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Lower limbs kinematic analysis during a jump landing task in soccer players with unilateral anterior cruciate ligament reconstruction

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Abstract

Background Fatigue leads to an acute decline in muscle strength, altered patterns of lower extremity muscle activation, changes in hip and knee kinematics. In terms of the effects of fatigue on knee joint kinematics during plyometric training, there is still a lack of knowledge regarding kinematic differences between athletes who passed the ACL reconstructions rehabilitation period and healthy athletes. Therefore, this study aimed to compare lower limb joint kinematic parameters between reconstructed cruciate ligament and healthy control soccer players during jump landing in a fatigued setting.

Methods Lower limb kinematic parameters were recorded in 20 professional soccer players (age, 24.95 ± 2.92 years; body mass, 77.20 ± 12.88 kg; height, 1.77 ± 3.19 m) during jump landing task before and after the fatigue protocol. The control group consisted of healthy subjects and the experimental group consisted of subjects with ACL reconstruction by thigh transplantation. Kinematic data was recorded with 4 cameras to measure lower limb angles at first foot contact and maximum range of motion.

Results The results showed that before fatigue, there was only a significant difference between the two groups in the maximum range of motion of the non-involved hip joint ($P = 0.022$) and angle of the involved hip at first contact ($P = 0.049$). In other data on joint range of motion or initial contact angle, no significant difference was observed between the two groups ($P > 0.05$). After fatigue protocol, there was a significant difference in initial foot contact in non-involved ($P = 0.030$), and involved ($P = 0.020$) hip joint angles between the two groups. However, no significant difference in initial contact angle or range of motion of other joints was observed between the groups.

Conclusions This study shows that plyometric fatigue does not contribute to numerous changes in contact angles and range of motion in lower extremity joints in healthy soccer players and those with a history of cruciate ligament repairs.

Keywords Knee Injuries, Anterior cruciate ligament (ACL), Jump-landing task, Kinematics, ROM

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Introduction

The anterior cruciate ligament (ACL) is one of the most commonly injured structures in the knee joint [1]. Eighty-five per cent of the ACL injuries in male professional football players resulted from non-contact or indirect contact mechanisms [2]. The anterior cruciate ligament, along with other ligaments, plays a key role in the function and stability of the knee joint. ACL disruption leads to changes in knee kinematics that are most likely to cause secondary degenerative changes and long-term functional impairment [3]. Acute ACL rupture is known to be a common orthopedic trauma, with an estimated incidence of up to 84 per 100,000 people in the United States [4]. Because the cruciate ligament tear can heal in a manner that potentially restores normal knee kinematics, reconstructive techniques have been highlighted for individuals wishing to restore their knee function and stability while returning to high physical capacity [5].

The incidence of ACL reconstruction has increased over the past decade, and instead of surgical intervention, patients must undergo a long rehabilitation period after reconstruction to ensure a safe return to sport [6]. The literature has shown certain benefits and a reduced risk of ACL (Anterior Cruciate Ligament) injury when using ACL injury prevention programs. These prevention programs can generally be divided into two main groups: neuromuscular exercises and specialized warm-up routines. Injury prevention programs typically have two main goals: (1) addressing and correcting risk factors, and (2) reducing the incidence of non-contact ACL injuries [7]. According to studies, most prevention programs are effective in reducing non-contact ACL injuries [8]. Some programs have also been found to improve neuromuscular and biomechanical factors. However, a few studies have reported no reduction in non-contact ACL injuries and no improvement in athlete performance after implementing multi-component prevention exercises [9]. Researchers have investigated various knee injury prevention programs, such as the Knee Injury Prevention Program (KIPP®) [10], Sports Metrics [11], 11 [12], 11+ [13], and the Prevent Injury and Enhance Performance (PEP) program, among others [14].

However, athletes who meet these return-to-sport criteria still have a significant secondary ACL injury. Again, these injuries typically occur during landing maneuvers and non-contact mechanisms that combine valgus and internal rotation. According to the literature, other ligament injuries (e.g. medial collateral ligament (MCL) or meniscal rupture) are also frequently associated with ACL injuries [15]. In other words, researchers reported that there is a possible link between jump landings and injuries, and jump landings are often associated with injuries, including cruciate ligament and other knee injuries [16].

Additionally, ACL injuries usually occur during the contact phase of landing and cutting tasks, which are accompanied by sudden decelerations. Therefore, researchers have studied the lower limb biomechanics associated with ACL loading during a jump landing or cut and a combination of landing and cutting tasks that simulate maneuvers thought to cause ACL injuries [17]. It is well-accepted that fatigue affects lower limb kinematics and is likely to be context specific [18]. Fatigue leads to an acute decline in muscle strength, altered patterns of lower extremity muscle activation, changes in hip and knee kinematics, and increased ground reaction forces when landing or cutting resulting in the likelihood of non-contact ACL injury [19]. Many methods have also been used to assess the effect of fatigue on landings after a jump [20]. One of the best exercise modalities is plyometric exercises, which are often used to improve performance and can lead to muscle damage and fatigue with any training exercise [21]. Fatigue is modulated by a range of individual factors such as injury, age, level of physical activity and the type of activity performed. This phenomenon may be the result of central or peripheral nervous system failure.

Central fatigue is a disorder in the central nervous system, and peripheral fatigue is a disorder in the peripheral nerves, neuromuscular junction, or muscle contraction tissue [22]. Fatigue is a common and complex phenomenon that occurs in the form of a reduction in the power production capacity during sports activities and causes disturbances in various factors of the athletes' performance, causing weakness and a decrease in the coordination of the core muscles. In fact, fatigue is one of the factors that can cause a decrease in coordination and muscle performance [23]. It has been observed that the fatigue of different areas of the lower limbs can change the movement pattern For this part of the body to be effective, this effect can be through changing the amount of muscle activity or kinetic and kinematic changes related to the joints [24].

Also, fatigue can reduce the maintenance of balance related to the core stability of the body, and considering that the core muscles of the body are necessary to create a stable support surface to perform appropriate movements of the organs, the fatigue of this part may affect the performance or injury of people. It is especially effective for athletes or injured people [25].

In terms of the effects of fatigue on knee joint kinematics during plyometric training, there is still a lack of knowledge regarding kinematic differences between athletes who passed the ACL reconstructions rehabilitation period and healthy athletes, and this study aimed to investigate the effects of the plyometric training fatigue protocol on lower extremity function tests to assess the kinematic variables in soccer players with a history of ACL reconstruction. In addition, functional stability assessed by kinematic assessment provides valuable information for standardization that allows for a safe return to sport for athletes who have had their ACL reconstruction [26]. It was hypothesized that lower limb kinematic parameters (such as joint angle) would differ significantly between healthy and post-ACL reconstructed soccer players modified after jump landing and fatigue protocol. Because, Gao, Zhao [27], investigates the symmetry change in joint angle and joint moment of knee joints following a Running-Induced Fatigue counter movement Jump (CMJ). The results of the study showed that There was a significant increase in knee joint angle asymmetry in the horizontal plane during the push-off and landing stage following the prolonged - Running Protocol implementation. These increases in asymmetry are mainly caused by excessive external rotation of the dominant knee joint. These findings indicate that fatigue-induced changes during CMJ may progress knee movement pattern asymmetry in the horizontal plane. Therefore, this study aimed to compare lower limb joint kinematic parameters between reconstructed cruciate ligament and healthy control soccer players during jump landing in a fatigued setting.

Methods

Participants

The subjects of this study consisted of soccer players in Hamadan province (Iran). The subjects of this study were selected according to the available samples from a province. Subjects included soccer players with a history of ACL reconstruction ($n=15$) and a healthy control group ($n=15$). The inclusion criteria for the present study include (1) the age range of 20 to 30 years; (2) soccer experience at least 8 years. (3) History of ACL injury and its surgery (inclusion criteria for ACL reconstruction groups); (4) No history of ACL injury (inclusion criteria for healthy control group). Subjects who did not meet the inclusion criteria were excluded from the study. However, due to the lack of subjects who have inclusion criteria (age 20–30 years, soccer experience at least 8 years), based on lower limb landing biomechanics, it is estimated that a medium to large effect size (F=0.3) is selected. Based on the statistical significance of bilateral level at 0.05, magnitude at 0.8, and correlation between repeated measures at 0.5, at least 10 cases were identified for each group. Large effect sizes were chosen to reflect the strong biomechanical fatigue effect observed in the previous literature. Subsequently, according to the exclusion criteria, subjects with obvious body deformities or subjects with ligament reconstruction less than 6 months or more than 24 months, as well as athletes older than 30 or less than 20 years were excluded from the study. Finally, 20 professional soccer players between the ages of 20 and 30 with at least 8 years of soccer experience and three training sessions per week were selected. The subjects were divided into two groups: a healthy control group ($n=10$, age: 23.5 ± 2.5 years, weight: 72.5 ± 9.8 kg, height: 1.76 ± 0.07 m) and an experimental group ($n=10$, age: 26.4 ± 3.3 years, weight: 81.8 ± 15.9 kg, height: 1.78 ± 0.06 m) who had undergone cruciate ligament reconstruction with a hamstring graft. To decrease possible errors in the results due to differences in legs, both groups were matched according to the dominant leg and ACL reconstruction. For example, when we had an athlete with a right leg ACL reconstruction in the ACL group, we selected an athlete with a right leg in the healthy group. This approach was maintained for all participants. All participants were familiarized with the study procedure, benefits, and possible risks following their participation in the study and signed an informed consent form which was conducted by the Declaration of Helsinki and was approved by the University Ethics Committee.

Study design

This cross-sectional study used an experimental within-subjects study design. The participants reported twice to the laboratory. At the first visit, height (Seca 222, Terre Haute, IN, United States), body mass (Tanita, BC-418MA, Tokyo, Japan), and leg length (i.e., the distance between the anterior superior iliac spine and the distal tip of the medial malleolus in the supine position) of the participant were measured. During this session, the participants were introduced to the correct technique of plyometric training. One week after the first visit, participants returned to the laboratory and completed a session of plyometric training. Kinematic variables were measured before and immediately after plyometric training. Investigators carefully monitored the exercise to eliminate the risk of unexpected injuries. Participants abstained from all strenuous physical activity for at least 15 days before the trial period. Participants were instructed to maintain their normal eating habits for two weeks before data collection. The study received ethical approval from the Institute of Sport Sciences Research Institute R.SSRI.REC.1399.749; and all experiments were performed in accordance with relevant guidelines and regulations.

Plyometric exercise protocol

After a 10-minute warm-up (i.e., 5 min of cycling and 5 min of stretching), participants performed plyometric exercises including right-leg hop (2×10 m), left-leg hop (2×10 m), box jumps with alternates legged (2×10), left and right drop jumps in forward, sideways, and backward directions (2×10), resting 30 s and 1 min between sets and exercises, respectively. The box height for the plyometric exercise was 20 cm. Participants received verbal encouragement throughout the session. An experienced strength and conditioning coach oversaw all training logs [28].

Kinematic measures

A 4-camera (2000 Hz) motion analysis system (VICON Peak Ltd., Oxford, VICON UK) was used to measure the angles of the hip, knee, and ankle in the initial foot contact phase and the maximum range of motion (ROM) of these joints during the jump landing. The landing task used in this study is a common test to study biomechanical landing safety in ACL reconstruction athletes [29]. The markers are placed bilaterally on the specific anatomical landmarks of the anterior-posterior iliac spine, the lateral epicondyle of the knee, the lower third of the hip, the lateral ankle, the second metatarsal head, and the posterior aspect of the calcaneus. Before the landing trials, a three-second standing static trial was recorded to align the participant with the laboratory coordinate system and to create a static reference model for kinematic analysis. Four successful jump landing tests for each participant were used for further analyses. The subjects were asked to stay at the launch point, which is approximately 40% of their altitude from the landing site. They then vaulted over an obstacle 15% of their height, located between the take-off point and the center of the force plate, and landed with both feet on the force plate [29]. Hip, knee, and ankle kinematics and ROM in the anatomical plane of motion were used for statistical analysis.

Statistical analysis

Statistical analysis was performed with SPSS Statistics Version 24.0 (SPSS, Inc., Chicago, IL). The normality of the kinematic data was checked using Shapiro-Wilk normality tests. Independent samples t-test was used to measure the demographic characteristics of the subjects. Kinematic variables were compared between groups (ACL/Healthy) at pre and post exercise protocol using 2×2 (group x time) ANOVA. Statistical significance was set at $p \leq 0.05$.

Results

There was no significant difference between the two groups for weight ($P=0.101$) and height ($P=0.486$). The results showed that before the fatigue protocol, the maximum range of motion of the non-involved hip joint was significantly different between the two groups ($P=0.022$). Furthermore, no significant differences were observed between the groups in ROM of the involved hip, non-involved and involved knee, and ankle joints ($P>0.05$). No significant differences ($P>0.05$) were observed between the groups in contact angles in the non-involved hip, involved and non-involved knee, and ankle, but a significant difference ($P=0.049$) was observed in the involved hip. Significant differences were observed in non-involved and involved hip contact angles between the groups after the fatigue protocol. In contrast, no significant differences were found in the contact angles and ROMs of the non-involved and involved knee and ankle ($P>0.05$) (Table 1; Fig. 1).

Table 1 Changes in contact angles in hip, knee, and ankle from pre to post-plyometric exercise (mean ± SD)

Variable	Groups		Statistics
	Healthy ($n=12$)	ACL ($n=12$)	
Non-involved hip contact angle			
Pre	30.27 ± 16.59	36.89 ± 5.19	F = 1.697, $p=0.207$
Post	27.31 ± 9.10	39.2 ± 8.34*	F = 11.10, $p=0.030$
Involved hip contact angle			
Pre	29.58 ± 10.08	37.85 ± 9.35*	F = 4.340, $p=0.049$
Post	26.80 ± 7.42	40.05 ± 10.99*	F = 11.97, $p=0.020$
Non-involved knee contact angle			
Pre	17.07 ± 9.04	21.87 ± 7.08	F = 2.091, $p=0.162$
Post	16.88 ± 7.25	28.45 ± 21.12	F = 3.22, $p=0.08$
Involved knee contact angle			
Pre	20.69 ± 2.06	21.52 ± 8.18	F = 0.07, $p=0.793$
Post	18.19 ± 7.36	25.76 ± 10.66	F = 4.08, $p=0.553$
Non-involved ankle contact angle			
Pre	-6.86 ± 5.99	-5.74 ± 5.05	F = 0.245, $p=0.625$
Post	-3.29 ± 7.12	-3.63 ± 8.54	F = 0.011, $p=0.912$
Involved ankle contact angle			
Pre	-4.10 ± 6.01	-3.68 ± 5.24	F = 0.033, $p=0.857$
Post	-5.78 ± 7.91	-1.64 ± 8.77	F = 1.47, $p=0.237$

*Denotes significant differences between the groups ($p \leq 0.05$)

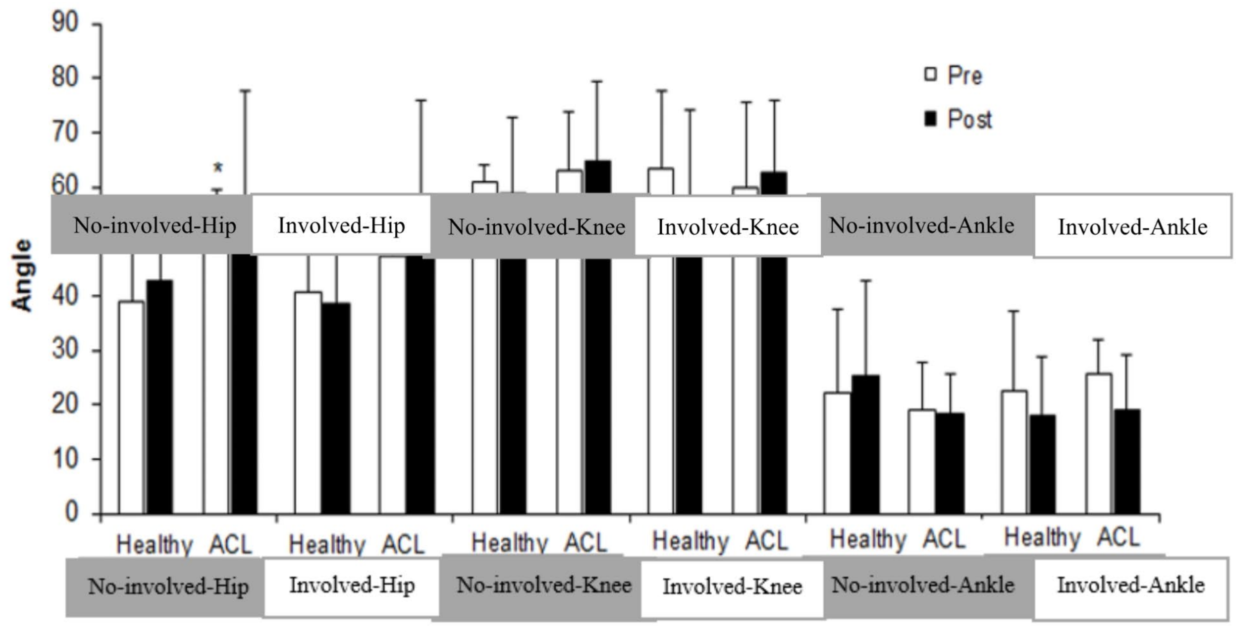

Fig. 1 Changes in ROM in hip, knee, and ankle from pre- to post-plyometric exercise (mean ± SD). *Denotes significant differences between the groups ($p \leq 0.05$)

Discussion and implications

The aim of this was to investigate the effects of the plyometric training fatigue protocol on lower extremity function tests to assess the kinematic variables in soccer players with a history of ACL reconstruction and healthy subjects. Based on the results of this study, it was determined that plyometric fatigue protocol did not induce differences in lower limb joint kinematics, including joint angles at initial foot contact and maximum range of motion between the two study groups. Plyometric fatigue may not have made a significant difference between the two groups. Among the different contact angles evaluated, the non-involved hip contact angle and the involved hip contact angle showed a significant difference between ACL reconstruction and the healthy control group. In a study by Norouzi, Esfandiarpour [30] the hip, knee, and ankle angular movements were evaluated at first contact after 10 attempts at a bilateral jump landing task. The results recorded for the knee showed that there were no significant differences between the control and experimental groups in knee kinematics [30]. Fatigue created in the hip and core stabilizers muscles can change the activity of these muscles and cause changes in the kinematics of the lower limbs, especially the hip joint [31]. However, the knee and hip kinematics in this study are contrary to the findings of Di Stasi et al., who examined knee and hip kinematics while walking on a treadmill [32], This controversy may be due to the differences in the task evaluated, as it has been shown that the kinematics of gait and landing tasks are not associated [33]. Also in our study, it was concluded that only the non-involved and involved hip contact angles were significantly different between ACL and healthy control group due to plyometric fatigue. All other angles, including non-involved and involved knee and ankle contact angles, were the same in both groups and there was no significant difference between the two groups in knee or ankle kinematics. It seems that one of the important factors that made the results of the studies different is the type of fatigue protocol. Acknowledging that fatigue affects muscle strength and increases cruciate ligament injury is not always accurate, Besides, in some studies, tired athletes who look to the ground (landing point) appear to have a higher flexion angle in the thigh and knee; it reduces the risk of damage to the cruciate ligament [34]. In the present study, the explored individuals were also familiar with the jump environment and the size and height of the obstacle before jumping; thus, such familiarity may be a reason for the non-significant changes in knee angles. This lack of change can also be due to the use of compensatory patterns. it seems individuals with cruciate ligament reconstruction may have used compensatory motor patterns before fatigue. They also dont need further compensation in response to neuromuscular fatigue. Those who have undergone reconstruction may also have used a standard protocol for rehabilitation. Moreover, these differences could certainly affect one's strength and biomechanics characteristics [35]. In a review study, Benjaminse, Webster [36], showed that different fatigue protocols have different results in preventing injuries in individuals with ACL reconstruction. Considering the small number of variables affected after fatigue, the question arises whether the same fatigue pathways are affected by the fatigue protocols used in the included laboratory studies as are experienced on the sports field. Therefore, it seems that the type of fatigue protocols, as well as whether the fatigue protocol is implemented in the laboratory or on the field, can produce different results.

In another study by Dai, Garrett [17] 36 recreational athletes performed a stop-jump task under three conditions and a side-cut task under two conditions. They reported that performing a jump landing at increased jump speed resulted in lower extremity movement patterns previously associated with increases in ACL loading [17]. Unlike the present study, in this study, different jumping and landing tasks were used, each of which had different results on the kinematics of the lower limbs. It seems that apart from the fatigue protocols, performing different tasks can also cause many changes on the kinematics of the lower limbs. Studies have shown that the use of higher speed and more complex tasks involve more motor units and can cause more extensive changes in kinematics in lower limb joints [33, 37]. In this study, the stop-jump tasks were associated with an increased risk of ACL injury. However, more research is needed in this area to determine which maneuvers are more effective in increasing the risk of ACL injury. de Marche Baldon, Lobato [38] studied 36 people who performed plyometric training for eight weeks and a control group who did not have physical training. Plyometric training alters lower limb kinematics and increases eccentric hip torque and functional performance, suggesting the inclusion of these exercises in ACL injury prevention programs [38]. This study suggested that this type of exercise is suitable to prevent ACL injuries. Schmitz, Cone [39] studied biomechanical factors in athletes to assess hip flexion at first contact and hip loading, ankle loading, and knee strength during the first half, at the end of the intermittent exercise, and after a 60-minute recovery period and found that a decrease in hip movement and workload, initial hip flexion and hip load, knee load, and ankle load from the beginning of the first half to the interrupted exercise [39]. Consistent with the results of the previous study, our study suggested that short-term, exhaustive fatigue protocols may have little or no effect on landing biomechanics, implying that our investigations explain that other protocols may cause more injury than our study protocol. In the study by Taylor, Ford [40] studied the biomechanics of the lower limbs in 15 recreationally active women performing jump landing tasks and concluded that standard bipedal sagittal plane jump landing tasks were useful for assessing the risk of ACL injury and the effectiveness of ACL injury prevention programs improve lower extremity biomechanics single-leg movements may not be adequately reproduced [40, 41].

As a result of this study, it can be concluded that plyometric fatigue did not make a significant difference between the ACL reconstruction and the healthy control group, however, it should be noted that greater fatigue could result if other study protocols could be used. Using other types of protocols may result in more fatigue, although our research showed that these types of jump-landing maneuvers did not cause a significant difference between the two study groups. The limitations of the present study include the fact that all of our participants were selected among soccer players and the second limitation is that our study was conducted in a laboratory setting and we could not take the equipment outside, perhaps if it was on the soccer field would have had different results.

Conclusion

This study demonstrates that plyometric fatigue protocol does not contribute to numerous changes in lower extremity joint contact angles and lower extremity joint range of motion between ACL reconstruction and healthy controls. Due to the conflicting results, it seems that further research on the effects of fatigue such as local fatigue, global fatigue, functional fatigue, and core stability muscle fatigue on lower limb kinematics is needed. To determine which types of fatigue, have a greater effect on the knee kinematics of soccer players with ACL reconstruction.

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Author contributions
M.G. & H.Z.: data acquisition and analysis. M.G. & H.N. & M.H. & M.MT. & H.Z.: data interpretation. H.Z.: wrote the main manuscript text and prepared the figures. M.G. & H.N. & M.H. & M.MT. & H.Z.: conception/design of the work. All authors reviewed and contributed to the manuscript.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Compliance with ethical guidelines
All study procedures were performed after the study was approved by the Research Ethics Committee of Sport Sciences Research Institute and was approved according to compliance with Ethical Standards in Research of the Ministry of Science. Ethics committee reference number: IR.SSRI.REC.1399.749.

Informed consent
All participants were informed of the purpose and procedure of this study, and informed consent was obtained from all participants.

Competing interests
No potential conflict of interest was reported by the authors.

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