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Changes of Knee Proprioception in Athletes With an Isolated Unilateral Complete Anterior Cruciate Ligament Rupture in a Six-Month Follow-up

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Abstract

Objectives: Diminished proprioception after an anterior cruciate ligament (ACL) rupture causes disabilities following injury. The aim of this study was to investigate the trend of this change during six months following an isolated unilateral complete ACL rupture.

Materials and Methods: In this cohort study, a total of 58 male and female athletes, aged 20-40 years, were surveyed in equal groups with 29 subjects. The healthy (first) and ACLD (second) groups included athletes with isolated unilateral complete ACL ruptures (the ACL-deficient knee group). Knee proprioception was investigated in both groups in three stages, namely, at the beginning of the study (two months after the injury in the ACL-D group) and the intervals of two and four months after the first assessment. The active reproduction of passive positioning (ARPP) method was used in this study. The selected angles were 45° and 60° of knee flexion, and an isokinetic device was the measuring instrument. Three reproduction angular errors were compared between three measurements in each test, including constant error (CE), absolute error (AE), and variable error (VE).

Results: The results showed that AE and VE, unlike CE, significantly changed within both groups. AE ($P \le 0.002$, $P \le 0.001$ for 45° and 60°, respectively) and VE ($P \le 0.043$ for 45°), as well as AE ($P \le 0.002$, $P \le 0.001$ for 45°and 60°, respectively) and VE ($P \le 0.005$, $P \le 0.016$ for 45° and 60°, respectively) were significant in the healthy and ACL-D groups, respectively. In addition, a significant difference was observed between healthy and ACL-D groups regarding knee proprioception. At 45°, CE, AE, and VE were significant in the first ($P \le 0.024$), the third ($P \le 0.014$), and all three ($P \le 0.001$, $P \le 0.027$, & $P \le 0.001$) tests, respectively. Finally, AE, VE, and CE were found to be significant in the second ($P \le 0.001$), second ($P \le 0.004$), and third ($P \le 0.026$) tests, at 60°, respectively.

Conclusions: In general, ACL rupture reduced knee proprioception after the injury in athletes compared to healthy individuals. Within-group differences, as well as differences between healthy and injured athletes diminished over time within six months after the injury. Eventually, knee proprioception improved in individuals with ACL rupture although the exact mechanism of these changes remains unknown.

Keywords: Knee joint, ACL-deficient knee, Proprioception, Trends, Biomechanics

Introduction

Approximately 50% of knee injuries and 20% of all sports injuries are related to anterior cruciate ligament (ACL) (1). Considering the increasing rate of injuries to ligaments, high costs of treatment (2), and significant disabilities in athletes, resulting in their long absence from the sports, it is important to study different aspects of this injury.

In the sagittal plane, the ACL is the main ligament, which stabilizes the knee. This ligament has a variety of receptors, which represent the position of the knee joint. In other words, it is involved in knee proprioception (3). Therefore, knee injury arising from damage to this ligament is partly related to disorders in knee proprioception.

Proprioception deficits following ACL injury have been confirmed in many studies (4-7). Various methods have been used to evaluate knee proprioception. These methods can be divided into three general categories of threshold to detect passive motion (TTDPM), active movement extent discrimination assessment, and joint position reproduction (JPR). The TTDPM is a passive procedure, which only evaluates passive structures (8) while in the JPR method, assessments can be performed both actively and passively.

Although many ACL studies have investigated proprioception (3,4,6,7,9-13), most of them have focused on people undergoing surgery or evaluated the effects of surgeries or interventions (14). A limited number of studies have evaluated non-reconstructed ACL injuries up to six months after the injury (4,12,14,15). Given that most ACL injuries are associated with damage to other knee structures (e.g., meniscus and cartilage), the number of studies on isolated ACL rupture is even more limited (16).

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Key Messages

- After studying the current study, the readers will have a deep understanding of the situation of knee proprioception following ACL-deficiency.
- They will find that proprioceptive sense is damaged immediately following the injury and will change constantly until a few months post-injury to return to sport.
- Most papers have studied just a time post-injury while neglecting the whole status of the proprioception.
- This study is highly important in rehabilitation following ACL-deficiency and must be recognized by all clinicians, particularly physiotherapists.

Based on our research, no study has yet examined and compared the trend of changes of proprioception (considering different error types) in isolated ACL ruptures in athletes and a homogeneous group of healthy individuals in a six-month follow-up. Accordingly, this study sought to investigate the trend of changes in knee proprioception over six months after an isolated unilateral complete ACL rupture.

Materials and Methods

Participants

This cohort study was conducted at the Faculty of Rehabilitation Sciences of Shahid Beheshti University of Medical Sciences, Tehran, Iran. Fifty-eight athletes in the age range of 20-40 years old were assigned to healthy and ACL-D groups each containing 29 cases (Table 1). The inclusion criteria for the ACL-D group were male and female athletes aged 20-40 years, the unilateral, isolated, and complete rupture of ACL confirmed by an orthopedic specialist, and magnetic resonance imaging indicating no damage to other knee structures.

Athletes had no history of lower extremity injury or surgery in the past year and did not intend to undergo surgery within the following six months. Two months should have been passed since the athlete's injury at the beginning of this study in order to ensure that the knee was asymptomatic. A healthy group of male and female athletes aged 20-40 years old with no history of injury or surgery in the lower extremity was selected as well. On the other hand, the exclusion criterion included having a systemic disease or other medical conditions that would prevent one from entering the study. All participants were selected among athletes who referred to the Physiotherapy Clinic of the Sports Medicine Federation of the Islamic Republic of Iran via convenience sampling.

Procedures

In this study, two healthy and ACL-D groups, each consisting of 19 male and 10 female athletes were evaluated based on the active reproduction of passive positioning (ARPP) method. The selected angles were 45° and 60° of knee flexion. In other words, these two angles were selected as the target angles for reproduction. The movement was knee extension. The participants were asked to extend the knee to target angles (60° and 45° of flexion) while the knee was at 90° of flexion as the starting position. A cooperative science and monitoring initiative isokinetic system (Humac Norm System, UK) was used to measure the knee angle in this study.

First, the subject was asked to sit on the isokinetic chair. After flexing the knee at 90° (Figure 1A), the foot was passively moved to the target angle (first 60°) with eyes open (passive positioning) held for 10 seconds (Figure 1B), and then returned to its original position, namely, 90° flexion (Figure 1C). After 30 seconds, the subject was asked to actively bring the knee to the target angle with eyes closed and press the stop button in his/her hand whenever he/she felt it reached the desired angle or active reproduction (Figure 1D). At this time, the angle was read on the device and the difference with the target angle was determined as well. This process was repeated three times at 30-second intervals. After a 30-minute break, the same process was repeated at a 45° angle (as the target angle) from the same starting position (90° flexion). Before the main test, the subjects participated in a trial to be familiarized with the test.

The same process was repeated two (the second test) and four (the third test) months after the first test (2 months after the injury in the ACL-D group). The dominant and injured legs were evaluated in the healthy and ACL-D groups, respectively. This method has been used in many studies (4,11,17-19) and its reliability has been confirmed by (9). However, first, a pilot study was performed on 10 individuals at a knee flexion angle of 45°. The intraclass correlation coefficient was 0.775 between repetitions, indicating the good reliability of the method.

Deviations from the target angle and the average of three attempts at angle reproduction were recorded to

Table 1. Demographic Characteristics of the Participants

Group		Age	Weight	Height (cm)	BMI
Healthy	Minimum	20	56	166	18.8
	Maximum	38	87	194	26.2
	Mean ± SD	27.3 ± 4.8	68.2 ± 7.2	174.6 ± 7.1	22.3 ± 1.9
ACLD	Minimum	20	57	162	18.9
	Maximum	38	89	193	26.6
	Mean ± SD	26.6 ± 5.4	70.2 ± 7.1	175.9 ± 7.1	22.7 ± 1.8

Note. ACLD; Anterior cruciate ligament deficient; BMI: Body mass index; SD: Standard deviation.

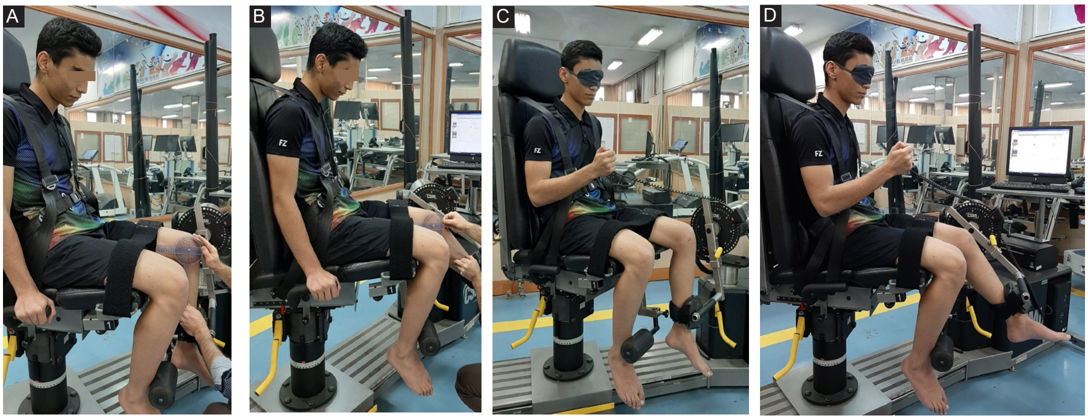

Figure 1. (A) Setting out the Starting Position (flexion 90). (B) Setting out the Target Angle Passively (Passive Positioning) With Eyes Open. (C) Starting Position of the Test With Eyes Closed. (D) Active Reproduction of the Target Angle With Eyes Closed.

calculate the errors. For a more comprehensive study, angle reproduction errors were measured, including constant (CE), absolute (AE), and variable (VE) errors. Generally, CE indicates the number of deviations from the target angle with respect to the direction of the deviation. In addition, AE represents the number of deviations from the target regardless of the direction of the deviation whereas VE indicates a deviation from the mean. In other words, VE denotes the degree of deviations when the angle is reproduced based on the average of three attempts rather than the target angle (20).

Statistical Analysis

First, the homogeneity of the groups was examined in terms of gender (chi-square test), height, weight, body mass index, and the dominant leg (the 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 an independent *t* test. It was found that these factors did not influence the results. The distribution of dependent variables was examined as well. Considering the abnormal distribution of most variables, the Friedman test was used to evaluate within-group changes over time. Furthermore, an independent *t* test was used to compare groups if data distribution was normal. On the other hand, the Mann-Whitney test was applied if data in one or both group(s) were not distributed normally. Finally, statistical analyses were performed in SPSS, version 17 (SPSS Inc., Chicago, IL, USA).

Results

Table 1 presents demographic characteristics of the participants and Table 2 provides the mean values and standard deviations of all three types of errors in three tests.

The results of the Friedman test (Table 3) showed no significant difference between three intervals in either of the groups at the 45° flexion angle based on CE ($P > 0.05$). Conversely, there was a significant difference between the two groups in terms of VE, which shows that the knee proprioception improved in both groups although this change was greater in the ACL-D group (0.043 for the healthy group vs. 0.005 for the ACL-D group). Regarding AE, there was a significant difference between the two groups over time ($P \leq 0.002$ for both groups) and the changes indicated improvements according to the mean AE values.

The results were similar at the flexion angles of 60° and 45° except for VE, where a significant difference was only

Table 2. Mean Value and SD of Three Types of Error in Three Tests

Group	Test Number	Angle					
		45			60		
		Error Type/Values (Mean ± SD)					
		CE	AE	VE	CE	AE	VE
Healthy	1st test	-1.9±2.4	3.1±1.2	2.2±0.8	1.4±2.4	3.6±1.7	2.7±1.3
	2nd test	-1.2±2	2.5±0.9	2±0.8	1.5±1.8	2.7±0.9	2.3±0.7
	3rd test	-0.8±1.5	1.9±0.7	1.9±1	1.1±1.3	2.2±0.9	2.1±0.6
ACLD	1st test	-0.5±2.6	3.3±1.6	3.3±1	1.2±3.6	3.9±1.5	2.3±1
	2nd test	-0.3±1.6	2.9±1	2.5±0.8	1.1±1.1	1.8±0.6	1.6±0.6
	3rd test	-0.05±1.4	2.6±1	2.5±0.8	1.6±1.2	2.4±0.7	1.8±0.5

Note. SD: Standard deviation; CE: Constant error; AE: Absolute error: VE: Variable error; ACLD: Anterior cruciate ligament deficient; 1st test: 2 months after the injury; 2nd test: 2 months after the 1st test; 3rd test: 4 months after the 1st test.

Table 3. Friedman (Within Group Comparison) Test Results

Group	Healthy		ACLD	
Angle	45	60	45	60
Error type	*P* value	*P* value	*P* value	*P* value
CE	0.164	0.108	0.168	0.155
AE	0.002	0.001	0.002	0.001
VE	0.043	0.068	0.005	0.016

Note. CE; Constant error; AE: Absolute error; VE: Variable error; ACLD; Anterior cruciate ligament deficient.

Table 4. Mann-Whitney and T-test (Between Group Comparison) Test Results

Angle	**Error type**	**Test Number**		
		1st test	**2nd test**	**3rd test**
		***P* Value**	***P* Value**	***P* Value**
45	CE	0.024*	0.057*	0.063
	AE	0.994	0.097*	0.014
	VE	0.001	0.027	0.001
60	CE	0.841*	0.289	0.152
	AE	0.368	0.001	0.097
	VE	0.233	0.004	0.026

Note. 1st test: 2 months after the injury; 2nd test: 4 months after the injury; 3rd test: 6 months after the injury; CE: Constant error; AE: Absolute error; VE: Variable error.
*Independent *t* test.

observed in the ACL-D group ($P \leq 0.016$). For between-groups comparisons, an independent t-test was used to compare the CE of the first and second tests at the flexion angle of 45°, the CE of the first test at the flexion angle of 60°, and the AE of the second test at the flexion angle of 45° given the normal distribution of data in both groups. Mann-Whitney test was applied if data distribution was not normal in one or both group(s).

The results of the comparison between the two groups are summarized in Table 4. At the flexion angle of 45°, a significant difference was observed between the two groups only in the first test based on CE ($P \leq 0.024$). Regarding VE, a significant difference was found in the first ($P \leq 0.001$) and the third ($P \leq 0.001$) tests. As regards AE, only a significant difference was detected in the third test ($P \leq 0.014$). Contrarily, there was no significant difference between the two groups at the flexion angle of 60° based on CE in either of the tests. A significant difference was observed between the two groups in terms of VE on the second ($P \leq 0.004$) and the third ($P \leq 0.026$) tests. Eventually, only a significant difference was found between the two groups considering AE on the second test ($P \leq 0.001$).

Discussion

The ARPP method was used in the present study. According to some previous studies, the measured difference by this method is larger than the one measured by the TTDPM method (6,13). Based on the findings, no significant difference was determined regarding CE within the groups or between the groups over time. Overall, CE represents the amount of a deviation from the target angle, along with its direction. If the reproduced angle is greater than the target angle, a plus sign is placed in the formula while if it is smaller than the target angle, a minus sign is placed in the formula. The neutralization of plus and minus signs can falsely indicate the lack of a deviation from the target angle in the CE. To eliminate this problem, the absolute error is measured, which is conducted using numbers in the calculation so that the error value (the deviation from the target angle) is determined regardless of its direction (20).

According to the results, a significant difference was found regarding AE within groups over time while only a significant difference was observed in the ACL-D group regarding VE. When considering VE and AE together, only the ACL-D group approached the average of their attempts and the target angle, indicating a greater recovery in the ACL-D group. Unlike CE and AE, which represent deviations from the target angle, VE demonstrates a deviation from the average of the individual's efforts, which is the amount of each deviation from the average of three angle reproductions. Based on between-groups comparisons, differences considering AE were found only in the third test at the 45° angle and in the second test at the 60° angle. The results revealed a significant difference between the groups considering VE although a relatively more constant improvement was observed at 60° of knee flexion.

The results of this study are in line with those of a study by Fridén et al in terms of the applied method and the study population. However, Fridén et al showed that the JPR method could not differentiate between healthy and injured groups (4). This discrepancy between the results may be because in the above-mentioned study, the participants' information was unavailable to the researcher 4-8 months after the injury and the evaluated injury was not an isolated ACL rupture. Moreover, Kalimuthu et al compared knee proprioception between healthy and injured legs at 30°, 60°, and 70° knee flexion angles and reported differences at only 70° of knee flexion between healthy and injured legs, which indicates the effect of the angle on knee proprioception (19).

Overall, our results revealed that knee proprioception in athletes suffering from ACL tear was lower compared to healthy individuals. However, a significant improvement was observed in the six-month follow-up. Despite some discrepancies, this finding is consistent with those of most previous studies in this area (4,6,8,12). There are multiple reasons accounting for differences and occasionally contradictions in the results of these studies, which makes it difficult to make definitive conclusions. The use of different methods and tools, evaluation criteria (11), heterogeneous samples (19), and evaluation angles

(21) is among these reasons. Some studies also show that these methods cannot accurately assess differences in proprioception, and consequently, new evaluation methods must be developed in this regard (5,22).

In clinical use, knowing how and when changes in the proprioception occur after the ACL injury can help in designing more effective and coordinated treatment with these changes in a rehabilitation program or in cases where surgery is decided, it may be helpful in choosing the best time for surgery.

Limitations of the Study

The limitations of this study were finding athletes with isolated cruciate ligament injury who would not have surgery within six months after the injury and the length of the study. Thus, it is recommended that future studies be conducted including more participants and further tests for examining changes more consistently.

Conclusions

The results of the present study showed that knee proprioception decreases after an ACL injury. Although significant improvements were observed within six months after the injury (Table 2), there was still a significant difference between the healthy and injured athletes (Table 3). Both healthy and ACL-D groups demonstrated significant improvements in proprioception although improvements were more significant in the ACL-D group based on the between-group comparisons and variable errors. According to some studies, most changes in proprioception occur in the first few months after the injury (5,7) whereas other studies have confirmed long-term changes (18).

In conclusion, to the best of our knowledge, this is the only study evaluating the isolated unilateral complete tear of ACL within six months after the injury in a group of athletes and comparing the results with a homogeneous group of healthy people based on three types of angle reproduction errors. The difference in knee proprioception between healthy and injured athletes was confirmed, which is in agreement with most previous studies.

In addition to calculating three types of errors in joint angle reproduction, which can show the application of different aspects of proprioception in a few studies, the relatively long duration of this study can be considered as the importance of this study. Long studies allow researchers to discover more changes and understand when changes stop or represent a decrease.

Authors' Contribution

Study concept and design: AfR, AbR, and KKK. Data acquisition: AfR. Data analysis and interpretation: AfR, AbR, and AAB. Manuscript drafting: AfR and AbR. Critical revision of the manuscript for important intellectual contents: AbR. and KKK. Statistical analysis: AfR and AAB. Study supervision: AbR.

Conflict of Interests

Authors have no conflict of interests.

Ethical Issues

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.

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Informed Consent

Questionnaires and data were collected after obtaining written informed consent from the patients and in accordance with the provisions of the Helsinki Declaration.

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References

1. Majewski M, Susanne H, Klaus S. Epidemiology of athletic knee injuries: a 10-year study. Knee. 2006;13(3):184-188. doi:10.1016/j.knee.2006.01.005
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. J Sci Med Sport. 2009;12(6):622-627. doi:10.1016/j.jsams.2008.07.005
3. Röijezon U, Clark NC, Treleaven J. Proprioception in musculoskeletal rehabilitation. Part 1: basic science and principles of assessment and clinical interventions. Man Ther. 2015;20(3):368-377. doi:10.1016/j.math.2015.01.008
4. Fridén T, Roberts D, Zätterström R, Lindstrand A, Moritz U. Proprioception after an acute knee ligament injury: a longitudinal study on 16 consecutive patients. J Orthop Res. 1997;15(5):637-644. doi:10.1002/jor.1100150502
5. Gokeler A, Benjaminse A, Hewett TE, et al. Proprioceptive deficits after ACL injury: are they clinically relevant? Br J Sports Med. 2012;46(3):180-192. doi:10.1136/bjsm.2010.082578
6. Kim HJ, Lee JH, Lee DH. Proprioception in patients with anterior cruciate ligament tears: a meta-analysis comparing injured and uninjured limbs. Am J Sports Med. 2017;45(12):2916-2922. doi:10.1177/0363546516682231
7. Lee DH, Lee JH, Ahn SE, Park MJ. Effect of time after anterior cruciate ligament tears on proprioception and postural stability. PLoS One. 2015;10(9):e0139038. doi:10.1371/journal.pone.0139038
8. Li W, Li Z, Qie S, et al. Biomechanical evaluation of preoperative rehabilitation in patients of anterior cruciate ligament injury. Orthop Surg. 2020;12(2):421-428. doi:10.1111/os.12607
9. Akbari A, Ghiasi F, Mir M, Hosseinifar M. The effects of balance training on static and dynamic postural stability indices after acute ACL reconstruction. Glob J Health Sci. 2015;8(4):68-81. doi:10.5539/gjhs.v8n4p68
10. Ashton-Miller JA, Wojtys EM, Huston LJ, Fry-Welch D. Can proprioception really be improved by exercises? Knee Surg Sports Traumatol Arthrosc. 2001;9(3):128-136. doi:10.1007/s001670100208
11. Hillier S, Immink M, Thewlis D. Assessing proprioception: a systematic review of possibilities. Neurorehabil Neural Repair. 2015;29(10):933-949. doi:10.1177/1545968315573055
12. Relph N, Herrington L, Tyson S. The effects of ACL injury on knee proprioception: a meta-analysis. Physiotherapy. 2014;100(3):187-195. doi:10.1016/j.physio.2013.11.002
13. Sanchez-Ramirez DC, van der Leeden M, Knol DL, et al. Association of postural control with muscle strength, proprioception, self-reported knee instability and activity limitations in patients with knee osteoarthritis. J Rehabil Med. 2013;45(2):192-197. doi:10.2340/16501977-1087
14. Beynnon BD, Good L, Risberg MA. The effect of bracing on

proprioception of knees with anterior cruciate ligament injury. J Orthop Sports Phys Ther. 2002;32(1):11-15. doi:10.2519/jospt.2002.32.1.11
15. Relph N, Herrington L. The effect of conservatively treated ACL injury on knee joint position sense. Int J Sports Phys Ther. 2016;11(4):536-543.
16. Al-Dadah O, Shepstone L, Donell ST. Proprioception deficiency in articular cartilage lesions of the knee. Knee Surg Relat Res. 2020;32(1):25. doi:10.1186/s43019-020-00042-7
17. Clark NC, Röijezon U, Treleaven J. Proprioception in musculoskeletal rehabilitation. Part 2: clinical assessment and intervention. Man Ther. 2015;20(3):378-387. doi:10.1016/j.math.2015.01.009
18. Han J, Waddington G, Adams R, Anson J, Liu Y. Assessing proprioception: a critical review of methods. J Sport Health Sci. 2016;5(1):80-90. doi:10.1016/j.jshs.2014.10.004
19. Kalimuthu M, Mokhtar AH. 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. doi:10.22452/jummec.vol20no1.1
20. Schmidt RA, Lee TD. Motor Control and Learning: A Behaviourial Emphasis. 5th ed. Human Kinetics; 2005.
21. Muaidi QI, Nicholson LL, Refshauge KM, Adams RD, Roe JP. Effect of anterior cruciate ligament injury and reconstruction on proprioceptive acuity of knee rotation in the transverse plane. Am J Sports Med. 2009;37(8):1618-1626. doi:10.1177/0363546509332429
22. Mahnan A, Holst-Wolf J, Konczak J. A new system to objectively measure ankle proprioception. In: 2020 Design of Medical Devices Conference. Minneapolis, Minnesota: American Society of Mechanical Engineers Digital Collection; 2020.