Negative Effects on Postural Control After Anterior Cruciate Ligament Reconstruction as Measured by the Balance Error Scoring System

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Context: Anterior cruciate ligament (ACL) reconstruction is the standard of care for individuals with ACL rupture. Balance deficits have been observed in patients with ACL reconstruction (ACLR) using advanced posturography, which is the current gold standard. It is unclear if postural-control deficits exist when assessed by the Balance Error Scoring System (BESS), which is a clinical assessment of balance. Objective: The purpose of this study is to determine if postural-control deficits are present in individuals with ACLR as measured by the BESS. Participants: Thirty participants were included in this study. Fifteen had a history of unilateral ACLR and were compared with 15 matched controls. Interventions: The BESS consists of 3 stances (double-limb, single-limb, and tandem) on 2 surfaces (firm and foam). Participants begin in each stance with hands on their hips and eyes closed while trying to stand as still as possible for 20 s. Main Outcome Measures: Each participant performed 3 trials of each stance (18 total), and errors were assessed during each trial and summed to create a total score. Results: We observed a significant group × stance interaction (P = .004) and a significant main effect for stance (P < .001). Post hoc analysis revealed that the ACLR group had worse balance on the single-leg foam stance than did controls. Finally, the reconstructed group had more errors when total BESS score was examined (P = .02). Conclusions: Balance deficits exist in individuals with ACLR as measured by the BESS. Total BESS score was different between groups. The only condition that differed between groups was the single-leg stance on the unstable foam surface.

Keywords: postural sway, BESS, static balance, knee injury

Injuries to the anterior cruciate ligament (ACL) continue to be a major health care concern that has serious long-term consequences well after surgery.1 It is estimated that 250,000 ACL ruptures occur in the United States each year,2 and as efforts to increase physical activity continue, it is likely that the number of ACL injuries will continue to be problematic. ACL rupture compromises the ligament’s primary function as a mechanical restraint.3 Additionally, rupture impairs motor control and coordination of muscles surrounding the knee by disrupting neural-feedback loops related to joint-position sense and movement.4-10 Surgical reconstruction of the ACL is effective at restoring the mechanical stability of the knee,11-13 but the extent to which neurologically connections of the mechanoreceptors and other proprioceptive mechanisms are restored is unclear.8,14 Initial injury to the ACL and subsequent reconstruction are potential risk factors for ligament reinjury or contralateral primary injury, as recent literature has observed high rates of second ACL injury (retear as well as contralateral) that are much higher than previously thought.15,16

Balance deficits have been identified in individuals after ACL reconstruction (ACLR) using instrumented testing devices. Bonfim et al14 used a force platform and observed greater sway when ACLR participants stood on their reconstructed limb compared with a healthy control group. In addition, they observed decreased joint-position perception, higher threshold for detection of passive motion, and increased hamstring latency in reconstructed limbs.14 Poor postural stability on the reconstructed limb predicts second ACL injury, as assessed by the Biodex SD.16 Finally, a recent systematic review concluded that postural control tends to be worse after ACLR.6 The review focused on instrumented testing devices that are costly and not readily available to clinicians.6 Clinical assessments of balance should be investigated to determine if they have similar construct validity as instrumented testing (ie, can they discriminate between different populations with known conditions such as ACLR?).17

Balance is essential to successful completion of any activity including basic activities of daily living, as well as sport. Assessment of balance traditionally takes place using expensive and time-intensive instrumented devices such as force plates. The Balance Error Scoring System (BESS) is a simple and cost-effective tool used
to objectively assess balance using a minimal amount of equipment. The BESS is a reliable,\textsuperscript{17,18} and valid,\textsuperscript{19} assessment of static balance that has been used in a variety of conditions including after sport-related concussion,\textsuperscript{20–23} functional ankle instability,\textsuperscript{24} and in community-dwelling adults.\textsuperscript{25} However, the ability of the BESS to assess balance in individuals with ACLR has yet to be investigated.

If balance deficits are not addressed during rehabilitation it is possible they will continue to persist and may lead to a higher risk of injury.\textsuperscript{16,26} This is especially important for ACLR individuals due to the reported high rate of second ACL rupture.\textsuperscript{15,16} The purpose of this study was to determine if postural control deficits are present in individuals with ACLR as measured by the BESS. We hypothesized that individuals with ACLR would commit more errors on the BESS than would healthy controls.

Methods

Participants

A total of 30 participants volunteered for these studies, who were divided into 2 groups based on their history of ACLR (ACLR age 19.2 ± 1.4 y, height 170.5 ± 4.1 cm, mass 70.8 ± 11.4 kg; control age 20.2 ± 1.7 y, height 166.5 ± 7.5 cm, mass 64.8 ± 8.3 kg). Mean time from surgery for the ACLR group was 34.8 ± 16.9 months. To qualify for the ACLR group, participants had to be women age 18 to 25 years, be free of lower extremity injury for the past 3 months, have a unilateral noncontact or indirect ACL tear that was reconstructed (8 bone-tendon-bone autografts, 5 semitendinosus-gracilis autografts, and 2 allografts), completed a standard rehabilitation program, be cleared by their physician to return to all levels of physical activity, and have no previous history of other lower extremity surgery. Control participants were matched by age and gender and had to be free of lower extremity injury for the past 3 months. Only women were included in this study because they suffer noncontact ACL injuries at higher rates than men\textsuperscript{27} and thus were more likely to meet all of the inclusion criteria.

All participants read and completed an approved consent form before participation, which was approved by the university’s institutional review board before testing. An a priori power analysis was performed using the effect sizes from previous studies that used the BESS as a dependent variable.\textsuperscript{17,18,24} This analysis indicated that a minimum of 9 participants per group would result in 80% power (alpha < .05) to detect balance differences between groups.

Procedures

Postural control was assessed in all participants using the BESS. The BESS consists of 3 stances on 2 surfaces, which create 6 unique testing conditions (double-leg firm, single-leg firm, tandem firm, double-leg foam, single-leg foam, and tandem foam). Each participant completed 3 trials of each stance (18 trials total) which has better reliability than 1 trial of each BESS stance.\textsuperscript{18} The firm-surface trials were completed on the floor of the laboratory, while the foam trials were completed on medium-density foam (48.5 × 40 × 6.5 cm, Perform Better, Airex Balance Pad, Craston, RI). Participants in the ACLR group stood on their reconstructed limb and control participants stood on their nondominant limb. The dominant limb was defined as the limb used to kick a soccer ball for maximal distance. Participants began each 20-second trial from a standardized position with their eyes closed and their hands on their hips. Errors were counted during each 20-second trial and were defined as opening the eyes, lifting hands off hips, stepping or stumbling out of position, lifting the forefoot or heel, abducting the hip more than 30°, or remaining out of test position for longer than 5 seconds.\textsuperscript{17} Errors were recorded in real time for each stance, and the average was used for analysis by a single investigator (D.R.B.) with 12 years of experience as a certified athletic trainer and researcher. Participants were also videorecorded completing each trial. Recorded conditions were evaluated more than 1 month after initial testing and compared with the live conditions to establish reliability. The investigator had excellent reliability for total score, as well as for each condition (ICC2,1 > .85). A reliability coefficient was not calculated for the double-leg-stance firm condition since no errors were committed.

Statistical Analysis

All statistical analyses were performed using SPSS (version 20, IBM SPSS, Chicago, IL). A group (2 levels: ACLR vs control) by stance (6 levels: 1 for each stance) repeated-measure ANOVA was used to investigate differences in errors between stances, and 95% confidence intervals (CI) were used to identify significant differences between groups and stances. In addition, we used an independent \( t \) test to investigate total BESS score between groups. Alpha was set a priori at .05 for all statistical tests.

Results

We observed a significant group × stance interaction \((F_{5,140} = 3.7, P = .004)\), a significant main effect for group (ACLR 3.0 ± 3.6, control 2.4 ± 2.8; \(F_{1,28} = 6.9, P = .01\)), and a main effect for stance \((F_{5,140} = 248.2, P < .001)\). Post hoc analysis using 95% confidence intervals for the interaction revealed that the ACLR group had worse balance on the single-leg foam stance than the control group (nonoverlapping 95%CI) and all other stances. All other between-groups comparisons were not significant (Table 1). When examining the results for the main effect for stance, none of the 95%CIs for the individual stances overlapped, indicating that all stances were significantly different from one another, with the single-leg foam stance resulting in the most errors. Finally, the independent \( t \) test confirmed our ANOVA findings that total BESS score differed between groups (ACLR 18.3 ± 3.9 errors, control 14.8 ± 3.2 errors; \( P = .02, t_{1,28} = –2.6\)).
Additionally, this stance has resulted in the occurrence of errors during the single-leg stances and stances on foam. This finding is consistent with other studies during rehabilitation.

Clinical decision making and identifying areas of focus to quantify balance, which may be useful to guide setting. The BESS can also be used during rehabilitation as an alternative in the clinical setting of patients with ACLR. Instead, the BESS can be used as an alternative in the clinical setting. The BESS can also be used during rehabilitation to quantify balance, which may be useful to guide clinical decision making and identify areas of focus during rehabilitation.

The ACLR group had more errors on the single-leg foam stance. This finding is consistent with other studies that have used the BESS and reported a larger number of errors during the single-leg stances and stances on foam. Additionally, this stance has resulted in the occurrence of errors in fatigued and healthy populations. The only previous study to examine the influence of musculoskeletal injuries on the BESS focused on patients with functional ankle instability. The BESS uses a combination of double- and single-limb stances, it is possible that deficits observed in single-leg stances may be “washed out” by using the double-limb stances. In this study, the single-limb stance on foam was associated with a large effect size and an effect size 95%CI that did not cross zero. Single-limb stances might be the most sensitive to unilateral musculoskeletal pathologies, so clinicians should be aware of this potential when administering the BESS.

Successful postural control requires neural input from the vestibular, visual, and somatosensory systems. Therefore, eliminating information from one of these pathways could result in decreased postural control. The mechanism underlying balance deficits after ACLR has yet to be completely understood, but joint mechanoreceptors are believed to play an important role in maintaining balance. These receptors detect joint motion and position, and ACL rupture disrupts these mechanoreceptors. The ACL provides sensory input to the knee, which influences afferent signaling that ultimately contributes to movement (reflex-mediated and voluntary). This reflexive activation is essential to normal function and joint stability. Alterations in these signaling pathways have been identified in individuals with ACL lesions, as well as those with reconstruction. Ligamentous mechanoreceptors are also thought to influence the gamma muscle-spindle system by contributing to joint stability via regulation of muscle stiffness. Interruption of this reflex after ACL rupture could lead to altered joint stability and changes in joint stiffness, which may contribute to the balance impairments noted in the ACLR population.

Having an easily accessible measure of postural control available in the clinic setting is vital. Poor balance has been shown to increase the risk of primary, as well as secondary, injury. Reconstruction is the standard of care for individuals with ACL rupture who plan on returning to sport. The role of rehabilitation is to return the patient to preinjury function, even though this is not always possible. Balance is an important component of the rehabilitation process and is positively correlated with higher scores on subjective knee-function assessments, higher self-reported knee satisfaction, and improved hop-index scores in ACLR and ACL-deficient individuals. Thus, using the BESS to ensure that a patient’s static balance ability has returned to normal levels may provide an estimate of patient satisfaction and progress during the rehabilitation process. Fortunately, balance deficits are modifiable, and previous research has shown a large decrease in BESS scores after neuromuscular training.

### Table 1: Average Errors Between Groups for Each Stance of the Balance Error Scoring System, Mean ± SD (95% Confidence Interval)

<table>
<thead>
<tr>
<th></th>
<th>Anterior Cruciate Reconstructed</th>
<th>Control</th>
<th>Effect size</th>
<th>Values for stance main effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double-limb firm</td>
<td>0.0 ± 0.0</td>
<td>0.0 ± 0.0</td>
<td>N/A</td>
<td>0.0 ± 0.0 (4.2, 5.4)</td>
</tr>
<tr>
<td>Single-limb firm</td>
<td>2.4 ± 1.7 (1.6, 3.3)</td>
<td>2.0 ± 1.6 (1.1, 2.9)</td>
<td>0.2 (–0.4, 0.8)</td>
<td>2.2 ± 1.6 (1.6, 2.8)</td>
</tr>
<tr>
<td>Tandem firm</td>
<td>1.0 ± 0.8 (0.6, 1.3)</td>
<td>0.9 ± 0.5 (0.5, 1.2)</td>
<td>0.2 (–0.1, 0.4)</td>
<td>0.9 ± 0.7 (0.7, 1.2)</td>
</tr>
<tr>
<td>Double-limb foam</td>
<td>0.1 ± 0.4 (–0.1, 0.3)</td>
<td>0.2 ± 0.4 (0.1, 0.4)</td>
<td>0.3 (0.1, 0.4)</td>
<td>0.2 ± 0.3 (0.1, 0.3)</td>
</tr>
<tr>
<td>Single-limb foam</td>
<td>9.4 ± 2.0 (8.5, 10.2)*</td>
<td>7.4 ± 1.1 (6.5, 8.2)</td>
<td>1.3 (0.7, 1.8)</td>
<td>8.4 ± 1.9 (7.8, 8.9)</td>
</tr>
<tr>
<td>Tandem foam</td>
<td>5.3 ± 1.9 (4.5, 6.2)</td>
<td>4.4 ± 1.4 (3.5, 5.2)</td>
<td>0.6 (–0.0, 1.1)</td>
<td>4.8 ± 1.7 (4.2, 5.4)</td>
</tr>
</tbody>
</table>

Note. Effect sizes were calculated as mean 1 – mean 2/(pooled SD).

*Statistically significant between groups according to 95% CI.
The ACLR participants used in this study included individuals who have been returned to sport for nearly 3 years (34.8 mo) and were satisfied with their functional status. The ACLR group had a slightly higher self-reported activity level than the control group, although this difference was not statistically significant (Marx Activity Scale: ACLR 12.0 ± 4.0, control 9.7 ± 3.4). It is concerning that, despite the increased activity level and sporting background, individuals with ACLR still have impaired balance. Since we recruited our sample from the general university community we were unable to control for graft type, time since surgery, and surgeon. Further research should control for these factors and investigate how the BESS, a measure of static balance, relates to dynamic balance in this population. Finally, we included only women who had suffered noncontact or indirect ACL injuries, since they are more likely to fit the inclusion criteria; however, men should be investigated for balance deficits after ACL reconstruction, as well.

Conclusions
In conclusion, balance deficits exist in individuals with ACLR compared with healthy controls as measured by the BESS. Differences were observed in total BESS score, as well as the single-limb stance on foam. The results of this study demonstrate that balance deficits exist even after successful completion of rehabilitation and return to activity. The BESS is a simple test capable of objectively measuring balance deficits in this population, and clinicians should pay close attention to the results of the single-leg foam stances.

Acknowledgments
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References


