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Original article

Predicting readiness for return to sport and performance after anterior cruciate ligament reconstruction rehabilitation

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A B S T R A C T

Background: Determining readiness to return to sport after anterior cruciate ligament (ACL) reconstruction is challenging.
Objectives: To develop models to predict initial (directly after rehabilitation) and sustainable (one year after rehabilitation) return to sport and performance in individuals after ACL reconstruction.
Methods: We conducted a multicentre, prospective cohort study and included 208 participants. Potential predictors – demographics, pain, effusion, knee extension, muscle strength tests, jump tasks and three sport-specific questionnaires – were measured at the end of rehabilitation and 12 months post discharge from rehabilitation. Four prediction models were developed using backward logistic regression. All models were internally validated by bootstrapping.
Results: All 4 models shared 3 predictors: the participant's goal to return to their pre-injury level of sport, the participant's psychological readiness and ACL injury on the non-dominant leg. Another predictor for initial return to sport was no knee valgus, and, for sustainable return to sport, the single-leg side hop. Bootstrapping shrinkage factor was between 0.91 and 0.95, therefore the models' properties were similar before and after internal validation. The areas under the curve of the models ranged from 0.74 to 0.86. Nagelkerke's R2 varied from 0.23 to 0.43 and the Hosmer-Lemeshow test results varied from 2.7 ($p = 0.95$) to 8.2 ($p = 0.41$).
Conclusion: Initial and sustainable return to sport and performance after anterior cruciate ligament reconstruction rehabilitation can be easily predicted by the sport goal formulated by the individual, the individual's psychological readiness, and whether the affected leg is the dominant or non-dominant leg.

Introduction

Anterior cruciate ligament (ACL) rupture is a common orthopaedic injury in both amateur and elite athletes [1,2]. ACL ruptures mostly occur in sports with high-impact loading on the knee, such as football [3]. Athletes who want to continue participating in pivoting sports after an ACL rupture often undergo ACL reconstruction to re-establish mechanical knee stability [4]. However, athletes may not return to their pre-injury sport activity after intensive ACL rehabilitation, despite a full physical recovery. On average, 81% of athletes return to any sport, 65% return to their pre-injury level of sport, and 55% return to competitive-level sport [5]. Owing to the long recovery time and the fact that many athletes do not return to their previous (level of) sport, the impact of ACL injury is considerable [6,7].

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Return to sport can be classified into 3 main phases: return to participation, return to sport (RtS) and return to performance (RtP) [8]. In the return to participation phase, athletes participate in modified or even full training sessions but do not yet play at their intended level of activity; in the RtS phase they resume their defined sport but do not yet perform at the intended level: some athletes might consider this a successful RtS. RtP refers to a gradual return to the defined sport with performance at or above the pre-injury sport level [8].

Several clinical practice guidelines have been developed to describe rehabilitation after ACL reconstruction and to encourage both standardization of physiotherapy treatment and the use of measurements of functional performance [9–14]. Although these clinical practice guidelines are of generally high quality, their applicability is poor [15] and physiotherapist adherence to the guidelines is low [16]. Determining whether and when athletes are ready to return to their pre-injury level of sport is challenging for physiotherapists. Therefore, criteria-based RtS programmes are increasingly being used [9]. These consist of meaningful criteria such as psychological and physical parameters (including muscle strength and functional tests) [17–21].

The development of a prediction model might guide decisions for RtS. Prediction models aid healthcare providers to estimate the likelihood that a specific event will occur in the future [22]. Such prognostic information could be used to advise individuals about the likelihood of developing or resolving a particular health outcome [23]. Predictions about RtS can provide insights that enable careful management of individuals' expectations, shared decision-making and understanding of the rehabilitation process. Multiple variables are associated with return to sport after ACL injury [6,17–21], but, to our knowledge, no prediction model has been developed to predict the probability of RtS or RtP after rehabilitation. Since predictors of RtS and RtP determined directly after rehabilitation might differ from predictors related to long-term, more sustainable, RtS and RtP, the development of a range of models would be valuable. The aim of this study was to develop models to predict: 1) initial RtS, 2) initial RtP, 3) sustainable RtS, and 4) sustainable RtP. We hypothesised that relevant predictors for RtS or RtP would include muscle strength, functional tests, jump tasks, and psychological characteristics, as are already used in criteria-based RtS programmes [9].

Methods

In this multicentre, prospective cohort study, participants who had undergone ACL reconstruction were followed for one year after discharge from rehabilitation. Participating physiotherapists had experience in ACL rehabilitation and worked at 52 physiotherapy practices in the Netherlands. The researcher used a detailed measurement protocol to explain and demonstrate the inclusion and testing of participants to each participating physiotherapist. Physiotherapists invited participants who completed rehabilitation between April 2018 and January 2019, and who fulfilled the inclusion criteria, to participate in the study.

The study was approved by the local Ethics Commission (ACPO 58.02/17) at HAN University of Applied Sciences in Nijmegen, the Netherlands. All participants gave written informed consent before data collection began. The study was conducted and reported according to the Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis (TRIPOD) statement for prediction model development and validation [22].

Participants

Inclusion criteria were aged 16 to 65 years, ACL rupture (with or without meniscus injury and/or collateral ligament injury and/or traumatic cartilage injury) treated with primary or revision ACL reconstruction surgery. All types of autograft techniques, allograft techniques and fixation options were allowed. We only included participants with a pre-injury Tegner Activity Score (TAS) [24,25] of 6 or higher who had the ambition to continue performing a sport, regardless of level or type. Individuals were excluded if complications developed during or after surgery that limited rehabilitation according to the clinical practice guidelines for rehabilitation after ACL reconstruction from the Royal Netherlands Society for Physical Therapy (KNGF) [9]. These individuals followed a standardized rehabilitation scheme using 3 criterion-based postoperative phases (impairment-based rehabilitation, sport-specific training and return to play). Individuals were also excluded if they were unable to properly understand and read the Dutch language.

Potential predictive factors

All measurements of the potential predictive factors were performed at the end of the rehabilitation period (baseline) when RtS or RtP was expected [8,9]. That moment was determined by the physiotherapist and was defined as being ready to return to sports, as assessed by the physiotherapist. At baseline, the participants filled in digital questionnaires and each underwent physical measurements with their own physiotherapist. All measurements were stored directly in a highly secured website to which only the physiotherapist, the participant and the researcher had access.

Predictive factors were categorised into personal characteristics and body functions and structures.

Personal characteristics

At baseline, personal characteristics were collected on an intake form. The following variables were collected: age, sex, Body Mass Index (BMI), side of the ACL reconstruction (left or right) and leg dominance (by answering the question 'If you were to shoot a ball into a goal, which leg would you shoot with?') [26]. If the dominant leg was the affected leg, it was scored as '0'; if the non-dominant leg was the affected leg, it was scored as '1'. We also collected information about additional injuries (e.g. meniscus and/or collateral ligament and/or traumatic cartilage injury), revision surgery, graft type (autograft/allograft), duration of rehabilitation after surgery, chronic diseases, sports goal (same level as pre-injury/lower level or other sports) and pre-injury TAS.

Body functions and structures

Pain during activities of daily living (ADL) was scored using the numeric pain rating scale (NPRS) [27].

Knee effusion (affected leg) was measured using the stroke test [28] and rated on a 5-point scale ranging from '0' (no wave produced on downstroke) to '3+' (so much fluid that it is impossible to move the effusion out of the medial aspect of the knee) [28]. Scores were then categorised as 'yes' for trace, 1+, 2+ and 3+, and 'no' for 0 only.

Passive extension test of the affected and non-affected knees was measured with a goniometer [29]. The participant lay supine with the feet elevated and resting on a bolster. The greater trochanter, lateral joint line, and lateral malleolus were used as landmarks. The physiotherapist then determined whether 0° was reached and coded with 'yes' or 'no'. They then indicated whether the affected and non-affected legs both scored 'yes', both scored 'no' or had different scores.

Movement quantity and quality were evaluated by measuring the strength of the quadriceps, hip abductor and hamstring muscles, the single-leg hop for distance, the single-leg side hop, the single-leg hop and hold test, and a double-leg countermovement jump. All tests are described in detail in Appendix A – Supplementary material. Instead of using absolute values, a limb symmetry index (LSI: affected side score divided by contralateral side score x 100%) [30] was calculated and used in the analysis for most tests (except the single-leg hop and hold test and the double-leg countermovement jump). For the single-leg hop and hold test, a stable landing with the knee in at least a 90-degree flexion for three seconds was scored as 'yes'. If a participant did not meet these criteria for the single-leg hop and hold test, it was scored as 'no' [31]. For the double-leg countermovement jump, the first landing was analysed for the affected leg by scoring 4 items based on the Landing Error Scoring System (LESS) [32]. Those items were: knee flexion angle at initial contact > 30°, lateral trunk flexion angle at initial contact, symmetric initial foot contact, and knee valgus.

Psychological readiness was measured using the Anterior Cruciate Ligament – Return to Sport after Injury (ACL-RSI) questionnaire (range 0–100) [21]. To assess fear of movement, participants filled in the Photographic Sports Activity-Anterior Cruciate Ligament Reconstruction (PHOSA-ACLR), which consists of 12 photographs of specific sport activities (range 0–100) [33]. The Knee Injury and Osteoarthritis Outcome Score (KOOS) was used to assess knee function [34]. The KOOS consists of 5 subscales (range 0–100): activities of daily living, pain, symptoms, sport and recreation function, and quality of life.

Outcome measures

Participants were followed up at 12 months post discharge from rehabilitation to obtain RtS and RtP information. This information was obtained online: participants indicated the type and level of sport performed. The purpose of this was to develop prediction models for 4 outcomes:

Initial RtS: defined as returning to sport in the period between discharge from rehabilitation and 2 months post discharge: scored as 'yes' or 'no' for the same sport compared to the pre-injury situation, regardless of the level.

Initial RtP: defined as returning to sport in the period between discharge from rehabilitation and 2 months post discharge: scored as 'yes' or 'no' for the same sport and the same level of sport compared to the pre-injury situation.

Sustainable RtS: (for participants who scored 'yes' for initial RtS) defined as still performing the same sport 12 months post discharge: scored as 'yes' or 'no', regardless the level of sport.

Sustainable RtP: (for participants who scored 'yes' for initial RtP) defined as still performing the same sport with the same level of participation 12 months post discharge: scored as 'yes' or 'no'.

Data analysis

To design the prediction models, we used a rule of thumb based on the number of events per independent variable to determine sample size: according to this rule, ten or more events per variable are required to avoid the problem of overfitting [35]. We defined an event as initial or sustainable return to the pre-injury level of sport. We evaluated 208 participants. Based on the expectation that 65% of participants would return to their pre-injury level of sport [5], up to 13 potential predictive factors could be analysed in each prediction model.

Statistical analyses were performed using IBM SPSS Statistics version 26 and R version 4.0.3. All variables were checked for normality using histograms, cross tables and Q-Q plots. Data were manually checked for outliers, which were omitted. Missing data were assumed to be missing completely at random (MCAR) and analyses were performed using complete case analysis [36].

Descriptive statistics were used to describe participant characteristics with data expressed as means and standard deviations (SD), and numbers and proportions (%). When data were not normally distributed, they were expressed as medians with interquartile ranges (Q1; Q3). To identify potential predictors, we studied bivariate associations of predictors and outcomes. We used the chi-squared test, Fisher's exact test and unpaired t-tests, depending on the measurement scale of the variable. A p-value <0.20 was used to select predictors for the final prediction model. Prediction modelling was performed for the 4 specified outcomes using multiple logistic regression analysis. All possible identified predictors were entered in the model and further analysed by a backward selection procedure, based on a p-value <0.05. To assess the performance of the prediction models, we used Nagelkerke's R2, which gives the explained variance of the model. It covers a full range from 0 to 1, with a larger R2 value indicating that a larger proportion of the variance can be explained by the model. Calibration was tested using the Hosmer-Lemeshow test to represent the goodness of fit between the data and the model: a non-significant value indicates a good fit. The model's ability to discriminate was established by estimating the area under the curve (AUC) of the receiver operating characteristics (ROC) curve of the model. An AUC between 0.6 and 0.8 was considered acceptable, and a value of 0.8 or higher represents good discriminative ability of the model [37]. To correct for optimism in the models, we applied an internal validation using a bootstrapping technique with 250 samples [37]. The calculated shrinkage factor was used to shrink the regression coefficients and to determine the performance of the adapted models. The formula for calculation of the probability (P) of RtS and RtP is shown below: $P_{RtS/RtP} = 1/(1 + \exp(-1^{*}\textit{Linear Predictor}))$ *The Linear Predictor* = $\beta_0+(\beta_1{}^{*}x_1)+(\beta_2{}^{*}x_2)+(\ldots)+(\beta_n{}^{*}x_n)$. β_0 represents the constant, and β_1, β_2 and β_n the regression coefficients of the predictors x_1, x_2 and x_n.

Results

Flow of participants through the study

We included 208 participants between April 2018 and January 2019. Of these, 162 (78%) initially returned to their sport post discharge, regardless of the level, and 146 (70%) initially returned to the same level of sport as pre-injury. Data for sustainable RtS and RtP 12 months post discharge from rehabilitation were available for 176 (85%) participants. Of these, 101 (57%) sustainably returned to their sport, regardless of the level. In total, 84 (48%) participants sustainably returned to the same level of sport as pre-injury.

We were unable to analyse all cases during the development and internal validation of the models owing to missing values among the potential predicting variables (Fig. 1: flowchart).

The 208 participants had a mean age of 24 years (6.7), a mean BMI of 23 kg/m^2 (2.7) and median rehabilitation time of 344 days (290; 376). Two-thirds of the participants were male (136, 65%). The rupture occurred on the dominant leg for half of the participants (106, 51%). Most participants had an autograft ACL reconstruction (195, 94%). A total of 28 participants underwent revision (14%). One third had collateral knee damage at the time of the ACL rupture (77, 37%). Pre-injury TAS was 6 or 7 in 89 participants (43%). The other participants (119, 57%) had a TAS of 8 or more. Pre-injury, most participants played football (63%), followed by handball (7%), korfball (7%), hockey (6%) and volleyball (3%). A chronic disease, mostly hay fever (20), allergies (4) or asthma (4), was reported by 1 in 7 (30, 14%). Most participants (166, 80%) aimed to return to their pre-injury sport level. Participant characteristics, potential prognostic factors and the number of missing values are summarized in Table 1.

Prediction models

The variables inputted in the models are shown in Table 2. After applying a backward selection procedure, the predictors in all models

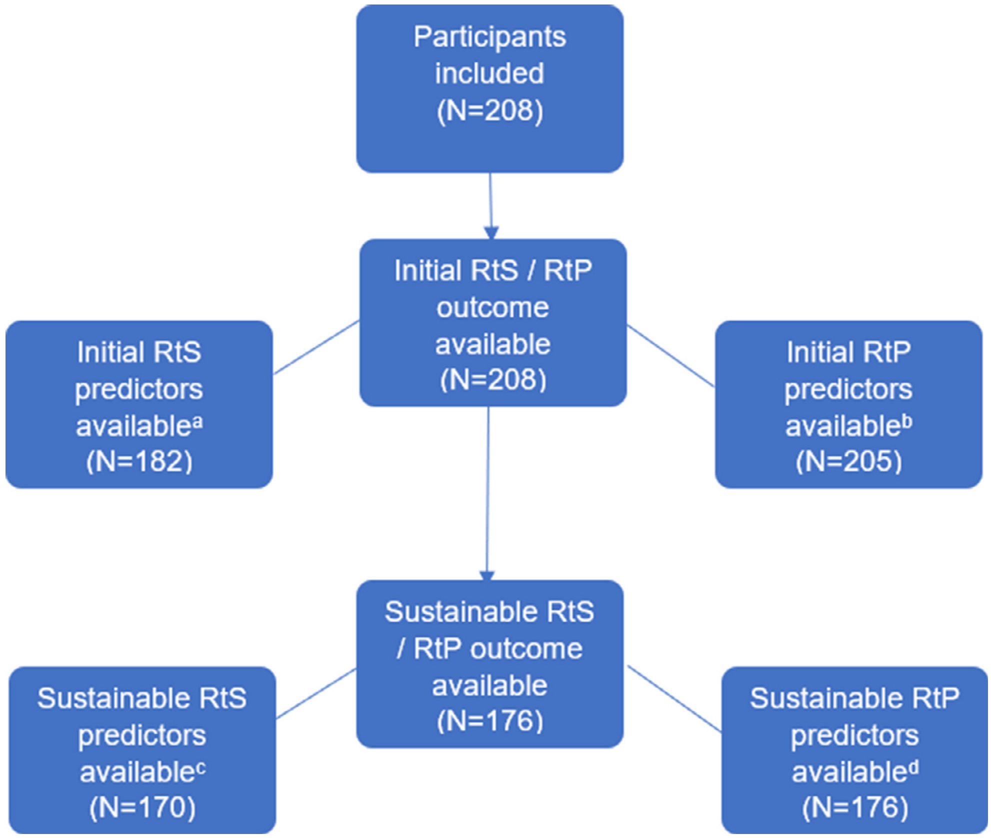

Fig. 1. Flow chart of participants during the development of the prediction models. *Fig. 1. Legend*. RtP = return to performance RtS = return to sport [a] = missing values for the countermovement jump knee valgus and The Anterior Cruciate Ligament – Return to Sport after Injury questionnaire [b] = missing values for The Anterior Cruciate Ligament – Return to Sport after Injury questionnaire [c] = missing values for The Anterior Cruciate Ligament – Return to Sport after Injury questionnaire and limb symmetry index single-leg side hop [d] = no missing values.

were: affected leg was the non-dominant leg, goal to return to pre-injury level of sport, and psychological readiness. Model 1 (initial RtS), also included no knee valgus during the countermovement, and model 3 (sustainable RtS) also included 'LSI single-leg side hop'. Model characteristics are shown in Table 3. Since the bootstrapping shrinkage factor was between 0.91 and 0.95, almost all model characteristics were similar before and after internal validation. The AUCs were acceptable in models 2, 3 and 4 (range 0.74 – 0.79) and good in model 1 (0.86). The power of the explanation of the model measured with Nagelkerke's R2 varied from 23% in model 4 to 43% in model 1. The Hosmer-Lemeshow test score ranged from 2.7 ($p = 0.95$) in model 1 to 8.2 ($p = 0.41$) in model 2, indicating a good fit in all models.

Discussion

In this study, we developed prediction models to predict initial (directly after rehabilitation) and sustainable (one year after discharge from rehabilitation) RtS and RtP after ACL reconstruction rehabilitation. We found 3 predictors in all 4 models: the non-dominant leg being the affected leg, the participant's goal to return to sport at their pre-injury level and the participant's psychological readiness. No knee valgus (measured by the countermovement jump) was also a predictor for initial RtS and a lower score on the LSI in the single-leg side hop was an extra predictor for sustainable RtS. The model characteristics were acceptable, and the model that predicted initial RtS performed the best.

The results of the models showed that when the non-dominant leg was affected, the probability of RtS and RtP was higher than when the dominant leg was affected. The effect of leg dominance on ACL injuries is widely discussed and controversial [38–40]. One study found that leg dominance does not have a significant impact on RtS and short-term functional outcomes [38], which is not in line with our results. Leg dominance is defined as the leg used to manipulate an object while the non-dominant leg plays a stabilising role [41]. We postulate that the preference to use one leg over the other might contribute to the psychological feeling of safety when performing a task. If the dominant leg is affected, the participant may have less confidence in their knee, reducing the likelihood of RtS or RtP.

An increasing number of studies underscore the importance of positive psychological drivers (e.g. motivation and confidence) and the concept of readiness to return to sport [7,17,19]. This was also seen in all 4 prediction models: a higher ACL-RSI score (i.e. more positive psychological readiness) was related to a higher likelihood of RtS and RtP. This positive psychological response was also reflected in the participant's goal to perform at the pre-injury level, formulated at the end of rehabilitation. This reflects their hope to achieve that goal and their trust in their own performance.

Another result of the prediction models was that the probability of initial RtS was lower if knee valgus was present during the countermovement jump. Previous research has already associated dynamic knee valgus with a higher risk of ACL injury in women [42]. The final predictor for sustainable RtS was a lower score on the LSI in the single-leg side hop. It must be noted that the odds ratio of the LSI was 0.97 (95%CI 0.95–1.00) showing only a low predictive value. Those who achieved sustainable RtS had a mean LSI of 96.6 (13.9) and those with no RtS scored 100.8 (20.6): both had an LSI score of >90%, which was maintained during rehabilitation [9].

The variables inputted into the models are not the most common physically measured items (such as strength measurements or hop

Table 1
Participant characteristics and potential prognostic factors for RtS and RtP at baseline.

Personal characteristics	n (%)	Missing (n /%)
Total	208 (100%)	0
Sex		0
Male	136 (65%)	
Age (years) *	23.9 (6.7)	0
Body Mass Index (kg/m^2) *	23.2 (2.7)	0
Side of ACL rupture		0
Right	105 (51%)	
Dominant leg		0
Right	177 (85%)	
Leg dominance vs side ACL		0
Dominant leg = side ACL rupture	106 (51%)	
Dominant leg ≠ side ACL rupture	102 (49%)	
Additional knee injury		0
Yes	77 (37%)	
Revision		0
Yes	28 (14%)	
Type of operation		0
Autograft	195 (94%)	
Allograft	13 (6%)	
Duration of rehabilitation (days) **	344 (290 - 376)	0
Chronic disease		0
Yes	30 (14%)	
Tegner Activity Score (TAS) pre-injury		0
TAS 6	20 (10%)	
TAS 7	69 (33%)	
TAS 8	23 (11%)	
TAS 9	91 (44%)	
TAS 10	5 (2%)	
Sport pre-injury		0
Football	131 (63%)	
Handball	14 (7%)	
Korfball	14 (7%)	
Hockey	12 (6%)	
Volleyball	7 (3%)	
Other (e.g., softball, skiing, judo, gymnastics, tennis, squash)	30 (14%)	
Sport goal at baseline		0
Same level as pre-injury	166 (80%)	
Lower level or other sport than pre-injury	42 (20%)	
Body functions and structures		
NPRS during ADL *	0.36 (0.91)	0
Effusion		0
Yes	44 (21%)	
Leg extension		0
Affected leg = non-affected leg	199 (96%)	
Affected leg ≠ non-affected leg	9 (4%)	
LSI isometric strength quadriceps *	100.1 (12.8)	37 / 18%
LSI isometric strength abductors *	102.8 (11.8)	29 / 14%
LSI isometric concentric strength hamstrings *	93.3 (16.7)	38 / 18%
LSI isometric eccentric strength hamstrings *	95.7 (14.6)	44 / 21%
LSI side hop *	98.6 (16.9)	10 / 5%
LSI hop for distance *	97.9 (8.0)	4 / 2%
Single-leg hop and hold affected leg		2 / 1%
Yes	181 (87%)	
Single-leg hop and hold non-affected leg		2 / 1%
Yes	184 (89%)	
CMJ Knee flexion >30°		33 / 16%
Yes	132 (64%)	
CMJ Lateral trunk flexion		25 / 12%
Yes	27 (15%)	
CMJ Symmetric initial foot contact		25 / 12%
Yes	137 (66%)	
CMJ Knee valgus		25 / 12%
Yes	94 (45%)	
ACL-RSI (0–100) *	65.3 (21)	3 / 1%
PHOSA-ACLR (0–100) *	25.4 (21.1)	3 / 1%
KOOS *		2 / 1%
Activities of daily living (0–100)	96.3 (8.74)	
Pain (0–100)	92.0 (10.6)	
Symptoms (0–100)	81.9 (13.1)	
Sports and recreation function (0–100)	83.6 (15.3)	
Quality of life (0–100)	70.9 (16.6)	

* Data presented as mean (standard deviation) ** Data presented as median (interquartile range) ACL = anterior cruciate ligament ACL-RSI = The Anterior Cruciate Ligament – Return to Sport after Injury questionnaire ADL = activities of daily living CMJ = counter movement jump KOOS = Knee injury and Osteoarthritis Outcome Score LSI = limb symmetry index = affected side score divided by contralateral side score x 100% NPRS = numeric pain rating scale PHOSA-ACLR = The Photographic Sports Activity-Anterior Cruciate Ligament Reconstruction questionnaire RtP = Return to Performance RtS = Return to Sport.

tests) that are recommended in clinical practice guidelines [9–14]. Before entering our study, the physiotherapists followed the clinical practice guideline for rehabilitation after ACL reconstruction from the KNGF. In accordance with those recommendations, this generally resulted in adequate and more homogeneous outcomes on the RtS criteria when participants entered the study [9]. Therefore, the outcomes of the common physically measured items varied little; therefore, they were not found to be predictors in the models. It is expected that lower scores on the physical tests recommended by the clinical practice guidelines would also contribute to a lower RtS or RtP [9,15].

The models in this study predicted the probability of initial and sustainable RtS and RtP, but did not directly show whether RtS or RtP were safe. It has been noted that younger individuals (<25 years) and those who return to a high level of activity (mostly in high-risk, pivoting sports) are at increased risk of re-injury after ACL reconstruction [43].

Strengths and limitations

We investigated a wide variety of predictive factors that are both mentioned in the literature and based on expert opinion. The variables used in the models are easy for a physiotherapist to collect during, or at the end of, the rehabilitation period. Use of the prediction rules allows the physiotherapist to quickly determine the probability of RtS or RtP. This increases the likelihood the models will be applied in clinical practice. The risk calculations based on the models can be used in shared decision-making in physiotherapy practice when RtS or RtP are considered.

A limitation of the study is that we did not externally validate the models. External validation is important before prediction models can be implemented in health care, particularly if variation in clinical practice is expected. This would require more data for the same predictors evaluated, in comparable groups. Therefore, we advise that future research should focus on external validation. However, we estimated internal validation using bootstrapping, which provides stable estimates with low bias [44].

Since different physiotherapists participated, and all baseline measurements were performed by the participant's own physiotherapist, some measurement bias is likely. Differences in measurement performances were prevented as much as possible by the provision of a detailed measurement protocol that was explained by the researcher and used by the physiotherapists.

Finally, we included participants who had undergone different surgical techniques (auto-/allograft), and some who had undergone surgical revision, since our aim was to encourage the clinical applicability of the prediction models. The models in our study were not intended for one subgroup within ACL rehabilitation, therefore heterogeneity was present within the group. Moreover, specific surgical techniques (autograft versus allograft) and revision surgery were taken into account during the analyses by including these variables as potential predictors in our models. Neither RtS nor RtP were predicted by type of surgery or revision.

Conclusion

Initial and sustainable RtS and RtP after ACL rehabilitation can be easily predicted by using variables that consider whether the affected leg is dominant or non-dominant, the sports goal formulated by the participant, and the participant's psychological readiness. Knowledge of these factors, as well as the most common physically measured items (e.g. strength measurements or hop tests), is important in shared decision-making in physiotherapy practice. Our findings support earlier findings that psychological factors, including desire and confidence in performance and risk appraisal, play an important role in RtS and RtP.

Table 2
Model variables for initial RtS, initial RtP, sustainable RtS and sustainable RtP.

	n[a]	Beta [b]	Adjusted beta [c]	OR (95% CI)	p-value
Model 1 - Initial RtS	*n* = 182				
Non-dominant leg affected [d]		1.32	1.20	3.74 (1.44–9.72)	0.01
Sport goal: same level as pre-injury [e]		2.39	2.17	10.91 (3.99–29.86)	<0.001
ACL-RSI [f] (continuous)		0.0	0.04	1.04 (1.02–1.06)	0.001
CMJ knee valgus [g]		−1.2	−1.13	0.29 (0.11–0.73)	0.009
Intercept		−2.6	−2.33		
Model 2 - Initial RtP	*n* = 205				
Non-dominant leg affected [d]		1.04	0.97	2.83 (1.39–5.76)	0.004
Sport goal: same level as pre-injury [e]		1.80	1.67	6.05 (2.72–13.46)	<0.001
ACL-RSI [f] (continuous)		0.02	0.02	1.02 (1.00–1.04)	0.01
Intercept		−2.29	−2.07		
Model 3 - Sustainable RtS	*n* = 170				
Non-dominant leg affected [d]		0.70	0.65	2.02 (0.97–4.21)	0.06
Sport goal: same level as pre-injury [e]		2.20	2.03	9.03 (3.41–23.86)	<0.001
ACL-RSI [f] (continuous)		0.03	0.03	1.03 (1.01–1.05)	0.002
LSI single-leg side hop [h]		−0.03	−0.03	0.97 (0.95–1.00)	0.02
Intercept		−1.12	−1.01		
Model 4 - Sustainable RtP	*n* = 176				
Non-dominant leg affected [d]		0.66	0.62	1.93 (1.00–3.71)	0.05
Sport goal: same level as pre-injury [e]		1.47	1.40	4.36 (1.71–11.12)	0.002
ACL-RSI [f] (continuous)		0.03	0.03	1.03 (1.01–1.05)	0.002
Intercept		−3.43	−3.26		

95% CI = 95% confidence interval ACLR = anterior cruciate ligament reconstruction OR = odds ratio RtP = return to performance RtS = return to sport.
[a] = complete case analysis.
[b] = positive beta indicates that a higher score results in a higher probability of RtS or RtP; a negative coefficient indicates that this risk increases with a lower score.
[c] = regression coefficients for the models were multiplied by the shrinkage factor retrieved from internal validation (model 1 = 0.909, model 2 = 0.930, model 3 = 0.922, model 4 = 0.950).
[d] = to score the equality between the dominant and the affected leg as a predictor, a dichotomous score was used. When the dominant leg was also the affected leg, it was scored as 0. When the non-dominant leg was the affected leg, it was scored as 1.
[e] = sport goal at baseline: score of 0 = lower level or other sport as pre-injury; and 1 = same level as pre-injury.
[f] = Anterior Cruciate Ligament – Return to Sport after Injury questionnaire scale ranges from 0 – 100 with a higher score indicating more readiness to return to sport.
[g] = CMJ knee valgus: Countermovement jump knee valgus = score of 0 = no knee valgus and 1 = knee valgus.
[h] = LSI single-leg side hop = Limb symmetry index score for the single-leg side hop.

Table 3
Model performance for initial RtS, initial RtP, sustainable RtS and sustainable RtP.

	R^2	H&L	AUC
Model 1 - Initial RtS			
Initial model + after internal validation [a]	0.43	0.95	0.86 (0.80; 0.92)
Model 2 - Initial RtP			
Initial model + after internal validation [a]	0.26	0.41	0.76 (0.69; 0.84)
Model 3 - Sustainable RtS			
Initial model	0.35	0.94	0.79 (0.72; 0.86)
After internal validation	0.35	0.93	0.79 (0.72; 0.86)
Model 4 - Sustainable RtP			
Initial model + after internal validation [a]	0.23	0.56	0.74 (0.66; 0.81)

AUC = area under the curve.
H&L = Hosmer and Lemeshow test.
R^2 = Nagelkerke's R2.
RtP = return to performance.
RtS = return to sport.
[a] = performance measures for the models before and after internal validation were equal.

Data Availability

The data that has been used is confidential, but are available from the corresponding author on reasonable request.

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.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.rehab.2022.101689.

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