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Strength and Stability Analysis of Rehabilitated Anterior Cruciate Ligament Individuals

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ABSTRACT

International Journal of Exercise Science 11(1): 817-826, 2018. The anterior cruciate ligament (ACL) serves as a vital stabilizer for the human knee, yet it is one of the most injured ligaments in the body. Function of the knee is restored through reconstruction and physical therapy, but long term functional deficits persist in some individuals. To better understand the influence of post rehabilitation outcomes on dynamic balance performance, this study evaluated bilateral differences in strength and stability in 11 participants who have rehabilitated from an ACL reconstruction or repair. The Y-Balance Test and an isokinetic strength assessment using the Biodex dynamometer were used to measure dynamic knee stability and strength, respectively. No significant differences were found in the strength test measurements. However, side to side differences in Y-Balance Test composite score (-2.8±3.1%, p = 0.014), maximal anterior reach (-2.8±2.4 cm, p = 0.01), and posterolateral reach (-2.75±3.5 cm, p = 0.02) were found to be significantly impaired in participants' involved limbs compared to the uninvolved limbs.

KEY WORDS: peak torque, ACL reconstruction, average power, work, dynamic stability

INTRODUCTION

Among the four major ligaments that stabilize the human knee, the anterior cruciate ligament (ACL) is debatably the most impactful. Opposing hyperextension of the knee, the ACL not only limits excessive movements, but also functions as the primary stabilizing ligament to the tibiofemoral joint (17). Despite its significance, the ACL has been reported as one of the most injured ligaments in the body, resulting in more than 200,000 tears annually, with a significant amount of those tears resulting from participation in sports (13). Restoration of function in the knee is most commonly accomplished by ACL reconstruction (ACLR) surgery, with roughly 100,000 people undergoing this procedure annually (1); however, some individuals may choose conservative treatment options and remain ACL deficient (14). Subsequent to surgery, individuals engage in extensive rehabilitation programs consisting of components such as strength, stability, and flexibility. For organized sports and physical activities, completion of specific "return to sport" and "return to activity" protocols at the conclusion of rehabilitation are recommended for physical therapists to safely discharge patients to perform in unrestricted physical activity (9,10). Although athletes are often required to reach these minimal requirements before being discharged and returning back to play, just over 50% of the individuals report returning to pre-injury level at time of return to sport and several years later (8) and do not elect to continue with additional rehabilitation. Furthermore, even with these protocols, long term outcomes are impacted, with the likelihood of developing osteoarthritis following ACLR increasing in individuals as they approach the 10-year mark post-reconstruction (9,14).

Of the various components tested with rehabilitation, dynamic stability is a key element to consider throughout a rehabilitation program for a reconstructed ligament of the knee. Dynamic stability, which involves a variety of muscle activations to elicit stabilization at the knee during dynamic tasks, has often been analyzed using normalized dynamic stability tests, such as the Star Excursion Balance Test (SEBT) and Y-Balance Test (YBT). When used in ACLR individuals at the time of return to sport, the SEBT has measured a decrease in dynamic stability in both limbs (3). Additionally, studies have linked diminished composite and anterior movement scores of the YBT and SEBT to increased future non-contact limb injuries in athletes (2,13). Even with continual ACLR, researchers have shown that the diminishment of knee impairments, such as knee pain and laxity, may take as much as a whole year to show significant improvements (12). Consequently, these findings suggest that ACL injury and ACLR have some connection to knee instability and potential risk for future knee injuries at time of return to activity and in the years following it. Thus, dynamic knee stability should continue to be a primary focus of researchers and health professionals when evaluating lower extremity function throughout a rehabilitation program, at the time of return to activity, and while an ACLR individual remains physically active.

Along with dynamic stability of the knee after ACLR, quadriceps muscle strength also plays a major role in functionality at the tibiofemoral joint. Similar to stability, researchers have examined the influence of ACLR on strength outcomes, using an isokinetic dynamometer to analyze torque and angular velocity, with results showing decreased torque production with an increase in angular velocity (15). Similar isokinetic testing research has shown quicker strength and range of motion gains for those who underwent accelerated ACL rehabilitation, relative to traditional ACL rehabilitation (5). Additionally, a direct linear relationship has been established between dynamic stability, using a single-legged functional test score, and isokinetic peak muscle torque in ACL rehabilitated individuals (16). Furthermore, significant differences in peak torque values were observed between the involved and uninvolved ACLR limbs (16).

This relationship between dynamic stability and muscle strength, along with observable differences between limbs, warrant further investigation to understand if deficits persist in the involved limb several years post ACLR and return to activity. Therefore, the purpose of this research was to analyze the strength and dynamic stability in the limbs of individuals who have underwent ACLR and rehabilitation. It was hypothesized that the involved limbs will show reduced performance on the strength and dynamic stability tests, relative to the uninvolved limbs. While several studies have tested these variables on those who underwent ACLR, the findings of this research will provide further knowledge to the field on the relationship between dynamic stability and strength measures following ACLR and rehabilitation, several years post reconstruction.

METHODS

Participants

Eleven moderately active individuals (7 male, 4 female) who rehabilitated from an ACL repair participated in the study. The participants had a mean age of 23.1±3.5 years (range 18-31), mean height of 174.6±9.4 cm (range 160.0-190.5), and mean weight of 82.5±10.8 kg (range 67.3-97.7). Individuals with high blood pressure, hemophilia, heart disease, sickle cell trait, an acute infection, edema in the limbs, a blood/bleeding disorder, a skin disorder on a lower extremity, or currently pregnant were excluded from the study. Additionally, individuals who were taking anti-inflammatories or muscle relaxers were excluded. To be included in the study, participants had to be released back to activities of daily living by a healthcare professional (self-reported), had one surgical knee intervention for an ACL injury over 6 months prior to partaking in the study, had underwent rehabilitation, and had no self-reported anterior knee pain. Individuals with an ACLR surgery or ACL avulsion fracture repair were included in the study. No stipulation on ACLR graft type was made. Additionally, six of these participants had meniscus repairs to accompany their ACL surgery; two had medial collateral ligament sprains, however no surgical intervention was required. There were nine who underwent surgery on their left limb, and the remaining two had surgery on their right limb. The mean time in physical therapy was 6.4±2.1 months, and the mean amount of time since surgery was 6.01±4.79 years. Prior to partaking in the study, participants completed an original health history questionnaire and informed consent form approved by the University of Texas at Arlington's Institutional Review Board. All testing was completed at the Biomechanics Lab in the Maverick Activity Center at the University of Texas at Arlington.

G*Power version 3.1.9.2 was used to determine sample size using a mean difference in anterior reach of 2.8 cm, an SD of 3.0, a 2-tailed *t*- test and an alpha level of 0.05. To obtain an estimated power of 70%, 10 subjects would be required.

Protocol

A Y-Balance device was made by hand with three long pieces of masking tape. The handmade Y-Balance design was directly based off Plisky et al.'s Y-Balance dimensions (10). Thus, the three pieces of tape were placed in the anterior, posterolateral, and posteromedial directions to form a "Y". A *Komelon® Speed Mark™* tape measure (Komelon USA, Waukesha, WI) was used after each trial to determine the participant's limb reach.

The procedures followed for the YBT were based on Plisky et al.'s study (10). However, instead of pushing a reach indicator, participants were instructed to extend their ungrounded limb in one of the three designated directions (posteromedial, posterolateral, anterior) and lightly tap the masking tape with their foot. Immediately after the participant touched the tape, a pen mark was made on the tape where the most distal portion of the foot hit the ground. A tape measure was used to determine the distance reached. The order in which participants completed the three directions remained the same: first anterior for both limbs, second posteromedial for both limbs, and third posterolateral for both limbs. Each direction began with the right foot first, and then the left foot. Following Plisky et al.'s standardized warm-up protocol, participants completed six practice trials on both limbs for all three directions to become familiarized with the movements (10).

Immediately after completing the warm up trials, participants were then instructed to complete three official trials (10). After acquiring these measurements, the furthest reach in each direction was used to evaluate the reach distances individually (10).

A set of criteria were met during each limb reach in order to consider the trial successful (10). Consequently, participants were required to stand on one limb throughout the trials. Participants were not allowed to have their reach foot use the ground for support. Participants had to return their reach foot to the starting position under control. Participants were not allowed to raise the heel of their grounded foot throughout the trial. In the event a participant violated any of the criteria, additional trials were completed until the required number of valid reaches were measured. Before moving from one direction to the next, participants completed any additional attempts necessary (10).

Limb length was measured in both the left and right limbs. Participants stood straight up, with feet shoulder-width apart. Each limb, was measured from the top of their greater trochanter to the floor. In order to stay consistent with the YBT, participants kept their shoes on during the measurement.

For Y-Balance scoring, after all measurements were documented, the furthest distance reached in the three official trials was deemed the maximal reach for each direction for each limb. A composite score was determined by summating the maximal reach distances from all three directions, dividing this value by both 3 and the participant's limb length, and then multiplying the value by 100 (10).

Participants were seated onto a Biodex™ Isokinetic Dynamometer (Biodex, Corp., Shirley NY), a standardized piece of equipment used to quantify concentric muscle torque generated by the muscles acting on a specified joint (7). As based on Biodex procedure, participants were strapped at the thigh, shin, and pelvis to the Biodex seat. After the participants were properly secured, they sat with their knees bent at 90° angles. Full extension of the knee was considered as 0°, while a 90° knee bend was the parameter for flexion of the knee. The Biodex was programmed to move at 180°/s to permit participants to perform isokinetic flexions and extensions at the knee. As done in previous studies, 180°/s has been a common angular velocity for isokinetic measurements (4,16). Starting on the right limb, participants were instructed to forcefully flex to a 90-degree bend and extend the knee fully during the isokinetic trials. The participants were also instructed to hold onto the designated handles beside their chair as they flexed and extended at the knee.

Participants had two practice trials of 10 flexions and extensions to become familiarized with the movements at submaximal strength; participants were instructed to practice at approximately 70% of their maximal effort. For the recorded trials, one set of three maximal flexions and extensions was recorded. Between practice trials the participants had 30 seconds of rest. Between the practice trials and the recorded trials, 1 minute of rest took place. After completing the isokinetic movements in the right limb, the participants alternated to the left limb.

Biodex System 3 software was used for data analysis. The torque signals were corrected for gravity. The start and end of each contraction was defined as the point where the velocity was greater than or equal to 95% of the criterion velocity of 180°/s. Power was computed by multiplying the torque by the angular velocity and then averaged over the contraction to determine average power. Work was computed by integrating the power with respect to time. The peak torque was defined as the highest value attained in each contraction. For both the extension and flexion phases the contraction with the highest peak torque was used for statistical analysis.

Statistical Analysis

All statistical analyses were performed using a commercial software package (SPSS version 23.0 IBM Corp., Armonk, NY). The distributions for the uninvolved and involved limbs for all dependent variables (Biodex measures: extension peak torque, flexion peak torque, extension work, flexion work, extension average power, and flexion average power; YBT dynamic balance measures: maximum anterior reach, posteromedial, posterolateral and composite score) were examined for outliers and normality using box plots and Kolmogorov-Smirnov goodness-of-fit test and the Shapiro-Wilk Normality test. Paired sample t-tests was used to determine the differences between uninvolved and involved limbs with alpha set at 0.05.

RESULTS

There were no outliers for any of the dependent variables. The Kolmogorov-Smirnov goodness-of-fit test and the Shapiro-Wilk Normality tests indicated that all of the dependent variables were normally distributed, $p > 0.05$. The means ± SD, 95% confidence intervals and percent deficit for all dependent variables by involved and uninvolved limbs are presented in Table 1. No significant differences were found between the uninvolved and involved limbs for the Biodex strength test: extension peak torque ($p = 0.356$), flexion peak torque ($p = 0.172$), extension work ($p = 0.488$), flexion work ($p = 0.195$), extension average power ($p = 0.633$), and flexion average power ($p = 0.355$) (Table 1).

Table 1. Performance on Biodex strength test and Y-Balance Test.

Variable	Uninvolved Mean±SD	Uninvolved 95% CI	Involved Mean±SD	Involved 95% CI	Percent Deficit Mean±SD	Paired Difference Mean±SD	p
Ext Peak Torque (N·m)	130.4±36.4	106.0-154.9	123.7±25.9	106.4-141.1	0.236±17.2	6.7±22.9	0.356
Flx Peak Torque (N·m)	76.8±18.4	64.4-89.2	72.6±17.4	60.9-84.3	4.436±12.8	4.1±9.3	0.172
Ext Work (J)	366.7±94.4	303.3-430.1	352.5±67.1	307.5-397.6	0.845±18.5	14.2±65.4	0.488
Flx Work (J)	254.6±79.1	201.5-307.7	234.2±66.9	189.2-279.1	5.909±19.2	20.4±48.8	0.195
Ext Avg Power (W)	216.5±60.8	175.7-257.3	211.7±50.0	178.1-245.3	-0.264±16.7	4.8±32.3	0.633
Flx Avg Power (W)	137.4±47.2	105.7-169.2	130.3±45.0	100.1-160.5	3.845±20.3	7.1±24.4	0.355

*Ext = Extension, *Flx = Flexion, *Avg = Average

Figure 1 depicts the composite score for the YBT for the involved and uninvolved limbs. The YBT composite score was significantly lower in the involved, 93.6±4.1%, than in the uninvolved limb, 95.9±5.0% ($p = 0.010$). The mean paired difference for the YBT composite score was -2.8±2.4%.

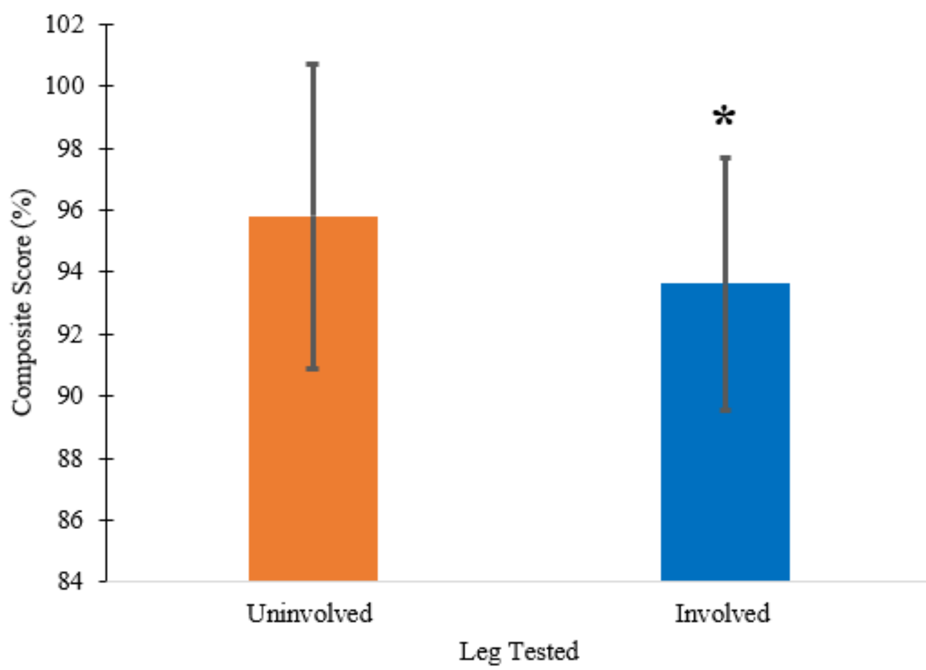

Figure 1. Mean and standard deviation for composite scores during Y-Balance Test for the involved and uninvolved limb. *Involved limb significantly different from uninvolved limb, $p < 0.05$.

Figure 2 depicts the maximal reaches in all three directions for the involved and uninvolved limbs. The YBT maximum anterior reach was significantly lower in the involved, 60.7±7.2 cm, than the uninvolved limb, 63.5±5.8 cm ($p = 0.014$). The mean paired difference for the anterior reach was -2.8±3.1 cm. There was no significant difference between the involved and uninvolved limb for the maximum posteromedial YBT reach ($p = 0.716$). The YBT maximum posterolateral reach was significantly lower in the involved, 96.3±6.9 cm, than in the uninvolved limb, 99.1±6.9 cm ($p = 0.026$). The mean paired difference for the posterolateral reach was -2.8±3.5 cm.

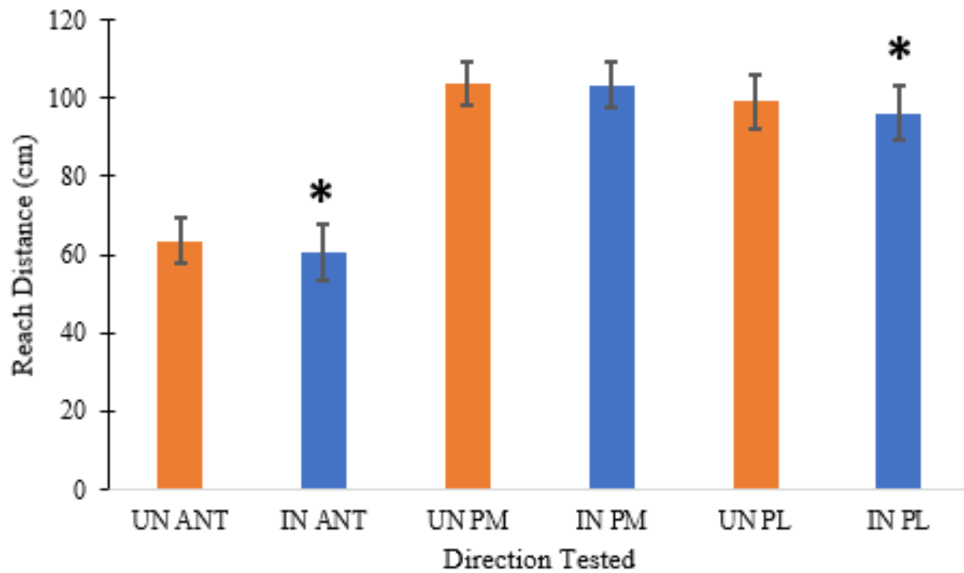

Figure 2. Mean and standard deviations for maximal reach distances in anterior (ANT), posterolateral (PL), and posteromedial (PM) directions during Y-Balance Test for the involved (IN) and uninvolved (UN) limb. *Involved limb significantly different from uninvolved limb, $p < 0.05$.

DISCUSSION

The purpose of this study was to evaluate the relationship of dynamic stability and strength in individuals several years post-reconstruction that have rehabilitated from ACLR. The uninvolved limb displayed greater dynamic stability for maximal anterior reach, maximal posterolateral reach, and composite scores. These findings support the authors' hypothesis and also strengthen the current literature involving the YBT and SEBT (2,3,11). Similar to findings of this study, Clagg et al. found a decrease in anterior reach for the ACL reconstructed group, compared to healthy controls (3). Furthermore, Clagg et al. also determined that individuals within the ACLR group, specifically those with a bone-patellar-bone graft, produced decreased reach distance scores on the SEBT (3). Other studies, conducted by Plisky et al. and Butler et al., share similar results to our study, with decreased anterior knee reach and decreased composite scores during the SEBT (2,11). While our study did not focus on re-injury risk, the aforementioned studies support the concept that individuals with surgical intervention to reconstruct their ACL are at increased risk of re-injury, due to a lack of knee stability, even following rehabilitation. Few studies demonstrate contradictory findings to that of our study on limb differences during dynamic stability tasks. The results from Delahunt et al. differ from the findings of this study, by not observing any significant differences in anterior reach on the SEBT between healthy and ACL reconstructed female athletes (6). Similar to our study, Delahunt et al. only measured posterolateral, posteromedial, and anterior reach directions in the SEBT (6). However, Delahunt et al.'s population solely consisted of club and county-level female athletes in field and court-based sports, while this study examined self-identified moderately active adults. Therefore, due to a potential difference in fitness level, Delahunt's subjects may have inherently improved strength and dynamic stability following ACLR, allowing for less anterior reach score differences between limbs relative to our participants' differences.

This study also evaluated the strength of individuals who have received rehabilitation following ACLR. No significant difference was found between the uninvolved and involved limbs for any of the strength variables: peak torque, total work, and maximal power. The authors believe these results were due to a small sample size and the potential for the involved limb to have matched the strength to that of the uninvolved limb. We are unsure whether the involved limb strength increased or decreased to that of the uninvolved limb over time because of the absence of previous strength measures. This outcome did not support this study's hypothesis and the findings of various studies that also evaluated isokinetic strength in ACLR limbs (4,16). For instance, Wilk et al. evaluated peak torque during isokinetic testing and observed a significant decrease in peak torque production in the involved limb, compared to the uninvolved limb in ACLR individuals. Furthermore, Wilk et al., found an improved ability to generate force, with greater extension peak torque values, when subjects reported greater subjective knee assessment scores (16). Cvjetkovic's et al., found that ACLR individuals had generated a significantly reduced peak torque in the quadriceps at 180°/s compared to healthy controls, but did not find a significant difference between groups for 60°/s peak torque in the quadriceps (4).

The contrasting results found in this study could very possibly be due to the several limitations encountered within this study. First, the population size used was relatively small in comparison to many of aforementioned studies that evaluated 50 or more individuals. Secondly, the medical history screening may also have served as a limiting factor for this study with, participants not being excluded from having a specific ACL graft type or additional complications (i.e., meniscus tear, MCL sprain) in the involved leg, which influenced variability of the participants. Furthermore, all medical history and rehabilitation was self-reported, and no restrictions were made on when the surgery and rehabilitation occurred. Additionally, any activity completed outside of the lab prior to testing could decrease performance in one leg over the other.

In conclusion, ACLR individuals displayed a significant difference between their involved and uninvolved limbs for maximal anterior reach, maximum posterolateral reach, and composite score of the YBT. These same participants failed to display any significant difference in their involved limb for peak torque, work, and maximal power during concentric extension and flexion at 180°/s. The YBT results reflect findings from previous studies, which suggest that greater instability exists in the knee following an ACL injury and ACLR. Accordingly, an emphasis on maintaining and increasing dynamic knee stability should be continued after rehabilitation concludes and the return to activity transition occurs to prevent future injury risk and eliminate any existing differences between limbs.

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