in kg (MVIC/body mass). Within participant, raw hamstrings strength (in kg) was divided by raw quadriceps strength (in kg) to calculate the hamstrings to quadriceps ratio, subsequently expressed as a percentage.

2.3.2. Hop performance

To replicate previous studies [10], single (one unilateral jump and land) and triple (three consecutive unilateral jumps followed by a land) hops for distance were recorded at six- and nine-months post-operative (see Figure 2). Both single and triple hop tests have previously been reported as valid and reliable in ACLR cohorts [16]. Participants were instructed to hop as great a distance as possible whilst still making a 'successful landing', defined as there being no immediate loss of balance or additional hop to stabilise. Participants started the test with their toes on a marked start line on the floor and performed three attempts of each task, with their maximum hop distance recorded in cm by measuring from the start line to their heel. A limb symmetry index score was subsequently calculated (operated limb/contralateral limb $\times$ 100).

2.3.3. Running/cutting

Agility was evaluated using an 11-meter slalom run performed at nine months post-operative (see Figure 3). Six cones were placed two meters apart, with the first cone one meter away from the start line. Participants started behind a line with both feet facing forwards. After a verbal countdown (3, 2, 1, go), participants started the course by breaking to the right and running in and out of the cones, before turning 180° and running back to the start line in and out of the cones, a total of 22 meters. Participants performed three attempts and their fastest time (in seconds) was manually recorded using a digital stopwatch. The 11-meter slalom run has previously been reported to be a valid and reliable measure of agility in football players [19].

2.4. Patient-reported outcomes (PROMS)

HRQOL specific to ACL injury was evaluated using the ACL-Quality of Life (ACL-QoL) questionnaire, at all-time points. The ACL-QoL is a 32-item patient reported questionnaire that is subdivided into five domains and scored out of 100: symptoms and physical complaints, work-related concerns, recreation activities and sport participation, lifestyle, and social and

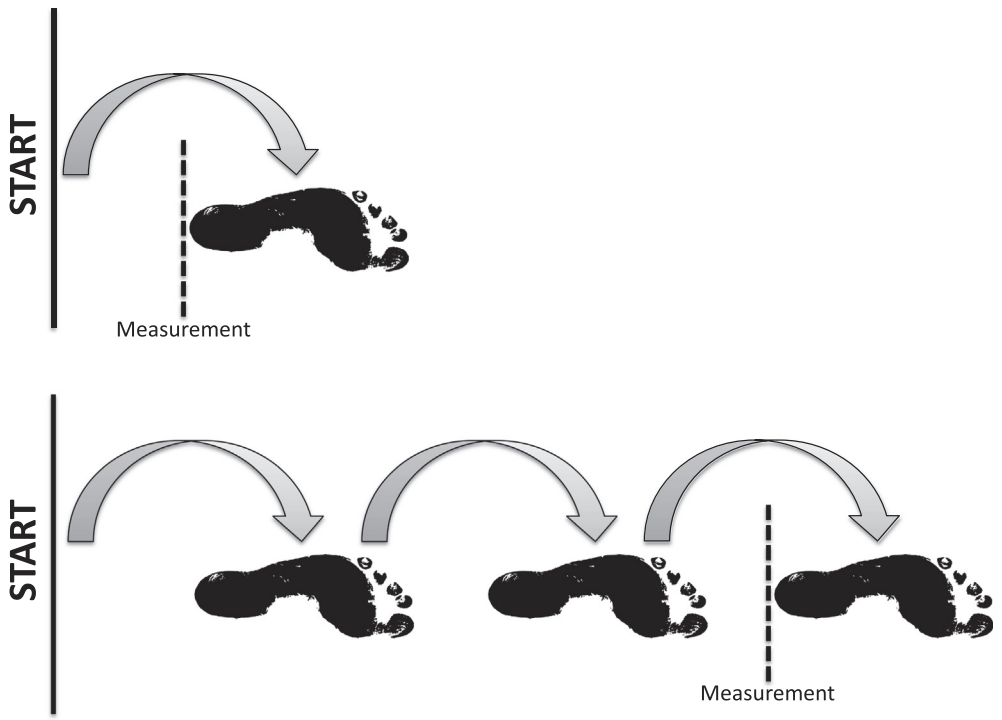

Figure 2. single and triple hop.

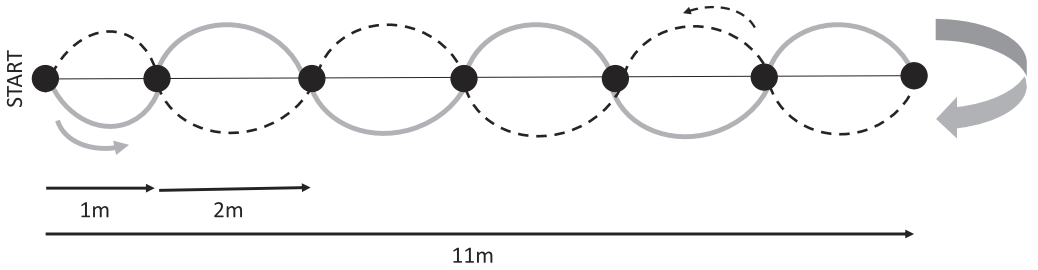

Figure 3. 11-meter slalom run.

emotional aspects. This has previously been reported to be a valid and responsive tool for use in patents with ACL injury [14] and was chosen specifically as it contains content relating to psychological readiness for sports participation.

All subdomains of the Knee Injury and Osteoarthritis Outcome Score (KOOS) were also collected at all time points. The KOOS was developed to assess both the short- and long-term patient reported opinion about their knee and associated problems. It contains 42 items in five separately scored subscales; pain, other symptoms, function in daily living (ADL), function in sport and recreation (sport/rec), and knee-related quality of life [17]. The KOOS was chosen as it has previously been reported to be valid and responsive for individuals' under-going ACLR [18] and has specific domains relating to both sports/recreational activities and quality of life. We calculated a mean score containing all five subdomains (x/100), as opposed to calculating mean scores for each subdomain, to limit the number of variables in our logistic regression.

Participants failing to present for follow up at an appropriate time point were contacted up to three times one week apart by a member of the research team before being defined as lost to follow up.

2.5. Statistical analysis

Data were stored in a custom designed Excel spreadsheet (Microsoft Corporation, Washington, USA), before being exported into *R* (R Core Team, 2019) for further analysis, which involved summary statistics followed by univariate analysis. Data were initially dichotomised relative to recovery status at nine months post-operative. Participants who were lost to follow up were included in the descriptive analysis but not the univariate analysis, and no intention to treat analysis was conducted. Median and inter-quartile range for each sub-group (recovered/not/lost to follow up) were calculated for each time point (baseline/three/six/nine months post-operative).

Pairwise comparisons between participants who were recovered or not was performed using a Wilcoxon signed rank test on the rank transformations. As the group sizes differ for those recovered or not, along with the variances and shape of distributions (i.e., non-normality), the Wilcoxon signed rank test was chosen as it has been reported to be robust against these violations. For the univariate analysis, a binomial logistic regression was performed for each variable at each time point, with odds ratios (OR), 95% confidence intervals (CI) and the associated p values reported. A multivariate binomial logistic regression was planned a priori, but we decided that this was inappropriate due to a low events per variable (n = 20) secondary to the attrition rate (see results).

3. Results

3.1. Participants

Recruitment was completed between March 2017 to June 2018. Of the 90 eligible patients invited to participate (see Table 1), 87 consented to baseline measures. Thirty-nine independent surgeons performed the ACLR procedures, 91% of participants received an arthroscopic hamstring autograft, and 64% were male. Participants that used a post-operative brace did

Table 1
participant demographics.

	Baseline (n = 90)	Lost to FU (n = 40)	Successful (n = 21)	Non successful (n = 26)
Sex (male/female)	58/32	27/13	12/9	17/9
Age (years; mean ± SD)	32.8 ± 7.9	32.4 ± 8.2	33.3 ± 7.8	33.0 ± 7.6
Height (cm; mean ± SD)	173.5 ± 10.0	173.5 ± 9.7	173.2 ± 11.7	173.5 ± 9.3
Mass (kg; mean ± SD)	74.0 ± 15.8	71.7 ± 14.4	74.1 ± 15.8	77.7 ± 17.7
Operated knee (left/right)	41/49	17/23	11/10	13/13
Time to surgery (days; median, IQR)	98, 136	144, 165	82, 98	81, 98
Post-operative brace (no/yes)	63/27	25/15	14/7	20/6
ACL graft (HTG/ALL)	82/8	35/5	21/0	23/3

Key: SD; standard deviation, IQR; inter-quartile range, HT; hamstring tendon autograft, ALL; allograft.

so at the request of their individual surgeon. 47/90 participants provided nine-month post-operative measures, reflecting an attrition rate of 48%. Participant retention throughout the study is detailed in Figure 4 and individual participant data for all variables and groups (recovered/non/lost to follow up) are included in our supplementary material.

3.2. Primary outcome

Of the 47 participants who were retained to provide nine-month post-operative measures, 21/47 (45%) reported a successful post-operative outcome at this time point. Median and inter-quartile ranges of secondary outcomes for participants with successful and unsuccessful outcomes who completed follow up at the primary end point are provided in Table 2.

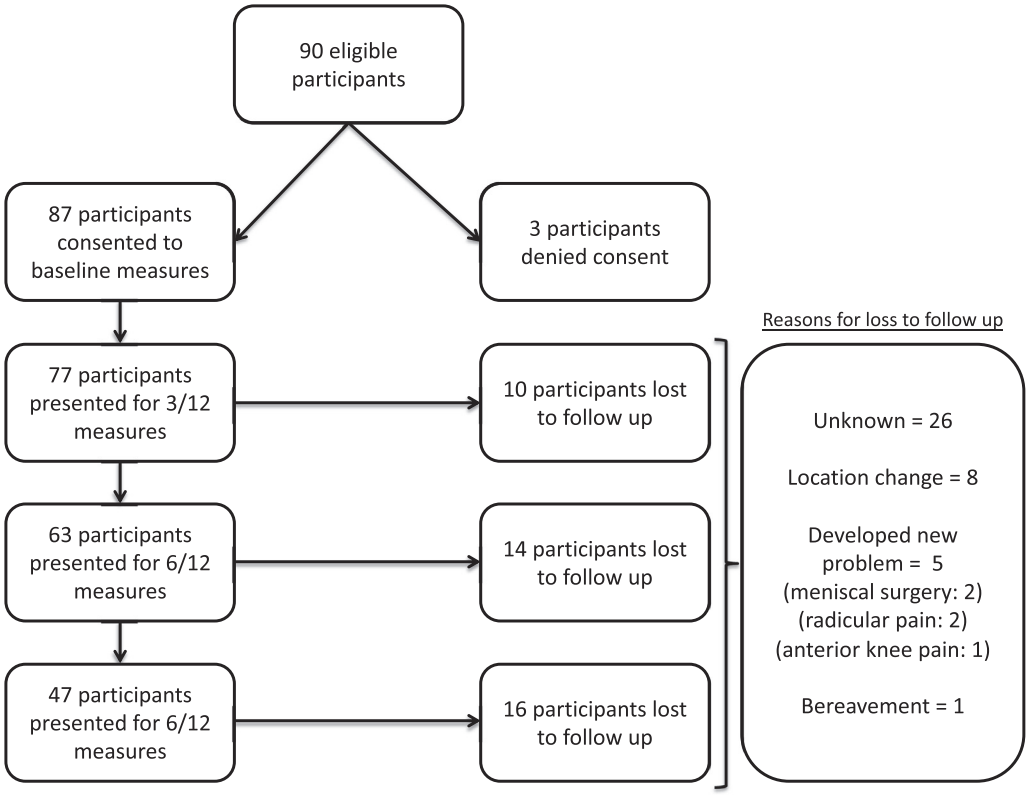

Figure 4. participant retention throughout the study.

Table 2
dichotomized outcome data at various time points.

Variable (Data are presented as median and inter-quartile range)	Three months		Six months		Nine months	
	Successful	Non successful	Successful	Non successful	Successful	Non successful
PSFS	4.0 (3.8–5.3)	4.0 (3.0–6.0)	7.0 (7.0–8.0)	7.0 (6.0–7.0)	9.0 (9.0–9.0)	8.0 (7.0–8.0)
KOOS	71.4 * *(64.5–76.3)*	62.5 *(52.2–67.7)*	80.6 *(75.6–86.8)*	73.6 *(69.1–81.6)*	92.0 * *(89.0–93.7)*	81.9 *(79.6–85.9)*
ACL-QoL	54.8 * *(42.2–70.5)*	40.6 *(36.1–49.5)*	69.5 * *(58.1–77.4)*	54.1 *(45.3–59.8)*	88.8 * *(82.9–94.3)*	68.0 *(62.4–79.1)*
Operative H:Q ratio	0.66 *(0.59–0.78)*	0.63 *(0.56–0.85)*	0.64 *(0.54–0.88)*	0.75 *(0.66–0.93)*	0.67 *(0.58–0.85)*	0.73 *(0.61–0.80)*
Non-operative H:Q ratio	0.66 *(0.57–0.72)*	0.76 *(0.61–0.85)*	0.63 *(0.56–0.78)*	0.74 *(0.61–0.89)*	0.68 *(0.62–0.88)*	0.70 *(0.59–0.88)*
SHLSI (operative/non-operative)	NT	NT	0.84 *(0.73–0.94)*	0.79 *(0.59–0.91)*	0.93 *(0.85–0.98)*	0.88 *(0.78–0.94)*
THLSI (operative/non-operative)	NT	NT	0.83 *(0.72–0.95)*	0.82 *(0.69–0.93)*	0.92 *(0.86–0.98)*	0.90 *(0.80–0.96)*
Slalom run (s)	NT	NT	NT	NT	7.4 *(7.1–8.1)*	7.7 *(7.2–9.0)*

Key: PSFS; patient specific functional scale, KOOS; knee osteoarthritis outcome score, ACL-QoL; anterior cruciate ligament quality of life, H:Q; hamstring to quadriceps ratio, SHLSI; single hop limb symmetry index, THLSI; triple hop limb symmetry index, NT; not tested.
* Significant variable in univariate binomial logistic regression.

3.3. Univariate binomial logistic regression

3.3.1. Three months

A higher mean KOOS score at three-months post-operative was significantly associated with a successful outcome at nine-months post-operative (OR 1.07, 95% CI 1.01, 1.14, p = 0.02). A higher ACL-QoL score at three-months post-operative was significantly associated with a successful outcome (OR 1.06, 95% CI 1.02, 1.11, p = 0.01) at nine-months post-operative. No other variables at this time point were associated with a successful outcome at nine-months post-operative.

3.3.2. Six months

A higher ACL-QoL score at six-months post-operative was significantly associated with a successful outcome at nine-months post-operative (OR 1.10, 95% CI 1.04, 1.17, p < 0.01). A higher PSFS score at six-months post-operative was significantly associated with a successful outcome at nine-months post-operative (OR 3.02, 95% CI 1.47, 8.29, p = 0.01). No other variables at this time point were associated with a successful outcome at nine-months post-operative.

3.3.3. Nine months

A higher mean KOOS score at nine-months post-operative was significantly associated with a successful outcome at nine-months post-operative (OR 1.15, 95% CI 1.05, 1.28, p < 0.01). A higher ACL-QoL score at nine-months post-operative was significantly associated with a successful at nine-months post-operative (OR 1.08, 95% CI 1.03, 1.15, p < 0.01). No other variables at this time point were associated with a successful outcome at nine-months post-operative.

4. Discussion

This study aimed to investigate the association between patient-reported and performance-based measures, and a successful outcome post-ACLR, in people who participate in recreational sport(s). Accepting our hypothesis, higher patient-reported readiness, in the form of both ACL-QoL and KOOS, were associated with a successful outcome. Contrary to our hypothesis, the performance-based measures investigated in this study were not associated with successful outcome post-ACLR in the studied cohort.

47 participants (52%) completed this study and 21 (45%) reported a successful outcome at the nine-month post-operative primary end point. This is superior to the outcomes reported by Larsen et al., [11] with just 26% of recreational athlete participants successfully returning to sport between 9 and 12 months post-operative. 40 participants (46%) failed to complete our study and 26 of these were lost to follow up without a provided reason despite up to three attempts to contact them. This is in line with the United Kingdom National Ligament Registry, with under 40% of participants providing follow up data at 12-months [4]. Clinicians should anticipate that some recreational athletes will have achieved a successful outcome by nine months post-operative, but that there will be others who are likely to require ongoing rehabilitation, and some who will fail to remain engaged through to this timepoint.

Patient-reported measures were consistently associated with a successful outcome, reflecting their importance in this recreational athlete population. This is in comparison to professional or competitive athletes, where a combination of patient-reported and performance-based measures [1,6,10] are associated with successful outcomes. Our chosen primary outcome may explain the observed differences, with PSFS designed to identify what the patient considers the most important aspect(s) of their life [9]. This again may differ between elite and recreational athlete populations, with the latter linking their PSFS as much to their activities of daily living as their sporting function.

The performance-based measures previously associated with successful outcome post-ACLR in athletic cohorts; hamstrings to quadriceps ratio and cutting performance [10]; quadriceps symmetry [6]; and hopping performance [2], were not singularly associated with a successful outcome in this study. Although some performance-measures overlaid the boundary between successful and non-successful outcomes, it was insufficiently consistent to reflect a strong association. The lower physical demands of recreational athletes may not be reflected by the properties measured by a battery of tests that looks to examine higher level performance and knee function. Measurement of patient-reported readiness after ACLR is imperative. Whilst it may supersede the measurement of performance-based measures in recreational athletes to determine a successful outcome, both measures retain a role in clinical decision making and optimisation of an individual's function.

4.1. Limitations and future directions

Our primary outcome measure (PSFS) was chosen to reflect wider clinical practice and to allow a broad spectrum of activities to be incorporated. Whilst this appropriately reflects the day-to-day function of people post-ACLR, a direct comparison to outcomes used in elite athletes, such as a defined return to sport or re-injury rate, is not possible. The decision to dichotomise PSFS scores into successful/unsuccessful categories (as opposed to using other patient-reported measures with established cut-offs) is novel and may affect the validity of our results. Our participant sample has a bias towards males that reflects the population from which we recruited, and this should be considered when applying these outcomes to females post-ACLR. A high attrition rate (48%) was identified in this study, but one that reflects previous studies investigating ACL rehabilitation in recreational athletes and wider clinical practice. Greater participant retention may have led to different

outcomes. We did not explore the potential confounding influence of any rehabilitation components on the variables associated with a successful outcome. Future studies are encouraged to investigate the effect of specific rehabilitation components (e.g., strength training) in relation to optimising the variables associated with successful outcome in specific populations.

Secondary outcome data were collected across multiple sites, with inter-rater reliability not established between investigators. This was mitigated by defining a project-wide protocol following previously established methods for each measurement a priori, with training delivered by a single investigator (BSN) at each site. Our hopping protocol did not include either crossover hop or timed hop, both of which have previously been associated with successful outcomes post-ACLR [2,10]. This may explain why we did not identify an association between hopping performance and successful outcome post-ACLR, but we felt that single and triple hop were more reflective of the task demands of a typical recreational athlete.

We conducted our sample size calculation using quadriceps to hamstring to quadriceps ratio data from a prospective cohort study investigating associations with graft rupture post-ACLR. Whilst graft rupture reflects an unsuccessful outcome post-ACLR, conducting our sample size calculation using alternative published data may have resulted in increased statistical power. We had planned to undertake a multivariate analysis to inform future studies, but we were left with a low events per variable due to the attrition rate that would have led to over-fitting of the resultant model. Future studies are advised to use the results of the univariate analysis presented here to inform larger planned cohort studies to build multivariate models.

5. Conclusions

A successful outcome at nine-months post-ACLR in recreational athletes was associated with patient-reported readiness rather than performance-based measures. Clinicians involved in the rehabilitation of people post-ACLR should therefore ensure that both patient-reported and performance-based measures are used to guide successful return to function.

Funding

This project was part-funded by a Private Physiotherapy Education Foundation Scheme A1 research award (funding application number 270). The funding body played no role in the study design, data collection, data analysis and interpretation, the writing of the report, or the decision to submit the article for publication.

Conflict of interest

The authors have no conflicts of interest to declare.

Ethical approval

Ethical approval was sought and subsequently granted by the Queen Mary Ethics of Research Committee (QMERC2014/24/127).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.knee.2022.08.017.

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