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The Relationship Between Lateral Trunk Control During Landing and Lower Extremity Muscle Strength in Young Athletes After ACL Reconstruction

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Abstract

Background: Lower extremity landing asymmetries are common and associated with strength deficits after anterior cruciate ligament reconstruction (ACLR). However, less is known regarding

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COMPETING INTERESTS

The authors have no competing interests or financial or personal relationships to declare.

trunk control during landing. This study's purpose was to test the hypotheses that lateral trunk instability during single-leg landing (SLL) would be greater in young athletes after ACLR compared to controls and would be associated with strength deficits.

Methods: Participants included 130 young athletes recently cleared for return-to-sport following ACLR and 56 uninjured young athletes. Lateral trunk instability was defined as total frontal plane trunk excursion (FPTE) during a SLL task. Limb symmetry indices were calculated to quantify landing symmetry between limbs. Quadriceps femoris (QF) and hip abduction strength were measured using an isokinetic dynamometer. FPTE was compared between the ACLR and control groups and among QF strength subgroups using independent t-tests and one-way ANOVA. Linear regression examined the association between FPTE and strength in the ACLR group.

Findings: The ACLR group demonstrated greater FPTE and FPTE asymmetry compared to the control group. The low-QF strength group demonstrated greater FPTE and FPTE asymmetry compared to both the high-QF strength and control groups. Additionally, the high-QF strength group demonstrated greater FPTE and FPTE asymmetry compared to controls. In the ACLR group, lower involved limb QF and hip abduction strength and lower QF strength symmetry were associated with greater FPTE and FPTE asymmetry.

Interpretation: Young athletes after ACLR at time of return-to-sport demonstrated increased lateral trunk instability during SLL. Additionally, increased lateral trunk instability was associated with strength deficits; primarily QF strength.

Keywords

ACL Reconstruction; Quadriceps Strength; Landing Mechanics; Young Athletes; Trunk Control

1 INTRODUCTION

A tear to the anterior cruciate ligament (ACL) is a devastating injury that has a long-lasting impact on knee joint health and is often treated with ACL reconstruction (ACLR) (Luc et al., 2014). It is estimated that up to 200,000 ACLRs are performed annually in the United States (Beynon et al., 2014; Dodwell et al., 2014; Gornitzky et al., 2015; Griffin et al., 2006; Kim et al., 2011; Shea et al., 2004), and the goal of this surgical intervention is to restore functional stability of the knee and facilitate return to pre-injury function, often including sports participation (Bruce D Beynon et al., 2005; Bruce D. Beynon et al., 2005; Failla et al., 2015; Lynch et al., 2015). However, significant proportions of the young population do not return to pre-injury levels of activity after ACLR (Brophy et al., 2013; Lentz et al., 2013; McCullough et al., 2013). A systematic review and meta-analysis by Ardern and colleagues that included 69 studies found that 81% of individuals reported returning to any level of sport after ACLR, with only 65% reporting returning to pre-injury level of sports participation (Ardern et al., 2014). In addition to suboptimal return-to-sport (RTS) rates after ACLR, rates of second ACL injury remain high following RTS (Laboute et al., 2010; Paterno et al., 2015). The prevalence of these poor outcomes emphasize the importance of continuing to evaluate musculoskeletal and movement-related impairments in young athletes following ACLR to identify important targets for rehabilitation interventions.

Individuals who have undergone ACLR demonstrate movement asymmetries during a variety of limb-loading tasks when compared to healthy controls. Previous studies have shown that asymmetric lower limb biomechanics during jumping and landing are commonly observed at the time of RTS and also persist until two years following ACLR and beyond (Ernst et al., 2000; Ithurburn et al., 2015; Orishimo et al., 2010; Paterno et al., 2011, 2007; Schmitt et al., 2015). Importantly, certain biomechanical movement asymmetries of the lower limb during landing have also been identified as risk factors for sustaining a second ACL injury, including increased frontal plane knee motion during landing (Paterno et al., 2010). In addition to alterations in lower limb biomechanics during landing, individuals after ACLR also demonstrate altered trunk control in the sagittal plane, demonstrating increased trunk flexion when landing on the ACL-reconstructed limb (Ithurburn et al., 2015; Lessi et al., 2017; Oberländer et al., 2013). While previous studies suggest increased trunk motion in the frontal plane may be predictive of initial knee injury risk, including ACL injuries (Hewett et al., 2014; Zazulak et al., 2007), to our knowledge, trunk motion in the frontal plane has not been examined during landing tasks after ACLR.

After ACLR, lower extremity muscle strength deficits on the involved limb are known. Specifically, between-limb quadriceps femoris (QF) muscle strength symmetry is recommended as an important clinical benchmark for determining if an athlete is ready for RTS after ACLR (Adams et al., 2012; Logerstedt et al., 2017, 2010). Even though QF strength symmetry has been identified as an important determinant of successful recovery post-ACLR (Lentz et al., 2013; Lynch et al., 2015), patients are commonly cleared for RTS with deficits that are larger than clinical recommendations (>10% of the uninvolved limb) (Ithurburn et al., 2015; Lepley, 2015; Palmieri-Smith and Lepley, 2015; Schmitt et al., 2015, 2012; Toole et al., 2017). While decreased QF strength has been associated with altered lower limb and sagittal plane trunk biomechanics during landing tasks after ACLR (Ithurburn et al., 2015; Palmieri-Smith and Lepley, 2015; Schmitt et al., 2015, 2012), the relationship between QF muscle strength and lateral trunk control after ACLR after landing has not been examined. Additionally, weaknesses in the hip abductor (HA) muscles is often associated with dynamic valgus of the knee during landing activities, a motion pattern associated with both primary and second ACL injury risk (Myer et al., 2011; Paterno et al., 2010; Petersen et al., 2014). However, the relationship between HA muscle strength and lateral trunk control after ACLR has not been previously examined. The purpose of this study was to examine the presence of lateral trunk instability in young individuals during a single-leg landing (SLL) task at the time of RTS after ACLR, and then determine its relation to QF and HA muscle strength. The primary hypotheses tested were: 1) that individuals after ACLR would demonstrate greater lateral trunk instability during a SLL task when compared to healthy control participants; 2) that greater lateral trunk instability would be associated with deficits in both QF and HA strength in individuals after ACLR; and 3) that individuals after ACLR with greater QF strength asymmetry would demonstrate greater lateral trunk instability compared to individuals after ACLR with more symmetric QF strength and compared to healthy control participants.

2. METHODS

2.1 Participants

A total of 186 individuals, ranging in age from 11–26 years, were recruited from the community, local orthopedic practices, and local physical therapy clinics to take part in this study. The data collected from these participants were part of a prospective study of outcomes following ACLR. Of the entire cohort, 130 individuals, who had undergone primary, unilateral ACLR, were included in the ACLR group (age range: 13–26 years; Table 1). To be included in this study, participants in the ACLR group must have completed rehabilitation, gained clearance for return to high-level activity by both their surgeon and rehabilitation specialist, and planned to return to cutting and pivoting sports regularly (≥ 50 hours/year). The data collection took place within four weeks of participants being cleared for RTS. Potential participants in the ACLR group were excluded from the study if they (1) suffered any other ligament damage on the involved limb during ACL injury (except grade I medial collateral ligament sprain) or (2) reported a history of low back pain or lower limb injury (cared for by physician) within the last year. Participants in the current analyses were also excluded if they required a modified pediatric ACLR procedure. All graft types (patellar tendon autograft, hamstrings tendon autograft, and allograft) were included, and meniscus repair or meniscectomy were not considered as exclusion factors. 56 healthy, active individuals were recruited as a control group (age range: 11–23 years; Table 1). Control group participants reported regular participation (≥ 50 hours/year) in cutting and pivoting sports and did not report a history of low back pain or lower limb injury within the last year. The Institutional Review Board approved the protocol for this study, and participants were enrolled only after providing written, informed consent (provided by parents/legal guardians when participants were younger than 18 years old along with participant assent).

2.2 Motion Analysis

Testing Procedure.—Three-dimensional motion analysis was used to calculate trunk kinematic data during a SLL task. A 10-camera motion analysis system (240 Hz cameras; Motion Analysis Corp., Santa Rosa, CA, USA) was used to track 37 retroreflective markers attached to specific locations and anatomical landmarks on the upper and lower extremities and trunk of each participant. These markers were utilized to determine joint centers and segment position, as well as track segment motion during SLL trials (Ford et al., 2003; Ithurnburn et al., 2015; Schmitt et al., 2015). During the SLL task, participants stood on one limb on top of a 31-cm box, and then were instructed to drop off of the box and land on a force plate (1200 Hz; AMTI, Watertown, MA, USA) on that same limb. Participants were required to maintain a controlled landing for at least 3 seconds, and performed three acceptable trials on each limb. The preferred limb of the control participants was defined as the limb that first contacted the force platform most often during three previously performed drop-vertical jump tests (Ford et al., 2018). The SLL task using similar methods has been reported in previous studies to identify landing asymmetries in individuals after ACLR limb (Ithurnburn et al., 2015; Ortiz et al., 2008).

Data Processing.—Specific trunk kinematic variables were calculated during the landing phase of a SLL task using Visual 3D (Version 5.0, C-motion, Inc., Germantown, MD, USA)

and custom-written MATLAB software (Version 7, The Mathworks Inc., Natick, MA, USA). The landing phase was defined as the point of initial contact on the force plate (>10 N) to the lowest point of the body's center of mass (Ithurburn et al., 2015; Schmitt et al., 2015). Lateral trunk stability was quantified as frontal plane trunk excursion (FPTE), and was the sole kinematic variable of interest. FPTE was calculated as the sum of the peak lateral trunk position to the right and to the left during the landing phase of the SLL task for each trial on each limb. The mean of the FPTE values for the involved/nonpreferred limb and uninvolved/preferred limb for the three SLL trials were used to calculate a limb symmetry index (LSI) (Formula 1).

$$LSI = \left(\frac{\text{Involved or nonpreferred limb value}}{\text{uninvolved or preferred limb value}} \right) \times 100\% \quad \text{Formula 1:}$$

2.3 QF and HA Strength Assessment

Quadriceps femoris strength assessment.—QF strength was measured using an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) during a maximal isometric contraction. This methodology is commonplace for quantifying QF strength following ACL injury or ACLR, and provides reliable measurements of strength asymmetries between limbs (Fitzgerald et al., 2003; Ithurburn et al., 2015; Lewek et al., 2002; Schmitt et al., 2012). Participants were positioned in the dynamometer with the hips flexed to approximately 90°, the trunk supported, and the knee flexed to 60°. The knee joint line was aligned with the dynamometer axis, and the resistance pad was secured to anterior aspect of the distal shank. The pelvis and thigh were stabilized with straps. Following 1 practice trial, 3 maximum effort trials (5 seconds in duration separated by 15 seconds of rest) were completed for each knee. For the ACLR group, the uninvolved side was always tested first, and for the CTRL group, the order of testing was randomized. The peak torque value obtained for each limb from the three trials was normalized to body mass (Nm/kg). From the peak torque, quadriceps indices (QI) were calculated (Formula 2).

$$QI = \left(\frac{\text{involved QF peak torque}}{\text{uninvolved QF peak torque}} \right) \times 100\% \quad \text{Formula 2:}$$

Hip abduction strength assessment.—HA strength was also measured using an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA), with the participant standing with the axis of rotation of the testing hip in line with the dynamometer axis. The limb being tested was secured to the dynamometer head with a custom-made attachment and a strap extending from the moving arm positioned around the thigh just superior to the knee. Before performing collected trials, participants were familiarized with how to perform the test and with the testing technique. Participants then performed 5 maximal repetitions at 120°/s, within a range of HA that did not cause lateral trunk compensation during testing. Subjects were also asked to stabilize their trunk position by resting their hands on the dynamometer head during testing. These methods have been described in previous work

(Brent et al., 2013). The peak torque obtained for each limb from the 5 trials was normalized to body mass (Nm/kg), and also used to calculate LSI values (Formula 1).

2.4 Statistical Analyses

IBM SPSS (version 24) software was used to perform statistical analyses, with statistical significance established *a priori* ($\alpha < 0.05$) for all analyses. Demographic and strength data were compared between the ACLR group and the control group using independent t-tests and chi-square tests. To test the hypothesis that lateral trunk instability would be greater in the ACLR group compared to the control group during the SLL task, independent t-tests were performed. The independent variable was the group assignment (ACLR vs. control), and measures of lateral trunk stability (involved limb FPTE, FPTE LSI) were the dependent variables. Linear regression modeling was used to test the second hypothesis that increased lateral trunk instability would be associated with strength deficits in the ACLR group. Separate regressions were performed for involved limb FPTE and FPTE LSI, using involved limb QF peak torque, QI, involved limb HA peak torque, and HA LSI as the independent variables (established *a priori*). Finally, the calculated QI values were used to divide the ACLR group into a high-quadriceps (HQ; QI $\geq 90\%$) and low-quadriceps (LQ; QI $< 85\%$) strength subgroups. These symmetry cutoff values were based on previous similar studies (Ithurburn et al., 2015; Palmieri-Smith and Lepley, 2015; Schmitt et al., 2015, 2012), commonly recommended QF strength values for RTS (QI $> 90\%$) (Lynch et al., 2015), as well as research demonstrating that side-to-side differences in peak QF output of greater than 10% reflect differences in muscle performance beyond measurement error (Sapega, 1990). One-way analysis-of-variance was used to detect the differences in lateral trunk instability between QF strength groups during SLL. Group assignment (HQ, LQ, control) was the independent variable, and measures of lateral trunk instability (involved limb FPTE, FPTE LSI) were the dependent variables. Post hoc testing was performed using pairwise t-tests if significant between-group differences were identified.

3. RESULTS

3.1 ACLR and Control Group Comparisons

The age and sex distribution between the two groups showed no differences (Table 1). During the SLL, the ACLR group demonstrated increased total FPTE when landing on the involved limb compared to the control group (Table 1; $p < 0.001$). Additionally, the ACLR group demonstrated greater FPTE asymmetry compared to the control group (Table 1; $p < 0.001$). Additionally, the ACLR group demonstrated lower QF strength symmetry compared to the control group, while the ACLR group demonstrated greater HA strength symmetry compared to the control group (Table 1; both $p < 0.001$). There were no differences between the group on total FPTE when landing on the uninvolved/preferred limb, nor in involved limb peak QF or HA torque (Table 1; all $p \geq 0.05$).

3.2 Linear Regression

In only the ACLR participants ($n=130$), lower QI was a predictor of greater involved limb FPTE ($R^2: 11.3\%$, $p < 0.001$) (Figure 1A) and FPTE LSI ($R^2: 6.3\%$, $p = 0.004$) (Figure 1B); however, the percent explained variance was small. Likewise, lower involved limb QF peak

torque was a predictor of greater involved limb FPTE (R^2 : 12.7%, $p < 0.001$) (Figure 1C) and FPTE LSI (R^2 : 4.9%, $p = 0.011$) (Figure 1D). While lower involved limb HA peak torque was a predictor of greater involved limb FPTE (R^2 : 4.6%, $p = 0.015$) (Figure 2A) explaining a small percent of variance, it was not a significant predictor of FPTE LSI (Figure 2B). HA LSI was neither a significant predictor of involved limb FPTE (Figure 2C) nor FPTE LSI (Figure 2D).

3.3 QF Strength Group Comparisons

One-way analysis-of-variance revealed group differences in both involved limb FPTE ($p < 0.001$) and FPTE LSI ($p < 0.001$) among the QF strength groups. Post-hoc tests revealed that the LQ group demonstrated greater involved limb FPTE [mean 16.6° (SD 4.3°)] compared to both the HQ group [mean 14.7° (SD 4.5°); $p = 0.049$] and control group [12.9° (SD 3.6°); $p < 0.001$]. Additionally, the HQ group demonstrated greater involved limb FPTE compared to the control group ($p = 0.048$) (Figure 3A). Post-hoc tests also revealed that the LQ group demonstrated greater FPTE asymmetry [mean 155.8% (SD 44.1%)] when compared to both the HQ group [mean 134.7% (SD 47.2%); $p = 0.021$] and control group [mean 105.7% (SD 33.0%); $p < 0.001$]. Additionally, the HQ group demonstrated greater FPTE LSI when compared to the control group ($p = 0.001$) (Figure 3B).

4 DISCUSSION

The purpose of this study was to examine the presence of lateral trunk instability in young individuals at the time of RTS after ACLR, and determine its relationship to QF and HA strength. The results support our first hypothesis that individuals in the ACLR group would demonstrate greater lateral trunk instability during landing than those individuals in the healthy control group. Specifically, the ACLR group demonstrated greater total FPTE when landing on the involved limb as well as greater FPTE limb asymmetry compared with those in the control group. The results also supported our second hypothesis that lateral trunk instability would be related to QF and HA muscle strength deficits. Involved limb QF peak torque and QF strength symmetry (as measured by QI) were both stronger predictors of lateral trunk instability than any of the HA strength measures; although the percent variance explained by any variable was small. Regarding our third hypothesis evaluating the effects of QF strength on lateral trunk control, individuals after ACLR who had greater QF strength asymmetry (LQ group) were found to have greater lateral trunk instability compared with both the HQ and control groups. Interestingly, the HQ group also demonstrated significantly greater lateral trunk instability when compared with the control group.

Suboptimal RTS rates (Ardern et al., 2014) and re-injury rates as high as 29.5% in young athletic individuals following ACLR (Paterno et al., 2015) necessitate detailed examination of biomechanical factors associated with ACLR outcomes. While increased trunk flexion during SLL tasks after ACLR has been identified in several previous studies (Ithurburn et al., 2015; Oberländer et al., 2013, 2012), to our knowledge, trunk adaptations in the frontal plane during SLL following ACLR have not been previously examined. To address this, FPTE was chosen as a variable of interest in the current study. Previous studies have shown that decreased lateral trunk control was a risk factor for sustaining an initial knee injury

(Hewett et al., 2014; Zazulak et al., 2007). Specifically, a prospective study of 277 collegiate athletes by Zazulak and colleagues (Zazulak et al., 2007) found that the strongest predictor of ligament injuries was lateral trunk displacement ($P=0.009$). Likewise, lateral trunk movement and knee abduction loading patterns may be related, and a potential mechanism for sustaining noncontact ACL injuries (Hewett et al., 2014, 2005). In the current study, increased lateral trunk instability was observed after ACLR in individuals who had been cleared for RTS. ACLR participants exhibited on average 2.8° more involved limb FPTE and 37.2% greater asymmetry of FPTE between limbs (greater lateral trunk deviation when landing on the involved limb) when compared to control participants. Although these values were determined to be statistically different between the groups, the clinical significance of the difference on the risk of a 2nd ACL injury and other outcomes after ACLR is unknown.

Previous studies have identified a consistent association between QF strength deficits and altered movement mechanics after ACLR (Bush-Joseph et al., 2001; Ithurnburn et al., 2015; Lewek et al., 2002; Oberländer et al., 2013; Palmieri-Smith and Lepley, 2015; Schmitt et al., 2015). Unlike in previous studies, QF strength was used in this study to explain variation in movement mechanics in the frontal plane, as opposed to the sagittal plane (Bush-Joseph et al., 2001; Ithurnburn et al., 2015; Lewek et al., 2002; Oberländer et al., 2013; Palmieri-Smith and Lepley, 2015; Schmitt et al., 2015). The percent of variance explained by any QF and HA strength variable was small. Interestingly, QF strength measures, typically considered muscles operating in the sagittal plane, were predictors of lateral trunk instability, and were also stronger predictors than HA strength measures. One potential explanation of this result may be that knee joint stiffness during SLL in those with QF strength deficits might create a larger hip joint reaction force lateral to the trunk, requiring lateral trunk compensation (Ithurnburn et al., 2015). Importantly, the small R^2 values observed indicate that other factors influence FPTE beyond only measures of muscle strength. When the ACLR group was subdivided into HQ and LQ groups, and compared with controls for between-group differences, the association between QF strength symmetry and lateral trunk control was further elucidated. As seen in previous studies (Ithurnburn et al., 2015; Palmieri-Smith and Lepley, 2015; Schmitt et al., 2015, 2012), individuals in a LQ group (QI = 85%) exhibited more asymmetric movement than the HQ group and control groups with greater FPTE in the LQ group when landing on the involved limb. These results illustrate the clinical importance of attaining symmetric QF strength at the time of RTS to ensure normalized lower limb and trunk movement patterns during landing tasks. While previous studies have identified HA strength deficits as a potential risk factor of knee injury (Myer et al., 2011; Paterno et al., 2010; Petersen et al., 2014), HA strength deficits were only weak predictors of lateral trunk instability and asymmetry in the current study. Potentially, this may be due to HA strength being similar between those after ACLR and healthy control participants, and less affected by surgery and rehabilitation. Additionally, to perform standing HA strength testing, participants are required to kick and mobilize with one leg, while stabilizing with the other side. Thus, this test may not truly isolate HA strength, but rather measure proximal control and stability during testing.

There are several factors to consider when interpreting the results from the current study. First, the young, athletic nature of this cohort may limit the ability to generalize the results of this study to the entire population of individuals after ACLR. As previously mentioned,

the small R^2 values from the linear regression results indicate that other variables likely account for the variation in lateral trunk control, and other variables (ACLR graft type; demographic variables; other clinical factors) were not considered in the current analyses. Specifically, fear of 2nd ACL injury is one of the most commonly reported reasons for not returning to sports (Ardern et al., 2011), and may be associated with altered movement mechanics during SLL, including trunk control. Additionally, the strength measures used in this study were chosen based on previous studies and their potential ability to predict lateral trunk instability. However, other strength deficits (ankle, hamstring, and hip strength) have previously been reported after ACLR (Kline et al., 2017; Nakamura et al., 2002; Petersen et al., 2014; Thomas et al., 2013; Vairo, 2014) and may have been associated with lateral trunk control during landing. Additionally, based on previous studies (Ford et al., 2003; Ithurburn et al., 2015; Schmitt et al., 2015), the landing phase used during SLL was defined as when the center of mass was at its lower vertical position. However, using a longer stance period may have further elucidated group differences in trunk control. Lastly, this study was not designed to determine a specific strength cutoffs to normalize lateral trunk control during landing. However, the results do indicate that strength deficits (QF; and to a lesser degree, HA) are associated with increased trunk instability in the frontal plane. Further study is needed to investigate the persistence of FPTE over time, as well as the association between FPTE and 2nd ACL injury after RTS post-ACLR.

5 CONCLUSION

Young athletes at the time of RTS after ACLR exhibited increased lateral trunk instability and asymmetry during a SLL task when compared with healthy control participants. Lateral trunk instability was weakly associated with QF muscle strength deficits and, to a lesser extent, HA strength deficits. Additionally, the low-QF strength group demonstrated greater lateral trunk instability when compared with both the high-QF strength and control groups. Further investigation is needed to determine if FPTE is associated with the risk of future 2nd ACL injury.

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Highlights

- Young athletes after ACL reconstruction demonstrated increased frontal plane trunk excursion during single-leg landing compared to healthy control participants
- In those after ACL reconstruction, increased frontal plane trunk excursion was weakly associated with quadriceps muscle strength deficits and, to a lesser extent, hip abduction strength deficits
- In those after ACL reconstruction, a low-quadriceps strength group demonstrated greater frontal plane trunk excursion when compared with both a high-quadriceps strength group and the healthy control participants

Figure 1- Scatterplot only in ACLR group (n=130) of (A) involved FPTE vs. quadriceps strength symmetry, (B) FPTE symmetry vs. quadriceps strength symmetry, (C) involved FPTE vs. involved peak quadriceps torque, and (D) FPTE symmetry vs. involved peak quadriceps torque. INV, involved; FPTE, frontal plane trunk excursion; LSI, limb symmetry index

Figure 2- Scatterplot only in ACLR group (n=130) of (A) involved FPTE vs. involved peak hip abduction torque, (B) FPTE symmetry vs. quadriceps strength symmetry, (C) involved FPTE vs. hip abduction strength symmetry, and (D) FPTE symmetry vs. hip abduction strength symmetry. INV, involved; FPTE, frontal plane trunk excursion; LSI, limb symmetry index; HA, Hip Abduction

Figure 3- Boxplot of comparison between control group (n=56), high-quadriceps group (n=67), and low-quadriceps group (n=53) for (A) Involved FPTE and (B) FPTE symmetry. INV, involved; FPTE, frontal plane trunk excursion; QF, quadriceps femoris; CTRL, control; HQ, high-quadriceps; LQ, low-quadriceps; **P< 0.05 for pairwise comparison.

Table 1-
Participant characteristics.

ACLR, anterior cruciate ligament reconstruction; RTS, return to sport; HS, hamstring; BPTB, bone-patellar tendon-bone; Allo, allograft; QF, quadriceps femoris; HA, hip abduction; FPTE, frontal plane trunk excursion; LSI, limb symmetry index; INV, involved; UNINV, uninvolved; SD, standard deviation

	ACLR Group (n=130)	Control Group (n=56)	P value
Age (years)	17.3 (SD 2.4)	17.2 (SD 2.5)	0.840
Sex (n)			
Female	94	41	0.899
Male	36	15	
Graft Type (n)			
HS	65	-	-
BPTB	52	-	-
Allo	13	-	-
Time from ACLR to RTS (months)	8.3 (SD 2.5)	-	-
INV Limb FPTE (°)	15.7 (SD 4.5)	12.9 (SD 3.6)	<0.001
UNINV Limb FPTE (°)	11.6 (SD 3.7)	12.8 (SD 3.6)	0.050
FPTE LSI (%)	142.9 (SD 46.6)	105.7 (SD 33.0)	<0.001
INV Limb Peak Torque (Nm/kg)			
QF	2.36 (SD 0.51)	2.51 (SD 0.54)	0.072
HA	1.09 (SD 0.23)	1.09 (SD 0.21)	0.908
Strength Limb Symmetry Indices (%)			
QF	88.8 (SD 16.1)	99.9 (SD 14.5)	<0.001
HA	101.7 (SD 22.6)	83.9 (SD 5.2)	<0.001