IJSPT

ORIGINAL RESEARCH

THE RELATIONSHIP BETWEEN PRE-OPERATIVE AND TWELVE-WEEK POST-OPERATIVE Y-BALANCE AND QUADRICEPS STRENGTH IN ATHLETES WITH AN ANTERIOR CRUCIATE LIGAMENT TEAR

Cassidy Hallagin, PT, DPT, SCS[1]
J Craig Garrison, PhD, PT, ATC, SCS[1]
Kalyssa Creed, MS, CCRP[1]
James M Bothwell, MD[1]
Shiho Goto, PhD, ATC[1]
Joseph Hannon, PT, DPT, SCS, CSCS[1]

ABSTRACT

Background: Pre-operative quadriceps strength may have a positive influence on post-operative function and outcomes at time of return to sport. Little consideration has been given to quadriceps strength during the early post-operative timeframes. Twelve-week post-operative anterior cruciate ligament reconstruction (ACL-R) is considered a critical time point for progression in the rehabilitation process. There is currently limited research looking at the relationship between clinical measurements pre-operatively and at 12-weeks following ACL-R.

Purpose/Hypothesis: The primary purpose of this study was to examine the differences between Y-Balance Test Lower Quarter (YBT-LQ) and isokinetic quadriceps strength tested pre-operatively and post-operatively following ACL-R (12-weeks).

Study Design: Within subject, repeated measures

Methods: Thirty-nine participants (15.6 ± 1.5 y/o) were diagnosed with an ACL tear and were undergoing rehabilitation to return to a sport requiring cutting and pivoting were included. YBT-LQ and isokinetic quadriceps strength were assessed pre-operatively and at 12-weeks after ACL-R. YBT-LQ composite scores were calculated bilaterally and isokinetic quadriceps strength was tested using the Biodex Multi-Joint Testing and Rehabilitation System. Paired T-tests were used to determine mean group differences between YBT-LQ and isokinetic quadriceps strength scores pre-operatively and at 12-weeks post-operative. A Pearson Correlation was performed to determine relationships between variables at both time points.

Results: There was a significant improvement in YBT-LQ composite scores from pre-operative to 12-weeks post-operative on both the involved (Pre-operative: 89.0 ± 7.7; 12-weeks: 94.1 ± 7.1, $p < 0.001$) and uninvolved (Pre-operative: 92.6 ± 6.2; 12-weeks: 97.6 ± 6.8, $p < 0.001$) limbs. Quadriceps strength decreased significantly from pre-operative to 12-weeks on the involved limb (Pre-operative: 82.3 ftlbs ± 38.6; 12-weeks: 67.9 ftlbs ± 27.4, $p < 0.01$), but no differences were found on the uninvolved limb (Pre-operative: 117.3ftlbs ± 42.0; 12-weeks: 121.7ftlbs ± 41.5, $p = 0.226$).

Conclusions: Involved limb quadriceps strength decreases from time of pre-operative to 12-weeks following ACL-R.

Level of Evidence: 3

Key words: Anterior cruciate ligament reconstruction, pre-operative, quadriceps strength, Y-balance test

CORRESPONDING AUTHOR
Cassidy Hallagin PT, DPT, SCS
6301 Harris Pkwy, Suite 150
Fort Worth, TX 76132
E–mail: CassidyHallagin@texashealth.org

[1] Texas Health Sports Medicine, Fort Worth, TX, USA

DOI: 10.16603/ijspt20170986

INTRODUCTION

With the ever increasing prevalence of anterior cruciate ligament (ACL) tears and subsequent re-tears, there is a need to improve return to sport outcomes. Extensive research has been performed to examine the relationship between quadriceps strength and function at the pre-operative time point and time of return to sport (RTS) in patients who have undergone anterior cruciate ligament reconstruction (ACL-R). Greater quadriceps strength pre-operatively has been correlated to increased quadriceps strength post-operatively. However, it is well documented that quadriceps strength deficits may remain for two years and beyond, following ACL-R.[1-5] Multiple authors have shown that those individuals with greater quadriceps strength pre-operatively have significantly greater quadriceps strength at RTS, and those with lower quadriceps strength pre-operatively have lower functional scores on single and triple hop tests (time and distance) at time of RTS and may take longer to RTS after ACL-R.[1,2,6] Quadriceps strength is important as it relates to outcomes and performance at time of RTS.[2,7] Recently, researchers have found that decreased quadriceps strength, and larger asymmetries between limbs, lead to shorter distances on hop tests.[1,8] This suggests that strength deficits and side to side symmetry are important to consider when looking at readiness to RTS. Limb asymmetry following ACL-R has been found to negatively affect return to sport time and these asymmetries may persist even past RTS. Despite the variability in study design and methodology, it has been consistently demonstrated that pre-operative quadriceps strength is important in the rehabilitation process.

The Y-Balance Test – Lower Quarter (YBT-LQ) is one of the functional tools used to measure single limb performance and neuromuscular control and has been studied in individuals with ACL-R.[9,10] The YBT-LQ requires an individual to load on a single leg and squat while reaching with the contralateral limb. This test not only measures neuromuscular control but has also been correlated to quadriceps and hip strength.[9,10] Particularly the anterior reach portion demonstrates high activation of the vastus medialis and lateralis.[11] The YBT-LQ has not been studied pre-operatively in an ACL-R population to date. Garrison et al.[12] found a relationship between the YBT-LQ performance at 12-weeks post-operatively (12-weeks) and at time of RTS. Participants who demonstrated a greater than 4 cm YBT-LQ anterior reach (ANT) difference between sides at 12-weeks did not meet criteria to RTS for the single and triple hop tests for distance.[12] This 12-week mark may be an important indicator of performance and affect outcomes at time of RTS, however the value of the YBT-LQ in the pre-operative time frame is still unclear.

There is currently limited research looking at the relationship between pre-operative measurements and outcomes at 12-weeks following ACL-R. Although research shows that quadriceps strength is not restored until well after 12-weeks, it is important to track improvements throughout the rehabilitation process in order to make modifications based on patient performance.[5] If patients reach a specific threshold on the YBT-LQ at 12-weeks they may be more likely to pass functional testing at time of return to sport. Likewise, if patients have more quadriceps strength and better YBT-LQ scores pre-operatively, this could have a positive effect on outcomes at 12-weeks. The primary purpose of this study was to examine the differences between YBT-LQ and isokinetic quadriceps strength pre-operatively and at 12-weeks following ACL-R. The secondary purpose was to examine relationships between these same variables, at both time points. The authors hypothesized that there would be a statistically significant improvement in both quadriceps strength and YBT-LQ scores from pre-operative to 12-weeks post ACL-R. In addition, it was hypothesized that there would be a statistically significant relationship between all variables at both time points.

PARTICIPANTS

This study was a within subjects, repeated measures design. Thirty-nine participants (21 males, 18 females) with an average age of 15.6 ± 1.5 years volunteered for this study. Each participant was diagnosed with an ACL tear by a fellowship trained, board certified, orthopedic surgeon which was confirmed by MRI. Participants were enrolled prior to ACL-R with an average starting date of five days pre-operatively. All participants had an ACL reconstruction using patellar tendon autograft performed by the same surgeon. Demographics for the participants are listed in Table 1. Testing was conducted on

Table 1. *Participant demographics including means and standard deviations.*

Age (yrs)	Gender		Height (cm)	Weight (kg)	Dominant Side		Injured Side	
	Male	Female			Right	Left	Right	Left
15.6±1.5	21	18	172.1±9.6	72.1±16.8	37	1	20	19

each participant pre-operatively, within one week of ACL reconstruction and within one week of their 12-week post-operative time point. While each individual physical therapy session was not controlled for, treating therapists were provided the institutions ACL rehabilitation protocol, which included range of motion, patellar and fat pad mobility, quadriceps and hamstrings strengthening, neuromuscular control training, and hip strengthening exercises and averaged two times per week in physical therapy, immediately post-operative until the time of retesting at 12 weeks. No formal pre-operative rehabilitation was performed by these individuals. Inclusion criteria for participation in the study were 1) first time ACL-R on the involved limb, 2) between the ages of 13 and 25, 3) involved in, and planning to return to, a sport involving cutting, planting, pivoting, jumping, and landing, in which they were active a minimum of three times per week, and 4) participation in a physical therapy return-to-sport rehabilitation program. The participants were excluded from the study if there was 1) a previous ACL tear and/or reconstruction on either side, 2) other ligamentous injuries to the knee, including meniscal injuries, or 3) an associated chondral defect requiring surgical intervention. Participants volunteered and were consented into the study by an investigator in the outpatient sports physical therapy facility once they were confirmed to meet the inclusion and exclusion criteria. Child assent and parental permission were obtained for those participants who were minors at the time of the study. Once consented into the study, objective measurements were taken on the participant's knee and patient outcome forms were completed. The Institutional Review Board of Texas Health Resources approved the research procedures.

Y-BALANCE TEST

The YBT-LQ was utilized as a measure of trunk and lower extremity function. The YBT-LQ assesses ROM, strength, and neuromuscular control of the lower extremity and was chosen to assess the participants' lower limb balance. Numerous prior studies have demonstrated its utility as a clinical test to assess for lower limb balance deficits in the athletic population [10,13-15]. Measurements were taken in three distinct directions of anterior (ANT), posteromedial (PM) and posterolateral (PL) on both the dominant and non-dominant limbs. The dominant limb was determined as the limb with which the individual would primarily kick a ball with, thus identifying the opposite limb as the non-dominant limb. The participants were instructed in the YBT-LQ protocol using a combination of verbal cues and demonstration.[13] The Y Balance Test Kit™ was utilized throughout the study. All participants wore shoes during testing and began on their dominant limbs. The participants were asked to perform single limb stance on the extremity while reaching outside their base of support to push a reach indicator box along the measurement pipe.[13] Elevation of the heel, toe or loss of balance resulting in a stepping strategy was recorded as a trial error indicating the trial should then be repeated. Subjects were allowed at least four practice trials in the ANT, PM and PL directions prior to recording the best of three formal trials in each plane. Three trials were completed on the dominant limb in the ANT direction followed by three trials completed on the non-dominant limb.[13] This protocol was then replicated in the PM and PL directions. The maximal reach distance of the three trials was recorded at the place where the most distal part of the foot reached based on the measurement pipe.

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.[13,14] The leg length was determined using the distance between the most prominent portion of the greater trochanter and the floor while the individual was in a standing position. Composite YBT-LQ scores of the involved and uninvolved limbs were computed for each of the athletes in this study. Inter-rater reliability was determined prior to the initiation of this study using an intraclass correlation coefficient (ICC). Reliability of the measurements for the anterior

(ICC3,1 = 0.86; SEM, 3.3 cm), posteromedial (ICC3,1 = 0.99; SEM, 1.7 cm), and posterolateral (ICC3,1 = 0.95; SEM, 2.7 cm) directions for the testers participating in the study was considered to be acceptable. These values are similar to previously published data on intrarater (ICC3,1 = 0.91) and interrater (ICC2,1 = 0.99) reliability of composite scores for this test.[13,16] Validity of the test has been previously shown in relation to hip kinematics and gluteal muscle activation.[16]

BIODEX TESTING

The Biodex Multi-Joint Testing and Rehabilitation System (Biodex Medical Systems, Shirley,NY) was used for testing extensor peak torque. For the purpose of this study extensor peak torque will be referred to throughout the manuscript as quadriceps strength. Subjects were seated on the Biodex system and secured with padded straps around the thigh, pelvis, and torso to minimize accessory and compensatory movements during testing.[17,18] The test limb femoral condyle was aligned with the Biodex axis of rotation as per the manufacturer instructions. Participants performed five submaximal knee extension/flexion repetitions to familiarize themselves with the testing motion. To measure knee strength at 60º/sec, participants performed five consecutive concentric contractions.[19] All subjects began testing on their uninjured side followed by the injured side and the average of the five trials for each side was normalized to body weight and used for data analysis.

DATA ANALYSIS

Paired t-tests were used to determine differences between pre-operative and 12-week quadriceps strength and YBT-LQ composite and normalized ANT. Pearson correlations were used to determine relationships between all variables at both time points. Statistical significance was defined as $p < 0.05$. All data analysis was completed using SPSS version 23.0 (Chicago, IL 60606). A priori statistical power analysis was performed using quadriceps strength as the primary outcome, and we determined that a total of 25 participants would be needed to detect statistical significance based on an 80% power calculation.

RESULTS

A main effect for time existed in ACL patients at pre-operative and 12-weeks. There was a significant increase between pre-operative and 12-week YBT-LQ composite scores on both the involved ($t = -5.109$, $p < 0.001$) and uninvolved ($t = -5.333$, $p < 0.001$) limbs. There was a significant decrease in involved limb quadriceps strength between pre-operative and 12-weeks ($t = 3.649$, $p = 0.001$). There was not a statistically significant difference in uninvolved quadriceps strength, although there was an increase from pre-operative to 12-weeks ($t = -1.232$, $p = 0.226$). Means and standard deviations for YBT-LQ and quadriceps strength at both time points are listed in Table 2.

When examining the relationships between variables, there was a moderate positive correlation between pre-operative YBT-LQ composite scores and 12-weeks composite scores on the involved ($r = 0.660$, $p < 0.001$) and uninvolved ($r = 0.601$, $p < 0.001$) limbs. There was a positive correlation between pre-operative and 12-week quadriceps strength, which was moderate on the involved limb ($r = 0.772$, $p < 0.001$), and highly correlated on the uninvolved limb ($r = 0.855$, $p < 0.001$). There was a high positive correlation between quadriceps strength pre-operatively on the involved limb and at 12-weeks on the uninvolved limb ($r = 0.804$, $p < 0.001$). There

Table 2. *Means and standard deviations for measurements taken at both pre-operative and 12-weeks post-operative in both limbs.*

	YBT-LQ		Quadriceps Strength (ftlbs)	
	Involved*	Uninvolved*	Involved*	Uninvolved
Pre-operative	89.0 ± 7.7	92.6 ± 6.2	82.3 ± 38.6	117.3 ± 42.0
12-weeks, post-op	94.1 ± 7.1	97.6 ± 6.8	67.9 ± 27.4	121.7 ± 41.5

YBT-LQ= Y-balance test, lower quarter

*Denotes statistically significant differences between time points.

was a moderate positive correlation between uninvolved limb quadriceps strength pre-operatively and 12-weeks on the involved limb ($r = 0.664$, $p < 0.001$). No correlations existed on either limb between YBT-LQ composite scores and quadriceps strength at pre-operative or 12-weeks. No correlation exists between involved limb quadriceps strength and normalized ANT on either limb at either time point. A weak positive correlation exists between pre-operative and 12-week normalized ANT on the involved ($r = 0.398$, $p = 0.012$) limb. All other correlational statistics can be found in Table 3.

DISCUSSION

The primary purpose of this study was to compare quadriceps strength and YBT-LQ pre-operatively and at 12-weeks in individual's status-post ACL-R. Following ACL-R participants demonstrated significantly reduced quadriceps strength on the involved limb at 12-weeks compared to pre-operative measures. It was hypothesized that there would be an increase in bilateral quadriceps strength between the two time points. The involved limb quadriceps strength decreased from 82.3 ± 38.6ftlbs pre-operatively to 67.9 ± 27.4ftlbs at 12-weeks, representing a 17% decrease. There was an increase in uninvolved quadriceps strength between pre-operative (117.3 ± 42.0 ftlbs) and 12-weeks (121.7 ± 41.5 ftlbs), however this difference was not statistically significant. Although there was a difference from pre-operative to 12-weeks in quadriceps strength in both limbs, the uninvolved limb showed a positive increase in strength while the involved limb showed a significant deficit at a critical time point in the rehab process.

Peak extensor torque is an important objective measure used in ACL-R rehabilitation in order to gauge readiness for return to sport. Extensive research demonstrates quadriceps deficits can be present at six months and even up to and exceeding one year.[1-5] Quadriceps strength has recently been shown to help predict reinjury rate. Grindem et al.[20] found that individuals following ACL-R with a quadriceps strength deficit of greater than 10% are significantly more likely to reinjure their ipsilateral ACL. Hartigan et al.[7] investigated pre-operative quadriceps strength in relation to readiness to return to sport and found that individuals who were unable to RTS at six months had a pre-operative quadriceps deficit of 14% compared to those who did return at six months having a pre-operative deficit of 1%. The current study found a pre-operative quadriceps strength deficit of nearly 30% when comparing involved to uninvolved, which is a much greater deficit than that found in the retrospective studies by de Jong et al.[1] and Knezevic et al.,[21] who found pre-operative deficits of 17% and 15% respectively. In both the aforementioned Hartigan[7] and de Jong[1] studies their subjects received some duration of pre-operative rehabilitation which is in contrast to the current study. Despite the differences in study methodology, the aforementioned studies point to

Table 3. *Pearson Correlational coefficients (r-value) for all variables at all time points.*

			Pre-operative						12-Weeks Post-operative				
			YBT-LQ Composite		Quadriceps Strength		Normalized ANT		YBT-LQ Composite		Quadriceps Strength		Normalized ANT
			Involved	Uninvolved	Involved	Uninvolved	Involved	Uninvolved	Involved	Uninvolved	Involved	Uninvolved	Involved
Pre-operative	YBT-LQ Composite	Uninvolved	0.732**										
	Quadriceps Strength	Involved	0.119	0.770**									
		Uninvolved	-0.101	-0.098	0.820**								
	Normalized ANT	Involved	0.806**	0.578**	-0.093	-0.319							
		Uninvolved	0.588**	0.691**	-0.226	-0.356	0.705						
12-Weeks Post-operative	YBT-LQ Composite	Involved	0.660**	0.534**	0.189	-0.050	0.505**	0.335**					
		Uninvolved	0.489**	0.601**	0.043	-0.136	0.399**	0.427**	0.852**				
	Quadriceps Strength	Involved	-0.136	-0.089	0.772**	0.664**	-0.264	-0.295	0.167	0.093			
		Uninvolved	-0.200	-0.118	0.804**	0.855**	-0.378**	-0.396**	-0.024	-0.094	0.818**		
	Normalized ANT	Involved	0.433**	0.390**	0.168	-0.050	0.524**	0.398**	0.738**	0.569**	0.188	-0.017	
		Uninvolved	0.314	0.528**	-0.053	-0.176	0.440**	0.612**	0.546**	0.712**	0.060	-0.151	0.717**

** indicates statistical significance, $p<0.05$.

the importance of the relationship between pre-operative measures and post-operative success.

In early post-operative stages following ACL -R protocols call for weight-bearing as tolerated, although some require periods of non-weight-bearing on the involved lower extremity ranging from two weeks to six weeks depending on surgeon preference and meniscal involvement. Regardless of surgical precautions, patients often self-select to decrease weight-bearing due to pain or fear. This decrease or lack of lower extremity use may lead to immediate atrophy of all musculature in that extremity. Chung et al.[22] found that there is a bilateral decrease in quadriceps strength following ACL-R and attributed that decrease to a change in the neurological response of the muscle. Decreased use could potentially also diminish strength on the uninvolved side, as these individuals significantly reduce their activity level immediately following surgery, which includes a decrease in overall use of the uninvolved limb.

The percent quadriceps strength deficit between limbs of 44% at three months post-operatively found in this study is similar to the findings of de Jong et al.[1] who investigated quadriceps strength at 6, 9 and 12 months, and found between limb deficits of 36%, 25% and 19% respectively. Previously, Shelbourne and Johnson[5] measured quadriceps strength at three months following ACL-R with an average between limb strength deficit ranging from 25% to 35%, which is less than the 44% deficit found in the current study at the same three month mark. Likewise Knezevic et al.[21] found quadriceps strength asymmetries at four months post-operative with deficits near 32%. Quadriceps strength at the 12-week mark following ACL-R sets the foundation for success when returning to sport.[23]

The significant quadriceps deficit identified in the current study at the 12-week mark is alarming for many reasons. At three months, many protocols call for the initiation of higher level activities such as hopping and jogging.[23] Often objective measures such as YBT-LQ composite and single leg squat endurance/quality are used to determine readiness to perform these higher level activities. Other important factors to consider at this point in rehabilitation include equal weight bearing with double leg squatting, reactive effusion to an increase in activity and amount of kinesiophobia. Questions arise about an individual's readiness to perform higher level activity, with this alarming difference in quadriceps strength. Although neuromuscular control may be adequate to perform YBT-LQ and extensive single leg squatting, these tasks do not point to the quadriceps muscles ability to generate adequate force for higher level activities.

Participants had improved YBT-LQ composite score on both the involved and uninvolved limbs at 12-weeks compared to pre-operative measures. These findings support the secondary hypothesis that there would be a significant increase in YBT-LQ in both extremities from pre-operative to 12-weeks. Along with being significantly improved, YBT-LQ scores were also highly correlated between limbs and both time points. Even when the YBT-LQ ANT reach was normalized to leg length, there was an insignificant relationship between this measure and quadriceps strength. Normalized ANT in both limbs was moderately correlated between pre-operative and 12-weeks. Previous research by Texas Health Sports Medicine drew attention to YBT-LQ ANT reach at 12-weeks, and its ability to help predict return to sport at six months.[12] The current study found poor positive correlations between YBT-LQ normalized ANT in the involved leg at pre-operative and 12-weeks, as well as in the uninvolved leg at those same time points. There was no correlation between YBT-LQ normalized ANT and quadriceps strength measures at either time point, in either the involved or uninvolved limb. It is impossible to draw a causal relationship, however similarly to quadriceps strength the results point to those individuals with better pre-operative YBT-LQ comp scores continuing to have better scores at 12-weeks in relation to those with lower scores pre-operatively.

The increase in YBT-LQ from pre-operative to 12-weeks is in line with the current study's hypothesis despite the significant decrease in involved limb quadriceps strength. This finding may point to the fact that the YBT-LQ is a trainable skill in which quadriceps strength plays a role in improvements following ACL-R, in addition to neuromuscular control, hip strength and range of motion of the entire lower extremity. Garrison et al.[24] found that gluteal

strengthening contributes to YBT-LQ ANT. Individuals that scored higher on the YBT-LQ at 12-weeks, but had decreased quadriceps strength may have had an increase in gluteal strength between the pre-operative assessment and assessment at 12-weeks.

LIMITATIONS

One of the limitations of the current study is the fact that pain could have limited participant function during both the YBT-LQ and quadriceps strength testing. All of the patients in this study had a patellar tendon autograft which has been shown to cause greater anterior knee pain and graft site irritation compared to hamstring graft following ACL-R.[24] Ipsilateral patellar tendon use puts a disruption in the quadriceps complex impeding the pulley system utilized at the knee joint. The tendon and surrounding structures including the infrapatellar fat pad play a crucial role in the ability to generate strength.[3] Although patients were instructed to stop all testing secondary to an increase in pain, none chose to do so. All participants were able to complete testing without complaints of pain.

As previously mentioned, core and hip strength, as well as lower extremity range of motion play a role in YBT-LQ scores.[25] For the purpose of this study core and hip strength were not quantified, and therefore make it difficult to ascertain the cause of increase in YBT-LQ scores.

CONCLUSION

Involved limb quadriceps strength is significantly weaker pre-operatively and remains significantly reduced at 12-weeks status post ACL-R. Despite a significant reduction in quadriceps strength, individuals were able to improve their YBT-LQ scores bilaterally between pre-operative and 12-weeks.

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