LONGITUDINAL ASSESSMENTS OF BALANCE AND JUMP-LANDING PERFORMANCE IN COLLEGIATE ATHLETES PRE AND POST ACL INJURIES

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The purpose was to quantify the effect of anterior cruciate ligament (ACL) injuries on performance in a lower extremity reaching test and a jump-landing test in collegiate athletes. Eight Division I athletes performed these two tests prior to their ACL injuries. They also performed the reaching test 3 and 6 months after their ACL reconstruction surgeries and the jump-landing test 6 months after their surgeries. Participants demonstrated decreased reaching distances for the injured leg and increased reaching distance asymmetries at 3-month and 6-month post-surgery compared pre-injury (p<.02). Participants also showed increased asymmetries in jumping forces and landing forces at 6-month post-surgery compared pre-injury (p<.03). The findings may help understand the high ACL re-injury rates to both legs and establish guidelines for post-surgery rehabilitation.

KEYWORDS: BIOMECHANICS, FORCE, KINETICS, KNEE.

INTRODUCTION: Approximately 200,000 cases of anterior cruciate ligament (ACL) injuries occur in the United States each year, causing an economic burden up to $17.7 billion annually (Mather et al., 2013). Despite ACL reconstruction and post-surgery rehabilitation, athletes younger than 25 years suffer a 10% re-injury rate to the injured leg and an 11% re-injury rate to the contralateral leg (Wiggins et al., 2016). The extremely high re-injury rate and devastating health consequences posit an urgent need to understand the injury mechanism and develop effective prevention strategies.

Many risk factors have been identified for ACL injuries. Factors such as sex, age, type of sports, and knee geometry could contribute to both primary and secondary ACL injuries. Factors such as surgical techniques and graft strength may be associated with re-injury risk of the injured leg. Individuals following ACL injuries commonly demonstrate decreased strength and balance performance and increased strength and balance asymmetries compared to matched controls (Clagg et al., 2015; Schmitt et al., 2015). In addition, these patients tend to load the contralateral leg more to complete athletic tasks such as double-leg jump-landings (Dai et al., 2014). Whether these asymmetries exist prior to the injury or result from the injury and how they may affect ACL re-injury risk, however, is unclear.

One study compared military cadets' jump-landing mechanics between pre-injury assessments and 21 months following ACL reconstruction and found that both the injured and non-injured knees demonstrated increased hip adduction and knee abduction after the injury (Goerger et al., 2015). This study, however, was limited to quantifying landing biomechanics for either the injured or the non-injured leg without assessing bilateral asymmetries. Understanding how an ACL injury may affect strength, balance, and jump-landing asymmetries may provide additional information for understanding the high ACL re-injury rates to both legs. Meanwhile, recent studies have questioned the use of the non-injured leg as a reference to guide the rehabilitation of the injured leg for patents following ACL injuries, as the non-injured leg could demonstrate decreased performance compared to matched controls as well as its own performance before the reconstruction but after the injury (Wellsandt et al., 2017). Pre-injury assessments will help establish more accurate reference data to identify the changes in both injured and non-injured legs and provide information for guiding rehabilitation and return-to-play.

Therefore, the purpose of this study was to quantify the effect of an ACL injury and reconstruction on performance and bilateral asymmetries in a lower extremity reaching test and a countermovement jump-landing test in collegiate athletes. It was hypothesized that participants would demonstrate decreased reaching distances for both injured and non-injured legs as well as increased bilateral asymmetries three months and six months after the ACL reconstruction compared to pre-injury assessments. It was also hypothesized that participants would have decreased jump height, peak jumping forces, and peak landing forces for both injured and non-injured legs as well as increased bilateral asymmetries in jumping forces and landing forces six months after the ACL reconstruction compared to pre-injury assessments.

METHODS: The current study was a continuation of a previous study, in which approximately 500 collegiate athletes from a National Collegiate Athletic Association Division I university performed baseline assessments (Dai et al., in press). In the follow-up, 8 athletes (five men's American Football, one women's soccer, one women's basketball, and one women's volleyball; baseline age: 19.4 ± 1.2 years; baseline height: 1.83 ± 0.10 m; baseline mass: 85.2 ± 16.5 kg) suffered ACL injuries and were included in the current study. Individuals were excluded if they (a) were less than 18 years old at the baseline assessment, (b) had a major lower extremity injury at the baseline assessment, (c) possessed any conditions that prevented them from performing the tests, or (d) were pregnant. The University of Wyoming Institutional Review Board approved this study. Participants signed informed consent forms for both baseline and post-surgery assessments.

For 7 athletes, the post-surgery assessment was performed after their primary ACL injuries. One athlete suffered two ACL injuries to the same knee after the baseline assessment, and the post-surgery assessment was performed after the second ACL surgery. The time between their ACL injuries and ACL reconstruction was 0.84 ± 0.68 months. The time between their baseline assessments and ACL reconstruction was 11.3 ± 5.2 months. Participants performed the lower extremity reaching test 3 months (3.15 ± 0.44 months) after surgeries, and both the lower extremity reaching and countermovement jump-landing tests 6 months (6.25 ± 0.97 months) after surgeries. All participants were treated with a standard rehabilitation program under the direction of team physicians and athletic trainers.

Participants wore their own athletic shoes and attire during data collection and performed their self-selected warm-up activities. A Y-balance apparatus (Move2Perform, Evansville, IN, USA) was used to record reaching distances in the lower extremity reaching test (Figure 1) (Dai et al., 2018). Participants stood on the testing leg and reached anteriorly with the free leg. Participants could move their bodies as well as lift the heel of the testing leg as long as they maintained balance, but they could not touch the top of the box or the ground. A minimum of 3 practice and 3 official trials were performed for each leg. The right leg length was measured from the anterior superior iliac crest to medial malleolus.

Two force platforms (Bertec, Columbus, OH, USA) were used to collect bilateral vertical ground reaction forces at a sampling frequency of 1000 Hz in the countermovement jump-landing test (Figure 2) (Dai et al., 2018). Participants started with each foot on a force platform with feet shoulder-width apart. Participants lowered the body and jumped vertically as high as possible with an arm swing and landed with each foot on a force platform. A minimum of 1 practice and 3 official trials were performed.

For the reaching tests, the greatest reaching distance of 3 trials was used and normalized to the leg length for analysis. For the jump-landing test, the average of 3 trials was used for analysis. Jump height was calculated from the take-off velocity quantified using the impulse-momentum theorem. The peak forces for each leg during the jumping and landing phases were extracted and normalized to body weight (Figure 3). Bilateral asymmetry index was calculated for bilateral reaching distances, peak jumping forces, and peak landing forces as: (non-injured side – injured side) / (larger value of the two sides). As such, positive numbers indicate the non-injured side has greater distances or forces while negative numbers indicate the injured side has greater distances or forces.

For the reaching test, dependent variables were compared among the three time points (pre-injury, 3-month post-surgery, and 6-month post-surgery) using repeated measures analyses of variance, followed by paired t-tests ($\alpha = .05$). For the jump-landing test, dependent variables were compared between pre-injury and 6-month post-surgery using paired t-tests.

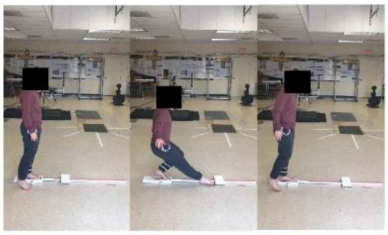

Figure 1. Lower extremity reaching test.

Figure 2. Jump-landing test.

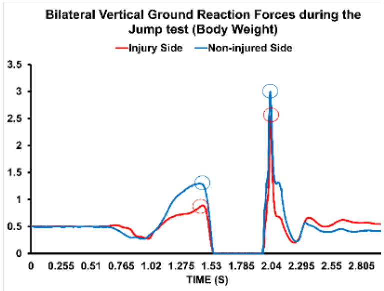

Figure 3. Vertical forces during a jump-landing.

RESULTS: Participants demonstrated decreased reaching distances for the injured leg and increased reaching distance asymmetries at 3-month and 6-month post-surgery compared pre-injury (Table 1, $p<.02$). Participants showed increased asymmetries in jumping forces and landing forces at 3-month and 6-month post-surgery compared pre-injury (Table 2, $p<.03$).

Table 1. Means ± standard deviations of reaching distances and asymmetries

	Pre-injury	3-month post-surgery	6-month post-surgery
Non-injured leg reaching distance (leg length)	0.72 ± 0.09	0.72 ± 0.07	0.72 ± 0.10
Injured leg reaching distance (leg length)	0.71 ± 0.07 ^{A}	0.60 ± 0.10 ^{B}	0.65 ± 0.07 ^{B}
Reaching distance asymmetry (%)	0.00 ± 0.05 ^{B}	0.16 ± 0.11 ^{A}	0.10 ± 0.06 ^{A}

Note: significant effects of time points were indicated by superscript, where A > B

Table 2. Means ± standard deviations of jumping and landing forces and asymmetries

	Pre-injury	6-months post-surgery
Jump height (m)	0.40 ± 0.08	0.36 ± 0.14
Non-injured leg jumping force (body weight)	1.36 ± 0.17	1.39 ± 0.15
Injured leg jumping force (body weight)	1.35 ± 0.20	1.19 ± 0.22
Jumping force asymmetry (%)	0.01 ± 0.07 ^{B}	0.15 ± 0.09 ^{A}
Non-injured leg landing force (body weight)	2.66 ± 0.59	2.99 ± 0.93
Injured leg landing force (body weight)	2.91 ± 0.50	2.29 ± 1.06
Landing force asymmetry (%)	-0.08 ± 0.16 ^{B}	0.24 ± 0.24 ^{A}

Note: significant effects of time points were indicated by superscript, where A > B

DISCUSSION: The purpose was to quantify the effect of an ACL injury and reconstruction on performance and bilateral asymmetries in a balance test and a jump-landing test in collegiate athletes. The findings support the hypothesis that ACL injuries would increase bilateral asymmetries in reaching distances, jump forces, and landing forces. The asymmetries after surgeries were consistent with previous studies, showing increased asymmetries in a variety of dynamic tests for injured athletes compared to matched controls (Dai et al., 2014; Schmitt et al., 2015). Meanwhile, participants showed relatively small asymmetries before their ACL injuries, especially for reaching distances and jumping forces. Therefore, the great asymmetries following surgeries were likely the consequences of the injuries instead of being present prior to the injuries. The increased asymmetries following injuries were mainly caused by the decreased performance of the injured leg. Significant decreases in reaching distances were observed for the injured leg. Jumping and landing forces also tended to decrease for the injured leg, although these changes were not statistically significant likely due to a small sample size. The findings may provide insight into understanding the high ACL re-injury rates to both legs. For the injured leg, the decreased strength and balance could result in abnormal movement controls during athletic tasks and increase its re-injury risk. On the other hand, for the non-injured leg, the inter-limb compensatory strategies could increase its loading during athletic tasks and elevate its risk of injury.

The findings may also provide information for post-surgery rehabilitation. First, as participants demonstrated small asymmetries before the injury, the findings support the general notion of using 10% as a goal of rehabilitation and a return-to-play criterion (Wellsandt et al., 2017). A small asymmetry, however, could be achieved by decreased performance of both the injured and non-injured sides, so it's important to include performance measurements (Wellsandt et al., 2017). Since minimal changes were observed for reaching distances of the non-injured leg between pre-injury and 3-month post-surgery, the non-surgical leg's performance at this time point might be used as a reference for training the injured leg for this specific balance test. In addition, participants on average achieved 90% of their jump height at 6-month post-surgery compared to pre-injury, suggesting a good recovery of overall jump performance in this population. Meanwhile, as relatively large variations were observed in changes of jump performance and jump and landing forces between pre-injury and 6-month post-surgery, baseline assessments prior to potential ACL injuries are encouraged to establish an individual's pre-injury data for guiding post-injury rehabilitation.

CONCLUSION: ACL injuries increased balance and jump-landing asymmetries in collegiate athletes. The decreased performance of the injured leg and the inter-limb compensatory strategy to load the non-injured leg might contribute to the high ACL re-injury rates to both legs. Normalizing asymmetries to be less than 10% or lower should be encouraged in post-surgery rehabilitation. While the performance of the non-injured leg at certain time points might be used as a reference for training the injured leg, baseline assessments prior to potential ACL injuries should be considered for establishing an individual's pre-injury data.

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ACKNOWLEDGEMENTS: This study was supported by research grants from the College of Health Sciences and the Research Office at the University of Wyoming. Jacob Layer's graduate assistantship was provided by a grant from the National Institute of General Medical Sciences (P20GM103432) from the National Institutes of Health.