Studying the Changes of Time to Stabilization and Center of Pressure Velocity in Athletes with an Unilateral Isolated Anterior Cruciate Ligament Rupture in a Six-Month Follow-Up

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Abstract

Introduction: Anterior cruciate ligament rupture has shown vast changes in kinematics and kinetics parameters of lower limbs. The aim of this study was to investigate the balance changes including time to stabilization (TTS) and velocity of the center of pressure (CoP) displacement in professional male and female athletes aged between 20 and 40 years. **Methods and Materials:** The present cohort study was conducted on 58 male and female professional athletes (mean age: 26.9). The individuals were divided into two healthy and ACL-deficient knee groups, each with 29 people. The TTS and velocity of CoP displacement in both anterior-posterior and medial-lateral directions were calculated in the forward jumping test on a force platform. The test was performed three times consisted on the end of the 2nd, 4th and 6th months post injury. Based on the type of data distribution, either Repeated Measures or Friedman test was used to evaluate within-group changes over time, and an Independent or Mann-Whitney test was utilized to compare between-group changes. **Results:** The results showed significant difference between the healthy and ACL-D groups in TTS and CoP velocity. The TTS was different between groups (P=0.494 for 2nd, P=0.008 for 4th, and P=0.041 for 6th month post injury). The CoP velocity in AP direction showed no significant difference between groups (P=0.419 for 2nd, P=0.196 for 4th, and P=0.36 for 6th month after injury). However, there was a significant difference between groups in 4th month post injury (P=0.359 for 2nd, P=0.01 for 4th, and P=0.331 for 6th post injury) in ML direction. **Conclusion:** Considering all parameters, it seems that improvement was occurred between 2nd and 4th months but not between 4th and 6th months. It can be said that most of the changes of TTS and CoP occur in the first months after the injury.

Keywords: ACL Deficient Knee; Balance; Center of Pressure; Time to Stabilization; Velocity

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Introduction

The high prevalence of ligament injuries in sports particularly anterior cruciate ligament (ACL), the high cost of their treatment, and the serious disabilities caused for athletes (1-3), show the importance of studying different aspects of this injury. The ACL is one of the main structures in stability of the knee joint, especially in the sagittal plane. So, it is expected that postural stability and balance parameters change with damage to this ligament. There is almost no consensus on the occurrence of changes in postural balance after ACL injury (4-8). Most studies have been performed on people who have undergone ligament reconstruction surgery (9-11) or the effect of a treatment (9, 12). Few studies have been performed on people who have not had surgery for a relatively long period of time (13, 14). Due to the fact that most cases of ACL injury are associated with damage to another knee structure such as the meniscus, the number of studies performed on isolated ACL injury is even more less. In the present study, we tried to reduce these limitations and examine only the effect of damage to this ligament. Prospective

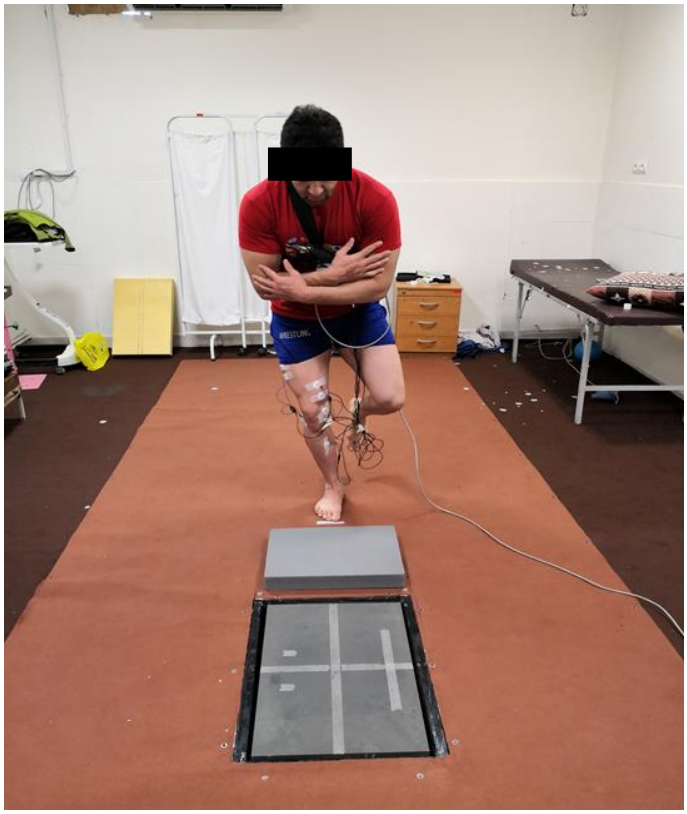

Figure 1. Forward jumping

investigations have been conducted to examine the relationship between balance parameters and the likelihood of future ligament damage. Steffen et al. evaluated 837 male and female handball and soccer athletes and concluded no significant relationship between balance parameters such as time to stabilization (TTS) and center of pressure(CoP) velocity with the likelihood of future ACL injury (15), whereas Oshima et al. in a study of 278 handball and soccer athletes confirmed a weak relationship between CoP velocity and the likelihood of future ACL injury (16).

Among these parameters' can replace with "Among balance parameters. Among these parameters, the TTS and CoP velocity, according to Steffen *et al.* (15) are more important and show more sensitivity to changes. Therefore, these two parameters were used in the present study with the aim of discovering balance changes.

Participants

This cohort study was conducted at the School of Rehabilitation, Sciences of Shahid Beheshti University of Medical Sciences, Tehran, Iran. Ethics approval was obtained to perform the study (IR.SBMU.RETECH.REC.1398.820). Fifty-eight athletes, aged between 20 and 40 years, were divided into two groups (29 cases per group) including healthy controls and ACL-deficient knee (ACL-D) group (Table 1). The inclusion criteria for the ACL-D group were as follows: 1) male and female athletes with aged 20-40 years, 2) unilateral, isolated, complete rupture of ACL confirmed by an orthopedic specialist, and 3) magnetic resonance imaging (MRI) indicating no damage to other knee structures. The athletes had no history of lower extremity injury or within the past year and did not intend to undergo surgery within the following six months. Two months had passed since the athlete's injury at the beginning of this study to ensure that the knee was asymptomatic. A healthy control group of male and female athletes, aged 20-40 years, with no history of injury or surgery in their lower extremity was also selected. The exclusion criteria for healthy group were having a systemic disease or other medical conditions that would prevent person from entering the study. All participants were selected among athletes, referred to the Physiotherapy Clinic of the Sports Medicine Federation of the Islamic Republic of Iran (SMFIRI) via convenience sampling.

Methods and Materials

In this study, the forward jumping test (Figure 1) was used for both groups. First, a distance equal to half the participant's height was determined from the center of force plate (a 60 * 40 cm Kistler force plate with sampling rate of 1000/s) and marked on the ground (17, 18). He/she was then asked to stand on two legs in a relaxed position with his/her arms crossed on the chest. At the command of the examiner, he/she first stood on one (injured) leg and then jumped on the force plate with the same leg. The person held his/her balance for 20 seconds. After landing on the force plate, the participant had to look at a point in front of him/her on the wall and avoid talking. To create a minimal challenge, a light and stable foam with 8 cm thick was placed on the ground in the middle of the jump distance (10). The jump test was repeated 3 times with a 30-second interval. Before the main test, the participants were tested once to get familiar with the test method. The final data was extracted from the average of three jumps. The preferred leg for healthy individuals and the injured leg in injured ones were selected for the jump test. The velocity of CoP displacement in the anterior-posterior (AP) and medial-lateral (ML) directions was calculated by the force plate in millimeters per millisecond (due to the sampling rate of the device=1000) and the TTS using the MATLA B software in terms of seconds. The jump test at the beginning of the study (which was two months after the injury for the ACL-D group), was repeated two and four months after the first test. Considering that in the case of velocity of CoP, the values of standard deviation of

Table 1. Demographic characteristics of the participants (n=29) and homogeneity test results

Group		Gender	Age	Weight(kg)	Height(cm)	BMI
Healthy	Min	19 male+10 female	20	56	166	18.8
	Max		38	87	194	26.2
	Mean (SD)		27.3 (4.8)	68.2 (7.2)	174.6 (7.1)	22.3 (1.9)
ACLD	Min	19 male+10 female	20	57	162	18.9
	Max		38	89	193	26.6
	Mean (SD)		26.6 (5.4)	70.2 (7.1)	175.9 (7.1)	22.7 (1.8)
Homogeneity test *P*-Values		1.0	0.631	0.277	0.483	0.488

ACLD; Anterior Cruciate Ligament Deficient, BMI; Body Mass Index

Table 2. *Mean value and SD of TTS and CoP velocity in both groups (n=29)*

Variable	Unit	Groups					
		Healthy			ACL-D		
		Min	Max	Mean (SD)	Min	Max	Mean (SD)
TTS2	Seconds	1.4	3.4	3.01 (0.47)	2.2	3.4	3 (0.032)
TTS4		2.2	3.2	2.7 (0.34)	2.2	3.2	2.9 (0.34)
TTS6		1.4	3.4	3.05 (0.36)	1.4	3.4	3.1 (0.36)
APsdv2	Millimeters/ Milliseconds	1560.2	4342.4	2691.2 (665.7)	1537.8	4369.1	2575.4 (677.6)
APsdv4		1537.9	3416.7	2440.2 (579.9)	1478.6	4067.4	2650.4 (642.6)
APsdv6		1559.8	3496.9	2635.9 (535.9)	1401.4	4191.2	2479.8 (535.5)
MLsdv2		721.1	2171.4	1176.3 (357)	656.7	2085.7	1225.2 (321.8)
MLdsv4		657.2	1663.1	1216.5 (253.6)	720.9	2168.4	1074.8 (286.3)
MLsdv6		721.6	2168.4	1109.7 (277.4)	656.9	3078.6	1208.9 (443.1)

TTS2; time to stability 2 months after injury, TTS4; time to stability 4 months after injury, TTS6; time to stability 6 months after injury, APsdv2; standard deviation of cop velocity in AP direction 2 months after injury, APsdv4; standard deviation of cop velocity in AP direction 4 months after injury, APsdv6, MLsdv2; standard deviation of cop velocity in ML direction 2 months after injury, MLsdv4; standard deviation of cop velocity in ML direction 4 months after injury, MLsdv6; standard deviation of cop velocity in ML direction 6 months after injury

velocity are used instead of velocity itself, the standard deviation of Cop velocity was utilized in this study including standard deviation of CoP velocity in anterior-posterior direction (APsdv) and standard deviation of CoP velocity in medial-lateral direction (MLsdv). TTS is the time in seconds that it takes for a person to reach a stable position or relative immobility after a jump or landing (19). In sport injuries including ACL rupture the TTS and the CoP velocity increase. So, reducing the values of these parameters after injury and approaching them to healthy people can be considered as balance improvement (16).

Statistical Analysis

First, the homogeneity of the two groups was examined in terms of gender (Chi-square test), height, weight, body mass index (BMI), and dominant leg (independent t-test); the results confirmed the homogeneity of the groups. Next, the effects of gender and preference (or non-preference) of the injured leg were investigated using independent t-test; it was found that these factors did not influence the results. Moreover, the normal distribution of dependent variables was examined with Shapiro-Wilk test. Considering the distribution of variables, repeated measure or Friedman test was used to evaluate within-group changes over time. Independent t-test or Mann-Whitney was also utilized to compare between-group changes based the data distribution. Statistical analyses were performed in SPSS Version 17 (SPSS Inc., Chicago, IL, USA).

Results

Table 1 shows the demographic characteristics of the participants and Table 2 indicates the descriptive statistics of the values of the TTS and the CoP velocity in two groups. The APsdv in both groups had a normal distribution and TTS and MLsdv had no a normal distribution.

Regarding within-group comparison, none of the TTS and CoP velocity parameters showed a significant difference during the six months after the injury in the ACL-D group (P=0.686 for TTS, P=0.603 for CoP velocity in AP direction, and P=0.185 in ML direction). In the healthy group, there was a

Table 3. *The* test results of Friedman and repeated measure (within-group comparison)

Groups			
Healthy		ACL-D	
Variable	P value	Variable	P value
TTS	0.006	TTS	0.686
APsdv	0.711*	APsdv	0.603*
MLsdv	0.075	MLsdv	0.185

TTS; time to stability, APsdv; standard deviation of cop velocity in AP direction, MLsdv; standard deviation of cop velocity in ML direction, (repeated measure test)*

Table 4. Test results of Mann-Whitney and independent T-Test (between-group comparison)

Test number/month Variable	1st test (2 months after injury)*P*-value	2nd test (4 months after injury) *P*-value	3rd test (6 months after injury) *P*-value
TTS	0.494	0.008	0.041
APsdv	0.419	0.196*	0.36*
MLsdv	0.359	0.01	0.331

TTS; time to stability, APsdv; standard deviation of cop velocity in AP direction, MLsdv; standard deviation of cop velocity in ML direction, (independent T-test)*

significant difference between three tests for TTS (*P*=0.006) but not for CoP velocity (*P*=0.711 for AP direction and *P*=0.075 for ML direction). Mean values of the TTS in both groups showed more difference in 4th month in comparison to 2nd and 6th months after injury (2.7 second for healthy and 2.9 second for ACL-D group). The same can be said about the CoP velocity in ML direction (MLsdv).

The between-group comparison demonstrated that TTS in the fourth and sixth month tests was significantly different between the two groups, with more decrease in 4thmonth test in healthy group (*P*=0.008 and *P*=0.041, respectively). However, in the second month test, no difference was found between the two groups (*P*=0.494). The CoP velocity in the APsdv did not differ between the two groups in any of the tests. The CoP velocity in the MLsdv in the fourth month indicated a significant difference between the two groups (*P*=0.01), but in the second and sixth months, there was no difference between the two groups (Table 4). In comparison between the two groups, it seems that there are more clear changes between the second and fourth months than between the fourth and sixth months.

Discussion

Based on the findings, TTS in the healthy group changed over time (*P*=0.006); but in the ACL-D group, there has been no significant change (*P*=0.686) which seems to be unexpected. According to the mean value of each test, both groups have gone through the same process. Between the 2nd and 4th month test, the results were better and TTS was decreased. Also, between the 4th and 6th month test, the TTS was increased. In the ACL-D group, although there was no significant difference between the tests over time, but a significant difference was found between the healthy group and the ACL-D groups in the 4th and 6th months (*P*=0.008 and *P*=0.041, respectively).

The TTS has been examined in a number of studies. In a prospective study in 2016, Duprey *et al.* (20) studied the TTS in the two tests including forward and backward jumping. Results showed that in people with ACL rupture and in the backward jumping test, the TTS was significantly increased, but not in jumping forward which is in line with the findings of our study. They concluded that TTS could be used as a risk factor in predicting ACL injury. The lack of difference between healthy and injured limbs in injured people was attributed to the existence of a general disturbance in the dynamic stability of these people due to ACL rupture.

In the present study, the test was performed in the form of forward jumping and in the ACL-D group, unlike the healthy group, there was no difference between the tests over time, but there is a difference between the two groups in the 4th and 6th months. This can be attributed to the occurrence of changes in the healthy group, while the occurrence of the general disorder mentioned by Duprey *et al.* (20) in the injury group can prevent a significant improvement of the TTS in the injured group. Unlike backward jumping, forward jumping is probably more adapted to the neuromuscular system, perhaps because of a natural and repetitive activity in sports. It therefore is expected to accelerate in the recovery process after injury, while vision (eyes) helps maintain balance in these conditions. For this reason, some researchers believe that test type can be effective in the results obtained (20-22).

In the present study, the APsdv and MLsdv have been utilized. The results showed that in none of the groups, the changes in the Cop velocity were significant. However; in

between-group comparison in the second test (four months after the injury), there was a difference in the medio-lateral direction. This result is consistent with some studies and contradicts others. In Lanier's study, there was a difference between healthy and operated people in both directions, but the difference was seen only in the anterior-posterior direction between operated and non-operated people (9). In the Steffen's prospective study, none of the parameters of the CoP indicated a difference between healthy and injured individuals (15), whereas in a prospective study by Oshima *et al.* the CoP velocity of the healthy and injured individuals was different (16). Given that most common mechanism in ACL injury is adduction and flexion, inward knee movement is a condition that injured people usually avoid for fear of injury recurrence. Perhaps, this is one of the reasons for more difference in ML direction than AP between healthy and injured limbs or between healthy and injured people. Learning effect is one of other probable reasons to the results. Other probable reason is the level of the challenge of the test; maybe we ought to use more challenging test(s) to better reveal changes

Limitation and recommendation

Finding athletes with isolated cruciate ligament injury, who would not have surgery within six months after the injury and the relatively long time between tests (2 months), were limitations that the authors faced. Future studies with more participants and more number of tests are recommended to examine changes more consistently.

Conclusion

According to the findings of this study, it can be said that most of the changes occur in the first 4 months after injury and there was no big change between 4th and 6th months after injury that this has been confirmed at least in one other study (6). Despite the different methods used in the studies which can cause differences in the results obtained, this study confirms the change of balance parameters (TTS and CoP velocity) in agreement with several studies(4,6,24). Nevertheless, there is not a fixed and stable trend to the changes based on the results of this study.

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Conflict of interest:

None

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Authors' contributions:

Study concept and design: AR, AR., KKK. Acquisition of data: AR. Analysis and interpretation of data: AR., AR., AAB. Drafting of the manuscript: AR, AR. Critical revision of the manuscript for important intellectual contents: AR. KKK. Statistical analysis: AR., AAB. Study supervision: AR. YS Biomechanical calculations

Ethical Approval

This research was approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences under the code of ethics IR.SBMU.RETECH.REC.1398.820

Informed Consent

After obtaining the written informed consent from the patients and in accordance with the provisions of Helsinki Declaration, the questionnaires and data were collected.

References

1. Majewski M, Susanne H, Klaus S. Epidemiology of athletic knee injuries: a 10-year study. The knee. 2006;13(3):184-8.
2. Gianotti SM, Marshall SW, Hume PA, Bunt L. Incidence of anterior cruciate ligament injury and other knee ligament injuries: a national population-based study. Journal of science and medicine in sport. 2009;12(6):622-7.
3. Röijezon U, Clark NC, Treleaven J. Proprioception in musculoskeletal rehabilitation. Part 1: Basic science and principles of assessment and clinical interventions. Manual therapy. 2015;20(3):368-77.
4. Soltani N, Rahimi A, Naimi S-S, Khademi K, Saeedi H. Studying the balance of the coper and non-coper ACL-deficient knee subjects. Asian journal of sports medicine. 2014;5(2):91.
5. Huang H, Keijsers N, Horemans H, Guo Q, Yu Y, Stam H, et al. Anterior cruciate ligament rupture is associated with abnormal and asymmetrical lower limb loading during walking. Journal of science and medicine in sport. 2017;20(5):432-7.
6. Fernandes TL, Felix ECR, Bessa F, Luna N, Sugimoto D, Greve JMDA, et al. Evaluation of static and dynamic balance in athletes with anterior cruciate ligament injury–A controlled study. Clinics. 2016;71(8):425-9.
7. Negahban H, Mazaheri M, Kingma I, van Dieën JH. A systematic review of postural control during single-leg stance in patients with untreated anterior cruciate ligament injury. Knee surgery, sports traumatology, arthroscopy. 2014;22(7):1491-504.
8. 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):1527-37.
9. Lanier AS, Knarr BA, Stergiou N, Snyder-Mackler L, Buchanan TS. ACL injury and reconstruction affect control of ground reaction forces produced during a novel task that simulates cutting movements. Journal of Orthopaedic Research®. 2020;38(8):1746-52.
10. Sell TC, Hufnagel M, Heebner N, Lephart SM. Reliability, discriminant validity and sex comparisons of dynamic postural stability during a landing task designed to challenge transverse plane knee stability. Sports biomechanics. 2019.
11. Akbari A, Ghiasi F, Mir M, Hosseinifar M. The effects of balance training on static and dynamic postural stability indices after acute ACL reconstruction. Global journal of health science. 2016;8(4):68.
12. Kartus J, Magnusson L, Stener S, Brandsson S, Eriksson BI, Karlsson J. Complications following arthroscopic anterior cruciate ligament reconstruction A 2–5-year follow-up of 604 patients with special emphasis on anterior knee pain. Knee Surgery, Sports Traumatology, Arthroscopy. 1999;7(1):2-8.
13. Alkjær T, Henriksen M, Simonsen EB. Different knee joint loading patterns in ACL deficient copers and non-copers during walking. Knee Surgery, Sports Traumatology, Arthroscopy. 2011;19(4):615-21.
14. Fridén T, Roberts D, Zätterström R, Lindstrand A, Moritz U. Proprioception after an acute knee ligament injury: a longitudinal study on 16 consecutive patients. Journal of orthopaedic research. 1997;15(5):637-44.
15. Steffen K, Nilstad A, Krosshaug T, Pasanen K, Killingmo A, Bahr R. No association between static and dynamic postural control and ACL injury risk among female elite handball and football players: a prospective study of 838 players. British Journal of Sports Medicine. 2017;51(4):253-9.
16. Oshima T, Nakase J, Kitaoka K, Shima Y, Numata H, Takata Y, et al. Poor static balance is a risk factor for non-contact anterior cruciate ligament injury. Archives of orthopaedic and trauma surgery. 2018;138(12):1713-8.
17. Howard JS, Fazio MA, Mattacola CG, Uhl TL, Jacobs CA. Structure, sex, and strength and knee and hip kinematics during landing. National Athletic Trainers' Association, Inc; 2011.
18. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett Jr WE, Beutler AI. The Landing Error Scoring System (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: the JUMP-ACL study. The American journal of sports medicine. 2009;37(10):1996-2002.
19. Rocchi L, Chiari L, Cappello A. Feature selection of stabilometric parameters based on principal component analysis. Medical and Biological Engineering and Computing. 2004;42(1):71-9.
20. DuPrey KM, Liu K, Cronholm PF, Reisman AS, Collina SJ, Webner D, et al. Baseline time to stabilization identifies anterior cruciate ligament rupture risk in collegiate athletes. The American journal of sports medicine. 2016;44(6):1487-91.
21. Kalimuthu M, Mokhtar A. Muscle Bulk, Strength And Proprioceptive Difference Between Anterior Cruciate Ligament Deficient And Normal KNEE. Journal of Health and Translational Medicine. 2017;20(1):1-5.
22. Ross SE, Guskiewicz KM, Yu B. Single-leg jump-landing stabilization times in subjects with functionally unstable ankles. Journal of athletic training. 2005;40(4):298.