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Static and dynamic postural control in competitive athletes after anterior cruciate ligament reconstruction and controls

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Abstract
Purpose To evaluate the test–retest reliability and compare the static and dynamic postural control values in competitive athletes following anterior cruciate ligament (ACL) reconstruction and controls.
Methods Thirty athletes, 8.4 ± 1.8 months after ACL reconstruction, and thirty healthy matched controls were asked to execute single-leg stance and single-legged drop jump tests onto a force plate. Amplitude and velocity in anteroposterior and mediolateral directions, and mean total velocity were measured for static evaluation. Peak vertical ground reaction force (PVGRF) during landing and takeoff and loading rate were measured for dynamic evaluation. To evaluate test–retest reliability, 15 participants of each group repeated the tests 6–8 days after the first session. Mixed model of analysis of variance was used to determine differences between the involved, uninvolved, and control limbs. The test–retest reliability was measured using intraclass correlation coefficient and standard error of measurement.
Results Greater postural sway has been observed in the operated leg of ACL-reconstructed athletes compared with the non-operated side ($P < 0.01$) and the matched limb of the control group ($P < 0.01$). During landing, PVGRF and loading rate on the uninvolved limb of the athletes who had undergone ACL reconstruction were greater in comparison with those of the control group ($P < 0.001$). Both static and dynamic postural measures have high test–retest reliability, ranging from 0.73 to 0.88.
Conclusions Static and dynamic postural measures are reliable tests to evaluate functional performance of athletes following ACL reconstruction. Eight months postsurgery, competitive athletes still demonstrated postural asymmetries, compared to matched controls, which might result in their susceptibility to future ACL injury.
Level of evidence Prognostic study, case-control, Level III.

Keywords Posture · Balance · Anterior cruciate ligament · Sport

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Introduction

Anterior cruciate ligament (ACL) is the most frequently injured knee ligament [9]. The majority of injuries occur during sports activities. Soccer, basketball and handball are the sports with the highest incidence of ACL injury [16, 29]. Individuals who wish to participate in competitive sports are usually recommended to undergo ACL reconstructive surgery [40]. Mechanical stability can be successfully recovered through ACL reconstruction. However, the restoration of sensory and motor functions remains controversial, because many of the original mechanoreceptors are not restored [10, 25]. It has been suggested that athletes may compete with great risks of subsequent injuries, especially in the first year after ACL reconstruction [35]. It may be the result of either risk factors that were present prior to the injury or the changes that occurred following ACL reconstruction [32]. One difficult challenge in the rehabilitation of athletes is to identify potential risk factors for re-injury and determine full recovery of knee function, also to estimate whether it is safe to return to strenuous activities [32]. Functional outcome measures have been suggested as appropriate criteria to estimate the effectiveness of surgical and rehabilitative interventions [36].

Static and dynamic balance tests are valid outcome measures to determine the restoration of knee function after ACL reconstruction [1]. Measuring the differences between two limbs of ACLR subjects and control group in static postural control is a controversial topic [23]. As some researchers reported no difference between the limbs of the patients following ACL reconstruction [19, 20, 22, 26], the others found that static postural balance on the reconstructed side was worse than the non-operated side or the matched limb of the controls [1, 5, 10, 12]. It has been reported that although static postural control is a valuable measure of somatosensory integration, measurement of the dynamic aspects of postural control may also provide critical information related to factors that might predispose athletes to injury during functional activities [22]. Regarding the dynamic postural control, differences between the two limbs of ACL-reconstructed group and between the ACL-reconstructed subjects and control group have been reported [14, 15, 17, 20, 27, 30, 32, 41].

Hewett et al. [21] indicated that limb asymmetries during landing may be predictive of ACL injuries in healthy athletes. Moreover, it was also hypothesized that side-to-side differences during postural tasks in competitive athletes may result in increased risk of future injury [21]. To the authors' knowledge, no study has specifically compared the postural balance in professional athletes with and without ACL reconstruction. The first aim of the present study, therefore, was to evaluate static and dynamic postural control in ACL-reconstructed athletes and healthy controls with higher level of sports activity.

Moreover, there is no study to evaluate reliability of the mentioned values in competitive athletes. Since the reliability of outcome measures depends on patients characteristics, like physical activity, further evaluation is needed to confirm the efficiency of mentioned outcomes in athletic populations. The second aim of the present study was to determine the reliability of some indices of postural control in athletes with and without a history of ACL reconstruction.

Materials and methods

A sample of convenience including a group of thirty athletes with a unilateral ACL injury who had previously undergone ACL reconstruction, using either a bone–patellar tendon–bone or semitendinosus-gracilis tendon graft, and matched control athletes, with no prior history of knee injury or pathology in either limb were participated in this study. Demographic characteristics of both groups are shown in Table 1. ACL-reconstructed subjects followed accelerated rehabilitation protocol in the same rehabilitation center (incorporating strengthening, balance, proprioception, stability, agility, plyometrics, and return to sport training). All the participants had the Tegner score of 9 (participation in competitive sports) [39]. The exclusion criteria for ACL-reconstructed subjects included any other orthopedic injuries (except meniscal injuries), neurological deficits, strength deficits, range of motion restriction, pain and joint effusion at the time of testing.

Table 1 Demographic characteristics of anterior cruciate ligament reconstructed and healthy athletes

	ACL reconstructed ($n = 30$)	Healthy ($n = 30$)	*P* value
Males/females	22/8	24/6	N/A
Age (years)	25.0 (2.7)	24.8 (2.4)	ns
Height (cm)	177.3 (8.1)	175.6 (7.7)	ns
Weight (kg)	72.7 (9.9)	73.4 (8.6)	ns
Type of surgery (bone-patellar tendon-bone/Semitendinosus-gracilis tendon)	13/17	N/A	N/A
Time after surgery (months)	8.4 (1.8) (6–10)	N/A	N/A
Operated limb (dominant/non-dominant)	16/12	N/A	N/A
Meniscus injury	16	N/A	N/A
Tegner score	9	9	N/A
Sport (soccer/basketball)	18/12	18/12	N/A

The values are mean (SD). Range of Tegner scores is from 0 to 10

SD, standard deviation; *ACL*, anterior cruciate ligament

The study was approved by the Ethics Committee for Health Sciences Research involving human subjects, and the informed consent was obtained.

Procedure

Each subject was asked to perform static and dynamic postural tests, by the same evaluator. Each measurement was repeated 3 times, and average scores were used for analysis. One-minute rest was given between every test. The test order was randomized to control for sequence effects. A second data collection was conducted a week later for the assessment of between-day reliability ($n = 15$).

Static postural evaluation

During the static balance test, the participants were instructed to assume bare foot single-limb stance on the center of a 40 × 60 cm force platform (Kistler Instrument Company, Amherst, NY), with the weight-bearing knee semiflexed about 15–20°, keeping the arms along the body, and focusing on a fixed point localized at a 2-m distance on a wall. Subjects were instructed to lift the contralateral limb and hold it in approximately 90° of knee flexion and 45° of hip flexion. Once this position had been attained, data collection was initiated with a computer keystroke. Balance was maintained for 30 s on each limb, in two levels of difficulty, including standing on the force platform and on a 40 × 60 cm foam of 10-cm-thick medium-density polyfoam placed over the platform. All participants were able to hold the test position for the full 30 s during all three trials. The 100-Hz frequency was chosen to obtain a better detection of movements of the center of pressure (COP) [11]. Anteroposterior (AP) and mediolateral (ML) displacement of COP was measured along the x-axis and y-axis, respectively. COP signals were filtered with a sixth-order Butterworth, zero-phase low-pass filter at 10 Hz. Parameters calculated from COP data were amplitude and velocity in AP and ML directions and mean total velocity.

Dynamic postural evaluation

During the dynamic balance test, the participants were asked to drop off a 40-cm platform and immediately jump as high as they can (takeoff phase) and then contact the center of the force plate again (landing phase). Participants were allowed to use their arms freely for balance purposes. All the participants were successful for three straight trials. The 40-cm height was selected based on findings by Huston et al. [24], in which the differences in landing mechanics were observed from heights starting at 40 cm. The platform was sampled at 1,200 Hz [17]. Peak vertical ground reaction force (PVGRF) during the landing and takeoff phases, normalized to body weight, and loading rate during landing (PVGRF normalized to body weight divided by time to reach PVGRF) were collected [14, 32]. Raw data were filtered with a fourth order Butterworth, zero-phase filter with a cutoff frequency of 6 Hz.

Statistical analysis

Statistical Package for the Social Sciences (SPSS) for windows (version 16.0, SPSS Inc, Chicago, IL, United States) was used for statistical analysis. The sample size was estimated for the groups on the basis of power calculations from a pilot study: based on a significance level of 0.05, a power of 0.8, and a standard deviation of 1.5, a sample size of 30 was required for each group. Age, height and weight of the 2 groups were compared using a series of independent t tests. The level of significance was set at $P < 0.05$.

To examine the postural performance in static condition, separate 2 × 2 × 2 (group by limb by postural difficulty) mixed model analysis of variance (ANOVA) was used to determine the main effects and interactions of the 3 factors for each static postural variable. Also, separate 2 × 2 (group by limb) mixed model ANOVAs were conducted to determine the main effects and interactions of the 2 factors for dynamic variables. Independent t-tests and paired t-tests were used to test post hoc pairwise comparisons.

The test–retest reliability was measured using the two-way random effects model of intraclass correlation coefficient (ICC) with 95% confidence interval (95% CI). An ICC equal or greater than 0.70 is considered acceptable [2]. To estimate measurement precision associated with repeated measurements, standard error of measurement (SEM) was calculated as the square root of the mean square error term derived from ANOVA table [2].

In order to test the association between performance on the static and dynamic postural tests in ACL-reconstructed athletes, two-tailed Pearson correlation coefficients were calculated.

Results

No statistically significant difference was found for age, height and weight between the two groups (Table 1). Mean and standard deviation (SD) values of balance measures are displayed in Table 2 and Fig. 1.

There was no three-way interaction (group × limb × postural difficulty) found for the static postural measures. Moreover, there was no interaction of group × postural difficulty or limb × postural difficulty, but there was a

Table 2 Descriptive statistics for static postural measures made under different conditions of postural difficulty for both limbs of anterior cruciate ligament reconstructed ($n = 30$) and healthy athletes ($n = 30$)

	Healthy				ACL reconstructed			
	Rigid surface		Foam surface		Rigid surface		Foam surface	
	Operated limb	Non-operated limb	Operated limb	Non-operated limb	Operated limb	Non-operated limb	Operated limb	Non-operated limb
AP amplitude	0.5 (0.1)	0.5 (0.1)	0.6 (0.1)	0.6 (0.1)	0.6 (0.1)	0.5 (0.1)	0.7 (0.1)	0.6 (0.1)
AP velocity	1.3 (0.1)	1.3 (0.1)	1.4 (0.1)	1.4 (0.1)	1.5 (0.1)	1.4 (0.1)	1.6 (0.1)	1.5 (0.1)
ML amplitude	0.7 (0.1)	0.7 (0.1)	0.8 (0.1)	0.8 (0.1)	0.8 (0.1)	0.7 (0.1)	0.9 (0.1)	0.8 (0.1)
ML velocity	1.6 (0.1)	1.6 (0.1)	1.7 (0.1)	1.7 (0.1)	1.7 (0.1)	1.6 (0.1)	1.8 (0.1)	1.7 (0.1)
Mean velocity	1.2 (0.1)	1.2 (0.1)	1.3 (0.1)	1.3 (0.1)	1.3 (0.1)	1.2 (0.1)	1.4 (0.1)	1.3 (0.1)

The values are mean (SD)

AP, anteroposterior; *ML,* mediolateral; *SD,* standard deviation; *ACL,* anterior cruciate ligament

Units of measures are as follows: cm (amplitude); cm/s (mean total velocity)

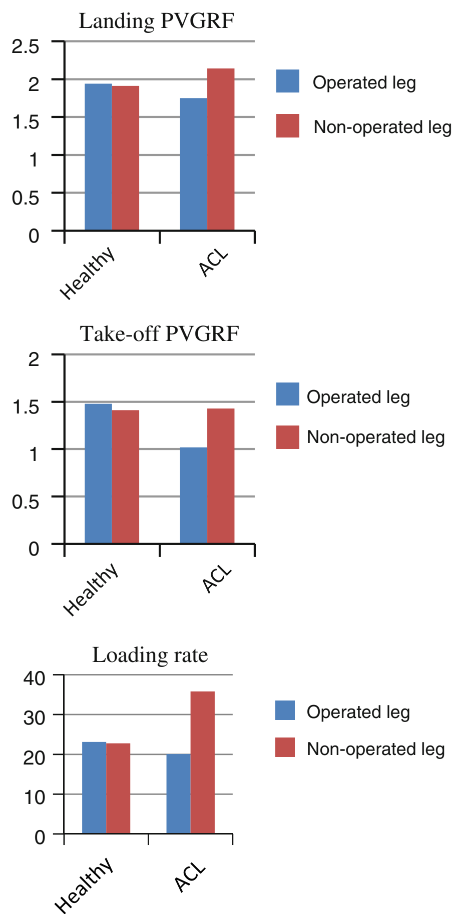

Fig. 1 Descriptive statistics for dynamic postural measures for both limbs of anterior cruciate ligament-reconstructed group ($n = 30$) and healthy controls ($n = 30$). *PVGRF,* peak vertical ground reaction force; *ACL,* anterior cruciate ligament-reconstructed group. Units of measures are as follows: N (PVGRF); N/s (loading rate)

significant group by limb interaction found for all COP measures ($P < 0.01$). Further analysis revealed greater postural sway while testing the operated limb of ACL-reconstructed athletes compared to the non-operated side ($P < 0.01$) and the matched limb of the control group ($P < 0.01$). There was no significant difference between the non-operated limb of ACL-reconstructed participants and its matched limb in the control group (n.s) as well as between the two limbs of healthy athletes (n.s). Main effect of postural difficulty was significant for all parameters ($P < 0.01$).

In dynamic condition, during the landing phase, there was a significant group by limb interaction for PVGRF normalized to body weight and loading rate ($P < 0.001$). The non-operated limb of the ACL-reconstructed group had greater PVGRF and loading rate than the operated limb as well as the matched one of the healthy athletes ($P < 0.01$). The values for operated limb of the ACL-reconstructed subjects were lower than the matched limb in the control group ($P < 0.001$). Also, during the takeoff phase, there was a significant group by limb interaction ($P < 0.001$) for PVGRF normalized to body weight. The value generated by the operated limb of the ACL-reconstructed group was significantly lower than that generated by the non-operated limb, as well as the control limb of healthy athletes ($P < 0.001$).

The mean, SD, ICC and SEM for the postural measures have been shown in Table 3. The ICC was higher than the acceptable level of 0.70 [2].

The correlations between loading PVGRF and takeoff PVGRF, loading PVGRF and loading rate, and takeoff PVGRF and loading rate were statistically significant (0.72, 0.69 and 0.66, respectively).

Discussion

The most important finding of the present study was that competitive athletes after ACL reconstruction had side-to-

Table 3 Descriptive statistics and test–retest reliability of static and dynamic postural measures made under different conditions of postural difficulty for both limbs in anterior cruciate ligament reconstructed ($n = 15$) and healthy athletes ($n = 15$)

	Healthy								ACL reconstructed							
	Rigid surface				Foam surface				Rigid surface				Foam surface			
	Test mean (SD)	Retest mean (SD)	ICC (95% CI)	SEM	Test mean (SD)	Retest mean (SD)	ICC (95% CI)	SEM	Test mean (SD)	Retest mean (SD)	ICC (95% CI)	SEM	Test mean (SD)	Retest mean (SD)	ICC (95% CI)	SEM
Operated limb																
AP amplitude	0.5 (0.1)	0.6 (0.1)	0.85 (0.79 0.89)	0.1	0.6 (0.1)	0.6 (0.1)	0.85 (0.81 0.88)	0.2	0.6 (0.1)	0.7 (0.1)	0.79 (0.75 0.83)	0.2	0.7 (0.1)	0.8 (0.1)	0.75 (0.72 0.78)	0.3
AP velocity	1.3 (0.1)	1.4 (0.1)	0.86 (0.79 0.89)	0.2	1.4 (0.1)	1.5 (0.1)	0.82 (0.78 0.86)	0.4	1.5 (0.1)	1.5 (0.1)	0.76 (0.72 0.78)	0.4	1.6 (0.1)	1.7 (0.1)	0.73 (0.69 0.75)	0.4
ML amplitude	0.7 (0.1)	0.7 (0.1)	0.84 (0.78 0.88)	0.3	0.8 (0.1)	0.8 (0.1)	0.82 (0.79 0.86)	0.4	0.8 (0.1)	0.8 (0.1)	0.78 (0.75 0.83)	0.4	0.9 (0.1)	0.9 (0.1)	0.75 (0.72 0.78)	0.5
ML velocity	1.6 (0.1)	1.6 (0.1)	0.83 (0.79 0.87)	0.4	1.7 (0.1)	1.7 (0.1)	0.80 (0.77 0.83)	0.4	1.7 (0.1)	1.7 (0.1)	0.76 (0.75 0.77)	0.6	0.8 (0.1)	0.8 (0.1)	0.73 (0.71 0.77)	0.6
Mean velocity	1.2 (0.1)	1.2 (0.1)	0.88 (0.83 0.92)	0.2	1.3 (0.1)	1.3 (0.1)	0.82 (0.78 0.85)	0.2	1.3 (0.1)	1.4 (0.1)	0.82 (0.80 0.84)	0.2	1.4 (0.1)	1.5 (0.1)	0.78 (0.75 0.84)	0.2
Landing PVGRF	1.9 (0.4)	1.9 (0.1)	0.81 (0.78 0.83)	1.6	N/A	N/A	N/A	N/A	1.7 (0.3)	1.8 (0.3)	0.74 (0.72 0.80)	2.7	N/A	N/A	N/A	N/A
Takeoff PVGRF	1.5 (0.3)	1.5 (0.3)	0.80 (0.78 0.83)	1.2	N/A	N/A	N/A	N/A	1.1 (0.1)	1.1 (0.1)	0.76 (0.73 0.80)	2.2	N/A	N/A	N/A	N/A
Loading rate	23.1 (4.1)	23.2 (4.1)	0.82 (0.78 0.85)	1.4	N/A	N/A	N/A	N/A	20.9 (5.8)	20.4 (5.8)	0.74 (0.71 0.79)	2.6	N/A	N/A	N/A	N/A
Non-operated limb																
AP amplitude	0.5 (0.1)	0.6 (0.1)	0.82 (0.79 0.85)	0.1	0.6 (0.1)	0.7 (0.1)	0.79 (0.75 0.84)	0.2	0.5 (0.1)	0.6 (0.1)	0.83 (0.79 0.88)	0.1	0.6 (0.1)	0.6 (0.1)	0.81 (0.79 0.83)	0.2
AP velocity	1.3 (0.2)	1.4 (0.2)	0.83 (0.80 0.86)	0.3	1.4 (0.1)	1.5 (0.1)	0.81 (0.75 0.85)	0.4	1.4 (0.1)	1.4 (0.1)	0.81 (0.79 0.83)	0.3	1.5 (0.1)	1.5 (0.1)	0.79 (0.72 0.83)	0.4
ML amplitude	0.7 (0.1)	0.7 (0.2)	0.80 (0.78 0.84)	0.4	0.8 (0.2)	0.8 (0.2)	0.79 (0.75 0.83)	0.5	0.7 (0.1)	0.7 (0.1)	0.83 (0.79 0.88)	0.4	1.8 (0.1)	1.8 (0.1)	0.79 (0.77 0.82)	0.5
ML velocity	1.6 (0.1)	1.6 (0.2)	0.79 (0.76 0.83)	0.5	1.7 (0.1)	1.7 (0.2)	0.77 (0.75 0.80)	0.5	1.6 (0.1)	1.6 (0.1)	0.81 (0.78 0.83)	0.4	1.7 (0.1)	1.7 0.1	0.75 (0.78 0.82)	0.5
Mean velocity	1.2 (0.1)	1.2 (0.1)	0.84 (0.80 0.88)	0.2	1.3 (0.1)	1.3 (0.1)	0.80 (0.77 0.83)	0.2	1.2 (0.1)	1.3 (0.1)	0.83 (0.81 0.85)	0.2	1.3 (0.1)	1.4 (0.1)	0.79 (0.76 0.84)	0.2
Landing PVGRF	1.9 (0.2)	1.9 (0.3)	0.77 (0.74 0.81)	2.4	N/A	N/A	N/A	N/A	2.1 (0.2)	2.2 (0.2)	0.79 (0.76 0.82)	1.6	N/A	N/A	N/A	N/A
Take-off PVGRF	1.4 (0.1)	1.4 (0.2)	0.78 (0.74 0.81)	2.1	N/A	N/A	N/A	N/A	1.4 (0.2)	1.5 (0.2)	0.78 (0.77 0.81)	1.4	N/A	N/A	N/A	N/A
Loading rate	22.8 (3.9)	22.8 (3.9)	0.76 (0.73 0.81)	2.4	N/A	N/A	N/A	N/A	35.8 (4.1)	35.8 (4.1)	0.80 (0.76 0.83)	1.5	N/A	N/A	N/A	N/A

AP, anteroposterior; *ML*, mediolateral; *PVGRF*, peak vertical ground reaction force; *ICC*, intraclass correlation coefficient; *SEM*, standard error of measurement; *SD*, standard deviation; *ACL*, anterior cruciate ligament

Units of measures are as follows: cm (amplitude); cm/s (mean total velocity); N (PVGRF); N/s (loading rate) side differences in balance measurements. Besides, they showed a significant difference in postural values in comparison with the matched controls. The results suggested that static and dynamic postural outcomes are reliable values in athletes.

Regarding the static measures, the results indicated that the postural balance of the athletes with ACL reconstruction was dislocated more on the operated limb than on the non-operated side and matched limb of control group. The same pattern of findings was obtained in other studies with different samples and different postsurgery intervals, such as the studies of Bonfim et al. [10], Ben Moussa et al. [5], and Dauty et al. [12], which showed that ACL-reconstructed subjects had greater displacement, velocity, area and total distance in the ACL-reconstructed lower limb in comparison with the contralateral limb and matched limb of controls. We found similar differences in the athletes. This may be due to damage of the ACL mechanoreceptors, which are sensitive to mechanical deformation of the tissue, and signal joint position and motion. Many areas of research provide supporting evidence that the ACL contains a vast neurologic supply [25]. Moreover, the existence of direct connections between neurologic structures of the ACL and the spinal cord, as well as supraspinal areas, has been suggested [20]. Thus, it is possible that the damage of the ligament which occurs during the lesion may diminish afferent information. Despite the fact that mechanoreceptors have been found in other structures around the knee, they may not furnish sufficient information, and therefore, deficits will still remain after ACL reconstruction [10]. Reduced afferent information from the knee may decrease the capability to stabilize the lower extremity adequately [1, 10]. Although one-limb standing balance of the patients after ACL reconstruction is impaired compared with that of healthy volunteers, Shiraishi et al. [38] reported that it is significantly better than that of the patients with ACL-deficient knees. It seems that the surgery might improve the balance, but not to the optimum point.

Several studies have found no differences in postural control following ACL reconstruction. The contradictions between those studies and ours could be a result of various circumstances of the postoperative period. For instance, the period after reconstruction in this study was shorter than that of the study of Harrison et al. [19], Hoffman et al. [22], Henriksson et al. [20], and Mattacola et al. [26] which showed no difference between the involved and non-involved limbs of the patients who had undergone ACL reconstruction. It can be speculated that after a long period of recovery, the graft used in ACL reconstruction may become re-innervated. This hypothesis has been demonstrated in animal studies [3, 4]. Another possible explanation may be that previous studies used one-legged stance with extended knee, while in this study, semiflexed position has been applied. This posture was difficult to perform, so it may have caused differences in postural control. In a recently published systematic review, Howells et al. [23] suggested that although there were inconsistent results for static balance tasks, there appeared to be a trend toward impaired postural control in people following ACL reconstruction when compared to controls.

The need for more functional tests of neuromuscular performance, which incorporate sport activities for athletes having undergone ACL reconstruction, has been highlighted [6, 8]. Although static balance measurement may partially achieve this goal, tasks that further challenge the various systems involved in postural control, and better mimic sport activities would provide additional information [7, 23]. Thus, single-limb jump landing has been applied, which is commonly used in sports such as basketball and soccer [27, 30]. It has been demonstrated that this task incorporates functionally relevant challenges in postural control [7]. The results showed that the uninvolved limb of the ACL-reconstructed group had greater landing PVGRF and loading rate than the involved limb as well as the limbs of the controls. Also, during the takeoff phase, PVGRF generated by the involved limb in the ACL-reconstructed group was significantly lower than that generated by the uninvolved limb as well as the limbs of the controls. The results might be comparable with the studies of Paterno et al. [32] and Hoffman et al. [22]. Paterno et al. [32] and Hoffman et al. [22] found significant differences between the ACLR and control groups on the measures of dynamic-phase duration and peak torque. Paterno et al. [32] showed that these asymmetries still exist up to 2 years after surgery. Although studies examining dynamic balance tasks were difficult to compare as the dynamic tasks evaluated were typically specific to the testing equipment used [23], the presence of side-to-side differences has been proved during other functional tasks such as squat [28] and step up [15]. These findings support the concept that after ACL reconstruction, subjects develop compensatory mechanisms in the non-operated limb to accomplish the specific task. They loaded their non-operated limb significantly more than the operated one [32]. The observed compensation might be indicative of reduced knee extensor strength in reconstructed limb, which has been reported in ACL-reconstructed subjects [26]. In agreement with these results, Decker et al. [14] showed that ACL-reconstructed subjects have quadriceps weakness, due to an altered motor plan during weight-bearing tasks. They reported that during a drop landing task, ACL-reconstructed patients have deficits in knee extensor moment and power at initial contact, compared with control group. Another possible explanation may be increased electromechanical delay of the knee flexors, which might impair knee performance (and safety) by modifying the transfer time of muscle tension to the tibia and therefore affecting muscle response during sudden movements in athletic activities such as landing task [34]. The existence of side-to-side differences might increase the risk of future ACL injury [33]. The combination of increased PVGRF and loading rate may place the non-operated limb at greater risk of ACL injury following return to sports [32]. It has been suggested that the non-operated limb might be injured more frequently than the reconstructed knee [37]. Paterno et al. [33] reported that altered neuromuscular control patterns during landing and deficits in postural stability may predict subsequent ACL injuries in a sample of athletes at the time of return to sports after initial ACL reconstruction.

In contrast to the above findings, Decker et al. [14] reported that the PVGRF during single-limb landing was not different between ACL-reconstructed recreational athletes and healthy ones. Only the reconstructed limb of ACL-reconstructed group had reduced loading rate. Also, Gokeler et al. [18] suggested that there was no significant difference between the two limbs for VGRF. Small sample sizes and different level of activity might be some possible explanations for the inconsistency in results.

This study demonstrates that the balance parameters are reliable outcomes to compare postural control between competitive athletes with ACL reconstruction and their controls. Although there is no study to assess reliability of these parameters in competitive athletes, the results of the present study may be comparable with the study of Dauty et al. [13], which showed acceptable levels of reliability (ICC > 0.75) for area and the average AP excursion of the COP on both limbs of recreational athletes undergoing ACL reconstruction. Similarly, Padua et al. [31] found good to excellent intrarater (ICC of 0.84) and interrater (ICC of 0.91) reliabilities for the Landing Error Scoring System, despite the fact that their samples consisted of subjects with different level of physical activity. High test–retest reliability for all measures in the current study revealed satisfactory stability of the balance tests over time in competitive athletes after ACL reconstruction and controls.

The results showed significant correlation between dynamic postural measures in ACL-reconstructed athletes. It seems that the athletes who perform poorly on landing PVGRF also perform poorly on takeoff PVGRF and loading rate. As takeoff PVGRF had the highest level of reliability, measurement of this value might suffice when evaluating postural stability of this population.

This study had some limitations. First, the sample was composed of soccer and basketball players. Further studies are needed to clearly ascertain differences between these two groups of athletes, as well as other sports. Moreover, the results of the present study may be more generalized to male athletes who constituted the majority of the participants.

Conclusion

In conclusion, the findings revealed that even 8 months after ACL reconstruction, balance function of competitive athletes was not restored in their reconstructed limbs. As movement patterns are important and modifiable factors that may influence the risk of ACL and other lower extremity injuries, the presence of residual limb asymmetries demonstrated in the current study may result in increased risk of future injuries. Identifying possible side-to-side and between group differences of ACL-reconstructed and control athletes in functional balance tests might help us to optimize the postoperative rehabilitation protocols and minimize the risk of further injuries after returning to sports. Based on these results, we suggest that clinicians should consider incorporating rehabilitation protocols to correct postural asymmetries into the last stages of rehabilitation in ACL-reconstructed athletes before let them return to sports.

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