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Importance of functional performance and psychological readiness for return to preinjury level of sports 1 year after ACL reconstruction in competitive athletes

Takuya Kitaguchi[1] · Yoshinari Tanaka[2] · Shinya Takeshita[1] · Nozomi Tsujimoto[1] · Keisuke Kita[3] · Hiroshi Amano[4] · Kazutaka Kinugasa[2] · Yuta Tachibana[2] · Takashi Natsuume[1] · Shuji Horibe[5]

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Abstract

Purpose This study aimed to identify independent predictive factors for return to sports (RTS) after anterior cruciate ligament (ACL) reconstruction in competitive-level athletes and to determine optimal cut-off values for these factors at 6 months after surgery.

Methods A total of 124 competitive athletes (50 males and 74 females; mean age, 17.0 years; preinjury Tegner activity scale > 7) who underwent primary ACL reconstruction were enrolled. Assessments at 6 months after surgery consisted of knee functional tests [quadriceps index, hamstrings index, and single-leg hop for distance (SLH)] and 2 self-report questionnaires [IKDC subjective score and ACL-Return to Sport after Injury scale (ACL-RSI)]. At 1 year after surgery, athletes were classified into the RTS group ($n = 101$) or non-RTS group ($n = 23$) based on self-reported sports activities. After screening possible predictive factors of RTS, multivariate logistic regression and receiver operating characteristic curve analyses were performed to identify independent factors.

Results Multivariate logistic regression analysis identified SLH (odds ratio, 2.861 per 10 unit increase; $P < 0.001$) and ACL-RSI (odds ratio, 1.810 per 10 unit increase; $P = 0.001$) at 6 months as independent predictors of RTS at 1 year after surgery. Optimal cut-off values of SLH and ACL-RSI were 81.3% (sensitivity = 0.891; specificity = 0.609) and 55 points (sensitivity = 0.693; specificity = 0.826), respectively.

Conclusion In competitive athletes, SLH < 81% and ACL-RSI < 55 points at 6 months after surgery were associated with a greater risk of unsuccessful RTS at 1 year after surgery. SLH and ACL-RSI at 6 months could serve as screening tools to identify athletes who have difficulties with returning to sports after ACL reconstruction.

Level of evidence III.

Keywords Anterior cruciate ligament · Reconstruction · Return to sports · Predictive factor · Cut-off value

Abbreviations

ACL	Anterior cruciate ligament
ACL-RSI	Anterior Cruciate Ligament-Return to Sport after Injury scale
AUC	Area under the curve
BTB	Bone–patellar tendon–bone
HI	Hamstrings index
LSI	Limb symmetry index
QI	Quadriceps index
ROC	Receiver operating characteristic
RTS	Return to sports
SLH	Single-leg hop for distance

✉ Takuya Kitaguchi
takusakimiyu@gmail.com

1 Department of Rehabilitation, Osaka Rosai Hospital, 1179-3 Nagasone-cho, Kita-ku, Sakai, Osaka 591-8025, Japan

2 Department of Sports Orthopaedics, Osaka Rosai Hospital, Sakai, Osaka, Japan

3 Department of Orthopaedics Surgery, JCHO Osaka Hospital, Osaka, Osaka, Japan

4 Department of Sports Orthopaedics, Aamano Orthopaedics Clinic, Osaka, Osaka, Japan

5 Faculty of Comprehensive Rehabilitation, Osaka Prefecture University, Habikino, Osaka, Japan

Introduction

The anterior cruciate ligament (ACL) is commonly injured during sports activities, particularly those that involve frequent pivoting and jumping. ACL reconstruction restores stability and knee function, and subsequent rehabilitation enables athletes to return to sports (RTS) activities, which is an important consideration among athletes after surgery [22, 28]. However, a meta-analysis conducted by Ardern et al. [1] found that only 65% of athletes returned to their preinjury level of sports following ACL reconstruction. Furthermore, just over half (55%) of the athletes returned to competitive-level sports after surgery [1]. Thus, identifying factors that predict the likelihood of RTS following ACL surgery in competitive-level athletes would be informative.

Regarding RTS criteria, a systematic review by Barber-Westin et al. [5] found that time after surgery was the most common criterion, whereas only 35 studies (13%) of the 264 assessed used objective criteria including muscle strength (11%), general knee examination (6%), and single-leg hop tests (4%) to determine RTS readiness. Harris et al. [17] in a systematic review of 49 evidence level I studies also reported that 90% and 65% of studies failed to use objective criteria or any criteria, respectively, to permit RTS. Furthermore, Feller et al. [9] noted the lack of information on how to predict successful RTS in athletes. These studies collectively highlight the lack of objective measures of RTS.

Several studies have reported on factors that affect RTS following ACL reconstruction, including postoperative muscle strength [25, 33], functional performance [1–3, 20, 44], self-reported function [2, 3, 25, 49], and psychological hindrances [1–4, 25, 47]. For instance, Ardern et al. [2] reported that RTS was associated with psychological responses in addition to physical recovery, such as hop-test symmetry and subjective knee function. Moreover, Lentz et al. demonstrated that pain-related fear of re-injury, quadriceps strength, and self-reported function at 6 months after ACL reconstruction influenced RTS at 1 year after surgery [25].

A recent meta-analysis showed that a positive psychological response, symmetrical hopping performance, and contextual factors favored returning to a preinjury level of sports activities [1]. This is consistent with the report by Muller et al. which found that single hop for distance and ACL–RSI were useful predictors of RTS [29]. However, most previous studies, which examined factors affecting RTS among variables such as muscle strength, functional performance tests, self-report of function, and psychosocial measures, included recreational sports level patients, or only conducted univariate analysis [3, 10, 16, 25, 26, 29, 37, 43, 49]. To the best of our knowledge, only a few studies have used multivariate analysis to identify independent predictors of RTS in competitive athletes.

Identifying independent predictors of RTS and their optimal cut-off values would help identify athletes who might experience difficulties with returning to sports. Both knee function and psychological readiness at 6 months would be influenced by the return to preinjury level of sports and that this combination could be used to identify athletes at risk of not returning to sports were our hypothesis. Accordingly, the present study aimed to (1) identify independent predictive factors of RTS at 1 year after surgery in competitive-level athletes and (2) determine optimal cut-off values for these factors.

Materials and methods

Between 2011 and 2013, primary ACL reconstruction was performed at Osaka Rosai Hospital on 221 athletes who aimed to return to competitive sports. Inclusion criteria were (1) unilateral isolated ACL reconstruction, (2) preinjury Tegner activity scale>7 [42], (3) participation in competitive sports at least 4 times a week before ACL injury, and (4) complete data at 6 and 12 months after surgery. Exclusion criteria were (1) previous ACL surgery, (2) bilateral ACL injuries, (3) concomitant ligament injury requiring repair or reconstruction, (4) not RTS following surgery for social reasons (e.g., graduation from school), (5) ACL grafts or contralateral ACL tears within a year after surgery, or (6) incomplete data at 6 or 12 months after surgery. Patients with meniscal and cartilage injuries were not excluded.

From the cohort of 221 athletes, 51 were excluded based on eligibility criteria at 6 months after surgery (Fig. 1). Of the remaining 170 athletes, 46 were excluded at 1 year after surgery for the following reasons: lost to follow-up ($n = 21$), graft failure or contralateral ACL tear ($n = 7$), and did not RTS for social reasons ($n = 18$). The remaining 124 athletes were included in the final analysis (50 males and 74 females; mean age, 17.0 ± 2.7 years; age range, 13–26 years).

Surgical procedures

Anatomic triple-bundle ACL reconstruction with an autologous semitendinosus tendon graft was performed in 86 athletes, as described by Shino et al. [36]. Briefly, after fixation of the graft with an Endobutton-CL (Smith & Nephew Endoscopy) on the femur, the graft was tensioned with a total initial tension of 30 N at 15°–20° of flexion and fixed to the tibia with a double spiked plate (DSP; Meira Corp) and screws. In the remaining 38 athletes, anatomic rectangular tunnel ACL reconstruction with a bone-patellar tendon-bone (BTB) graft was performed as previously reported [35]. Briefly, a rectangular shaped socket was made within the femoral footprint of the ACL through the far anteromedial portal, followed by creation of a rectangular shaped tunnel

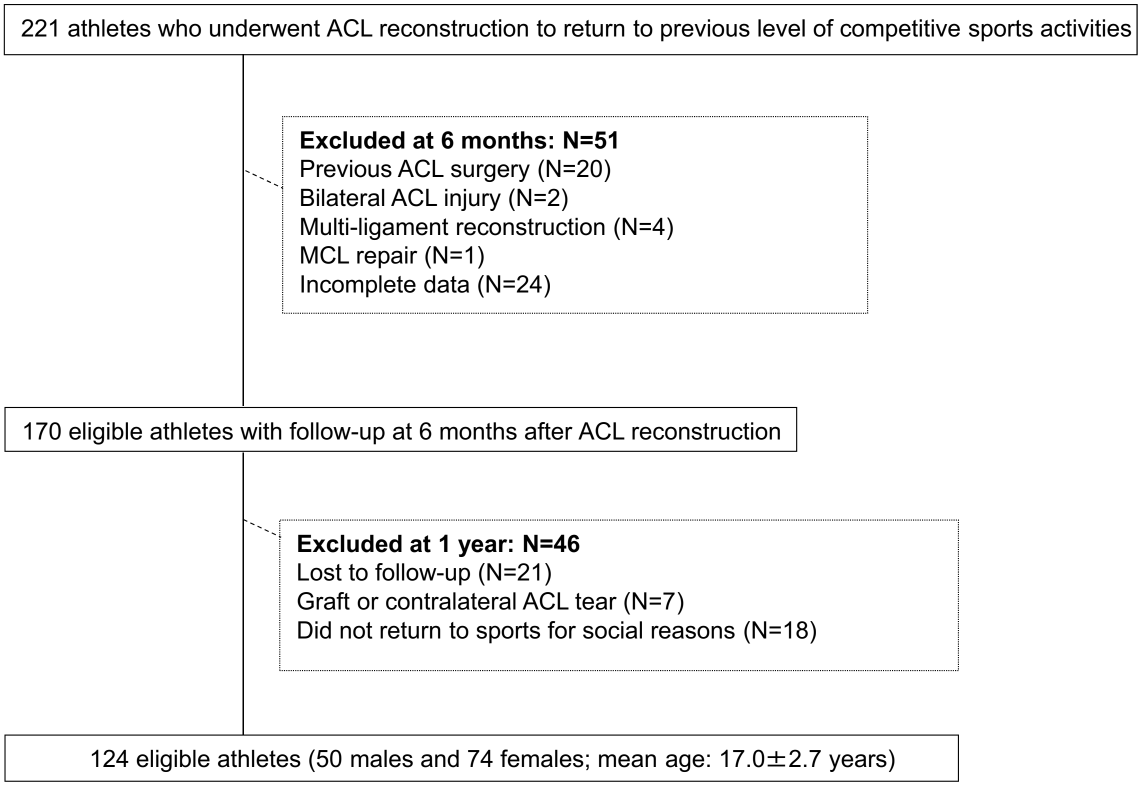


Fig. 1 Flow diagram of the study cohort

within the tibial footprint. After introduction of a BTB graft, the graft was fixed on the femur with a DSP and screw. The graft was then tensioned with a total initial tension of 20 N at 15°–20° of flexion and fixed to the tibia with a DSP and screw.

Postoperative rehabilitation and return to sports

After 2 weeks of immobilization with a brace at 20° of knee flexion, patients began range-of-motion exercises. Partial weight bearing was allowed at 3 weeks after surgery and full weight bearing after 4 weeks. Jogging was allowed at 3–4 months and return to strenuous labor at 6 months. As for muscle strengthening, hamstring resistance exercises were allowed at 4 weeks after surgery, while quadriceps resistance exercises were performed within a range of 60º–90º of flexion until 3 months after surgery to avoid the risk of graft failure. Restriction on quadriceps resistance exercises was completely removed at 6 months. Criteria for permitting RTS were symmetrical knee range of motion, adequate knee stability, and no knee joint effusion. RTS was permitted at 8–10 months after surgery.

At 1 year after surgery, patients were asked whether they had returned to preinjury level of sports activities and were then classified into either the RTS group or non-RTS (nRTS) group. The nRTS group also included patients who returned to a sports activity level lower than the preinjury level. Patients in the nRTS group were also asked about their reasons for the reduction in sports activity level or not returning to sports.

Assessment of knee function and psychological readiness

Assessments consisting of isokinetic knee muscle strength testing, single-leg hop for distance (SLH), evaluation of knee pain intensity, and two self-report questionnaires were performed at 6 months after surgery. All isokinetic strength and SLH tests were conducted by one of the three physical therapists who had an average of 13.3 years (range 8–18 years) of experience in physical therapy. Knee muscle strength was assessed with an isokinetic dynamometer (Cybex6000; Lumex Inc., Ronkonkoma, NY) at a velocity of 60°/s. Knee range of motion was set at 90°–0° of knee flexion using a dynamometer arm. Following a practice trial, patients performed a series of five isokinetic trials. Maximum peak torque was recorded, and the quadriceps index (QI) and hamstrings index (HI) were calculated by dividing the peak torque on the involved side by that on the uninvolved side and multiplying by 100.

Functional performance was evaluated by SLH as previously reported [15]. Briefly, patients stood on one leg with both hands behind their back to minimize the effect of arm swing. They were then instructed to hop forward as far as possible and land on the same leg, and the longest distance of three trials was recorded for each leg. Results were represented by the limb symmetry index (LSI), which was calculated by dividing the distance on the involved leg by the distance on the uninvolved leg and multiplying by 100.

Following the physical function tests, patients completed two self-report questionnaires: the International Knee Documentation Committee (IKDC), Subjective Knee Score [19], and the Anterior Cruciate Ligament-Return to Sport after Injury scale (ACL-RSI). The ACL–RSI is a 12-item patient-reported outcome measure assessing the psychological impact (athletes' emotions, confidence in performance, and risk appraisal) of returning to sports after ACL reconstruction [45]. The form of ACL-RSI has been translated into the Japanese language and the translated version was used to evaluate psychological readiness at 6 months after surgery [39, 40]. As a preliminary test for test–retest reliability, the Japanese version of ACL-RSI was evaluated twice at 1- and 2-day intervals by 41 athletes. This preliminary test revealed excellent test–retest reliability (ICC = 0.95).

Knee pain intensity was assessed with a numeric rating scale (NRS). Patients were asked to indicate the intensity of pain during the past 4 weeks on a scale of 0 (no pain) to 10 (worst pain imaginable).

Knee ligament laxity testing

To assess ACL graft laxity, anterior displacement of the tibia was measured using the KT-1000 arthrometer (MEDmetric Corp.) at approximately 30° of knee flexion at 6 months after surgery. The difference in values between the involved and uninvolved sides was recorded as anterior knee joint laxity difference.

This study was approved by the Ethics Committee of Osaka Rosai Hospital (ID.29-21), and written informed consent was obtained from all athletes.

Statistical analysis

Descriptive statistics were calculated for all outcomes, and are presented as mean±standard deviation for continuous variables and as frequency or percentage for categorical variables. Comparisons between RTS and nRTS groups were first performed using the Chi-square test for categorical data, and the Student's *t* test or Mann–Whitney *U* test for continuous data to select variables that significantly affected RTS. Variables with a P value < 0.20 were included in a multivariate stepwise logistic regression model to identify independent predictors of RTS after ACL surgery. Goodness of fit was assessed by the Hosmer–Lemeshow test [18]. Receiver operating characteristic (ROC) curve analyses were used to determine the area under the curve (AUC) and cut-off values for the independent predictors. Furthermore, sensitivity, specificity, and positive predictive value (PPV) were calculated [13]. Sensitivity was defined as the proportion of athletes above the cut-off value who were correctly identified as being in the RTS group, while specificity was defined as the proportion of athletes below the cut-off value who were correctly identified as being in the nRTS group. PPV was defined as the probability that athletes above the cut-off value will be able to RTS. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 20 (IBM Corp, Armonk, New York, USA). $P < 0.05$ was considered statistically significant.

An a priori sample size calculation was conducted with G*Power Software 3.1.9.4. With an effect size of 0.50 and an alpha of 0.05, 134 athletes were required to achieve a power of 0.80 [7].

Results

Return to previous level of sports activity and demographic factors

At 1 year after ACL reconstruction, 101 of the 124 athletes (81%) returned to their previous level of sports activities, while 23 (19%) did not. Subjective reasons for inability to RTS are summarized in Table 1. The most common reason was fear of re-injury (34.8%), followed by a combination of fear of re-injury and muscle weakness (21.7%). Eighteen athletes (78%) in the nRTS group indicated a fear of re-injury as the reason.

There was no significant difference in demographic factors between the RTS and nRTS groups, except for Tegner activity scale at 1 year after surgery ($P < 0.001$) (Table 2).

Knee function and psychological readiness

In terms of postoperative muscle strength at 6 months after surgery, mean QI was significantly higher in the RTS group (87%) than in the nRTS group (74%, $P = 0.002$), while HI showed no difference (Table 3). Functional tests also

Table 1 Subjective reasons for not returning to sports

	N	%
Fear of re-injury	8	34.8
Fear of re-injury/muscle weakness	5	21.7
Muscle weakness	4	17.4
Fear of re-injury/muscle weakness/pain	4	17.4
Fear of re-injury/pain	1	4.4
Muscle weakness/pain	1	4.4

Table 2 Athlete demographic factors

	Total	RTS group	Non-RTS group	P
Number of patients	124	101	23	
Age at surgery (years)	17.0 ± 2.7	16.9 ± 2.5	17.7 ± 3.1	n.s
Gender				n.s
Male, *n* (%)	50 (40.3)	42 (41.6)	8 (34.8)	
Female, *n* (%)	74 (59.7)	59 (58.4)	15 (65.2)	
Preinjury Tegner Activity Scale[a]	9 (8–9)	9 (9–9)	9 (8–9)	n.s
Postoperative Tegner Activity Scale at 1 year[a]	9 (7–9)	9 (9–9)	7 (5.5–7)	< 0.001*
Graft type				n.s
ST, *n* (%)	86 (69.4)	73 (72.3)	13 (56.5)	
BTB, *n* (%)	38 (30.6)	28 (27.7)	10 (43.5)	
Time from injury to surgery (months)	3.3 ± 4.2	3.2 ± 4.5	3.6 ± 2.7	n.s
Meniscal treatment				
Medial meniscus (%)	19.4	19.8	17.4	n.s
Lateral meniscus (%)	33.9	34.7	30.4	n.s
Cartilage lesions: ICRS ≥2 (%)	8.9	9.9	4.4	n.s
Mechanism of injury				n.s
Non-contact, *n* (%)	86 (69.4)	71 (70.3)	15 (65.2)	
Contact, *n* (%)	38 (30.6)	30 (29.7)	8 (34.8)	

*Significant difference between groups, $P < 0.05$

[a]Median (25–75th percentile)

Table 3 Knee function and questionnaire scores at 6 months after Acl reconstruction

	Total ($n = 124$)	RTS group ($n = 101$)	Non-RTS group ($n = 23$)	P
QI (%)	84.2 ± 16.8	86.5 ± 16.2	74.4 ± 15.8	0.002*
HI (%)	90.9 ± 16.0	92.3 ± 16.2	85.2 ± 14.0	n.s
LSI for SLH (%)	88.3 ± 11.4	90.6 ± 8.9	77.9 ± 15.2	< 0.001*
IKDC subjective score	83.5 ± 7.8	84.4 ± 7.8	79.3 ± 6.1	0.002*
ACL-RSI	59.8 ± 19.6	63.4 ± 18.7	43.7 ± 15.4	< 0.001*
Pain (NRS)	2.1 ± 1.5	2.0 ± 1.5	2.3 ± 1.2	n.s
KT-1000 SSD (mm)	0.8 ± 1.5	0.8 ± 1.6	1.1 ± 0.9	n.s

QI Quadriceps Index, *HI* Hamstrings Index, *LSI* limb symmetry index, *SLH* Single-leg hop, *IKDC* International Knee Documentation Committee, *ACL-RSI* Anterior Cruciate Ligament-Return to Sports after Injury scale, *NRS* numerical rating scale, *SSD* side-to-side difference

*Significant difference between groups, $P < 0.05$

revealed a significantly higher LSI for SLH in the RTS group compared to the nRTS group ($P < 0.001$; Table 3). There were no significant differences in knee pain and KT values between the two groups. Both IKDC subjective score and ACL-RSI in the RTS group were significantly higher than those in the nRTS group ($P = 0.002$ and $P < 0.001$, respectively; Table 3).

Prediction model for RTS

The multivariate logistic regression model combining variables most predictive of RTS included LSI for SLH (OR = 2.861 per 10 unit increase; $P < 0.001$) and ACL-RSI (OR = 1.810 per 10 unit increase; $P = 0.001$) (Table 4). The

Table 4 Multivariate logistic regression model for predictors of RTS after ACL reconstruction

	B	SE	OR[a]	95% CI	P value
LSI for SLH (%)	1.051	0.290	2.861	1.622–5.048	< 0.001*
ACL-RSI	0.593	0.175	1.810	1.283–2.553	0.001*

OR odds ratio, *CI* confidence interval, *LSI* limb symmetry index, *SLH* single-leg hop, *ACL-RSI* Anterior Cruciate Ligament-Return to Sports after Injury scale

*Significant difference between groups, $P < 0.05$

[a]Odds ratios per 10 units for potential to return to sports

Hosmer–Lemeshow test indicated that the model fit the data well (n.s.).

With regard to LSI for SLH and ACL-RSI at 6 months after surgery, the ROC analysis revealed a cut-off value of 81.3% (sensitivity 89.1%, specificity 60.9%) and 55 points (sensitivity 69.3%, specificity 82.6%), respectively, for differentiating between RTS and nRTS groups (Fig. 2). When both cut-off values were combined, the predictive ability showed high specificity (0.913) and high PPV (0.969).

Discussion

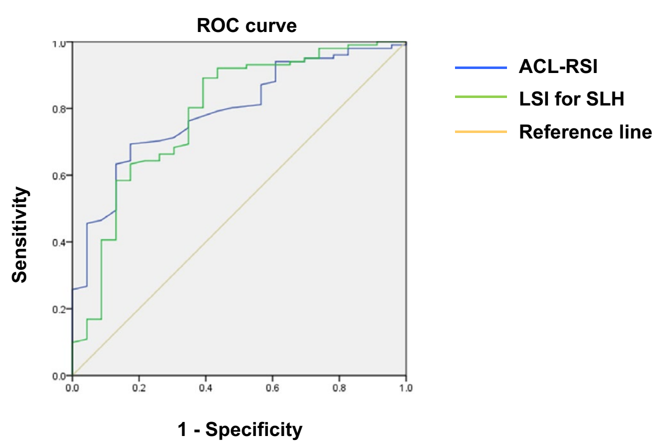
The major finding of the present study was that LSI for SLH and ACL-RSI score at 6 months after surgery were the most significant predictive factors of RTS following ACL reconstruction in competitive-level athletes. Optimal cut-off values were 81.3% and 55 points for LSI for SLH and ACL-RSI, respectively. In addition, the combination of LSI for SLH and ACL-RSI at 6 months after surgery could identify 91% of athletes in the nRTS group. A major strength of this study was that all athletes were young competitive-level athletes, which readily allowed for identification of factors that contribute to RTS after ACL reconstruction using multivariate analysis. Although Muller et al. also reported that both tests might predict patients at risk of not returning to a preinjury level of sports activities that study included only patients who participated in recreational level sports activities with a mean age of > 30 years [29].

Return to sports in highly-active athletes after ACL reconstruction

In the present study, 81% of highly-active athletes returned to their preinjury level of sports activities at 1 year after ACL reconstruction. According to a meta-analysis study of RTS, 81% of patients returned to participating in sports following ACL reconstructive surgery, but only 65% returned to their preinjury level [1]. However, in the same review, younger age and playing elite sports were reported to be contextual factors that favored returning to the preinjury level of sports [1]. As for age at surgery, several studies have reported that younger athletes were more likely to return to their preinjury level [8, 44]. For instance, Webster et al. examined RTS after ACL reconstruction in 140 patients aged < 20 years and found that 76% were able to return to the same preinjury sport [46]. Regarding activity levels, significantly more competitive-level athletes had returned to sports compared with recreational athletes [2]. A systematic review by Lai et al. [24] also found that 83% of elite athletes returned to their preinjury level of sports following ACL reconstruction. Taken together, the high RTS rate in the present study could at least in part be attributed to the younger age of athletes and their high activity levels.

Psychological readiness and return to sports

With regard to reasons for not returning to sports, 78% of athletes in the nRTS group claimed a fear of re-injury.



	AUC	P value	Cut-off point	Sensitivity	Specificity
LSI for SLH	0.79 ± 0.06	<0.001	81.3%	0.891	0.609
ACL-RSI	0.79 ± 0.05	<0.001	55	0.693	0.826

Fig. 2 Receiver operating characteristic (ROC) curves for limb symmetry index (LSI) for single-leg hop for distance (SLH) and ACL-RSI predicting return to sports (RTS) in young competitive-level athletes with ACL reconstruction. The area under the curves of LSI for SLH and ACL-RSI were 0.79 ± 0.06 (P = 0.000) and 0.79 ± 0.05 (P = 0.000), respectively. Optimal cut-off values of LSI for SLH and ACL-RSI were 81.3% and 55 points, respectively, for differentiating between RTS and nRTS groups

Previous studies have emphasized psychological readiness as a factor that influences RTS after ACL reconstruction [2, 4, 21, 23, 45, 47]. According to a clinical study by Kvist et al. [23], 24% of patients reported a fear of injury as the reason for not returning to their preinjury level of sports, while the main reason was problematic knee function. Webster et al. [45] measured athletes' emotions, confidence in performance, and risk appraisal using the ACL-RSI scale and reported that participants who had given up sports scored significantly worse than those who had returned or were planning to return to sports at 12 months after ACL reconstruction. In the present study, which targeted competitive athletes, ACL-RSI at 6 months was one of the most significant predictive factors of RTS following ACL reconstruction, and the optimal cut-off value for RTS in these athletes was 55 points (sensitivity 69.3%, specificity 82.6%). In a study that involved 40 patients aged > 30 years, Muller et al. [29] reported that ACL-RSI was one of the strongest predictive parameters for returning to recreational sports at 6 months following ACL reconstruction, with a cut-off value of 51 points. The higher optimal cut-off value in the present study could reflect differences in age and activity levels of athletes between the studies. According to a clinical study by Webster et al. [47] younger patients who participated frequently in sports before ACL injury were more likely to have a higher psychological readiness to RTS, as assessed by ACL-RSI. Although ACL-RSI score could be one of the strongest predictive factors of RTS, further studies will be needed to determine whether age and activity level influence the ACL-RSI score threshold for RTS.

Single-leg hop testing and return to sports

Another strong predictive factor of RTS was LSI in the SLH test. The SLH test is a performance-based measure used to assess knee functional performance in individuals after ACL reconstruction [29, 32, 38]. In general, LSI has been used as a criterion for RTS [12, 27, 30, 48] and better results in the SLH test have been associated with a higher RTS rate [3, 20, 25, 26, 29]. According to Ithurbum et al. [20], participants who returned to preinjury sports participation demonstrated greater performance at RTS clearance in the involved limb on the single hop, compared with those who did not. Moreover, Müller et al. [29] reported that the SLH test was one of the strongest predictive parameters for return to recreational sports activity at 6 months after ACL reconstruction, with a cut-off value of 75%. The present study revealed that the optimal cut-off value of LSI for RTS in young competitive athletes was 81% [high specificity (0.891) and moderate sensitivity (0.609)] and that competitive athletes required a higher LSI for SLH. In the previous studies, RTS criteria included an LSI for SLH > 85% [30] or > 90% [12, 27, 48]. The mean LSI for SLH at 6 months in all cases was 88%, and this high LSI could be one of the reasons for the high RTS rate observed in the present study. However, there are views that LSI should be treated with caution when used as a criterion for RTS following ACL reconstruction given the possibility of underestimating performance deficit [11]. Taken together, LSI for SLH > 81% could be an RTS criterion for competitive athletes to aim for at 6 months after surgery.

Muscle strength and return to sports

Mean QI in the nRTS group (74%) was significantly lower than in the RTS group (87%). However, the multivariate logistic regression model which combined variables most predictive of RTS did not include QI. Quadriceps strength asymmetry has been commonly used as an RTS criterion [14, 27]. According to a systematic review by Barber-Westin et al. [5], 25 studies included quadriceps strength testing as a criterion for return to athletics, and reported that recommendations ranged from greater than 80–90% for isokinetic testing of the quadriceps compared with the contralateral side. Previous studies have found that, at the time of RTS following ACL reconstruction, individuals with weaker quadriceps strength demonstrate altered landing patterns [34] and displayed greater movement asymmetries at the knee joint in the sagittal plane [32]. Grindem et al. [14] also reported that quadriceps strength deficit prior to RTS was a significant predictor of knee re-injury. A recent study by Barfod et al. [6] which examined the association between quadriceps strength and SLH following ACL reconstruction, reported that although 67% of patients demonstrated satisfactory hopping symmetry (≥ 85% in hop tests), only 28% had recovered satisfactory knee extensor strength symmetry (≥ 85% in strength tests) at 6 months after surgery. The authors concluded that the SLH test cannot be used as a surrogate measure for knee extensor strength [6]. Nagai et al. reported discrepancies in the results of three types of functional tests, including isokinetic dynamometry, the hop test, and leg press. While these studies appear to suggest the desirability of including QI in RTS criteria, our multivariate logistic regression model did not find QI to be a predictive factor of RTS.

This study has some limitations. One limitation relates to potential issues with cross-cultural adaptation of the Japanese version of the ACL-RSI. However, after publication of the ACL-RSI in 2008 by Webster et al., Takeshita et al. performed preliminary studies using the translated version and obtained similar results to those reported in the original study [39, 40, 45]. In general, ACL-RSI scores increased as postoperative time increased, and ACL-RSI scores in subjects who returned to sports were significantly higher than scores of those who planned to RTS [39, 40].

Another limitation relates to surgical procedure heterogeneity. Graft choice in our hospital for competitive athletes has gradually shifted from hamstring tendon grafts to BTB grafts after experiences with high ACL graft rupture rates in female basketball players [41]. Approximately 30% of athletes in the present study were treated with BTB grafts and no significant effect of graft selection was observed based on ACL-RSI scores. However, LSI for SLH after ACL reconstruction with BTB grafts (84.7%) was significantly lower than that with hamstring grafts (89.8%). Further studies will be needed to clarify the effects of graft selection.

Finally, the actual sample size was slightly smaller than the sample size calculated by power analysis. At 1 year, 46 athletes had to be excluded due to lost to follow-up, social reasons, and second ACL injury, which were much more than expected (Fig. 1). In addition, due to the relatively small sample size of the nRTS group as a result of the high rate of RTS in the present study, some factors might have been found to have no significant association with RTS. In terms of functional tests, although four hop tests are commonly used in the field to assess knee functional performance [14, 27, 31], the SLH test was used in the present study. While Müller et al. [29] reported that SLH was the strongest predictive parameter among multiple single-leg tests after ACL reconstruction for assessing RTS, Nawasreh et al. [31] found that the 6-m timed hop test was the strongest predictor of RTS at 12 months after ACL reconstruction. This highlights the importance of assessing multiple performance-based measures, such as the triple cross-over hop, triple hop for distance, and 6-m timed hop, in addition to SLH.

Conclusion

The present study found that LSI for SLH and ACL-RSI score was the most significant predictive factors of RTS following ACL reconstruction in competitive young athletes. Athletes with LSI for SLH <81% or ACL-RSI score <55 points were at greater risk of unsuccessful RTS relative to those with higher scores. Furthermore, the combination of LSI for SLH and ACL-RSI score at 6 months was able to identify 91% of athletes in the nRTS group at 1 year after ACL reconstruction. Competitive-level athletes with scores lower than these cut-offs at 6 months after surgery require further training to achieve successful RTS.

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Compliance with ethical standards

Conflict of interest The authors have no conflict of interest to declare.

Ethical approval This study was approved by the Ethics Committee of Osaka Rosai Hospital (ID.29-21).

Informed consent Informed consent was obtained from all subjects.

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