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Association of Knee Function at 6 Postoperative Months With Second ACL Injury Within 2 Years After Primary ACL Reconstruction

■ **OBJECTIVES:** To determine the association between second anterior cruciate ligament (ACL) injury within 2 years after ACL reconstruction and knee function at 6 postoperative months.

■ **DESIGN:** Retrospective cohort study.

■ **METHODS:** We included patients who had undergone primary ACL reconstruction. Knee strength was measured using an isokinetic dynamometer, dynamic balance was measured using the anterior leg reach test, and single-leg hop distances were measured in 3 directions (anterior, lateral, and medial). The limb symmetry index (LSI) was calculated. Ipsilateral and contralateral second ACL injuries were observed within 2 postoperative years.

■ **RESULTS:** This study included 77 participants; 13 participants were in the second ACL injury group. The second ACL injury group had lower hamstring strength LSI (60°/s) than the no-injury group (*P*<.05). The cutoff point of hamstring LSI for predicting second ACL injury was 83.6%. Logistic regression analysis showed that higher participation level (*P* = .035; odds ratio [OR] = 6.131; 95% confidence interval [CI]: 1.123, 33.465) and hamstring strength LSI <83.6% (*P* = .007; OR = 8.723; 95% CI: 1.766, 43.090) were associated with second ACL injury.

■ **CONCLUSION:** There was an association between hamstring strength weakness on the operative side at 6 months after primary ACL reconstruction and second ACL injury within 2 postoperative years. *JOSPT Open 2024;2(1):20-28. Epub 15 December 2023. doi:10.2519/josptopen.2023.0609*

■ **KEY WORDS:** *ACLR, flexor strength, reinjury, subsequent injury*

Approximately 20% of athletes who have undergone primary anterior cruciate ligament (ACL) reconstruction sustain a second ACL injury.[38] After revision ACL reconstruction, along with time constraints, functional knee outcomes and return to sport (RTS) rates have been found inferior to those after primary ACL reconstruction.[3,24]

Recently, Cronström et al published systematic reviews and meta-analyses on the risk factors for graft rupture[12] and contralateral ACL injury.[13] Although these reviews reported differences between graft rupture and contralateral ACL injury, they found that demographic factors, including young age, return-to-preinjury high activity level, and family history of ACL injury, were consistently associated with second ACL injury. However, there has been limited research on asymmetries in knee function, including knee strength, hop performance, and balance, which may be associated with second ACL injury.[2,14,42,45] Therefore, it is important to examine knee function in relation to second ACL injury.

Typically, knee function evaluations are performed at approximately 6 postoperative months, which inform the initiation of modified sports activity (eg, agility, coordination drills) or unrestricted RTS.[23,25,26] Detection of the risk of second ACL injury based on functional recovery status at 6 postoperative months could inform safe RTS and prevention of second ACL injury.[4] Few studies have analyzed the association between second ACL injury and functional assessments performed 6 months after ACL reconstruction.[4,44] In these studies,[4,44] the single-leg hop test was only performed in the anterior direction. The inclusion of sideways movements, including lateral and medial hops, could better detect asymmetry than anterior single-leg hops and may reveal functional variables that are more relevant to second ACL injury.[16] Previous studies on dynamic balance have shown that excessive dynamic postural stability on the operative side is associated with second ACL injury[40]; however, this previous study used a specialized instrument that is difficult to clinically implement. Further, there is a need for studies using the sideways single-leg hop test and leg reach test,[10,22,46] which can be more easily implemented in clinical and sports settings.

This study aimed to determine the association between knee function at 6 postoperative months and second ACL injury within 2 years after ACL reconstruction. We hypothesized that asymmetries

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in knee joint function at 6 months after ACL reconstruction surgery would be associated with a second ACL injury within 2 postoperative years, even after adjusting for factors such as age and participation level.

METHODS

Study Design and Participants

This 2-year retrospective cohort study included patients who underwent primary ACL reconstruction between June 2015 and April 2020. The inclusion criteria were as follows: (1) patients aged 16 to 45 years at the time of surgery, (2) preinjury modified Tegner activity scale[21] ≥7, and (3) completion of a 6-month postoperative knee functional assessment. The exclusion criteria were as follows: (1) difficulty in visiting the clinic due to distance or social reasons, including pregnancy and employment; (2) lost to follow-up before 6 months after ACL reconstruction; (3) having undergone surgery other than ACL reconstruction 6 months prior to reconstruction; (4) occurrence of new complications affecting RTS after ACL reconstruction; (5) failure to complete a 6-month postoperative knee functional assessment; or (6) no desire for RTS at the time of surgery. Ethical approval was obtained from the review board of Tokyo Medical and Dental University (approval no. M2019-019-1). Patients admitted prior to November 2019 were given the opportunity to opt out of the study, whereas those admitted after December 2019 provided written consent at the time of assessment.

Surgical Technique and Postoperative Rehabilitation

Surgeries were performed by 13 orthopedic surgeons who specialized in the knee joint (mean experience, 20.6 years). A graft was created using autografts of the semitendinosus (ST), ST and gracilis (STG), bone-patellar tendon-bone (BPTB), or quadriceps tendon (QT). The postoperative rehabilitation protocol was based on a previous study.[37] Three days after surgery, active assistive range-of-motion and isometric quadriceps contraction exercises were initiated. Four weeks after surgery, crutches and a straight-position knee immobilizer (knee brace, ALCARE Co, Ltd, Tokyo, Japan) were gradually discontinued. Three months after surgery, jogging began, with a steady increase in the running speed. Sports participation was allowed when the following were achieved: ≥6 months had passed after surgery, the limb symmetry index (LSI) for the single-leg hop test exceeded 80%, and the LSIs of isokinetic extension and flexion torque measured using an isokinetic dynamometer (BIODEX System 4, BIODEX Medical Inc, Shirley, NY) at 60°/s and 180°/s were >80%. Participants who underwent middle-posterior meniscal repair were not allowed to conduct deep squats with >90° knee flexion until 3 months after ACL reconstruction. Sports participation was defined as partial return (including practice) to the sport the participant played before the ACL injury.

Procedures

Demographic characteristics, including age, sex, body mass index, sports classification at the time of injury, participation level, weekly frequency of playing sport (including practices and games), date of injury, type of injury, number of months that sports participation is permitted by the physician, and surgical details, were obtained from the patients' medical records. Based on a previous study, sports were classified as collision, contact, limited contact, noncontact, or fixed-object high-impact rotational landing.[34] Participation level was categorized as recreational, competitive, or elite.[9] Knee functional assessments were performed at 6 postoperative months. Knee functional assessments were performed by 5 trained physical therapists (mean experience, 15.8 years).

Knee Functional Assessment at 6 Months After ACL Reconstruction

Knee strength peak torque (Newton meters) was measured using an isokinetic dynamometer for the quadriceps (extension) and hamstrings (flexion) at angular velocities of 60°/s and 180°/s. These angular velocities have been commonly used in previous studies.[31,51] After completing 2 practice repetitions to get comfortable with the task, participants completed a maximum of 5 repetitions.[20] The ratio of the peak torque on the operated side to that on the unoperated side was used to determine the LSIs of the peak torques. This procedure has been found to have high intrarater reliability (intraclass correlation coefficient [ICC]: 0.82-0.97).[5]

Dynamic balance was measured with the anterior leg reach using the Y-Balance Test Kit™ (Functional Movement Systems, Chatham, MA).[22] Participants were instructed to stand on 1 leg on the Y-Balance Test Kit™ and push the reach indicator box farther away from the opposite leg. Any kicking of the box or stepping-off balance was recorded as a trial error, followed by repetition of the trial. Participants were allowed at least 3 practice trials in the leg reach direction, with the best of the 3 formal trials. The maximum reach was measured at the end of the reach indicator where the most distal part of the foot was reached. Finally, the LSI was calculated. This method has shown excellent intrarater and interrater reliability.[41]

The single-leg hop tests were performed based on a previous study.[2] Participants wore shoes with no air cushions (step101, Lucky Bell, Kobe, Japan). Single-leg hop distances in 3 directions (anterior, lateral, and medial) were measured in a random order to reduce the effect of fatigue.[16] Trials were performed for each leg, starting on the nonoperated side. Arm movement during jump landing was not restricted. The test was considered successful if the landing was stable. If the opposite limb touched down early on landing and lost balance, or if the supporting limb hopped further after landing, the trial was considered a failure and repeated. The ICCs of the single measurement values of the operative and nonoperative sides have been found to be in the range of 0.91 to 0.99 and 0.91 to 0.96, respectively.[2]

Main Outcome: The Second ACL Injury

The follow-up period was 2 years after ACL reconstruction, which is a period that second ACL injury is likely to occur.[35] The second ACL injury was diagnosed by an orthopedic surgeon based on magnetic resonance imaging findings and a ≥3-mm side-to-side difference in anterior laxity measured using KT-1000.[27] We assessed for both ipsilateral and contralateral second ACL injuries. For ipsilateral second ACL injuries, only second ACL injuries caused by obvious injury episodes, including giving-way or contact to the knee, were included, with exclusion of cases of graft failure without obvious reinjury status (eg, technical errors or biological factors[8]). Participants were classified into the "second ACL injury group" or "no-injury group."

Statistical Analysis

A priori sample size estimation was performed using the G*Power software package (version 3.1.9.4, Kiel University).[19]. Considering a hypothetical approximately 25% rate of second ACL injuries, the input parameters were as follows: statistical test = means: difference between 2 independent means (2 groups); tail = 2; effect size (ES) = 0.8; α error probability = 0.05; power = 0.8; and allocation ratio = 0.25. As a result, the target sample size was 80 participants (second ACL injury group = 16, no-injury group = 64). The normality of distribution of each variable was established using histograms and the Shapiro-Wilk test. The chi-square test, Fisher's exact test, unpaired *t* test, or Mann-Whitney U test was used to analyze between-group differences in demographic data and knee functions. ESs were determined for each variable (chi-square test = Φ coefficient, Fisher's exact test = Cramer's V, *t* test = Cohen's *d*, Mann-Whitney U test = r).

For functional variables significantly associated with second ACL injury, receiver operating characteristic (ROC) curve analysis was performed. The cutoff points were calculated using the Youden index. The area under the ROC curve was interpreted as follows: 0.5 is random, 0.7 to 0.8 is acceptable, and 0.8 to 0.9 is excellent.

A logistic regression analysis (forced-entry method) was performed to characterize a second ACL injury. The dependent variable was the presence of a second ACL injury, and the independent variable was the variable for which $P<.1$ in the 2-group comparison. The demographic variables of age and participation level, which have been shown to be associated with second ACL injury, were included in the regression analysis as covariates regardless of their statistical significance.[48] This logistic regression analysis was defined as Model 1. Moreover, we performed a logistic regression analysis using the cutoff points of the knee function variables indicated in the ROC curve analysis. First, we changed the knee functional variable in Model 1 to the cutoff point calculated by ROC analysis (Model 2). Next, we conducted a sensitivity analysis excluding these factors to ensure that the model results (robustness) were not changed by demographic factors shown to be associated with second ACL injury (Model 3). Finally, a post hoc analysis of the knee function variables in the logistic regression of Model 2 was conducted using G*Power software to confirm the statistical power of the study. A power >0.5 is considered the minimum statistical power for rejecting the null hypothesis,[15] whereas a power >0.8 is considered sufficient.[32] Data analyses were performed using SPSS 28.0 (SPSS, Inc, Chicago, IL). A *P* value of <.05 was considered statistically significant.

RESULTS

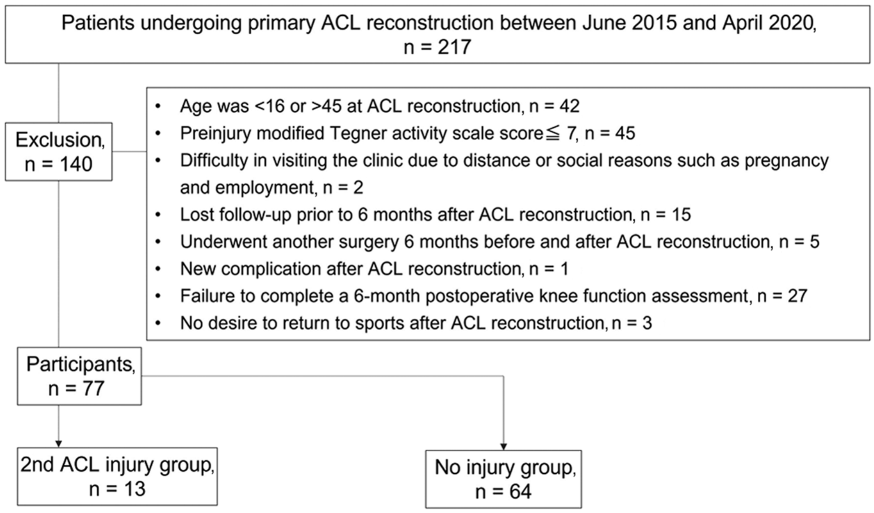
We included 77 patients who underwent primary ACL reconstruction (male, n = 37; mean ± standard deviation age, 18.7 ± 1.5 years); among them, 13 patients (ipsilateral, 8; contralateral, 5) were in the second ACL injury group (**FIGURE 1**). Univariate group comparisons revealed significant between-group differences in age, level of participation, and weekly frequency of playing sports ($P<.05$) (**TABLE 1**).

The second ACL injury group had a lower LSI of hamstring strength (60°/s) than the no-injury group ($P = .034$, ES = 0.68) (**TABLE 1** and **TABLE 2**). There were no significant between-group differences in the single-leg hop distance, anterior leg reach, and quadriceps strength.

Logistic regression analysis showed that higher participation level ($P = .025$; odds ratio [OR] = 6.839; 95% confidence interval [CI]: 1.268, 36.876) and lower LSI of hamstring strength ($P = .019$; OR = 0.940; 95% CI: 0.893, 0.990) were associated with second ACL injury (**TABLE 3**, **Model 1**).

For the LSI of hamstring strength (60°/s), the area under the curve was 0.74 ($P = .01$; 95% CI: 0.58, 0.89; acceptable), with 0.667 sensitivity and 0.750 specificity at a cutoff point of 83.6% (**FIGURE 2**). Regarding the distribution of the LSI of hamstring strength (60°/s), approximately 50% of participants in the second ACL injury group had an LSI below 80% (**FIGURE 3**).

FIGURE 1
Flowchart showing the participant enrolment process of this study. Abbreviaton: ACL, anterior cruciate ligament.



Finally, logistic regression analysis was performed again using the calculated cutoff point of LSI of hamstring strength (83.6%) (**TABLE 3**, **Models 2** and **3**). In Model 2, higher participation level (P = .035; OR = 6.131; 95% CI: 1.123, 33.465) and an LSI of hamstring strength <83.6% (P = .007; OR = 8.723; 95% CI: 1.766, 43.090) were associated with second ACL injury. Similarly, in Model 3, a sensitivity analysis without the adjusted covariates revealed an association between LSI of hamstring strength <83.6% and second ACL injury (P = .014; OR = 5.857; 95% CI: 1.432, 23.955). Post hoc power analysis of the cutoff point (83.6%) for hamstring LSI in Model 2 yielded a power of 0.83 (tail = 2, OR = 8.723, Pr (Y=1|X=1) H0 = 0.052, α error probability = 0.05, total sample size = 74, R^2 other X = 0, X distribution = binomial distribution, X parm π = 0.41).

DISCUSSION

In our study, compared with the no-injury group, the second ACL injury group was younger, had a higher participation level, and played sports more frequently. Among these factors, participation level was selected using logistic regression analysis. Previous studies[12,13] have reported that younger athletes with higher activity levels are more likely to have a second ACL injury, which is consistent with our findings. Experts involved in the treatment of post-ACL reconstruction should carefully consider RTS among athletes with high participation levels.

We observed a significant association between hamstring strength asymmetry at 6 postoperative months and second ACL injury within 2 years after ACL reconstruction. King et al[29] analyzed factors associated with ipsilateral injury after ACL reconstruction. They found that the rate of achieving hamstring LSI <90% at 9 postoperative months was lower in the reinjury group (45%) than in the noninjury group (69%). Although their measurement timing differs from ours, our results partially support these previous findings. The hamstring is an important target for ACL injury prevention given its role in controlling ACL strain.[33,45,49] In a previous study examining hamstring strength and biomechanics during gait and jogging after ACL reconstruction, individuals who had an LSI of hamstring strength <85% had less tibial internal rotation during the load response phase of gait and greater tibial external rotation during jogging than those who did not.[1] Our findings demonstrate the importance of improving hamstring asymmetry, which affects ACL strain and abnormal knee mechanics after ACL reconstruction.

ROC analysis with second ACL injury as the outcome showed that the cutoff point for the LSI of hamstring was 83.6%. Logistic regression analysis using this cutoff point increased the odds of second ACL injury by 8.723 times (**TABLE 3**, **Model 2**). An LSI >85% to 90% for strength is commonly used as a criterion for RTS after ACL reconstruction,[26] and the cutoff point obtained in this study is reasonable. However, the sensitivity (0.667) and specificity (0.750) at this cutoff point were not excellent (**FIGURE 2**). This could be attributed to the difficulty of predicting multifactorial second ACL injury based on hamstring strength asymmetry alone. In a previous study analyzing the LSI for hamstring strength at 6 months after ACL reconstruction, the mean LSI exceeded 95% and was not significantly associated with second ACL injury.[4,36] However, in another previous study, <50% of participants obtained an LSI of hamstring strength >90% at 6 months after ACL reconstruction,[11,28] whereas others did not achieve an LSI of 90% even after 3 years.[1] These data suggest that hamstring strength recovery may vary among participants in each study. Despite the inconsistency across studies, our findings suggest that insufficient hamstring strength (LSI<83.6%) at 6 postoperative months increased the odds of second ACL injury within 2 postoperative years.

The LSI of quadriceps strength was not associated with second ACL injury, which is consistent with the findings of recent systematic reviews and meta-analyses[12,13,52]; however, it conflicts our

TABLE 1
Between-Group Comparison of Demographic Characteristics

	All	Second ACL Injury Group	No-Injury Group	*P* Value	Effect Size
Pre-ACL Injury Variables					
Sex, n				0.646	0.21
Male	37	7	30		
Female	40	6	34		
Age, y	18.7±1.5	18.7±1.5	22.3±7.2	< 0.001	0.54
Body mass index (kg/m²)	24.4±2.7	24.4±2.7	23.3±3.1	0.246	0.36
Participation level, n				0.018	0.34
Recreation	3	0	3		
Competitive	47	4	43		
Elite	27	9	18		
Weekly frequency of playing sport[a] (n = 76)	6.0 (3.0-6.0)	6.0 (5.5-6.0)	5.0 (3.0-6.0)	0.043	−0.23
Sports classification, n				0.328	0.27
Collision	10	4	6		
Contact	45	7	38		
Limited contact	13	2	11		
Noncontact	5	0	5		
Fixed-object high-impact rotational landing	4	0	4		
Days from initial injury to primary ACL reconstruction[a] (n = 77)	67.0(37.0-165.5)	54.0 (26.0-114.0)	73.5 (39.0-172.0)	0.107	−0.19
Postsurgery-Related Variables					
Graft type, n				0.143	0.31
ST	59	8	51		
STG	8	1	7		
BPTB	8	4	4		
ST+QT	1	0	1		
BPTB+ST	1	0	1		
Meniscus suture, n				0.747	−0.06
Yes	52	8	44		
No	25	5	20		
Cartilage damage above grade 2, n				1.000	0.00
Yes	18	3	15		
No	59	10	49		
Second ACL injury type, n			-	-	-
Contralateral injury	-	5			
Ipsilateral injury	-	8			
Months from surgery to permitted participation in sports[a] (n = 75)	7.0(6.0-8.0)	7.0 (6.5-9.0)	7.0 (6.0-8.0)	0.488	−0.08
Months from participation in sports to second ACL injury	-	16.5±6.6	-	-	-

Abbreviations: ACL, anterior cruciate ligament; BPTB, bone-patellar tendon-bone; QT, quadriceps tendon; RTS, return to sports; ST, semitendinosus; STG, semitendinosus and gracilis.
[a]Median (interquartile range).

hypothesis. Second ACL injury has been associated with greater quadriceps strength symmetry[4] or lower quadriceps strength on the operative side than on the nonoperative side.[27,29] These inconsistent reports impede the elucidation of the relationship between quadriceps strength and second ACL injury. Grindem et al[27] showed that after ACL reconstruction, the graft rupture group had a lower LSI for quadriceps strength (60°/s) than the no-reinjury group (84.4% vs 75.0%). Bodkin et al[4] reported a higher LSI of quadriceps strength at 6 months after ACL reconstruction and an increased risk of second ACL injury among individuals who achieved return to activity within 8 months. However, no data were presented on quadriceps muscle strength between the second ACL injury group and the no-injury group.[4] For reference, LSIs for quadriceps strength measured at 6 postoperative months were 73.04%, 75.18%, and 70.86% for all participants, the return-to-activity group at <8 months, and the return-to-activity group at >8 months, respectively.[4] Therefore, the mean quadriceps LSI of the second ACL injury group (81.1%) in our study was relatively high compared with those in previous studies conducted during the same period, which suggests that there is no significant between-group difference.

In our study, the single-leg hop test and anterior leg reach test were not associated with second ACL injury. A previous study showed that asymmetry is easier to detect in medial and lateral hops than in anterior hops.[16] Therefore, we assessed hops in 3 directions. The LSIs in the single-leg medial and lateral hop test were comparable to that in a previous study (medial: 87.3%; lateral: 87.5%)[16] and had a similar degree of symmetry with or without a second ACL injury. Hop distance symmetry has been shown not to be associated with normal lower extremity

TABLE 2
Between-Group Comparison of Limb Symmetry Index for Knee Function Variables

	All	Second ACL Injury Group	No-Injury Group	*P* Value	Effect Size
LSI for Knee Functional Variables					
Anterior hop (n = 77)	85.0±15.9	84.4±12.2	84.7±16.1	.960	0.02
Lateral hop (n = 74)	85.4±14.2	87.4±12.8	85.3±14.6	.627	0.15
Medial hop (n = 74)	86.7±15.1	82.5±13.6	87.9±15.2	.249	0.36
Anterior leg reach (n = 76)	97.4±5.5	95.6±7.0	97.5±5.3	.266	0.34
Quadriceps strength (60°/s) (n = 76)	84.0±12.0	81.1±11.5	84.7±12.0	.316	0.30
Quadriceps strength (180°/s) (n = 77)	82.7±11.5	83.0±10.8	82.4±12.1	.871	0.05
Hamstring strength (60°/s) (n = 76)	90.0±16.6	80.9±13.3	91.8±16.4	.034	0.68
Hamstring strength (180°/s) (n = 77)	89.3±13.0	83.7±13.9	90.7±12.8	.082	0.54

Abbreviation: LSI, limb symmetry index (%).

TABLE 3
Logistic Regression Analysis of Factors Associated With Second ACL Injury

			95% Confidence Interval	
Independent Variables	***P* Value**	**Odds Ratio**	**Lower**	**Upper**
Model 1 (Multiple Logistic Regression Analysis)[a]				
Age	.246	0.826	0.599	1.141
Weekly frequency of playing sport	.929	0.969	0.486	1.931
Participation level	.025	6.839	1.268	36.876
LSI of hamstring strength (60°/s)	.019	0.940	0.893	0.990
Model 2 (Multiple Logistic Regression Analysis)[b]				
Age	.212	0.799	0.561	1.137
Weekly frequency of playing sport	.965	1.015	0.515	2.003
Participation level	.035	6.131	1.123	33.465
LSI of hamstring strength (60°/s) < 83.6%	.007	8.723	1.766	43.090
Model 3 (Univariate Logistic Regression Analysis)[c]				
LSI of hamstring strength (60°/s) < 83.6%	.014	5.857	1.432	23.955

Abbreviation: LSI, limb symmetry index.
Age, weekly frequency of playing sport, and participation level are variables controlled as covariates.
[a]*Model χ^2 test, P<.01; Hosmer-Lemeshow test, P = .962; percentage of correct classification, 83.8%.*
[b]*Model χ^2 test, P<.01; Hosmer-Lemeshow test, P = .604; percentage of correct classification, 86.3%.*
[c]*Percentage of correct classification, 83.8%.*

biomechanics.[30,50] Further research including biomechanics is warranted.

In our study, both the second ACL injury group (95.6%) and no-injury group (97.5%) achieved sufficient symmetry in the LSI of the anterior leg reach, which is consistent with previous findings.[10] Dynamic postural stability deficits on the operative side, as measured using a multiaxial device that objectively measures postural balance ability on a dynamic and unstable platform, were associated with second ACL injury.[40] The single-leg hop and anterior leg reach tests are simple and easy to use in clinical practice. However, it may be important to include biomechanics and detailed postural control.

Our findings suggest that it is desirable for the LSI of hamstring strength to exceed 83.6% at 6 postoperative months in order to reduce the probability of a second ACL injury within 2 postoperative years. If a hamstring graft is used, knee flexion training should be delayed for 6 to 8 weeks to allow healing of the harvested area.[7,17] When the BPTB is used as a graft, hamstring exercises can begin earlier than when hamstring grafts are used.[7,43] Hamstring training should be performed with consideration of the healing of the harvested area, strain to the ACL, knee condition (pain, swelling, and range of motion), and postoperative timing.[6,7,17]

Limitations

Knee function at 6 postoperative months could guide postoperative treatment and inform RTS. However, we did not consider knee function after RTS; instead, we only characterized hamstring muscle strength at 6 postoperative months among individuals who had a second ACL injury within 2 years after reconstructive surgery. Therefore, our findings may differ from previous studies that included other time periods.[29,39] Similarly, the follow-up period in this study was 2 postoperative years, and thus, our findings may differ from those of studies with longer follow-up periods.[18,47] Considering ipsilateral and contralateral injuries were included and analyzed, detailed injury mechanisms cannot be examined.

Participants who did not meet the criteria for the knee function test were not allowed to RTS. Accordingly, these participants were not exposed to the risk of second ACL injury, leading to the possibility of selection bias. Although many participants were allowed to participate in sports, we did not measure the timing to unrestricted RTS and achievement of RTS at preinjury competitive levels. Therefore, it is important to consider the possibility of these biases when interpreting our findings.

FIGURE 2
Receiver operating characteristic (ROC) curve for limb symmetry index (LSI) of hamstring strength for predicting second anterior cruciate ligament (ACL) injury.

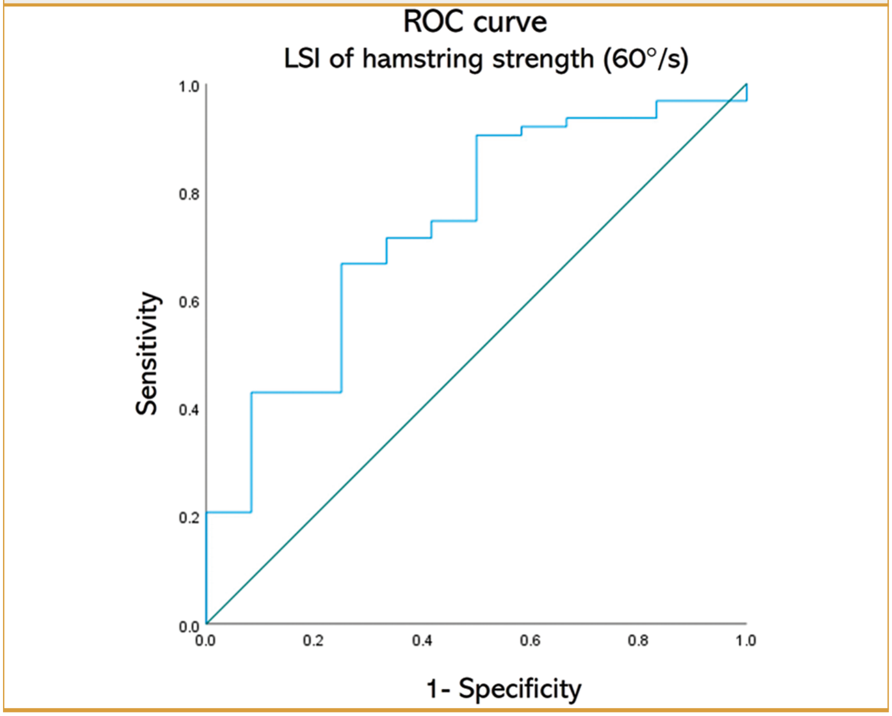
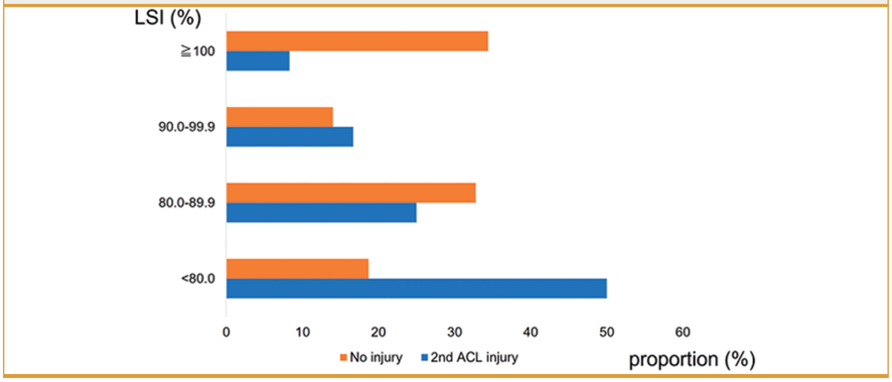


FIGURE 3
Distribution of limb symmetry index (LSI) of hamstring strength according to group. Abbreviation: ACL, anterior cruciate ligament.



Although this study generally met the calculated target sample size, the sample size of the second ACL injury group was slightly smaller because the participants' activity levels were set at a modified Tegner activity scale[38] score ≥7. These factors may have limited our ability to adjust for potential confounding variables. Although the post hoc power analysis showed acceptable power, the sample size was small for logistic regression analysis. Further large-scale studies are warranted. Furthermore, the small sample size of some subgroups (patellar tendon grafts, quadriceps tendons) raises concerns about type II error risk since these measures could not identify risk for future outcomes.

CONCLUSION

There was an association between hamstring strength weakness on the operative side at 6 months after primary ACL reconstruction and second ACL injury within 2 postoperative years. ■

KEY POINTS

FINDINGS: LSI of hamstring strength (60°/s) measured using isokinetic dynamometry at 6 postoperative months was associated with second ACL injury, with a cutoff point of 83.6%. Other knee function variables (quadriceps strength, single-leg hop performance, and dynamic balance) were not significantly related to second ACL injury.

IMPLICATIONS: Individuals with an LSI of hamstring muscle strength ≤83.6% at 6 postoperative months and those with higher participation levels have an increased probability of subsequent second ACL injury.

CAUTION: We cannot rule out the possibility of selection bias. The timing of knee evaluation and follow-up periods in this study were 6 months and 2 years, respectively, which impeded rigorous comparisons with previous studies that examined other time periods.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors made significant contributions to the conception and design, acquisition of data, or analysis and interpretation of data. All the authors made significant contributions to drafting the manuscript or revising it critically for intellectual content. S.O. participated in the conception and design, analysis and interpretation of data, and writing the manuscript. J.A. participated in the design, acquisition and interpretation of data, and revision of the manuscript. K.H. participated in

the acquisition of data, performed the statistical analysis, and helped revise the manuscript. T.O. and S.M. participated in acquisition of data, interpretation of data, and revision of the manuscript. H.K. and K.Y. participated in the conception and design, analysis and interpretation of data, and drafting the manuscript as a researcher in the field of orthopedics. All the authors have read and approved the final version of the manuscript.

DATA SHARING: There are no data available.

PATIENT AND PUBLIC INVOLVEMENT: The patients had no involvement in the design, conduct, interpretation, or translation of the research.

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