***Journal of Advanced Sport Technology*** *6(2):51-64.*

*Received: December, 25, 2022* *Accepted: February, 03, 2023*

Journal of Advanced Sport Technology

**Original Research**

# Postural Control and Weight Distribution of Men with Anterior Cruciate Ligament Reconstruction during Quiet Standing

**Leila Ghazaleh[1], Safoura Ghasemi[2*], Fateme Badie[3]**

*1. Department of Exercise Physiology, Faculty of Sport Sciences, Alzahra University, Tehran, Iran. Email: l.ghazaleh@alzahra.ac.ir, ORCID: 0000-0002-5228-2703*
*2. Department of Sports Physiology and Pathology, Faculty of Sport Sciences, Arak University, Arak, Iran. Email: s-ghasemi@araku.ac.ir , ORCID: 0000-0003-4819-6447*
*3. Department of Mechanical Enginnering, Jundi-Shapur University of Technology, Dezful,Iran. Email: Badie-fateme@aut.ac.ir, ORCID: 0000-0002-1954-6484*

## ABSTRACT

Anterior cruciate ligament reconstruction (ACLR) has been considered one of the common treatments for ACL injury. Decrease in the proprioceptive function following ACLR, which may remain between 2 and 3 years after the surgery, provides the possibility of re-injury. Therefore, this study aims to investigate the postural control, weight distribution, and center of pressure (COP) Symmetry Index in individuals with ACLR during quiet standing, in open and closed eyes conditions, compared to healthy people. In the present study, 12 men with right ACLR and 12 healthy men were recruited as participants. Participants stood barefoot on the two force plates. Each foot was placed on one of the 2 platforms. Postural control was assessed during quiet standing in two conditions (open and closed eyes conditions). The positions of COP in antero-posterior and medio-lateral directions are detected under the right and left foot separately and also as net. Postural sway quantified based on five parameters included the amplitude (AMP), total excursions (TOTEX), mean velocity (MVELO), standard deviation (SD), and 95% confidence ellipse area (AREACE). Weight distribution percentage on the lower limbs and COP Symmetry Index in antero-posterior direction were also calculated. The results showed that the COP parameters in some investigated parameters (TOTEXap, SDap, AREACE, AMPap, TOTEXml) were higher in individuals with ACLR than in the healthy group ($P<0.05$). There was no difference between the two groups regarding the Symmetry Index in the eyes open and closed conditions ($P>0.05$). Weight distribution, in eyes open condition, in ACLR group on the operated limb is more than that in healthy people ($P<0.05$).We concluded that individuals with ACLR has a poor postural control in anteroposterior (AP) and mediolateral (ML) directions during quiet standing. The Symmetry Index was the same in both groups. In contrast to the able-bodied participants, individuals with ACLR bear more body weight on the operated limb than on the non- operated limb.

**Keywords**: COP, Symmetry Index, ACL, Static postural control

**Corresponding Author:** Safoura Ghasemi, Department of Sports Physiology and Pathology, Faculty of Sport Sciences, Arak University, Arak, Iran. Email: s-ghasemi@araku.ac.ir, Tel: 09188117079

Anterior cruciate ligament (ACL) is one of the ligaments in the knee joint that is prone to injury, especially during sports. The ACL plays an important role in providing proprioceptive information and is therefore very effective in knee stability [1]. It is obvious that the occurrence of a lesion in this organ leads to a decrease in postural stability [2-4] and functional disorder in motor coordination [5,6]. Several studies have reported changes in sensorimotor control after ACL injury [7,8]

Surgery is one of the common treatments for ACL injury, known as anterior cruciate ligament reconstruction (ACLR). The final goal of the surgery is to reconstruct the damaged ligament in order to improve joint stability (which leads to postural control). But it has been shown that ACLR diminishes somatosensory feedback and proprioceptive functioning [9]. Snapple et al. (2020) have reported the improvement of postural stability after ACLR [10]. However, the deficit of proprioceptors may persist up to 2 years after ACLR [11]. Pahnabi et al. (2014)[12] stated that the survival of imbalance in the operated leg may remain for 7 months. Henrikson (2001)[13] reported this duration to be 3 years. These results show the necessity of evaluating postural control disorders after ACLR with the aim of returning to activities and sports as quickly as possible.

Postural control is defined as the ability to monitor body position and alignment in space [4]. In patients with ACL tear, the individual's attempt to maintain their center of mass over a stationary base of support on their injured vs. non-injured limb and compared to the healthy people reflects postural stability [14]. Therefore, the evaluation of postural stability indicates the possible lower extremity proprioceptive deficits [15]. In the laboratory, postural stability can be obtained via spontaneous sway and induced sway of posture. It can be evaluated on a force platform using static and dynamic measurements, and quiet standing tests are an ideal assessment method for this purpose in individuals with ACLR. In this assessment, the subject is required to stand on a stable support surface and keep the COP within this support surface. Actions or conditions that increase the difficulty of postural control can be added during the assessment, such as standing with eyes closed, or standing on an elastic cushion.

In the research conducted in this field, COP is a comprehensive control variable and the force platform is an optimal tool for quantitative assessment of postural control. In this way, information is provided about spatial and temporal alterations in body position for maintaining balance in the vertical and horizontal axes and these data are used to calculate oscillations in the center of pressure (COP) in the AP and ML directions, as well as the velocity of the oscillations and the sway area [16-19]. As COP has been identified as a measure of the neuromuscular response to control posture, differences in right and left foot COP variables can serve as a measure of sensorimotor control and function. In this way, the respective COP variables for either foot and the congruence between both points of application signify the ability of the central nervous system to integrate information from the sensory systems and then activate different postural muscles so that upright stance is preserved.

Most of the studies are based on using a single force plate and thus measure the exerted force simultaneously for both feet [20-26]. Limited research has investigated these assessments using more than one force plate separately for the right and left foot in individuals with ACLR. Since the maintenance of COP is the result of the action of two feet, it is necessary to use two independent force plates placed under the left and right foot to measure the ground reaction force and COP under each foot, which can be more objective than using a single force plate or one foot to analyze the balance mechanism [20, 27-28]. This is especially important for people with asymmetric weight distribution, such as hemiplegia and amputation [29] and individuals with ACLR. For example, Soangra and Lockhart [30] and Brauer et al. [31] investigated the similarities and dissimilarities between right and left foot COP variables.

However, in studies that have used two force plates, the investigation of useful variables such as oscillation, range and velocity of oscillation in regards to the level of symmetry (or asymmetry) and weight distribution between the operated limb and non- operated limb of ACLR patients has been neglected. Using such measurements, previous research has shown that this type of injury and subsequent ACLR have different effects on body sway [32-34]. Lehman (2017) showed that static standing stability, when standing on the operated limb, decreases after ACLR [4]. Parus et al. (2015) also reported such a decrease [35]. On the other hand, in the research of Lehman et al. (2020), the reduction of sway in postural stability after ACLR was not recorded [36]. Such a lack of reduction was also observed in the research of Jiganti et al. (2020) [37]. Such contradictory results show the need for more research that includes different measurements.

In addition to variables such as postural control, attention to the distribution of weight on the operated limb will also help to better understand the conditions of joint stability and posture. Reduction in the quality of weight distribution may also increase the likelihood of rupture and re-injury of the operated ACL [38]. Bartels et al. (2018) reported a significant effect between weight distribution index (mediolateral) before and 2 years after ACLR. They concluded that normalization of weight distribution needs at least one year. Among the other influential variables in the postural sway, which it seems necessary to measure, is the Symmetry Index. Mansfield et al. (2001) showed in their research that the symmetry index can predict the risk of falling in the daily life of patients who have had a stroke, asymmetry of weight distribution in quiet standing, decrease in gait velocity and asymmetry in the temporal and spatial parameters of gait in these people [38]. More research is needed to obtain a comprehensive view of this variable in ACLR patients. These assessments will also help develop rehabilitation strategies.

Briefly, it should be said that on the one hand, recovery and resumption of activities, both in daily affairs and in sports, show the necessity of examining variables such as body posture, weight distribution, and Symmetry Index in ACLR patient. On the other hand, the decrease in the proprioceptive function following ACLR, which may remain between 2 and 3 years after the surgery, provides the possibility of re-injury [40-41]. This is especially important for athletes. It has been shown that only 63% of athletes can return to sports after ACLR [42] because the possibility of re-injury in the injured area and other injuries in that area still remains [43]. The researchers also showed increased muscle activity across different running patterns increase the risk of secondary injury in people with ACL injuries [44]. Therefore, considering the importance of the topic, this research aims to investigate the postural control, weight distribution and Symmetry Index of young men after ACLR compared to healthy people.

## MATERIAL AND METHODS

### Participants

12 individuals with right ACLR (174.54±7.13 cm; 78.51±12.8 kg; 25.71±3.36 $Kg/m^2$) as a ACLR group and 12 health men as a control group (174.12±5.73 cm; 75.76±8.92 kg; 24.98±2. 6 $Kg/m^2$) participated in this study. Using G*Power software, the sample size needed to achieve the effect size of 0.50 at the significance level of 0.05 and statistical power of 0.95 was determined to be at least 22 subjects for two groups.

All the subjects were males at the age range of 20-35. The individuals with ACLR were referred from Bone, Joint and Related Tissues Research Center of Shahid Beheshti University of Medical Sciences. These patients were evaluated by orthopedist physician and referred to Motion Analysis Laboratory of Alzahra University.

Inclusion criteria for subjects with right ACLR were as follows: Right ACLR with hamstring auto graft; age limit between 20 and 37 years; 6 months to 2 years after reconstruction; the patients underwent the same rehabilitation program; without any pain, and using no drugs; normal condition in musculoskeletal system (except for right knee); and they were physically active. Exclusion Criteria: Pain or any deformities in lower limbs; visual or vestibular disturbance. The control group consisted of healthy individuals who did not have any injury, surgery or deformity in the lower limbs. They were also neuromuscularly healthy. The current study was done in accordance with Helsinki Declaration. This study was approved by the ethics committee in the research of the Institute of Physical Education and Sports Sciences. Moreover, every subject was asked to sign a consent form before data collection.

### Procedure

The static postural control of the participants during quiet standing was evaluated with two Kistler force plates (9286BA, 9260AA3 Kistler, Switzerland). Participants stood barefoot on the two force plates side by side separated by 5 cm. Each foot was placed on one of the 2 platforms. The subjects were free to adopt their feet. postural control was assessed during quiet standing in two conditions (eyes open and eyes closed). The duration of each test was 65 seconds. The number of trials was 3 times in each condition and the rest period between trials was 2 minutes.

The data were collected with frequency of 250 Hz and filtered with Butterworth low pass filter with cutoff frequency of 5 Hz. The first 5 seconds of the data were deleted to remove the effects of sudden standing on the force plates. The positions of center of foot pressure (COP) in anteroposterior and mediolateral directions are detected under the right and left foot separately. Postural sway quantified based on five parameters included the amplitude (AMP), total excursions (TOTEX), mean velocity (MVELO), standard deviation (SD) standard deviation (SD) of COP and 95% confidence ellipse area (AREACE).

The mentioned parameters were calculated for COP position under the right and left foot separately and also as net. Weight distribution percentage on the lower limbs and COP Symmetry index in anteroposterior direction were also calculated. The Symmetry Index is the root mean square (RMS) of antroposterior COP on the right side divided by the sum of the RMS of antroposterior COP on both sides. This provides a measure of the contribution of each limb to antroposterior postural control; a value of 0.5 indicates that both limbs contribute equally to postural control, whereas less than 0.5 indicates that the left side contributes more, and greater than 0.5 indicates that the right side contributes more to postural control [45].

## Data analysis

Shapiro-Whilk test was used to check the normality of the distribution. To assess the effect of group (ACLR and healthy), vision (open and closed eyes), and limb side (right, left and net) on the postural sway parameters, Multivariate analysis of variance (MANOVA) was used. To compare weight distribution and anteroposterior COP Symmetry Index independent t-test was used between 2 groups. The significant level at 0.05 was used for final analysis. The statistical analysis was done using SPSS 25 software.

## RESULTS

Table 1 shows the results related to the effect of factors (group, vision and foot) on COP parameters. As can be seen, group factor (ACLR and healthy) and vision (eyes open and eyes closed) and foot (right foot, left foot and net) had a significant effect on COP parameters (p=0.000). Also, there was an interaction between group and vision (p=0.040), as well as group and foot (p=0.003).

**Table 1. The results of multivariate analysis of variance for the effect of group (ACLR and healthy), vision (eyes open and eyes closed) and leg (right foot, left foot and net) on COP parameters**

| | F | df | p-value | *ηp2* |
|---|---|---|---|---|
| **Group** | 5.270 | 9 | 0.000 | 0.103 |
| **Visual** | 10.568 | 9 | 0.000 | 0.188 |
| **Limb side** | 17.399 | 18 | 0.000 | 0.275 |
| **Group &Visual** | 1.986 | 9 | 0.040 | 0.042 |
| **Group & Foot side** | 2.192 | 18 | 0.003 | 0.046 |
| **Visual & Limb side** | 1.499 | 18 | 0.083 | 0.032 |
| **Group & Visual & Limb side** | 1.376 | 18 | 0.135 | 0.029 |

Table 2 shows the mean and SD of COP parameters in different vision conditions (eyes open and closed) and limb side (right, left and net) in the ACLR and healthy groups.

**Table 2: Mean and standard deviation of COP parameters in different vision conditions (eyes open and closed) and limb side (right, left and net) in ACLR and healthy groups**

| | | | AMP (mm) | | TOTEX (mm) | | TOTEX (mm) | SD (mm) | | AREACE ($mm^2$) | MVELO (mm/s) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | AP | ML | AP | ML | | AP | ML | | AP | ML |
| ACLR | Open Eyes | RF | 32.76±13.45 | 7.33±5.21 | 320.37±79.52 | 70.45±20.47 | 333.35±81.87 | 5.49±2.04 | 1.21±0.54 | 50.3±38.45 | 21.51±5.14 | 4.73±1.35 |
| | | LF | 32.3±13.5 | 6.34±3.75 | 360.25±144.99 | 80.38±31.37 | 374.81±118.45 | 5.49±1.76 | 1.1±0.59 | 43.11±30.81 | 24.28±7.88 | 5.42.±2.15 |
| | | Net | 28.09±8.74 | 3.76±2.47 | 325.7±67.68 | 41.71±13.46 | 332.45±69.88 | 5.08±1.48 | 0.59±0.29 | 48.94±34.53 | 21.24±4.32 | 2.72±0.87 |
| | Closed Eyes | RF | 36.82±13.05 | 7.52±2.81 | 422.13±96.29 | 98.1±46.75 | 444.08±110.86 | 6.23±2.09 | 1.73±2.17 | 53.21±34.52 | 28.48±6.29 | 6.59±2.94 |
| | | LF | 41.5±31.22 | 8.66±5.51 | 493.22±261.04 | 108.42±60.03 | 513.45±267.45 | 6.35±2.04 | 1.35±0.72 | 56.5±55.21 | 33.13±16.78 | 7.30±3.95 |
| | | Net | 35.84±14.61 | 3.38±1.18 | 409.08±89.55 | 46.28±16.12 | 416.56±91.44 | 6.09±1.99 | 0.83±1.52 | 54.71±31.25 | 26.8±6.03 | 3.03±1.08 |
| Healthy | Open Eyes | RF | 27.2±7.63 | 6.46±3.61 | 311.28±75.77 | 75.04±28.78 | 324.55±76.77 | 4.96±1.43 | 1.16±0.63 | 28.17±15.22 | 20.73±4.97 | 5.00±1.92 |
| | | LF | 26.07±10.73 | 5.83±3.12 | 295.9±128.16 | 72.56±34.77 | 311.01±129.66 | 4.54±1.49 | 0.98±0.52 | 30.71±22.55 | 19.81±8.9 | 4.86±2.38 |
| | | Net | 25.02±7.55 | 3.09±1.44 | 294.67±66.39 | 36.47±8.47 | 300.4±66.36 | 4.43±1.04 | 0.56±0.27 | 36.36±16.4 | 19.49±4.42 | 2.41±0.56 |
| | Closed Eyes | RF | 34.61±12.38 | 8.6±3.95 | 388.22±71.41 | 98.59±35.29 | 406.72±73.43 | 5.89±2.57 | 1.47±0.81 | 41.81±28.42 | 26.51±4.76 | 6.73±2.39 |
| | | LF | 31.46±10.18 | 7.88±3.18 | 407.6±138.45 | 100.08±41.9 | 427.8±140.92 | 5.41±1.64 | 1.14±0.62 | 44.47±26.99 | 27.87±9.55 | 6.83±2.83 |
| | | Net | 31.01±9.98 | 3.59±1.27 | 382.33±84.93 | 42.01±11.41 | 388.52±85.33 | 5.24±1.83 | 0.61±0.24 | 49.18±25.97 | 25.29±5.66 | 2.78±0.76 |

The results related to the group effect showed that the values of TOTEXap, SDap, AREACE, AMPap, MVELOAP ($p<0.001$), and TOTEXml ($p<0.05$) parameters in the ACLR group were significantly higher than those in the healthy group. The results related to the effect of the vision showed that the values of all COP parameters except TOTEXml were significantly higher in closed eyes compared to those in open eyes ($p<0.003$).

The results of the post hoc tests related to the interaction between the group and the vision showed that the values of TOTEXap, TOTEXml, MVELOap, and AREACE were significantly higher in the ACLR group compared to those in the healthy group ($p<0.03$). In the eyes closed condition, the values of MVELOap, TOTEXap, and SDap in the ACLR group increased significantly compared to those in the healthy group ($p<0.04$).

The results related to the effect of the limb side (pairwise comparison) showed that the value of MVELOml under the right and left foot was significantly higher than the same value in the net condition ($p=0.000$). The values of SDml and AMPml under the right foot were significantly higher than the same values under the left foot ($p<0.02$) and the net condition ($p=0.000$). These values were also significantly higher under the left foot than the same value in the net condition ($p=0.000$). The AREACE value under the right foot was significantly higher than those in the net condition ($p=0.026$). But the AREACE value under the left foot was significantly lower than the same value in the net condition ($p=0.001$). The value of AMPml under the right foot was significantly higher than the same value under the left foot ($p=0.022$) and the net condition ($p=0.000$).

The results of the post hoc tests related to the interaction between group and foot showed that the AREACE parameter under the right foot in the ACLR group was significantly higher compared to the healthy group ($p=0.001$). COP parameters including TOTEXap, SDap under the left foot in the ACLR group were significantly higher compared to the healthy group ($p<0.03$). The average TOTEXml parameter (net) was significantly higher in the ACLR group compared to the healthy group ($p=0.005$).

The results related to the symmetry index and weight distribution are presented in Table 3. Independent t-test results showed that there was no significant difference between the two groups in the symmetry index in both open and closed eyes conditions ($p>0.05$). The results related to weight distribution showed that there was a significant difference between the two groups in the condition of open eyes ($p=0.016$; $t=2.47$) so that individuals with ACLR put more body weight on the right foot than healthy people.

**Table 3. Independent t-test for the symmetry index and weight distribution in two groups**

| | symmetry index | | weight distribution | |
|---|---|---|---|---|
| **Group** | open eyes | closed eyes | open eyes | closed eyes |
| ACLR | 0.49±0.11 | 0.48±0.11 | 48.57±2.99* | **48.83±2.90** |
| Healthy | 0.52±0.10 | 0.51±0.09 | 50.53±3.73 | **50.00±2.99** |

## DISCUSSION

The aim of the present study was to investigate the posture control, weight distribution and symmetry index of individuals with ACLR in quiet standing in open and closed eyes conditions compared to healthy people. The results showed that some COP parameters, includin TOTEXap, SDap, AREACE, AMPap and TOTEXml, were higher in ACLR subjects than in the healthy group. These findings indicate that the postural control system is impaired after ACLR. Comparing the operated limb with the non- operated limb between the two groups, the results showed that the AREACE in the operated limb (in both eyes open and closed conditions) was higher than the healthy group. But the values of COP parameters including TOTEXap and SDap in the non-operated limb were higher than those in the healthy group. Also, the comparison of the mean between the two groups showed that TOTEXml in the ACLR group was more than the healthy group. In eyes closed condition, the ACLR group had more MVELOap, TOTEXap, and SDap than the healthy group. But the TOTEXAP, TOTEXml, MVELOml, and AREACE parameters were significantly higher in the ACLR group compared to the healthy group in open eye conditions. The above data shows that postural control can change in the AP and ML directions during quiet standing, so that people after ACLR have a higher swing velocity during quiet standing compared to healthy people. There was no difference between the two groups regarding the symmetry index under the eyes open and closed conditions, which means that the symmetry of the right and left foot is the same in both groups. But regarding the weight distribution, the results showed that when the eyes are open, the weight distribution in ACLR group on the operated limb is more than healthy people. This article points to the fact that the operated limb bears a greater percentage of weight than the non-operated limb and also compared to healthy people. But in the eyes closed condition, the weight distribution was similar to that the healthy group.

The findings of previous studies have shown that after ACR, COP parameters are changed during postural control; these findings indicate a decrease in automaticity and an increase in attention to postural stability [46,47]. In line with the present study, Kubisz et al`s. (2011) research also showed that after ACLR, selected COP parameters increased significantly [48]. They stated that this increase indicates a disorder in body postural control systems or sensorimotor systems. Palm et al. (2013) and Bartels et al. (2019) also reported a reduction in postural stability following an ACL-tear [49,50]. Of course, Bartels et al. (2019) showed that with the passage of time after surgery, instability is largely reduced so that six-weeks after surgery difference with the control group reduced and six-months postoperative the ACLR patients were similar to healthy matched control population. From this point of view, the current study is inconsistent with the aforementioned studies, because in the current study, the comparison of COP between healthy and ACLR individuals was made at least six months and at most two years after their surgery, and the difference was still observed. The lack of longitudinal study of postural changes is one of the limitations of the present study. However, it is suggested COP parameters be reviewed and more research be conducted before and after surgery. Despite the findings of the present study regarding the difference in COP parameters between ACLR and healthy subjects, Howells et al. [51] and Lepley et al. (2019) did not report a difference in postural sway between ACLR subjects and the controls [52]. In addition, Lehman et al. (2017) showed in a meta-analysis that the postural stability variables in ACLR decreased compared to the control group [4]. Mazaheri et al. [53] showed the difference in the kinematic parameters of gait between both groups.

Some studies attributed the lack of stability reduction following ACL injury to compensatory reactions (Lehman et al. (2021) [54]. They reported a significant difference between balance with eyes open and eyes closed in ACLR patients [55]. In the present study, such a difference was observed in the stability of the posture while the eyes were open and closed. It has been stated that CNS adaptations are very important to maintain and restore limb stability after ACL surgery. Therefore, after an injury, reliance on sensory nerve afferents may be prioritized [56] and some kind of compensatory reaction occurs. In consistence with our results, Some researchers also showed that eight months after ACLR, subjects have been shown to have greater displacement, velocity, area and total distance in the involved limb in comparison with the contralateral limb and matched limb of controls [11,34,57]. They stated that damage of the ACL may diminish afferent information [34].

Knee proprioceptive deficiency leads to reduce in the sensorimotor of the muscles around the joint [58]. Mechanoreceptor damage due to the ACLR may lead to a disorder of sensory transmission, contributing to alterations of afferent feedback and stabilizing reflexes that may implicate increased instability [4]. Of course, in addition to the proprioceptive factors, the decrease in vertical stability can be attributed to the damage of the quadriceps muscle; a part of these muscles is used for ligament reconstruction. these muscles stabilize the hip joint during extension. The maximum extension of the knee is one of the effective mechanisms in the functional stability of the joint. The quadriceps muscles belong to a part of anti-gravity muscles. therefore, dysfunction of the quadriceps muscles can explain the reduction in stability after ACLR [59]. In addition, it has been shown that the neurophysiological pathways in the sensorimotor system to control posture may be affected by pain [60]. Knee pain may disrupt postural stability [61]. Of course, in the current study, all the subjects were pain-free, so the last explanation is not very likely.

In the COP Symmetry Index section, the results of this research showed that there was no significant difference between the ACLR group and the healthy in both open and closed eyes conditions. We did not find a study that investigated the COP Symmetry Index in ACLR people, but there have been studies conducted in healthy people [62] and also people with stroke [39] that showed the existence of asymmetry in these people. Stodolka et al (2020) observed the existence of asymmetry in 67% of healthy young people and showed that only 3% of these people have symmetry in the mediolateral direction [62]. From a biomechanical point of view, it is difficult to understand this type of postural control, and we assume that this is the reason for the lack of difference between the two groups in the present study. Although in the mentioned research, the positive correlation between COP of the right and left foot was considered to indicate symmetry and the negative correlation was considered to indicate asymmetry. However, in the present research, this variable has been investigated by measuring the COP Symmetry Index [45]. Agerberg et al. (2003), Lin et al. (2009) and Rosario et al. (2011) in their research, which examined two force plates and between the dominant and non-dominant lower limbs in quiet standing, have shown the occurrence of asymmetry during postural control as a result of disturbance musculoskeletal function or lower limb dominance [63-65]. Future research and especially meta-analysis methods are suggested to further investigate these contradictions between studies. Disruption of the ACL may lead to an altered, decreased or lack of sensory input from these mechanoreceptors, and subsequent proprioceptive deficits in the injured and uninjured knee [66]. Therefore, apart from the exact cause of the present results, our data support the assumption that the non-operated limb cannot be used as a comparative reference for the operated limb when evaluating the postural stability and even Symmetry Index in ACLR subjects, as some researchers have done. [11,67,13].

Also, the results of the present study showed that there was a significant difference between the two groups in the variable of weight distribution in the eyes open condition. ACLR subjects placed more body weight on the operated limb than healthy people. Similar to the present study, Mohammadi et al. (2012) and Bartels et al. (2019) also reported the existence of a difference in weight distribution between the two groups and confirmed the persistence of this difference up to eight months after ACLR [34,50]. They showed that ACL patients put more of their weight on the non-operated limb. One of the limitations of the present study was the lack of temporal investigation of this index and the comparison between the two groups at times close to surgery and after. ACLR patients likely adopt this type of weight distribution to help reduce the anterior shear force on the ACL and subsequent activation the quadriceps muscles [67]. Bartels et al. (2019) introduce the use of the visual system as a compensatory response to weight distribution [48]. However, in the present study, the difference in weight distribution on the operated limb was greater in opened eyes than closed eyes conditions. Weight distribution may function independently of vision, so visual occlusion may not be the ideal method for determining weight distribution disorders in ACLR individuals. Finally, several studies suggest that ACL injury and subsequent surgery can negatively affect postural adjustment, mechanical stability, and sensory function [38,50]. Such a reduction in postural stability and weight distribution may lead to an increased risk of subsequent ACL injuries, creating a vicious pathological cycle.

.

## CONCLUSION

The results of the present study showed that despite the passage of 6 to 24 months after ACLR, the postural sway parameters of individuals with ACLR were significantly higher compared to healthy subjects in open and closed eye conditions during quiet standing; which indicates that these subjects may have the potential to reduce stability. The difference in the weight distribution percentage of the operated and non-operated limb suggests the need for further investigation as to whether this is a risk factor for ACL re-injury. Since the body acts as a connected and interdependent system and the reduction of stability can also be the result of misplaced movements at different points of this kinetic chain. Therefore, it is suggested that instead of focusing only on the affected joint (knee) to control the posture of the whole body, other parts that are involved during the weight bearing activity should also be investigated. Also, research in this field is recommended between unilateral athletes and other athletes and between the dominant and non-dominant side of the lower limbs.

**Author Contributions:** Conceptualization, methodology, LGh; formal analysis, FB, LGh; investigation, SGh; resources, SGh; data curation, LGh; writing—original draft preparation, SGh; writing—review and editing, SGh, LGh, FB; project administration, LGh. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research is extracted from the research project of Al-Zahra University.

**Institutional Review Board Statement**: The protocol of this study was approved by the Institute of

Physical Education and Sports Sciencesethics committee with the number IR.SSRI.REC.1400.1239.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** Data will be available at request.

**Acknowledgments:** The authors are thankful to all the participants for their participation in this study.

## REFERENCES

1. Friemert B, Franke S, Gollhofer A, Claes L, Faist M. Group I afferent pathway contributes to functional knee stability. Journal of neurophysiology. 2010;103(2):616-622.
2. Bartels T, Brehme K, Pyschik M, Pollak R, Schaffrath N, Schulze S, Delank KS, Laudner K, Schwesig R. Postural stability and regulation before and after anterior cruciate ligament reconstruction–A two years longitudinal study. Physical Therapy in Sport. 2019;38:49-58.
3. Diermann N, Schumacher T, Schanz S, Raschke MJ, Petersen W, Zantop T. Rotational instability of the knee: internal tibial rotation under a simulated pivot shift test. Archives of Orthopaedic and Trauma Surgery. 2009;129:353-358.
4. Lehmann T, Paschen L, Baumeister J. Single-leg assessment of postural stability after anterior cruciate ligament injury: a systematic review and meta-analysis. Sports medicine-open. 2017;3(1):32.
5. Ageberg E, Roberts D, Holmström E, Fridén T. Balance in single-limb stance in patients with anterior cruciate ligament injury: relation to knee laxity, proprioception, muscle strength, and subjective function. The American journal of sports medicine. 2005;33(10):1527-1237.
6. Denti M, Randelli P, Lo Vetere D, Moioli M, Bagnoli I, Cawley PW. Motor control performance in the lower extremity: normals vs. anterior cruciate ligament reconstructed knees 5–8 years from the index surgery. Knee Surgery, Sports Traumatology, Arthroscopy. 2000;8(5):296-300.
7. Cohen J. Statistical power analysis for the behavioral sciences (2nd edition). Hillsdale: LawrenceErlbaum Associates; 1988.
8. Fridén T, Roberts D, Zätterström R, Lindstrand A, Moritz U. Proprioception in the nearly extended knee: measurements of position and movement in healthy individuals and in symptomatic anterior cruciate ligament injured patients. Knee Surgery, Sports Traumatology, Arthroscopy. 1996;4:217-224.
9. Fleming JD, Ritzmann R, Centner C. Effect of an anterior cruciate ligament rupture on knee proprioception within 2 Years after conservative and operative treatment: A systematic review with meta-analysis. Sports Medicine. 2022;1:1-12.
10. Staples JR, Schafer KA, Smith MV, Motley J, Halstead M, Blackman A, Haas A, Steger-May K, Matava MJ, Wright RW, Brophy RH. Decreased postural control in patients undergoing anterior cruciate ligament reconstruction compared to healthy controls. Journal of Sport Rehabilitation. 2019;29(7):920-925.
11. Moussa AZ, Zouita S, Dziri C, Salah FB. Single-leg assessment of postural stability and knee functional outcome two years after anterior cruciate ligament reconstruction. Annals of physical and rehabilitation medicine. 2009;52(6):475-584.
12. Pahnabi G, Akbari M, Ansari NN, Mardani M, Ahmadi M, Rostami M. Comparison of the postural control between football players following ACL reconstruction and healthy subjects. Medical journal of the Islamic Republic of Iran. 2014;28:101.

13. Henriksson M, Ledin T, Good L. Postural control after anterior cruciate ligament reconstruction and functional rehabilitation. The American journal of sports medicine. 2001;29(3):359-566.
14. Sell TC. An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults. Physical Therapy in Sport. 2012;13(2):80-86.
15. Heinert B, Willett K, Kernozek TW. Influence of anterior cruciate ligament reconstruction on dynamic postural control. International journal of sports physical therapy. 2018;13(3):432.
16. Mochizuki L, Duarte M, Amadio AC, Zatsiorsky VM, Latash ML. Changes in postural sway and its fractions in conditions of postural instability. Journal of applied biomechanics. 2006;22(1):51-60.
17. Bonfim TR, Paccola CA, Barela JA. Proprioceptive and behavior impairments in individuals with anterior cruciate ligament reconstructed knees. Archives of physical medicine and rehabilitation. 2003;84(8):1217-1223.
18. Swanenburg J, de Bruin ED, Favero K, Uebelhart D, Mulder T. The reliability of postural balance measures in single and dual tasking in elderly fallers and non-fallers. BMC Musculoskelet Disord. 2008;9:162;1-10.
19. Palmieri RM, Ingersoll CD, Cordova ML, Kinzey SJ, Stone MB, Krause BA. The effect of a simulated knee joint effusion on postural control in healthy subjects. Archives of physical medicine and rehabilitation. 2003;84(7):1076-1079.
20. Winter DA. Human balance and posture control during standing and walking. Gait & posture. 1995;3(4):193-214.
21. Winter, D.A. Biomechanics and Motor Control of Human Movement; JohnWiley and Sons, Inc.: Hoboken, NJ, USA, 2009.
22. Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM. Measures of postural steadiness: differences between healthy young and elderly adults. IEEE Transactions on biomedical engineering. 1996;43(9):956-966.
23. Winter DA, Patla AE, Prince F, Ishac M, Gielo-Perczak K. Stiffness control of balance in quiet standing. Journal of neurophysiology. 1998;80(3):1211-1221.
24. Karlsson A, Frykberg G. Correlations between force plate measures for assessment of balance. Clinical Biomechanics. 2000;15(5):365-359.
25. Gage WH, Winter DA, Frank JS, Adkin AL. Kinematic and kinetic validity of the inverted pendulum model in quiet standing. Gait & posture. 2004;19(2):124-32.
26. Kleipool RP, Blankevoort L. The relation between geometry and function of the ankle joint complex: a biomechanical review. Knee surgery, sports traumatology, arthroscopy. 2010;18:618-627.
27. Winter DA, Patla AE, Ishac M, Gage WH. Motor mechanisms of balance during quiet standing. Journal of electromyography and kinesiology. 2003;13(1):49-56.
28. Jafarnezhadgero AA, Shad MM, Majlesi M. Effect of foot orthoses on the medial longitudinal arch in children with flexible flatfoot deformity: A three-dimensional moment analysis. Gait & posture. 2017;55:75-80.
29. Rougier PR. Relative contribution of the pressure variations under the feet and body weight distribution over both legs in the control of upright stance. Journal of Biomechanics. 2007;40(11):2477-2482.

30. Soangra R, Lockhart TE. Determination of stabilogram diffusion analysis coefficients and invariant density analysis parameters to understand postural stability associated with standing on anti-fatigue mats. Biomedical sciences instrumentation. 2012;48:415-422.
31. Brauer SG, Burns YR, Galley P. A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 2000;55(8):469-476.
32. Dauty M, Collon S, Dubois C. Change in posture control after recent knee anterior cruciate ligament reconstruction?. Clinical physiology and functional imaging. 2010;30(3):187-191.
33. Fernandes TL, Felix EC, Bessa F, Luna N, Sugimoto D, Greve JM, Hernandez AJ. Evaluation of static and dynamic balance in athletes with anterior cruciate ligament injury–A controlled study. Clinics. 2016;71(8):425-429.
34. Mohammadi F, Salavati M, Akhbari B, Mazaheri M, Khorrami M, Negahban H. Static and dynamic postural control in competitive athletes after anterior cruciate ligament reconstruction and controls. Knee surgery, sports traumatology, arthroscopy. 2012;20(8):1603-1610.
35. Parus K, Lisiński P, Huber J. Body balance control deficiencies following ACL reconstruction combined with medial meniscus suture. A preliminary report. Orthopaedics & Traumatology: Surgery & Research. 2015;101(7):807-810.
36. Lehmann T, Büchel D, Cockcroft J, Louw Q, Baumeister J. Modulations of inter-hemispherical phase coupling in human single leg stance. Neuroscience. 2020;430:63-72.
37. Jiganti MR, Meyer BC, Chang E, Romanelli DA, An YW. Altered cortical activation after anterior cruciate ligament reconstruction during single- leg balance task. Translational Sports Medicine. 2020;3(5):496-503.
38. Bartels T, Brehme K, Pyschik M, Schulze S, Delank KS, Fieseler G, Laudner KG, Hermassi S, Schwesig R. Pre-and postoperative postural regulation following anterior cruciate ligament reconstruction. Journal of exercise rehabilitation. 2018;14(1):143-151.
39. Mansfield A, Inness EL. Force plate assessment of quiet standing balance control: perspectives on clinical application within stroke rehabilitation. Rehabilitation Process and Outcome. 2015;4:RPO-S20363.
40. Lephart E, Fu FH. Proprioception and neuromuscular control in joint stability. Percept Motor Skill. 2001;92(1):319–20.
41. Jafarnezhadgero AA, Pourrahimghoroghchi A, Darvishani MA, Aali S, Dionisio VC. Analysis of ground reaction forces and muscle activity in individuals with anterior cruciate ligament reconstruction during different running strike patterns. Gait & Posture. 2021;90:204-209.
42. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. British journal of sports medicine. 2014;48(21):1543-1552.
43. Cinque ME, Dornan GJ, Chahla J, Moatshe G, LaPrade RF. High rates of osteoarthritis develop after anterior cruciate ligament surgery: an analysis of 4108 patients. The American journal of sports medicine. 2018;46(8):2011-2019.
44. Pourrahim Ghouroghchi A, Jafarnezhadgero A, Abdollahpour Darvishani M. Determination of Selected Lower Limb Muscles Electromyography Frequency Spectrum

in Male Soccer Players with ACL Injury during Three Running Patterns. Journal of Advanced Sport Technology. 2022;6(2):1-9.
45. Rougier PR, Genthon N. Dynamical assessment of weight-bearing asymmetry during upright quiet stance in humans. Gait & posture. 2009;29(3):437-443.
46. Negahban H, Ahmadi P, Salehi R, Mehravar M, Goharpey S. Attentional demands of postural control during single leg stance in patients with anterior cruciate ligament reconstruction. Neuroscience Letters. 2013;556:118-123.
47. Mohammadi-Rad S, Salavati M, Ebrahimi-Takamjani I et al. Dual-tasking effectson dynamic postural stability in athletes with and without anterior cruciate ligament reconstruction. Journal of Sport Rehabilitation. 2016; 25(4):324–329.
48. Kubisz L, Werner H, Bosek M, Weiss W. Posture stability evaluation using static posturography in patients after cruciate ligament reconstruction. Acta Physica Polonica A. 2011;119(6A):957-960.
49. Palm HG, Schlumpberger S, Riesner HJ, Friemert B, Lang P. Influence of anterior cruciate reconstruction on postural stability: a pre-and postoperative comparison. Der Unfallchirurg. 2015;118(6):527-534.
50. Bartels T, Brehme K, Pyschik M, Pollak R, Schaffrath N, Schulze S, Delank KS, Laudner K, Schwesig R. Postural stability and regulation before and after anterior cruciate ligament reconstruction–A two years longitudinal study. Physical Therapy in Sport. 2019;38:49-58.
51. Howells B, Ardern C, Webster K, Feller J, Whitehead T, Bryant A, Clark R. Postural control and the influence of a secondary task in people with anterior cruciate ligament reconstructed knees. Journal of Science and Medicine in Sport. 2012;15:S354-5.
52. Lepley AS, Grooms DR, Burland JP, Davi SM, Kinsella-Shaw JM, Lepley LK. Quadriceps muscle function following anterior cruciate ligament reconstruction: systemic differences in neural and morphological characteristics. Experimental brain research. 2019;237:1267-1278.
53. Mazaheri M, Negahban H, Soltani M, Mehravar M, Tajali S, Hessam M, Salavati M, Kingma I. Effects of narrow-base walking and dual tasking on gait spatiotemporal characteristics in anterior cruciate ligament-injured adults compared to healthy adults. Knee Surgery, Sports Traumatology, Arthroscopy. 2017;25:2528-2535.
54. Lehmann T, Büchel D, Mouton C, Gokeler A, Seil R, Baumeister J. Functional cortical connectivity related to postural control in patients six weeks after anterior cruciate ligament reconstruction. Frontiers in Human Neuroscience. 2021;15:655116.
55. Okuda K, Abe N, Katayama Y, Senda M, Kuroda T, Inoue H. Effect of vision on postural sway in anterior cruciate ligament injured knees. Journal of Orthopaedic Science. 2005;10(3):277-283.
56. Kapreli E, Athanasopoulos S, Gliatis J, Papathanasiou M, Peeters R, Strimpakos N, Van Hecke P, Gouliamos A, Sunaert S. Anterior cruciate ligament deficiency causes brain plasticity: a functional MRI study. The American journal of sports medicine. 2009;37(12):2419-2426.
57. Dauty M, Collon S, Dubois C. Change in posture control after recent knee anterior cruciate ligament reconstruction?. Clinical physiology and functional imaging. 2010;30(3):187-191.
58. Konishi YU. ACL repair might induce further abnormality of gamma loop in the intact side of the quadriceps femoris. International journal of sports medicine. 2011;32(04):292-296.

59. Piontek T,Ciemniewska-Gorzela K, Szulc A, Pyda A, Dudzinski W, Hejna R, ChirurgiaNarzadów Ruchu i Ortopedia Polska. 2009;74, 353. (in Polish).
60. Ruhe A, Fejer R, Walker B. Center of pressure excursion as a measure of balance performance in patients with non-specific low back pain compared to healthy controls: a systematic review of the literature. European Spine Journal. 2011;20:358-368.
61. Hirata RP, Arendt-Nielsen L, Shiozawa S, Graven-Nielsen T. Experimental knee pain impairs postural stability during quiet stance but not after perturbations. European journal of applied physiology. 2012;112:2511-2521.
62. Stodółka J, Blach W, Vodicar J, Maćkała K. The characteristics of feet center of pressure trajectory during quiet standing. Applied Sciences. 2020;10(8):2940.
63. Ageberg E, Roberts D, Holmström E, Fridén T. Balance in single-limb stance in healthy subjects–reliability of testing procedure and the effect of short-duration sub-maximal cycling. BMC Musculoskeletal disorders. 2003;4:1-6.
64. Lin WH, Liu YF, Hsieh CC, Lee AJ. Ankle eversion to inversion strength ratio and static balance control in the dominant and non-dominant limbs of young adults. Journal of Science and Medicine in Sport. 2009;12(1):42-49.
65. Barone R, Macaluso F, Traina M, Leonardi V, Farina F, Di Felice V. Soccer players have a better standing balance in nondominant one-legged stance. Open access journal of sports medicine. 2010:1-6.
66. Reider B, Arcand MA, Diehl LH, Mroczek K, Abulencia A, Stroud CC, Palm M, Gilbertson J, Staszak P. Proprioception of the knee before and after anterior cruciate ligament reconstruction. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2003;19(1):2-12.
67. Hoffman M, Schrader J, Koceja D. An investigation of postural control in postoperative anterior cruciate ligament reconstruction patients. Journal of Athletic Training. 1999;34(2):130-136.

# کنترل پاسچر و توزیع وزن مردان با بازسازی رباط صلیبی قدامی زانو هنگام ایستادن آرام

لیلا غزاله[1]، صفورا قاسمی*[2]، فاطمه بدیعی[3]

1. گروه فیزیولوژی ورزشی، دانشکده تربیت بدنی و علوم ورزشی، دانشگاه الزهرا، تهران، ایران
2. گروه فیزیولوژی و آسیب شناسی ورزشی، دانشکده تربیت بدنی و علوم ورزشی، دانشگاه اراک، اراک، ایران
3. دانشکده مهندسی مکانیک، دانشگاه صنعتی جندی شاپور، دزفول، ایران

**چکیده:**

بازسازی رباط صلیبی قدامی (ACLR) یکی از درمان های رایج برای آسیب ACL در نظر گرفته شده است. کاهش فعالیت حس عمقی به دنبال ACLR که ممکن است بین ۲ تا ۳ سال پس از جراحی باقی بماند، امکان آسیب مجدد را فراهم می‌کند. لذا این تحقیق با هدف بررسی کنترل پاسچر، توزیع وزن و شاخص تقارن مرکز فشار (COP) بیماران ACLR در حالت ایستادن آرام با چشمان باز و بسته نسبت به افراد سالم انجام شد. در این مطالعه ۱۲ مرد با ACLR راست و ۱۲ مرد سالم به عنوان گروه کنترل انتخاب شدند. شرکت کنندگان با پای برهنه روی دو صفحه نیرو ایستادند. هر پا روی یکی از ۲ صفحه قرار گرفت. ارزیابی تعادل در حالت ایستادن آرام در دو حالت (چشم باز و چشم بسته) ارزیابی شد. موقعیت مرکز فشار پا (COP) در جهت قدامی خلفی (AP) و میانی جانبی (ML) زیر پای راست و چپ به طور جداگانه و همچنین به صورت میانگین (Net) ارزیابی شد. نوسان پاسچر بر اساس پنج پارامتر شامل دامنه (AMP)، کل گشت‌ها (TOTEX)، میانگین سرعت (MVELO)، انحراف استاندارد (SD) و ناحیه بیضی با ۹۵٪ اطمینان (AREACE) تعیین شد. درصد توزیع وزن در اندام تحتانی و شاخص تقارن COP در جهت قدامی خلفی نیز محاسبه شدند. نتایج نشان داد پارامترهای COP در برخی از عوامل مورد بررسی (TOTEXap، SDap، AREACE، AMPap و TOTEXml) در افراد ACLR بیشتر از گروه کنترل بود (P<۰/۰۵). بین دو گروه از نظر شاخص تقارن در شرایط باز و بسته چشم تفاوتی وجود نداشت (P>۰/۰۵). توزیع وزن هنگام باز بودن چشم در گروه ACLR روی پای عمل شده بیشتر از افراد سالم نشان داده شد (P<۰/۰۵). ما به این نتیجه رسیدیم که افراد مبتلا به ACLR کنترل پاسچر ضعیفی در جهت قدامی خلفی (AP) و داخلی جانبی (ML) دارند. در هنگام ایستادن آرام شاخص تقارن در هر دو گروه یکسان بود. بر خلاف افراد سالم، افراد بعد از ACLR وزن بیشتری را روی اندام جراحی شده نسبت به اندام جراحی نشده تحمل می‌کنند.

**واژه های کلیدی**: مرکز فشار، شاخص تقارن، رباط صلیبی قدامی زانو، کنترل پاسچر ایستا.