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Altered postural sway persists after anterior cruciate ligament reconstruction and return to sport

Mark V. Paterno [a,b,c,d,e,*], Laura C. Schmitt [a,b,k], Kevin R. Ford [a,b,d,f], Mitchell J. Rauh [g], Timothy E. Hewett [a,b,d,g,h,i,j,l]

[a] Cincinnati Children's Hospital Medical Center, Cincinnati, OH, United States
[b] Sports Medicine Biodynamics Center and Human Performance Laboratory, Cincinnati, OH, United States
[c] Division of Occupational Therapy and Physical Therapy, Cincinnati, OH, United States
[d] Department of Pediatrics, College of Medicine, University of Cincinnati, Cincinnati, OH, United States
[e] Graduate Program in Orthopaedic & Sports Sciences, Rocky Mountain University of Health Professions, Provo, UT, United States
[f] Division of Physical Therapy, High Point University, High Point, NC, United States
[g] Division of Physical Therapy, San Diego State University, San Diego, CA, United States
[h] Department of Orthopaedic Surgery, College of Medicine, University of Cincinnati, Cincinnati, OH, United States
[i] Department of Biomedical Engineering, University of Cincinnati, Cincinnati, OH, United States
[j] Department of Rehabilitation Sciences, University of Cincinnati, Cincinnati, OH, United States
[k] Department of Physical Therapy, Ohio State University, Columbus, OH, United States
[l] The Ohio State University, Columbus, OH, United States

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A B S T R A C T

Postural sway is defined as the movement of a body's center of mass within the base of support to maintain postural equilibrium. Deficits in postural sway are present after ACL injury; however, current evidence linking it to future injury risk is unclear. The purpose of this study was to determine if postural sway deficits persist after ACL reconstruction (ACLR). The hypothesis tested was that after ACLR, patients who return to sport (RTS) would demonstrate differences in postural sway compared to control (CTRL) subjects. Fifty-six subjects with unilateral ACLR released to RTS, and 42 uninjured CTRL subjects participated. Dynamic postural sway was assessed and 3-way ($2 \times 2 \times 2$) ANOVA was used to analyze the variables. A side $\times$ group $\times$ sex ($p = 0.044$) interaction in postural sway was observed. A side $\times$ group analysis also revealed an interaction ($p = 0.04$) however, no effect of sex was observed ($p = 0.23$). Analysis within the ACLR cohort showed less ($p = 0.001$) postural sway on the involved side ($1.82 \pm 0.84^\circ$) versus the uninvolved side ($2.07 \pm 0.96^\circ$). No side-to-side differences ($p = 0.73$) were observed in the CTRL group. The involved limb of subjects after ACLR demonstrated the least postural sway. In conclusion, these findings indicate that dynamic postural sway may be significantly altered in a population of athletes after ACLR and RTS compared to CTRL subjects. Further investigation is needed to determine if deficits in postural sway can be used as an effective criterion to assist in the decision to safely RTS after ACLR.

1. Introduction

The incidence of ACL injury is high among young, active, individuals [1] with the most frequent medical management being surgical reconstruction. Injury to the ACL results in biomechanical changes at the tibiofemoral joint as well as deficits in proprioceptive feedback and sensorimotor function [2–4]. While ACLR may successfully restore the mechanical stability of the knee; the resolution of certain proprioceptive measures and its importance in return to sport decision-making, remains controversial [5,6].

Proprioception of the knee joint as defined by Lephart et al. [7] is afferent information from the joint that contributes to sensation, posture and joint stability. Various assessment tools were traditionally used to quantify deficits in proprioceptive function after ACL injury and focused on static measures of joint position sense or the patient's ability to detect the onset of passive motion [2–4]. Collectively, these authors suggested the presence of altered position sense and deficits in movement perception after ACL injury [2,8] as well residual impairments after ACLR [3,4]. However, some authors have argued that these assessment methods lacked applicability to assess functional status, as they frequently use passive movements, assessed in non-weight bearing positions [7].

* Corresponding author at: Cincinnati Children's Hospital, 3333 Burnet Avenue, MLC 10001, Cincinnati, OH 45229, United States. Tel.: +1 513 636 0517; fax: +1 513 636 0516.
E-mail address: mark.paterno@cchmc.org (M.V. Paterno).

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Recent attempts to quantify proprioception with corollary measures have included assessment of dynamic postural stability and postural sway. Deficits in postural stability (total motion of the center of pressure of the foot) are reported post ACL injury [9], with subsequent improvement after surgical reconstruction [9,10]. In these cases, postural stability was defined as a dynamic postural response to an applied or volitional perturbation and was assessed by measurement of the deviation from a level position on a moveable force platform. Although this methodology represents a functional dynamic tool, what was not gleaned from these studies was the patient's variability of movement within each test trial. Postural sway is a distinct measure and is defined as the movement of a body's center of mass within the base of support to maintain postural equilibrium [7]. The magnitude and pattern of postural sway is the result of a dynamic incorporation of sensory inputs from the trunk and lower extremity, in addition to a coordinated neuromuscular response. Objective measures of postural sway in a variety of patient populations are prevalent in the literature. These measures included linear and non-linear measures to determine the optimal variability of movement in both normal and pathologic conditions [11–13]. These data indicate that normal, healthy individuals have an optimal range of postural sway between abnormal states of excessive or insufficient sway [12].

Early investigations of postural sway after ACL injury were controversial. The literature regarding the effect of variables that increase the complexity of the task, such as single limb stance or visual occlusion, on measures of postural sway after ACLR remain contradictory, but may be critical for assessing the complexity of postural deficits after ACL injury and ACLR [14,15]. Initial investigations of postural sway on a fixed force plate did not report altered sway in patients after ACL injury [14,15] or ACLR [16]. Conversely, a significant increase in postural sway while standing on a flat, unmovable force plate existed when the difficulty of the task was increased by removing visual input [14,15]. Furthermore, as studies increased the challenge of the balance task with the use of movable force plates, additional deficits were revealed. Finally, more robust measures that capture the complexity and difficulty of postural sway maintenance in a "less controlled environment" such as the playing field situation may reveal deficits that may be otherwise missed in simple controlled task.

The purpose of this study was to determine if postural sway deficits during single limb stance on a dynamic, movable platform persist in subjects following ACLR and completion of rehabilitation prior to their return to sport (RTS). The hypothesis tested was that after ACLR, young athletes who returned to sport would demonstrate significant differences in single limb postural sway compared to a cohort of healthy control subjects.

2. Methods

2.1. Subjects

We recruited 98 subjects between the ages of 10 and 25 years old to participate in this prospective, cohort study. The ACLR group included 56 subjects (35 females) who had recently undergone ACL reconstruction, completed their rehabilitation and had been cleared to return to sports [17]. Patients were eligible for inclusion if they intended to return to greater than 50 h per year of jumping, pivoting or cutting activity (Level I/II sports per Daniel et al. [18]), no prior history of a contralateral ACL injury and no recent history of an ankle, hip, spine or contralateral knee injury in the past 12 months. The control (CTRL) group included 42 subjects (29 females) recruited from the community, who also participated in comparable activities. The control group had no prior history of ACL injury and otherwise identical inclusion criteria. Demographic data for the study sample are displayed in Table 1. All testing was approved by the Institutional Review Boards.

2.2. Testing protocol

2.2.1. Postural sway assessment

After demographic data were collected, dynamic postural sway was assessed using the Biodex Balance System SD (BSS) (Biodex, Shirley, NY). The subject was positioned and balanced centrally on a single limb in the center of the dynamic, unstable platform. The subject stood with the test limb in slight flexion (less than 10 degrees) with the contralateral limb flexed and both arms crossed (Fig. 1). The subject was instructed to maintain a stable posture on the platform for 20 s while the stability system was set at a level 4 stability setting. The stability setting of the Biodex SD system ranges from 1 to 8 with 1 being the least stable setting and 8 being the most stable setting. The subject executed this 20 s trial 3 times on each limb. Limb testing order was randomized and all testing was completed with eyes open with no visual feedback on performance. During each trial, the Balance System recorded the displacement of the platform away from a level position in degrees. This displacement represented the patient's postural stability. In addition, the standard deviation of the movement was recorded to represent the variability of movement in degrees. This standard deviation represented postural sway and was the variable of interest in this study. Fig. 2 provides examples of postural stability and postural sway outcome tracings provided by the BSS. Subjects may demonstrate altered postural stability and postural sway as seen in Fig. 2a, or an independent deficit in postural stability with minimal variability or postural sway as seen in Fig. 2c. Fig. 2b represents optimal postural stability and minimal postural sway. Altered postural stability as measured on the BSS can be the result of erratic movement of the platform (Fig. 2a) or a consistently deviated position of the platform (Fig. 2c). The generated data represented the overall stability as well as deviations in the anterior–posterior and medial and lateral direction. These methods have been previously reported with high reliability [19].

2.3. Statistical analysis

Independent t-tests were used to assess mean differences in demographic characteristics between ACLR and CTRL subjects. A 3-way ($2 \times 2 \times 2$) analysis of variance (ANOVA) was used to analyze

Table 1
Mean (±SD) characteristics of study sample.

	ACL reconstructed ($N = 56$)			p-Value*	Controls ($N = 42$)			p-Value[a]	p-Value[b]
	Total	Female $n = 35$ (62.5%)	Male $n = 21$ (37.5%)		Total	Female $n = 29$ (69.0%)	Male $n = 13$ (31.0%)		
Age (years)	16.4 ± 3.0	16.2 ± 2.2	16.8 ± 4.0	0.51	16.8 ± 2.3	16.9 ± 1.9	16.4 ± 3.1	0.57	0.528
Height(cm)	167.3 ± 11.7	164.2 ± 6.4	172.3 ± 16.2	0.04	166.8 ± 8.9	164.3 ± 5.7	172.4 ± 12.1	0.04	0.826
Weight (kg)	66.8 ± 18.1	62.4 ± 10.0	74.2 ± 25.4	0.05	62.2 ± 13.1	59.1 ± 7.6	69.3 ± 19.2	0.09	0.173
BMI	23.5 ± 4.5	23.2 ± 3.6	24.2 ± 5.8	0.44	22.3 ± 3.4	22.0 ± 2.7	23.0 ± 4.5	0.48	0.129

[a] Difference between genders, independent t-test.
[b] Difference between ACLR and control groups, independent t-test.