

Original Research

No Difference in Static Postural Stability Bilaterally or Versus Control at 12 Weeks after Anterior Cruciate Ligament Reconstruction

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Background

Comparing static postural stability between the involved and uninvolved legs in individuals 12 weeks after ACL reconstruction (ACLR), and against healthy controls, may provide insight into rehabilitation progression.

Purpose

To compare static single-leg postural stability between the injured and uninjured legs of individuals 12 weeks post ACLR, and to a control group of healthy, physically active individuals.

Study Design

Case-control study

Methods

Twenty-nine participants (17 male, 12 female; age = 20.9 ± 5.0) 12 weeks post ACLR and 87 healthy controls (51 male, 36 female; age = 19.4 ± 1.2) volunteered. Static single-leg postural stability was assessed using an AMTI force plate under eyes open (EO) and eyes closed (EC) conditions. Ground reaction force in three directions were recorded for each condition. Comparisons were made between the ACLR group and controls, as well as between the involved and uninvolved legs within the ACLR group. Descriptive statistics were calculated for each variable. Kruskal-Wallis and Wilcoxon signed rank tests identified significant differences, and effect sizes were computed.

Results

There were no significant differences within the ACLR group or between the ACLR and control groups for any static postural stability variable.

Conclusions

Under the specific static postural stability test administered, individuals 12 weeks post ACLR did not show significant differences in static postural stability between their involved and uninvolved legs, or when compared to healthy controls. These findings suggest that static postural stability is either not significantly impacted by ACLR or that deficits resolve by 12 weeks post-surgery and may not need to be a primary focus of early

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rehabilitation. Alternatively, it is also possible that the challenge imposed in the current study was not sufficient to challenge the components required for postural stability and clinicians should consider integrating more difficult tasks.

Level of Evidence

3

INTRODUCTION

Injuries to the anterior cruciate ligament (ACL) are common in the athletic population, impacting athletes from various sports, ages, and levels of competition.¹⁻⁵ Despite advancements in injury prevention, athletes remain at a higher risk of injury compared to non-athletic individuals.^{6,7} Furthermore, athletes who have undergone ACL reconstruction (ACLR) are not guaranteed to return to their pre-injury activity levels, with an average of 65% returning to preinjury level, and 19% not returning to sport at all.⁸⁻¹⁰ While there are various reasons why an individual may not return to sport,^{11,12} a quality rehabilitation progression following ACLR is beneficial for getting athletes back to sport participation.^{13,14} However, even for those who return to sport (RTS) and pre-injury levels of activity, the risk of a second ACL injury is high.¹⁵⁻¹⁷ Up to 29% of individuals may sustain a second ACL injury within two years of RTS, and the risk is highest for younger athletes (i.e., under the age of 25) and those returning to a high level of competition.^{15,16} Given the high rates of dropout and reinjury following ACLR it is important to determine the best and most efficient rehabilitation process to prepare athletes for safe return to activity and sport.

Despite ACLR epidemiology being well documented, the rehabilitation process that follows ACLR is more nuanced and multifactorial. Protocols and recommendations after ACLR are both incredibly comprehensive and far from standardized. Over the past decade there have been several attempts to synthesize and recommend a standard of care following ACLR.^{13,14,18-22} One goal of the early stages of rehabilitation is restoring preinjury postural stability and proprioception. Proprioceptive training can have a positive impact on single leg stability, which is vital because a lack of postural stability can impact the ability to load the knee during walking and running tasks.^{23,24} There are few studies that have assessed postural stability during the early phases of rehabilitation, and those that have primarily focused on comparing the effectiveness of different rehabilitation approaches on clinical outcomes.²⁵⁻²⁸ As expected, double leg and single leg static postural stability is diminished immediately following surgery,²⁶ but incorporating proprioceptive exercises early in the rehabilitation program can result in better postural stability three months following surgery compared to waiting 30-45 days following surgery to begin these types of exercises.²⁵

Even though balance and proprioceptive exercises are a component of early rehabilitation, there is a lack of evidence classifying the length of time after ACLR to when postural stability is restored. Therefore, the purpose of this study was to compare static single-leg postural stability between the injured and uninjured legs of individuals 12

weeks post ACLR, and to a control group of healthy, physically active individuals. It was hypothesized that the ACLR leg would exhibit worse postural stability compared to the uninjured leg and the dominant leg of the control group. This research can be useful for rehabilitation professionals because it will give insight into static postural stability during a critical time point in the rehabilitation process. If there is a significant deficit in postural stability at 12 weeks post ACLR, the results can help emphasize the need for restoring static postural stability earlier in rehabilitation.

METHODS

PARTICIPANTS

A total of 116 subjects (68 males and 48 females) were recruited from a single institution and assigned to one of two groups: individuals 12 weeks post ACLR and healthy control. ACLR subjects were eligible if they were 12 years or older and had undergone primary ACLR performed by group of fellowship trained orthopaedic surgeons with similar protocols for rehabilitation. Recruitment for the ACLR group occurred between August 2018 and December 2019. Subjects were screened based on inclusion and exclusion criteria, contacted initially via email, and followed up with a phone call two weeks later. Exclusion criteria for the ACLR group included the presence of additional lower extremity injuries in either leg, lack of clearance for performance of single-leg balance exercises or not being at the 12-week postoperative time point. Control group data were sourced from multiple prior injury prevention and risk assessment studies involving athletes that included the balance testing protocol. Control subjects were excluded if they had a history of ACL injury or current lower extremity injury. Although not part of the exclusion criteria, the final control sample had no history of a grade 2 or higher sprain of the MCL, PCL or LCL, and no history of lower extremity surgery, back surgery, or concussion. All subjects provided informed consent prior to participation, and the study was approved by the university's institutional review board. Subject demographic details are presented in [Table 1](#).

INSTRUMENTATION

Static postural stability data were collected using a single AMTI force plate (Advanced Medical Technology Inc, type-BP600900 Watertown, Ma) with a sampling frequency of 1000Hz. Vicon Nexus Software (version 2.8.1, Vicon, Centennial, CO) was used to process and analyze the AMTI data.

Table 1. Participant Demographics

	Age (years)	Mass (kg)	Height (cm)
	Mean (SD)	Mean (SD)	Mean (SD)
ACLR Group			
Females (n=12)	20.2 (4.2)	71.0 (19.2)	166.4 (9.1)
Male (n=17)	21.5 (5.6)	80.7 (16.6)	178.7 (4.4)
Total (n=29)	20.9 (5.0)	76.7 (18.1)	173.6 (9.1)
Control Group			
Females (n=36)	19.4 (1.1)	66.1 (8.8)	171.5 (9.2)
Male (n=51)	19.4 (1.3)	81.5 (12.7)	185.5 (8.9)
Total (n=87)	19.4 (1.2)	75.1 (13.5)	179.7 (11.3)

Abbreviations: SD = standard deviation, n = sample size

PROCEDURES

All subjects completed a single leg balance (SLB) test bilaterally to assess postural stability under two conditions: eyes open (EO) and eyes closed (EC). The testing protocol was based on Goldie et al.^{29,30} The protocol's reliability and validity have been previously established.²⁹⁻³¹

In both the EO and EC conditions, subjects assumed a single-leg stance position with their hands on their hips and the non-stance leg flexed at the hip and knee to bring their foot to the same height as the mid-calf of the stance leg, without contacting the stance leg. In the EO condition, subjects were instructed to focus on a circular, green marker at eye level approximately three meters in front of them for the duration of each trial. For the ACLR group, subjects performed the SLB task on their uninvolved leg first, and in the control group subjects performed the task on their dominant leg first. Leg dominance was determined based on subject self-report prior to testing. If there was a loss of balance at any point during the trials, subjects were allowed to touch their non-stance leg down to the force plate to regain their balance but asked to assume the SLB position again as quickly as possible. Following one practice trial, three ten second trials of each leg and condition were collected for data analysis. Trials were repeated if the subject shifted their stance foot on the force plate, made contact between their non-stance and stance leg, or if the non-stance leg touched down off the force plate.

DATA REDUCTION

Data were processed using a MATLAB script file (Mathworks, v7.0.4, Natick, MA) and processed through a dual pass fourth order low pass Butterworth filter with a frequency cutoff at 20Hz. Standard deviations for ground reaction force (GRF) in the anterior-posterior (A-P), medial-lateral (M-L) and vertical (V) directions were calculated.^{29,30}

STATISTICAL ANALYSIS

The GRF data were used to examine postural stability through two comparisons: (1) compare GRF variables between the involved and uninvolved legs in the ACLR group,

(2) compare GRF variables of the involved leg ACLR group to the dominant leg of the control group. Data from the non-dominant leg in the control group was not included in this analysis.

Descriptive statistics were calculated for each postural stability variable (EO A-P, EO M-L, EO V, EC A-P, EC M-L, EC V) and assessed for normality using a Shapiro-Wilk test. Because the data for each leg and variable were not normally distributed, Kruskal-Wallis and Wilcoxon signed rank tests were used to identify statistically significant differences in static postural stability for each of the conditions. Effect sizes (Hedges's *d*) were calculated for each comparison. An effect size of 0.2 is considered small, 0.5 is considered moderate, and values greater than 0.8 are considered large.³² Statistical analysis was performed using Stata (Version 17, StataCorp, College Station, TX).

RESULTS

In the ACLR group, there was no significant difference in static postural stability between the involved and uninvolved legs for any variable testing condition (Table 2).

Higher GRF scores for each variable indicate worse postural stability. Postural stability during EO conditions was slightly better than EC conditions for all three directional variables, and GRF was highest in the V direction and lowest in the A-P direction for both conditions and legs. Furthermore, no significant difference was found comparing the involved leg of the ACLR group to the dominant leg of the control group (Table 3).

DISCUSSION

The aim of this study was to compare single-leg static postural stability within a population who were 12 weeks post ACLR to a healthy control group. Understanding postural stability during early rehabilitation is crucial, as it can provide insights into recovery progression and inform decisions about readiness for increased physical activity. The findings suggest that static postural stability is not significantly impaired at 12 weeks post ACLR. This may indicate that any deficits in static postural stability are resolved

Table 2. Differences in GRF between ACLR involved and uninvolved legs

Variable	ACLR Involved Leg		ACLR Uninvolved Leg		p-value	Effect size
	Mean (SD)	M	Mean (SD)	M		
EO A-P	2.86 (1.51)	2.42	2.87 (0.81)	2.85	0.355	0.013
EO M-L	4.18 (3.17)	3.06	4.01 (2.30)	3.31	0.484	0.059
EO V	8.48 (13.73)	5.52	5.34 (2.09)	4.79	0.519	0.315
EC A-P	5.35 (1.93)	5.83	5.69 (1.76)	6.02	0.401	-0.186
EC M-L	8.25 (4.15)	8.30	9.14 (3.66)	8.64	0.519	-0.259
EC V	11.83 (5.34)	11.55	11.54 (4.28)	11.57	0.907	0.061

Abbreviations: SD = standard deviation, M = median

Table 3. Differences in GRF between ACLR and control groups

Variable	ACLR Group		Control Group		p-value	Effect size
	Mean (SD)	M	Mean (SD)	M		
EO A-P	2.86 (1.51)	2.42	2.83 (1.35)	2.50	0.926	0.041
EO M-L	4.18 (3.17)	3.06	3.36 (1.77)	3.01	0.458	0.372
EO V	8.48 (13.73)	5.52	6.08 (9.86)	4.59	0.198	0.165
EC A-P	5.35 (1.93)	5.83	6.08 (2.40)	5.50	0.286	-0.318
EC M-L	8.25 (4.15)	8.30	9.89 (4.70)	8.39	0.255	-0.373
EC V	11.83 (5.34)	11.55	12.91 (6.71)	11.34	0.723	-0.167

Abbreviations: SD = standard deviation, M = median

by this stage of rehabilitation. Alternatively, it is possible that the testing protocol used in this study did not sufficiently challenge the components necessary to detect subtle deficits.

Previous research has shown that proprioception and postural stability deficits are common in individuals with ACL injuries and may persist after reconstruction.^{25,33-37} However, relatively few studies have examined static postural stability during the early phases of rehabilitation, and methodological inconsistencies across studies have led to conflicting results regarding the duration and extent of these deficits.

In the current study, no statistically significant differences in static postural stability were found at 12 weeks post ACLR either between the legs of the surgical group or compared to healthy controls. However, comparisons with previous literature reveal mixed results. For instance, Mohammadi et al.,³⁸ Bonfim et al.,³⁹ and Dauty et al.²⁶ reported differences in static postural stability in athletes following ACLR. Mohammadi et al.³⁸ observed increased postural sway at eight months post-surgery using both rigid and foam surfaces, and a semi-flexed knee position, which may have presented a greater challenge than the extended knee position used in the current study. Dauty et al.²⁶ assessed subjects just 15 days post ACLR and found differences in SLB with EO between ACLR subjects and controls, but not between involved and uninvolved legs. In EC conditions, only a small percentage of ACLR subjects could complete the test with an extended knee, suggesting the protocol may have been too difficult at that early stage.²⁶ A systematic review and meta-analysis by Lehmann et al.⁴⁰

found greater postural sway in ACLR involved legs compared to uninvolved legs and healthy controls, particularly in the A-P and M-L directions. However, nearly half of the participants in that review were treated conservatively (i.e., ACL-deficient), and those treated operatively had varied timelines from surgery to testing, often several months to years, when full return to activity is expected.

Conversely, the current findings align with studies by Henriksson et al.,⁴¹ Hoffman et al.,⁴² and Mattacola et al.,⁴³ which reported no significant differences in static postural stability between involved and uninvolved legs following ACLR. However, methodological differences complicate direct comparisons. For example, Henriksson et al.⁴¹ and Mattacola et al.⁴³ used different technologies to assess stability, each with unique scoring systems. Additionally, these studies assessed postural stability at time points after RTS, whereas the current study evaluated participants earlier in the rehabilitation timeline.⁴¹⁻⁴³ None of these previous studies specifically aimed to identify the time point at which static postural stability normalizes following ACLR. These methodological differences collectively limit the ability to make direct comparisons between the current study and existing literature.

Another key distinction in this study is the focus on single-leg static postural stability. It is possible that maintaining single-leg stance, whether with EO or EC, does not sufficiently challenge physically active individuals, limiting the sensitivity of the test to detect subtle deficits. Additionally, the simplicity of the balance protocol may have led to a ceiling effect, making it difficult to observe meaningful differences between groups. Understanding postural

stability during early rehabilitation is important for guiding progression into more advanced physical activity and sport participation. However, the results of this study suggest that static postural stability may not need to be a primary focus at 12 weeks post-surgery. Clinicians might consider incorporating more cognitively demanding or dynamic tasks to better assess and challenge postural stability.

This study has several limitations. It relied on a convenience sample from a single institution and assessed a single measure of postural stability, which may not have captured the full scope of postural stability. Additionally, the relatively small ACLR sample size and effect sizes may reflect the statistical power of the findings. The absence of comparisons to earlier time points post-surgery and pre-surgery also limits the ability to assess changes over time or generalize the results to individuals recovering from other orthopedic procedures. Without pre-injury or immediate post-surgery data, it is unclear whether postural stability in the ACLR group changed over time. Based on previous literature, postural stability is typically worse immediately after injury and reconstruction^{26,33,34,36} and may even be a risk factor for non-contact ACL injury.^{44,45} It is reasonable to surmise that postural stability was restored by 12 weeks through standard rehabilitation, but definitive conclusions are unable to be made. Further research should evaluate more demanding static balance tasks, potentially incorporating neurocognitive elements, to better evaluate postural stability and its relevance to rehabilitation outcomes.

CONCLUSION

In this study, individuals 12 weeks post ACLR did not show significant differences in static postural stability between their involved and uninvolved legs, or when compared to healthy controls. However, due to the absence of baseline data prior to surgery and immediately afterward, it remains unclear whether any initial deficits were present and subsequently resolved during early rehabilitation. While it is plausible that standard rehabilitation restored postural stability by the 12-week mark, this cannot be confirmed definitively. From a clinical perspective, these findings suggest that static postural stability may not require emphasis in rehabilitation at this stage of recovery. Instead, clinicians may benefit from using dynamic or cognitively challenging assessments to more effectively evaluate and target postural stability following ACLR.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to report.

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