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Correlation of Y Balance with Clinical Scores and Functional Tests after Anterior Cruciate Ligament Reconstruction in Young and Middle-Aged Patients

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Background: Criteria for return to sports (RTS) following anterior cruciate ligament (ACL) reconstruction have been extensively studied. But there is no consensus among investigators regarding which factors are most important in determining a safe RTS.

Methods: Sixty-one patients who underwent ACL reconstruction were included. Subjective knee scoring systems (International Knee Documentation Committee [IKDC] score and Lysholm score), functional performance tests (carioca test and single-leg hop for distance [SLHD] test), and isokinetic knee strength test were used for assessment and analyzed for association with the limb symmetry index (LSI) of the Y-balance test for lower quarter (YBT-LQ).

Results: The LSI of the YBT-LQ was significantly correlated with Lysholm score, IKDC score, Carioca, LSI for the SLHD, and extensor strength deficit at 6 months after ACL reconstruction. At 12 months, Lysholm score, IKDC score, LSI for the SLHD, and extensor strength deficit were significantly correlated with the LSI of the YBT-LQ.

Conclusions: The YBT-LQ test could be used conveniently as an additional tool to assess the patient's functional performance results after ACL reconstruction in outpatient clinics.

Keywords: *Anterior cruciate ligament, Return-to-sports, Functional performance, Y-balance test*

Criteria for return to sports (RTS) following anterior cruciate ligament (ACL) reconstruction have been extensively studied. There are various studies that suggest muscle strength, knee stability, and functional performance test as criteria that influence RTS after ACL reconstruction. Quadriceps and hamstring strength contribute to a successful RTS.[1,2] However, it is unknown whether strength is a risk factor for an ACL graft rupture.[3] Hop tests are also a functional assessment of the dynamic stability of the knee.[4,5] Among them, the one-leg hop test is one of the most frequently used functional tests with high test and retest reliability.[6] However, it considers stress on the knee only in the sagittal plane and has low sensitivity. Functional tests, such as carioca, co-contraction, and shuttle run tests put critical stress on the knee, requiring patients to demonstrate dynamic control of the knee.[6] But these functional evaluation methods need time, expense, and

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large space to perform and experts to measure the tests, and patients could feel some pressure to limit their maximum activities due to the possibility of getting re-injuries during these complex and stressful maneuvers. Also, there is no consensus among investigators regarding which factors are important in determining a safe RTS.

The Y-balance test for lower quarter (YBT-LQ) was built on previous research suggesting redundancy in the 8 directions of the Star Excursion Balance Test to develop a more time-efficient test that evaluates dynamic limits of stability and asymmetrical balance in only three directions (anterior [ANT], posteromedial [PM], and posterolateral [PL]).[7,8] The advantages of the YBT-LQ are that it is inexpensive, relatively quick, and simple to execute. Also, it has been shown to have high inter- (0.99–1.00) and intra-rater reliabilities (0.85–0.91).[9] Furthermore, it has been widely used to assess postural stability in adolescents, runners, and patients with an ankle sprain or an ACL injury and known to be predictive of lower extremity injury.[7,10]

To our knowledge, however, few studies have been conducted to correlate YBT-LQ and clinical and functional outcomes after ACL reconstruction. The purpose of this study was to evaluate the usefulness of YBT-LQ as a functional test to determine RTS by comparing it with previously accepted criteria to evaluate RTS. The authors hypothesized that there would be correlations between the YBT-LQ and widely used clinical and functional tests.

METHODS

Patient Selection

This study was approved by the Institutional Review Board of Keimyung University Dongsan Hospital (No. 2020-02-042). Written informed consent was obtained from all patients, and informed consent for publication of the photographs was obtained from the participants.

We retrospectively reviewed the medical records of 166 patients who underwent primary ACL reconstruction by a single experienced surgeon (JGK) between December 2015 and January 2017. To be included in the study, patients had to meet the following criteria: (1) active, young, and middle-aged patients (range, 16–55 years) who had pre-injury Tegner activity scale of 5 or higher; (2) patients who underwent single-bundle ACL reconstruction using hamstring autograft; (3) patients compliant with all required tests and questionnaires; and (4) patients who were available for follow-up for a minimum of 12 months after surgery. Exclusion criteria were presence of major injuries such as fracture and multiple ligament injuries, revision surgery, operation of the opposite limb, and different rehabilitation protocols because of other cartilage or meniscal procedures (Fig. 1).

All ACL reconstructions were performed arthroscopically using an autogenous ipsilateral hamstring tendon by one experienced surgeon (JGK). Quadruple semitendinosus autografts were prepared, and a modified transtibial technique was used. After graft passage, femoral fixation was achieved using the XO Button (ConMed Linvatec, Largo, FL, USA) and the Bio-Cross Pin (RIGIDFIX, DeupyMitek, Raynham, MA, USA). Tibial fixation was performed with a bioabsorbable interference screw (Matryx; ConMed Linvatec), and an additional cortical screw and washer were used for tibial fixation.[11]

Postoperative Rehabilitation

All patients underwent our accelerated postoperative rehabilitation program. Patients were permitted to bear weight with an ACL support brace (DonJoy Legend; DJO Global, Vista, CA, USA) and to start isometric quadriceps exercise and range of motion (ROM) exercise as tolerated immediately after ACL reconstruction. Closed kinetic chain exercises were started at 3 weeks, and open kinetic exercises (OKC) and perturbation training programs were started 6 weeks after surgery. After 12 weeks, progressively weighted OKC exercises without ROM limitation were allowed. At 3 months after surgery, light running and side-cutting activities were allowed, and functional exercises focusing on proprioception and neuromuscular control were initiated. RTS was allowed 6 months after surgery, with the functional progression of sports agility.

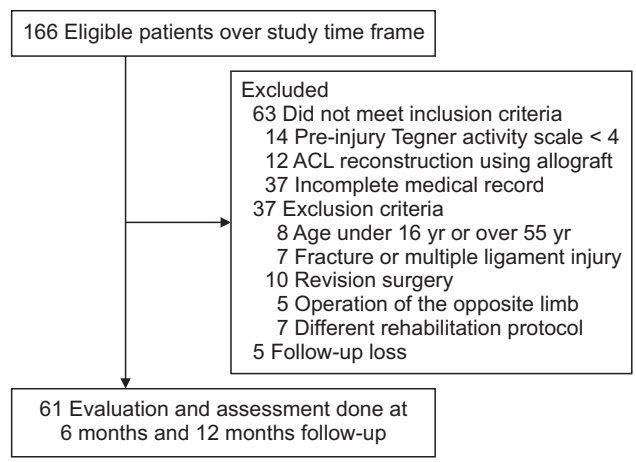

Fig. 1. Patient enrollment flow diagram. ACL: anterior cruciate ligament.

Y Balance Test for Lower Quarter

YBT-LQ was performed utilizing the Y-Balance Test Kit (Functional Movement Systems, Danville, VA, USA) at 6 months and 12 months after ACL reconstruction. Each participant was allowed a maximum of 6 trials to obtain 3 successful attempts for each reach direction. Participants stood on the center footplate, with the right foot's distal aspect at the starting line. While maintaining a single leg stance on the right leg, the patient reached with the free limb in ANT, PM, and PL directions in relation to the stance foot by pushing the indicator box as far as possible (Fig. 2). Participants completed three consecutive trials for each reach direction, and to reduce fatigue, they altered limbs between each direction. Attempts were discarded and repeated if a patient failed to maintain unilateral stance on the platform, failed to maintain reach foot contact with the reach indicator on the target area while the reach indicator is in motion, using the reach indicator for stance support, or failed to return the reaching foot to the starting position under control.[9] The composite scores were calculated by adding the reach distances of ANT, PM, and PL, dividing by three times the participant's leg length, and then multiplying by 100 to obtain a percentage. Leg length was measured from the anterior superior iliac spine to the most distal portion of the medial malleolus.[12] Limb symmetry index (LSI, %) was calculated by dividing involved limb data by uninvolved limb data, and the result was multiplied by 100.[13]

Clinical Evaluations

Assessments were conducted preoperatively and at 6 months and 12 months after ACL reconstruction by an independent research coordinator (SIC). The evaluation of subjective knee outcomes was conducted by an independent research investigator (SIC). Lysholm score and International Knee Documentation Committee (IKDC) score were assessed. Lysholm score consists of 8 items, including limping, locking, pain, stair climbing, use of supports, instability, swelling, and squatting. IKDC score system consists of 18 items addressing symptoms, sports activities, and functional performance and comprehensively covering an individual's health status.

Functional Tests

These tests were performed at 6 months and 12 months after ACL reconstruction by an independent study coordinator (SIC). After 5-minute warming-up, followed by 2-minute stretching, the patients were asked to perform three practice trials for each type of the functional tests, with adequate rest periods of at least 5 minutes between trials to minimize fatigue effects. These are to allow the patients to familiarize themselves with these tests and to minimize learning effects. The best trial score was utilized for data analysis, thus providing the best possible indication of maximal performance. We evaluated the carioca test first and then single-leg hop for distance (SLHD) test. All tests were performed in an indoor gym in the building.

Carioca test

This test was used to reproduce the pivot shift phenomenon in the ACL insufficient knee. The test was performed by requiring the patient to run laterally two lengths of a 12 m distance with a crossover step. The patient ran the course from left to right and then in a reverse direction, thus moving a total of 24 m in the minimum amount of time possible. The test was performed three times, and the fastest speed was recorded.[6,14]

SLHD test

The subjects were asked to hop forward as far as possible, jumping and landing with the same foot. It was performed single time, and the longest distance for the involved and uninvolved limb was measured in centimeters using a ruler on the ground. The test was performed single time, and the LSI was calculated.[5]

Strength Measures

The isokinetic knee muscle strength was measured at 6

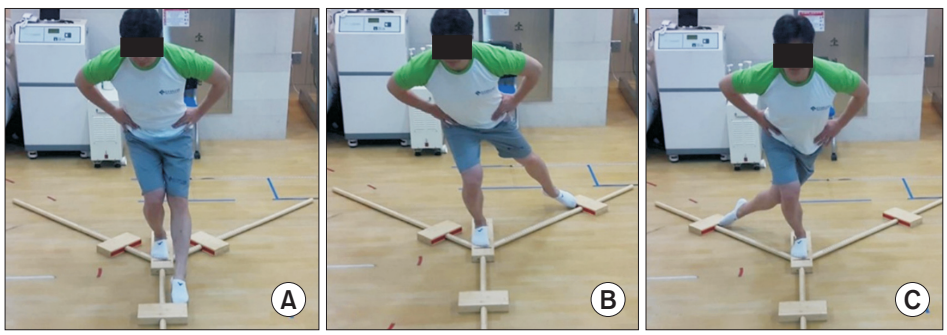

Fig. 2. Y balance test directions. (A) Anterior. (B) Posteromedial. (C) Posterolateral.

months and 12 months after ACL reconstruction using a Biodex System III dynamometer (Biodex Medical Systems, Shirley, NY, USA). It was performed at 60°/sec four times for each patient. First, the contralateral side was measured, and then the side treated with ACL reconstruction was examined. The peak torque (the maximum value during the 4 repetitions) of flexor and extensor muscles of the knee was measured, and the values of both knees were compared. The deficit in the isokinetic test was calculated as follows: (involved knee strength/uninvolved knee strength) × 100.[15]

Statistical Analysis

The SPSS ver. 25.0 (IBM Corp., Armonk, NY, USA) was used for statistical analyses. To assess the validity of the YBT test, the correlations between LSI for the composite score of the YBT-LQ and other subjective/objective evaluation methods were analyzed using the Pearson's or Spearman's correlation coefficient and simple regression analysis. The correlation was interpreted as follows: $|r| = 0.7 - 1.0$ as strong; $|r| = 0.7 - 0.3$ as moderate; and $|r| = 0.01 - 0.3$ as weak.[16] The level of significance was set as $p < 0.05$ for all statistical analyses.

RESULTS

A total of 61 patients (male : female = 46 : 15) met the inclusion criteria, and all of them completed testing at 6 months and 12 months after ACL reconstruction. Means and standard deviations are shown in Tables 1 and 2.

In Pearson's correlation and simple linear regression model, LSI for the composite of YBT-LQ was moderately correlated with Lysholm score, IKDC score, carioca, and extensor strength at 6 months after ACL reconstruction. And LSI for the SLHD deficit was weakly correlated with LSI for the composite of YBT-LQ at 6 months. IKDC score and LSI for the SLHD were moderately correlated at 12 months. Lysholm and extensor strength deficit were weakly correlated at 12 months (Tables 3 and 4).

In a subgroup analysis of each direction, Lysholm score, IKDC score, carioca, extensor, and flexor strength deficit were significantly correlated with performance in the ANT reach at 6 months after ACL reconstruction. IKDC score, carioca, and extensor strength deficit were significantly correlated with the PM reach at 6 months. Lysholm score, IKDC score, carioca, and extensor strength deficit were significantly correlated with the PL reach at 6 months. At 12 months after reconstruction, Lysholm score, IKDC score, LSI for the SLHD, and extensor strength deficit were significantly correlated with performance in the ANT reach. IKDC score and extensor strength deficit were correlated with the PL reach (Table 5).

Table 1. Demographics Data

Variable	Mean ± SD	95% CI
Age (yr)	26.9 ± 9.8	24.3–29.3
Height (cm)	171.9 ± 8.5	169.8–174.0
Weight (kg)	72.6 ± 13.4	69.3–76.0
Body mass index (kg/m^2)	24.4 ± 3.3	24.0–25.1
Limb Length (cm)	90.8 ± 7.3	89.0–92.6
Tegner activity scale	6.9 ± 1.9	6.4–7.4
Lysholm score	74.1 ± 14.0	70.6–65.6
IKDC score	68.6 ± 12.5	65.6–71.7

SD: standard deviation, CI: confidence interval, IKDC: International Knee Documentation Committee.

DISCUSSION

Our study was designed to evaluate whether the YBT-LQ was correlated with the widely used clinical and functional tests as an assessment for determining RTS.[14,17] We confirmed that there were considerable associations between the LSI for the composite score of YBT-LQ and the subjective clinical scores, functional tests, and isokinetic muscle strength. In subanalysis for each direction, the ANT reach was most correlated with variables than PM and PL reach.

The YBT-LQ is a functional test that requires strength, flexibility, neuromuscular control, stability, range of movement, balance, and proprioception. Especially, the YBT-LQ seems to be directly related to the strength of the lower extremity.[18,19] To perform the YBT-LQ, patients lean forward and backward to maintain their balance, and the knee flexors must eccentrically contact to resist trunk movement. Consequently, the knee flexors may contribute to a greater YBT distance when body sway is converted from forward to backward motion.[19] In addition, because the performance in the PM direction requires lateral stabilization of the pelvis, hip abduction strength should be related to the PM distance.[20] Although the hip and ankle strength was not evaluated in the present study, ANT, PM, and PL reaches were all significantly correlated with the deficit of knee extensor strength.

This study included only hamstring autograft, which might affect the isometric knee flexion power. Although several studies have reported the strength deficit after

Table 2. Postoperative Assessments

Type	Mean ± SD	95% CI
6 Months		
LSI for YBT composite score (%)	95.9 ± 5.7	94.6–97.2
Lysholm score	86.1 ± 9.5	83.9–88.3
IKDC score	79.8 ± 12.7	76.9–12.7
Carioca (sec)	9.4 ± 1.9	8.7–10.0
SLHD (cm)	118.4 ± 36.2	108.8–128.1
Extensor strength deficit at 60°/sec (%)	23.9 ± 19.5	19.3–28.4
Flexor strength deficit at 60°/sec (%)	15.2 ± 15.1	11.7–18.7
12 Months		
LSI for YBT composite score (%)	97.8 ± 5.3	96.6–99.0
Lysholm score	89.3 ± 10.3	86.9–91.7
IKDC score	87.7 ± 11.7	85.0–90.4
Carioca (sec)	9.0 ± 1.5	8.4–9.7
SLHD (cm)	122.4 ± 34.2	114.0–130.7
Extensor strength deficit at 60°/sec (%)	15.7 ± 17.3	11.6–19.8
Flexor strength deficit at 60°/sec (%)	11.6 ± 15.2	8.0–15.1

SD: standard deviation, CI: confidence interval, LSI: limb symmetry index, YBT: Y balance test, IKDC: International Knee Documentation Committee, SLHD: single-leg hop for distance.

Table 3. Correlation between the LSI for a Composite Score of Y Balance Test and Clinical, Functional, and Strength Tests at 6 Months and 12 Months Follow-up

Variable	6 Months		12 Months	
	Pearson's	*p*-value	Pearson's	*p*-value
Age	–0.213	0.075	–0.126	0.299
Lysholm score	0.386	0.001*	0.237	0.049*
IKDC score	0.393	0.001*	0.326	0.006*
Carioca	–0.509	0.002*	–0.132	0.547
LSI for the SLHD	0.287	0.035*	0.555	0.000*
Extensor strength deficit	–0.617	0.000*	–0.287	0.016*
Flexor strength deficit	–0.225	0.062	–0.008	0.947

LSI: limb symmetry index, IKDC: International Knee Documentation Committee, SLHD: single-leg hop for distance.
*Achieved statistical significance at $p < 0.05$.

hamstring harvest, the functional outcomes of hamstring harvesting after ACL reconstruction are controversial.[21,22] Kim et al.[23] found that the increase in knee flexor deficit in the hamstring harvested patients was significant when compared with that in the allograft patients. However, functional and clinical results were similar between both groups. The reasons for these results are not clearly elucidated. But, one reason is the knee flexion angle. According

Table 4. Simple Linear Regression Analysis Showing Variables Affecting the LSI for a Composite Score of Y Balance Test

Variable	*p*-value	Beta	R^2
6 Months			
Lysholm	0.001*	0.229	0.149
IKDC	0.001*	0.175	0.154
Carioca	0.002*	–1.410	0.235
LSI for the SLHD	0.035*	0.093	0.082
Extensor strength deficit	0.000*	–0.178	0.380
Flexor strength deficit	0.062	–0.084	0.050
12 Months			
Lysholm	0.049*	0.123	0.056
IKDC	0.006*	0.149	0.106
Carioca	0.547	–0.313	0.018
LSI for the SLHD	0.000*	0.200	0.308
Extensor strength deficit	0.000*	–0.088	0.082
Flexor strength deficit	0.947	–0.003	0.001

LSI: limb symmetry index, IKDC: International Knee Documentation Committee, SLHD: single-leg hop for distance.
*Achieved statistical significance at $p < 0.05$.

Table 5. Simple Linear Regression Analysis Showing Variables Affecting Reach Directions of Y Balance Test

Variable	Anterior		Posteromedial		Posterolateral	
	Beta	R^2	Beta	R^2	Beta	R^2
6 Months						
Lysholm	0.157	0.062*	0.219	0.051	0.352	0.114*
IKDC	0.191	0.163*	0.276	0.142*	0.309	0.155*
Carioca	–1.390	0.221*	–2.216	0.188*	–2.957	0.318*
LSI for the SLHD	0.058	0.055	0.026	0.004	0.046	0.011
Extensor strength deficit	–0.159	0.263*	–0.166	0.125*	–0.233	0.206*
Flexor strength deficit	–0.133	0.112*	–0.118	0.038	–0.143	0.047
12 Months						
Lysholm	0.189	0.088*	0.042	0.001	0.180	0.035
IKDC	0.181	0.104*	0.130	0.018	0.205	0.058*
Carioca	–0.120	0.001	0.091	0.000	–0.736	0.019
LSI for the SLHD	0.165	0.139*	0.192	0.059	0.130	0.038
Extensor strength deficit	–0.113	0.089*	–0.101	0.024	–0.148	0.067*
Flexor strength deficit	–0.047	0.012	–0.058	0.006	–0.096	0.022

IKDC: International Knee Documentation Committee, LSI: limb symmetry index, SLHD: single-leg hop for distance.
*Achieved statistical significance at $p < 0.05$.

to the study related to the flexion angle, the flexor deficit of the hamstring harvested knee occurred at deep knee flexion angles.[24] Another reason may be that the hamstring tendons regenerated in a high proportion of hamstring harvested patients.[25]

Although YBT-LQ could evaluate the overall function of the lower leg, few studies have been conducted to correlate it with an ACL injury or reconstruction. Garrison et al.[26] evaluated the relationship between the symmetry of the anterior reach of the YBT-LQ at 12 weeks and functional performance measures at the time of RTS after ACL reconstruction. They found that participants who demonstrated > 4 cm ANT reach deficits at 12 weeks after ACL reconstruction did not tend to achieve 90% of functional tests, such as single-hop distance and triple hop distance. Hallagin et al.[27] examined relationships between YBT and isokinetic quadriceps strength preoperatively and at 12 weeks after ACL reconstruction. They reported that despite a significant reduction in quadriceps strength, individuals were able to improve their YBT-LQ scores bilaterally. They explained that core and hip strength and lower extremity ROM played an important role in YBT-LQ. Based on the relationships reported in the study, ANT reach asymmetry and extension deficit in ACL reconstructed knees were related, and individual reach distances and peak knee extension and flexion torques demonstrated strong relationships in the involved knee versus uninvolved knee.[28] However, clinical and functional outcomes were not analyzed in their study. Although the present study did not investigate the re-rupture rate, LSI for YBT showed a reliable correlation with functional tests.

The asymmetry of YBT-LQ has been studied widely, including injury prediction. A prospective study revealed that lower limb injury could be predicted with differences of 4 cm from normal values in the ANT, PM, and PL directions in women and 4 cm in men's ANT direction.[7] Gonell et al.[29] also found that soccer players with a difference of equal or greater than 4 cm between lower limbs in PM direction were 3.86 more likely to sustain a lower extremity injury. However, several studies reported that the YBT-LQ had shown to be unable to predict lower extremity injury.[30,31]

This study has some limitations. First, this is a retrospective study; hence, there may have been a selection bias. Second, we did not measure the ROM of the lower extremities, and shorter YBT-LQ distances could have been the result of a decreased ROM of the lower extremity. Third, only hamstring graft reconstructions were included. Finally, the sample size was not determined prior to the retrospective review. Rather, all eligible patients within the defined timeframe, in which this testing was a standard practice, were targeted. However, it is of note that this is the first study, to the best of our knowledge, to analyze whether YBT-LQ was associated with various outcomes in patients with ACL reconstruction. In the future, a well-designed study is needed with the aim of determining whether the YBT-LQ can be used as a test that provides information regarding RTS decisions.

There were considerable correlations between YBT-LQ and IKDC score, SLHD test, carioca, and isokinetic muscle strength tests that have been recently used to determine RTS. The YBT-LQ test could be used conveniently to assess patient's functional performance results after ACL reconstruction in outpatient clinics.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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