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Changes in Y-Balance Test Scores During Months 4, 5, and 6 of Anterior Cruciate Ligament Reconstruction Rehabilitation

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Context: The anterior cruciate ligament (ACL) is well researched since injuries typically result in lengthy recoveries and rehabilitation periods until athletes can return to full activity. Although a large body of literature on the early and late stages of rehabilitation after ACL reconstructive (ACLR) surgery exists, less is known regarding the mid-phase of ACL rehabilitation and healthy versus injured limb differences in functional testing during this stage.

Objective: The purpose of this study is to determine if Y-Balance Test (YBT) scores obtained during the mid-phase of ACLR rehabilitation change over months 4, 5, and 6.

Design: Case series.

Setting: Research laboratory.

Patients or Other Participants: A total of 27 participants (17 females; 18.96 ± 3.02 years [range, 15–24]; 173.63 ± 10.29 cm; 72.55 ± 17.83 kg) who sustained a unilateral ACL injury, experienced no episodes of instability or knee giving away, had not suffered a previous ACL injury, and expressed a desire to return to sport at the end of rehabilitation came in once a month after ACLR to participate in a battery of tests.

Main Outcome Measure(s): Y-Balance Test scores in the anterior, posterolateral (PL), and posteromedial (PM) directions in the healthy and reconstructed limbs.

Results: A main effect for limb was observed for the anterior (healthy: month 4: 78.8 ± 5.8 cm, month 5: 79.5 ± 5.2 cm, and month 6: 79.4 ± 5.8 cm; reconstructed: month 4: 77.2 ± 5.9 cm, month 5: 78.5 ± 5.1 cm, and month 6: 78.1 ± 6.4 cm; $P = .023$) and PM (healthy: month 4: 80.0 ± 8.7 cm, month 5: 81.0 ± 9.1 cm, and month 6: 82.9 ± 8.9 cm; reconstructed: month 4: 79.3 ± 6.8 cm, month 5: 79.4 ± 8.2 cm, and month 6: 81.1 ± 8.5 cm; $P = .013$) directions, indicating that the reconstructed limb performed worse than the healthy limb. A main effect for time was observed for the PL direction (healthy: month 4: 74.5 ± 8.1 cm, month 5: 75.8 ± 7.4 cm, and month 6: 77.6 ± 8.2 cm; reconstructed: month 4: 74.1 ± 8.6 cm, month 5: 74.6 ± 7.7 cm, and month 6: 76.8 ± 9.8 cm; $P = .023$).

Conclusions: The YBT measured improvement in the PL direction across time in the reconstructed limb. In the PM and anterior directions, the YBT did not measure these same improvements across this period.

Key Words: rehabilitation, clinical outcomes, dynamic balance

Key Points

- The Y-Balance Test effectively measured a significant improvement in the reach distance of the reconstructed limb in the posterolateral direction across months 4, 5, and 6 of anterior cruciate ligament reconstruction rehabilitation.
- Y-Balance Test score changes across months 4, 5, and 6 of anterior cruciate ligament reconstruction rehabilitation are associated with small effect sizes and may not be useful clinically.

Anterior cruciate ligament (ACL) tears are a common and devastating injury that continue to affect athletes of all ages. It is estimated that over 250 000 ACL tears occur annually, with a large proportion affecting athletes between the ages of 15 and 25.[1] Although ACL reconstruction (ACLR) surgery is not required after an ACL tear, it is common for competitive and recreational athletes to choose surgical over conservative treatments to ensure improved joint stability with sport movements.[2] Even with surgical reconstruction, however, the likelihood of retear significantly increases after an initial ACL injury. Athletes that sustain an ACL injury have a 20% chance of reinjuring the same limb and are more likely to sustain an ACL injury on their contralateral limb.[2,3] This risk of reinjury can be mitigated through appropriate rehabilitation techniques and a timeline that avoids returning the athlete to sport before they are physically and psychologically ready to participate.[4] Typical rehabilitation programs after ACLR surgery are aimed at reducing swelling, regaining range of motion and strength, and redeveloping limb proprioception.[1,5] Although specific rehabilitation programs vary depending on the age, sex, skill level, strength, and postrehabilitation goals of the patient, it is recommended that patients do not return to activity before 9 months after surgery and functional stability has been achieved and proven through testing.[6]

A plethora of tools measuring different aspects of neuromuscular control exist to help clinicians determine the physical readiness of a patient to return to physical activity. A tool regularly used in ACLR testing and rehabilitation is the Y-Balance Test (YBT), originally developed as the Star Excursion Balance Test.[7] The YBT is a unilateral test in which the patient must balance on 1 leg and reach in the anterior, posterolateral (PL), and posteromedial (PM) directions as far as he or she can with the contralateral leg. Both healthy and reconstructed limbs are tested to identify asymmetries that may exist between the limbs. In much of the literature, use of the YBT regarding lower extremity rehabilitation and progress measurement in many different settings has been supported.[8–11] For example, the YBT has been shown to be correlated with lower extremity muscle strength as well as functional performance in sport-related activities.[12,13] In addition, the YBT has been shown to be effective in determining limb strength and range of motion asymmetries between healthy and reconstructed limbs, giving clinicians valuable information regarding the severity of deficiencies that exist in the reconstructed limb compared with the healthy limb.[14] Limb asymmetries, as reported by the YBT, have also been shown to be predictors of injury risk in some athlete populations.[15] Further, the YBT has been shown to be positively correlated with other helpful clinical patient-reported outcome tools for assessing patient knee perception and function.[16] Overall, the YBT is an easy, affordable, and quick measurement tool with high interrater (anterior median intraclass correlation coefficient [ICC]: 0.88, PM median ICC: 0.87, and PL median ICC: 0.88) and intrarater (anterior median ICC: 0.88, PM median ICC: 0.88, and PL median ICC: 0.90) reliability, allowing clinicians in most settings to access YBT data for their patients.[7–11]

The YBT is commonly used post-ACLR to measure a patient's strength, proprioception, and range of motion.[17,18] In the current literature, changes in YBT scores have been observed during early stages of rehabilitation to scores much later in the rehabilitation process, such as when the patient is getting ready to return to sport. However, measuring YBT scores during the mid-phase of rehabilitation may be useful to clinicians and researchers because patients are working on reducing strength deficits between limbs and increasing proprioception through single-legged tasks during this stage, both of which are skills tested using the YBT.[19] However, performance changes in the YBT over the mid-phase of rehabilitation after ACLR have not been studied. Therefore, the purpose of this study was to determine if YBT scores change during the mid-phase of ACLR rehabilitation, specifically across months 4, 5, and 6 after surgery. We accomplished this by examining the raw values in addition to between-limbs differences. We hypothesized that YBT scores of the reconstructed limb would gradually increase across all directions, while the scores for the healthy limb would remain constant. Therefore, we hypothesized that between-limbs asymmetries would gradually decrease across months 4, 5, and 6.

METHODS

This study was approved by the Institutional Review Board at the University of Wisconsin–Madison. All participants provided written consent to participate in this study, and parental consent was received for all participants under the age of 18 before data collection.

This was a single cohort study that included 27 participants recruited from the local community. We based our sample size off previous research by Boey and Lee (2020) to identify a clinically significant 10% change in YBT score in the anterior direction from month 4 to month 6.[20] We used G*Power (Version 3.1.9.7) to calculate our sample size using the reported mean of 62.6% of leg length and standard deviation of 5.1 ($P = .05$, $B = 0.80$, $r = 0.5$). A minimum sample size of 8 participants was needed to achieve appropriate power. We would also be appropriately powered to see a difference in a 5% change between participants (which would require a minimum of 23 participants).[20] Further demographic information can be seen in Table 1, including mean Knee Injury and Osteoarthritis Outcome Score (KOOS) scores, which were determined in each of the 5 categories (symptom, pain, activities of daily living [ADLs], sport, and quality of life [QoL]) to better understand the perceived limitations of our participants.[21] Participants were recruited from local hospitals and physical therapy clinics. To be included in the study, participants had to have sustained a unilateral ACL tear and subsequently had reconstruction surgery. Participants were included only if this was their first ACL injury. Anterior cruciate ligament reconstruction surgery was performed using either a bone-patellar tendon-bone, hamstring semitendinosus-gracilis, quadriceps tendon autograft, or a cadaveric allograft. Further information on the graft-type distribution of participants can be seen in Table 1. Participants had to be between 15 to

Table 1. Participant Demographics. Data Presented as Mean ± Standard Deviation or Frequency

	Participants
Sex	17 female, 11 male
Age (y)	18.96 ± 3.02
Height (cm)	173.63 ± 10.29
Weight (kg)	72.55 ± 17.83
Injured limb	16 dominant, 12 nondominant
Dominant limb	3 left, 24 right
Graft Type	
BTPB	14
Hamstring tendon	13
Allograft	1
Quadriceps tendon	1
KOOS Scores (%)	
Month 4	
Symptom	82.54 ± 11.05
Pain	90.17 ± 7.79
ADL	96.30 ± 4.44
Sport	67.96 ± 23.42
QoL	53.24 ± 21.27
Month 5	
Symptom	84.31 ± 12.91
Pain	88.94 ± 7.79
ADL	97.06 ± 3.88
Sport	79.11 ± 17.16
QoL	58.04 ± 20.47
Month 6	
Symptom	86.61 ± 11.97
Pain	92.16 ± 7.82
ADL	96.48 ± 6.46
Sport	81.43 ± 19.10
QoL	63.17 ± 21.27

Abbreviations: ADL, activities of daily living; BTPB, bone-patellar tendon-bone; KOOS, Knee Injury and Osteoarthritis Outcome Score; QoL, quality of life.

Table 2. Repeated Measures ANOVA Comparing Healthy and Reconstructed Limbs in Different Y-BT Reach Directions (cm) Across Months 4, 5, and 6 of ACLR Rehabilitation. Values are Mean ± Standard Deviation Reported in cm

					Interaction		Main Effect, Time[a]		Main Effect, Limb[b]	
Direction	Limb	Month 4	Month 5	Month 6	P	F (2, 25)	P	F (2, 25)	P	F (1, 26)
Anterior	Healthy	78.8 ± 5.8	79.5 ± 5.2	79.4 ± 5.8	.29	1.29	.27	1.37	.02[d]	7.04
	Reconstructed	77.2 ± 5.9	78.5 ± 5.1	78.1 ± 6.4						
PL	Healthy	74.5 ± 8.1	75.8 ± 7.4	77.6 ± 8.2	.88	0.13	.03[c,d]	4.19	.20	1.76
	Reconstructed	74.1 ± 8.6	74.6 ± 7.7	76.8 ± 9.8						
PM	Healthy	80.0 ± 8.7	81.0 ± 9.1	82.9 ± 8.9	.77	0.26	.11	2.42	.01[c]	5.87
	Reconstructed	79.3 ± 6.8	79.4 ± 8.2	81.1 ± 8.5						

Abbreviations: ACLR, anterior cruciate ligament reconstruction; ANOVA, analysis of variance; PL, posterolateral; PM, posteromedial.
[a] Main effect, time, PL direction: month 4 = 74.28 ± 7.91, month 5 = 75.34 ± 7.91, and month 6 = 76.85 ± 8.62, d (between months 4 and 6) = 0.31.
[b] Main effect, limb, anterior direction: healthy = 79.63 ± 5.31, reconstructed = 78.22 ± 5.64, d = 0.26. Main effect, limb, PM direction: healthy = 81.46 ± 8.70, reconstructed = 79.72 ± 7.70, d = 0.21.
[c] $P < .05$.
[d] Post hoc month 4 + month 5 < month 6.

26 years of age, intend to return to sport participation after their rehabilitation process, and be at least 80% compliant with their home exercise programs. Participants for whom this was not their first ACL tear or were not planning on returning to sport after rehabilitation were excluded from this study. Compliance was self-reported by the participants and was assessed by asking how many days per week they completed their prescribed rehabilitation exercises.

Each participant came into the research laboratory for testing, including YBT data collection, once per month across months 4, 5, and 6 of the patient's postoperative rehabilitation process. Demographic data (height, weight, and age) were obtained at the start of each session. Additionally, participants were asked to complete a series of questionnaires aimed at gathering data on perceived knee function. For YBT data collection, each participant was allowed up to 4 practice trials before their recorded trials. When the participant was ready, he or she would balance on a self-selected limb first (either healthy or reconstructed) and instructed to reach as far as possible in the anterior, PL, and PM directions. Participants reached 3 times in each direction, and the mean reach distance was calculated and used for analysis. Once the participant successfully completed 3 reaches in each direction with his or her self-selected limb, he or she switched limbs and would reach with the limb that had initially been the balancing limb. The same process was completed for the other side, with average reach distances calculated for the 3 directions.

A 2 × 3 repeated-measures analysis of variance (ANOVA) was used to compare each limb's (healthy versus reconstructed) mean reach in centimeters during participants' 3 trials across the months (4, 5, and 6). Because all analyses were done using only within-subjects values, we did not normalize reach distances to participant leg length. No comparisons were done between subjects, making normalization not necessary. Post hoc testing (Fischer least significant difference) was used when necessary. Effect sizes were determined using Cohen d. Similarly, a repeated-measures ANOVA was used to compare between-limb asymmetries. Limb asymmetry was calculated by subtracting the healthy limb reach score from the reconstructed limb reach score. An a priori P value of <.05 was used to determine statistical significance.

RESULTS

Thirty-seven total participants enrolled in the study; however, 10 participants had incomplete data for our period of interest and were removed from the analysis. Therefore, a total of 27 participants completed the protocol and had complete datasets for the YBT at months 4, 5, and 6 of their ACLR rehabilitation process. Participant demographics can be found in Table 1.

A main effect for limb in the anterior ($P = .013$; healthy: 79.6 ± 5.3 cm, reconstructed: 78.2 ± 5.6 cm; $d = 0.26$) and PM ($P = .023$; healthy: 81.4 ± 8.7 cm, reconstructed: 79.7 ± 7.7 cm; $d = 0.21$) reach directions was observed. Patients reached further standing on their healthy limbs than their reconstructed limbs (Table 2). A main effect for time was observed in the PL direction. Post hoc testing revealed significant improvement (P value = .027; month 4: 74.3 ± 7.9 cm, month 5: 75.3 ± 7.9 cm, and month 6: 76.9 ± 8.6 cm; $d = 0.31$) in both the healthy and reconstructed limbs at month 6 compared with both months 4 and 5 (Figure; Table 2). Effect sizes were calculated using Cohen d, for which 0.2 is considered *small*; 0.5, *moderate*; and 0.8, *large*. Therefore, all effect sizes found are considered small. Similarly, no statistically significant ($P < .05$) changes were seen in limb asymmetry scores in any direction across months 4, 5, and 6 (anterior P value = .179; PL P value = .936; PM P value = .542).

DISCUSSION

The primary purpose of this study was to determine changes in YBT scores between the healthy and reconstructed limbs after ACLR surgery during the mid-phase of return-to-sport rehabilitation. This mid-phase of the ACLR rehabilitation process is chronically overlooked within ACL literature, with most data focusing on the time points either immediately postoperative or at return to sport. The most important finding of this study was the improved performance in the PL direction over time. The second most important finding was that healthy limbs performed better than reconstructed limbs in the anterior and PM directions. While these findings were statistically significant, the associated effect sizes lead us to question the clinical relevance. We will dive deeper into this later in our discussion.

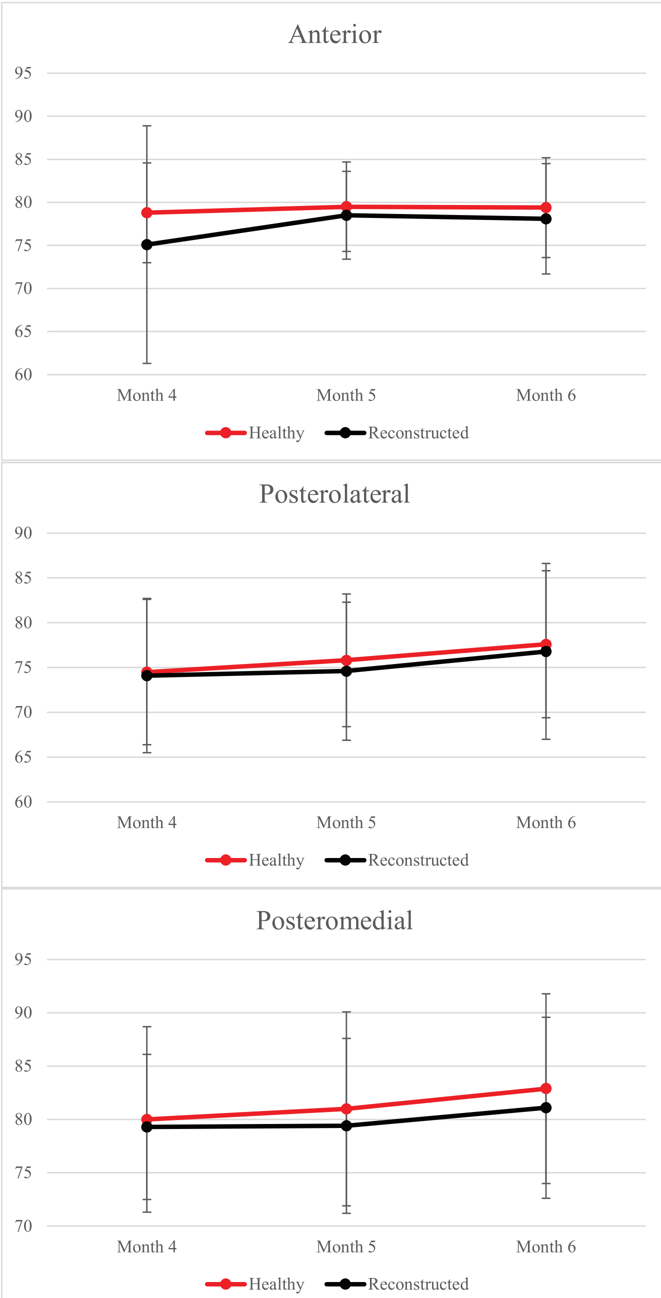

Figure. Change in mean reach scores in the Y-Balance Test (YBT) across months 4, 5, and 6 of anterior cruciate ligament reconstruction (ACLR) rehabilitation.

We hypothesized that patients would gradually improve their YBT scores over time in the reconstructed limb, thereby reducing between-limb asymmetries. This hypothesis was partially supported. In the PL direction, we observed increases in YBT scores by 2.6 cm between months 4 to 6 in the reconstructed limb. Although statistically significant, this finding was associated with a small effect size ($d = 0.31$), which brings into question its clinical relevance. Previous researchers have demonstrated that the minimal detectable change in YBT in the PL direction is 7.55%. Our observed change was only 3.3%, meaning that our observed change, although statistically significant, does not meet the threshold for a clinically relevant change.[8] Similarly, our hypotheses were partially supported in the anterior and PM directions, for which healthy limbs performed better than reconstructed limbs. It is important to note that these findings were also associated with small effect sizes ($d = 0.26$ in the anterior direction and $d = 0.21$ in the PM direction), and the differences between limbs were only 1.2% in the anterior direction and 2.2% in the PM direction. The minimal detectable changes in the anterior and PM directions are 5.87% and 7.84%, respectively, meaning that neither of the limbs changed to that degree over time.[8] Our findings are aligned with previous researchers that did not observe any clinically significant changes in the YBT reach distance in any direction across various time points during the ACLR rehabilitation process.[22,23]

Although authors of some previous studies have found the YBT effective in determining limb asymmetries, we did not reach this same conclusion, as we did not find any significant changes in limb asymmetry across time in any direction in our participants by using the YBT as a measure alone.[14] Several theories may explain this discrepancy. The first is that the YBT may not be a sensitive enough tool to determine if patients are improving across this short of a timeline. While quadriceps strength and activation are affected after ACL reconstruction, it is possible that participants were using alternate movement strategies to achieve results as opposed to relying on quadriceps strength.[4] For example, patients could have compensated with hip and posterior chain strategies. Previous researchers have demonstrated that hip strength is correlated with YBT performance.[24] The second theory is that our participants' balance and reach mechanics may not have been improving enough across this time after such a major surgery.

Regardless of these results, the YBT still has clinical utility in patients after ACLR.[8–16] The YBT is accessible in that it can be performed in almost all clinics without expensive tools or software. Additionally, it is important to note that some participants in our study had sizable asymmetries, with several participants' YBT scores measuring 10+ cm differences between healthy and reconstructed limbs (Table 3 range values). Notably, Plisky et al observed that a patient with a YBT limb asymmetry of >4 cm in the anterior direction was associated with a 2.5 times greater risk of lower extremity injury, highlighting the clinical importance of these large asymmetries.[25] Our data show that the YBT remains an important clinical tool to assess patients for large asymmetries to understand how to modify rehabilitation programs to target these deficits.

This study is not without limitations. Patients were tested monthly, but activities outside of the laboratory were not monitored. Patients were not required to follow a set rehabilitation plan; rather, they followed the guidance of the clinician in charge of their rehabilitation. This likely results in a large spectrum of treatments (ie, different exercises, dosage, and frequency) that participants were involved in outside of the study. Several confounding variables were not controlled for in this study, including age, sex, and graft type, that may have effects on how patients perform in the YBT in this mid-phase of rehabilitation. When performing the YBT, participants were allowed to self-select which limb they balanced on first, which may have unknown effects on their performance in the test. Additionally, other considerations were not factored into this analysis that could provide valuable information including muscle activation patterns and kinematic profiles. Finally, no measures

Table 3. Repeated Measures ANOVA Comparing Limb Asymmetries (cm) Between Healthy and Reconstructed Limbs in Different Y-BT Reach Directions Across Months 4, 5, and 6 of ACLR Rehabilitation[a]

	Month 4	Month 5	Month 6	*P* Value	*F* (2, 26)
Anterior	−1.82 ± 3.83 Min: −12.50 Max: 4.17	−0.60 ± 3.14 Min: −5.00 Max: 6.83	−1.48 ± 3.30 Min: −7.17 Max: 6.17	.179	1.84
PL	−0.53 ± 4.78 Min: −7.50 Max: 9.83	−0.93 ± 4.71 Min: −14.33 Max: 8.50	−0.76 ± 4.61 Min: −12.50 Max: 5.33	.936	0.07
PM	−1.18 ± 4.11 Min: −8.33 Max: 8.00	−1.57 ± 6.63 Min: −14.00 Max: 10.33	−2.11 ± 4.02 Min: −9.33 Max: 4.83	.542	0.63

Abbreviations: ACLR, anterior cruciate ligament reconstruction; ANOVA, analysis of variance; Max, maximum; Min, minimum; PL, posterolateral; PM, posteromedial.

[a] All mean and SD values are reported in cm. Asymmetry values calculated by subtracting the healthy limb reach score from the injured limb reach score. A negative value indicates the healthy limb reached further, and a positive value indicates the injured limb reached further.

of participant mental status were taken during this study, such as psychological readiness or goals after completion of the rehabilitation process, aside from ensuring that participants intended to return to sport, which could have provided valuable insights into the psychological processes of the participants during this period. Future directions for this line of research could include intervention studies in which authors determine rehabilitation methods to best improve strength and balance as well as how muscle activation patterns change across not only months 4, 5, and 6 of ACLR rehabilitation when performing the YBT but also comparing this middle phase of the rehabilitation process to later stages as well as beyond the return-to-play timepoint.

Patients progressing through rehabilitation do not improve in the YBT during months 4–6 after ACLR. We observed statistically significant findings that were associated with small effect sizes, which leads us to question the clinical significance of these findings. While, on average, the YBT might not change significantly during this phase of rehabilitation, the YBT may still have clinical utility. We were able to identify patients with significant asymmetries which could be valuable to clinicians to modify rehabilitation programming. Further research is needed to determine if the type or frequency of a rehabilitation program affects YBT scores during the mid-phase of ACLR rehabilitation or if muscle activation patterns during YBT change during this time.

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