Research Paper:

Effect of a Four-week Core Stability Training Program on the Kinetic Parameters in Athletes With Functional Ankle Instability During Single-leg Drop Landing

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ABSTRACT

Introduction: This study aimed to investigate the effect of a 4-week core stability training program on landing kinetic parameters in athletes with functional ankle instability during a single-leg drop landing exercise.

Methods: This study used a pre-post quasi-experimental design and was conducted in the biomechanics laboratory. A total number of 24 athletes with functional ankle instability participated in two experimental (n=12) and control (n=12) groups. The experimental group performed core stability training for 4 weeks. The kinetic variables (maximum vertical Ground-Reaction Force [GRF], maximum shear GRF, and time to peak vertical GRF) were measured with force plate at the frequency of 400 Hz, in the pre-test and post-test. The obtained data were compared using Analysis of Covariance (ANCOVA) and multivariate analysis of covariance MANCOVA in SPSS V. 18.

Results: In the experimental group, all variables significantly differ between the pre-test and post-test. Also, the ANCOVA and MANCOVA indicated significant differences between the experimental and control groups in all variables.

Conclusion: The results indicated that the core stability training improved the kinetic parameters of landing in people with functional ankle instability; thus, it can reduce the re-injury risk of the ankle.

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Introduction

Functional instability refers to the tendency of the ankle to repeated sprain or giving way because of the inability to maintain the stability of the ankle joint during dynamic activities. Also, it is the most important risk factor of the ankle sprain [1]. The ankle is one of the most commonly affected joints in sports and daily life; about 20% of all sports injuries include the sprain of this joint. The injury to the lateral ligament complex of the ankle joint is very common In athletes and accounts for 85% of total ankle sprains. Following the ankle sprain, more than 70% of people report residual symptoms for up to 18 months after the initial injury. Early symptoms include pain, muscle weakness, proprioception dysfunction, and repeated ankle sprain [2].

It is of particular importance to investigate Ground Reaction Force (GRF) in the biomechanical studies of the lower extremity. The mechanism of impact reduction plays an important role in the amount of load transferred to the bones. Moreover, the high rate of GRF is recognized as one of the risk factors for injury [3]. Since the ankle is the first joint that responds to the anterior and lateral GRF and the loading rate, Kuhlman et al. noted the increased vertical ground reaction force and loading rate as the biomechanical risk factors of lower extremity injury, especially ankle injury [4].

Studies have demonstrated that the GRF in people with functional ankle instability is greater than that in healthy individuals [5, 6]. During jump-landing, the maximal anterior and lateral components of GRF occur 10 to 13 ms earlier in the individuals with functional ankle instability than in the healthy individuals 6. Individuals with functional ankle instability achieve the maximal posterior GRF earlier than the healthy ones do 5. Also, the vertical component of the GRF reaches its maximum value earlier in these people [7].

Landing is used in many exercises and sports, so proper jump-landing technique is one of the basic requirements of these sports. Inappropriate jump-landing techniques and increased input forces during landing are considered as potentially dangerous indicators for the lower extremity injuries. Landing as a dynamic movement is often used to identify the biomechanical properties attributed to the increased risk of injury in athletes [8]. A large amount of vertical reaction force generated over a short period during landing results in the increased risk of lower extremity injury [9]. The ability to properly control and absorb forces during dynamic activities can reduce injury. Therefore, understanding the factors affecting the body's ability to absorb these forces can be effective in preventing the lower extremity injuries [10].

It is hypothesized that core muscle strength reduces the risk of lower extremity injuries. Initially, Bouisset assumed that the stability of the pelvis and trunk was essential for all movements in the organs [11]. Then, Hodges and Richardson stated that the core muscles act before the lower and upper extremity movements to form a firm base [12, 13]. Hodges's statement was the base of the statement of "proximal stability for distal mobility" [14]. The underlying assumption is that the greater stability in the core area of the body improves function, reduces the risk of injury, and results in better adaptation and prediction of changes in the conditions that lead to better performance in the extremities [15, 16].

Numerous works have been studied the ankle instability and investigated the joints and muscles of the distal region of individuals with ankle instability [17]. The studies of the joints and muscles of the proximal region support the theory that individuals with ankle instability use proximal muscles to compensate for neuromuscular defects in the lower extremity. According to the reports, people with functional ankle instability demonstrate changes in the activity of the gluteus medius [18], gluteus maximus [19, 20]; and biceps femoris [20]. The gluteus medius is activated earlier in people with functional ankle instability, compared with the healthy individuals [18]. Also, people with a history of ankle sprain have shown the delayed activation of the gluteus maximus muscle and the earlier activation of the biceps femoris muscle [19, 20].

Evidence has shown that the core stability exercises reduce the GRF. Arajo et al. (2015) examined the effect of a 6-week core stability training program on landing kinetics in the first and second phases of jump-landing among healthy participants. These researchers stated that the core stability training reduced the vertical force of ground reaction and improved landing kinetics; this training program may reduce the risk of lower extremity injury among female athletes [21]. Fatahi et al. (2016) examined the effect of an 8-week of core stability training on kinetics during single-leg drop landing in healthy participants. The results showed that eight weeks of core stabilization training significantly reduced the maximum vertical GRF and loading rate [22].

Given that the history of the previous injury is one of the most important risk factors for an ankle injury, studying the individuals with functional ankle instability can be particularly important to provide guidelines for injury prevention.

Few studies have evaluated the role of core stability programs and their effects on the extent of ankle injury in individuals with functional ankle instability. Most of these studies have included training programs involving either a combination of different exercises [23, 24] or only some of the core muscles [7]. Research focusing on strengthening the core muscles has been concentrated on healthy individuals [21, 22]. Therefore, the goal of the present study is to evaluate the effect of the four weeks of core stability training on landing kinetics in individuals with functional ankle instability.

Materials and Methods

Study design and participants

This study has a pre-test, post-test design. The participants were randomly assigned to the experimental and control groups. The core stability protocol was performed by the experimental group, while the control group was doing any kind of training.

The participants of this quasi-experimental study included 24 female athletes with functional ankle instability. Table 2 presents the demographic characteristics of the participants. According to the inclusion and exclusion criteria, the study participants were divided into experimental (n=12) and control (n=12) groups. The inclusion criteria were as follows: aged between 20 and 25 years, obtained the score of 0 to 27 in the Cumberland ankle instability tool, had at least one lateral ankle sprain injury that sometimes required to protect nonweight bearing with immobility, two or more instances of ankle instability or sense of giving way in the joint during daily exercises or training in the past two years, the ability of fully weight-bearing, normal walking, and the full range of the motion of the ankle joint during the study. Also, the exclusion criteria were dissatisfaction with ongoing participation, having pain that occurs during the tests, and prevents the participant to continue the participation, not participating in the post-test for at least one week after the end of the training program, and being absent in two consecutive training sessions. All the participants signed the informed consent form before the measurements. The experiments were performed at Biomechanical Laboratory, Faculty of Physical Education and Sport Sciences, University of Tehran.

Study procedure

Initially, the participants' characteristics, such as age, height, and weight were measured and recorded. They warmed up for 3 to 5 minutes and briefed on how to perform the landing task. The participant was to perform a single-leg drop landing from a 40-cm height box with a 10-cm distance from the force plate (manufactured by Danesh Salar Iranian Company at 400 Hz). The participants were placed in the weightless position while the arms were waist-lowered. Then, they landed on the center of the force plate on the same foot (Figure 1). Every participant repeated the drop landing exercise four times with a 1-minute break between the attempts. The GRF data were filtered using a 50-Hz Butterworth bidirectional quadratic low-pass filter. The mean value of the results of three correct attempts was used for statistical analysis and was normalized to the weight of the participant. In the present study, the amount of the vertical and shear components of GRF, and the time to reach maximum GRF were investigated. The moment of foot contact with the ground was considered when the vertical component of the GRF was greater than 10 N [24].

Next, the McGill core muscle endurance tests were performed. These tests were used to assess the core muscle endurance and the control effectiveness of core stability training. These tests included trunk flexors, trunk extensors, and the side right and left plank. Each test was performed once with a 3-min break in

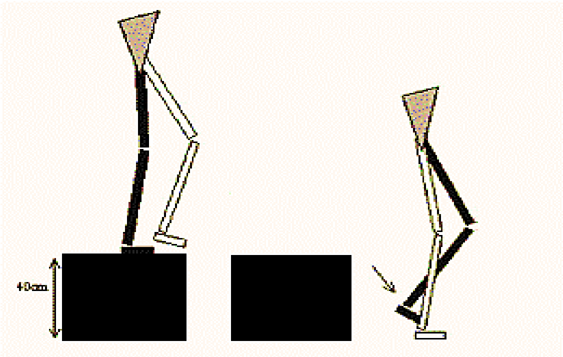

Figure 1. Method of performing a single-leg drop landing task 6

Table 1. Abdominal training protocol

Exercise	Weeks 1 and 2	Weeks 3 and 4
Plank	3x30-s hold	3x45-s hold
Side plank	3x30-s hold	3x45-s hold
Supine bridge	3x30-s hold	3x45-s hold
Abdominal crunch	3x20 repetitions	3x30 repetitions
Russian twist	3x20 repetitions	3x30 repetitions
Split leg scissors	3x20 repetitions	3x30 repetitions

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between. The sum of the time of these four tests was considered as the McGill trunk endurance test.

Study intervention

After the pretested stage, the experimental group performed core stability training. The training protocol consisted of six exercises performed by the experimental group for four weeks in three 45-min sessions per week. In the present study, the core stability training was based on the training protocol of Araujo and associates [21]. The training included plank, side plank, supine bridge, abdominal crunch, Russian twist, and split legs scissors (Table 1).

After completing the protocol by the experimental group, again, the kinetic data were collected from the experimental and control groups in the post-test stage, in the same way as the pre-test. Four weeks after the initial measurement, the participants of the control group were subjected to the second measurement without any training.

Statistical analysis

The obtained data were analyzed in SPSS V. 18 and Excel 2013 software. The ANCOVA test was used to investigate the inter-group differences of the time to peak vertical GRF and the McGill trunk muscle endurance test. Also, the MANCOVA test was performed to identify the differences between the maximum vertical and shear components of the GRF. The significance level of 0.05 was considered in these tests.

Results

Table 2 presents the characteristics of the study samples, including height, weight, Body Mass Index (BMI), and age. The results of the Shapiro-Wilk test approved the normality of all the study variables. Also, the results of the independent t-test showed no significant difference in the age, height, weight, and BMI between the experimental and control groups ($P \leq 0.05$). The homogeneity of variances was assessed by Levene's test. Since the significance levels of this test for the variables were more than 0.05, the assumption of the homogeneity of variances was approved, and parametric statistical tests were used.

Table 2. The Characteristics of the study samples

Index	Group	Mean±SD	P
Height (cm)	Control	168±5.91	0.339
	Experimental	167±4.98	
Weight (kg)	Control	60±7.96	0.631
	Experimental	61.45±9.01	
BMI (kg/m^2)	Control	21.44±2.30	0.795
	Experimental	21.25±3.75	
Age (y)	Control	22.75±2.34	0.798
	Experimental	22.5±2.39	

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Table 3. Descriptive statistics and inter-group t-test results from pre-test to post-test

Variables	Mean±SD			
	Experimental		Control	
	Post-test	Pre-test	Post-test	Pre-test
The maximum vertical GRF	3.70±0.75*	4.27±0.77	4.17±0.87	4.10±075
The maximum shear GRF	0.48±0.13*	0.63±0.13	0.64±0.12	0.70±0.11
Time to peak vertical GRF	54.12±10.61*	45.11±6.45	47.98±8.62	45.32±8.62

* The means differ significantly.

Table 4. Results of the analysis of covariance in the research variables

Dependent Variable	Sum Of Square	df	Mean of Square	P	F	Effect Size
Time to peak vertical GRF	38.577	1	38.577	0.021*	6.176	0.227
The maximum vertical GRF	0.86	1	0.86	0.012*	7.59	0.275
The maximum shear GRF	1.93	1	1.93	0.028*	5.64	0.220

* The means differ significantly.

Table 3 reports the descriptive statistics of the maximum vertical and shear components of GRF, the time to peak vertical GRF, and the results of inter-group dependent t-test from pre-test to post-test.

According to the results of the dependent t-test in Table 3, there is a significant difference between the pre-test and post-test values in the maximum vertical GRF (P=0.009), the maximum shear GRF (P=0.002), and the time to peak vertical GRF (P=0.001). Also, none of the control group variables significantly changed in the post-test (P≥0.05).

The MANCOVA was used to investigate the intra-group differences of the time to peak vertical GRF variables. Moreover, the univariate ANCOVA was used to examine the intra-group differences of the maximum vertical GRF and the maximum shear GRF variables. Table 4 reports the results of these tests.

As can be seen, the scores of the time to peak vertical GRF significantly differ between the two groups in the post-test (P≤0.05, F=6.176). The results of the MANCOVA test showed a significant difference in the vertical (P≤0.05, F=7.59) and shear (P≤0.05, F=5.64) components of GRF between the experimental and control groups in the post-test. The effect size demonstrates that the difference between the two groups after the adjustment of the scores in the post-test is caused by the independent variable.

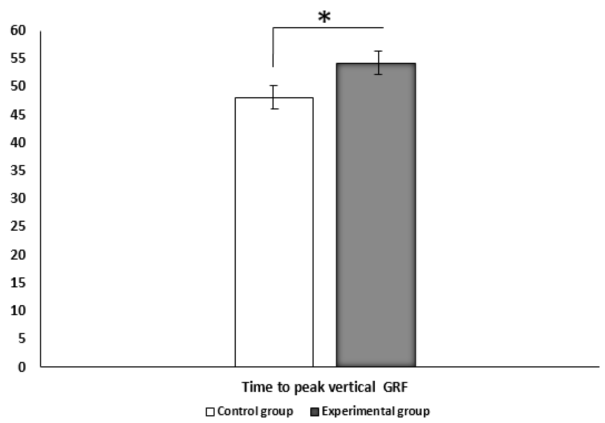
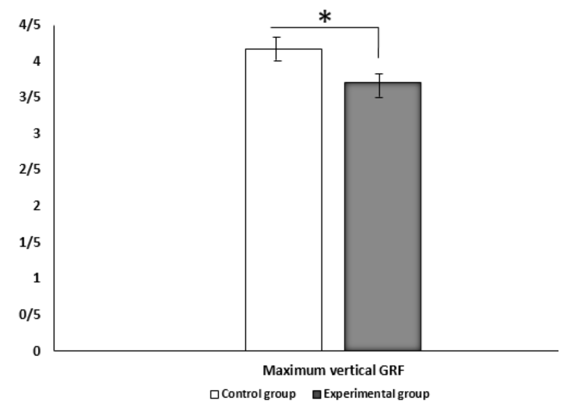


Figure 1. Comparing the intra-group variations of time to peak vertical GRF



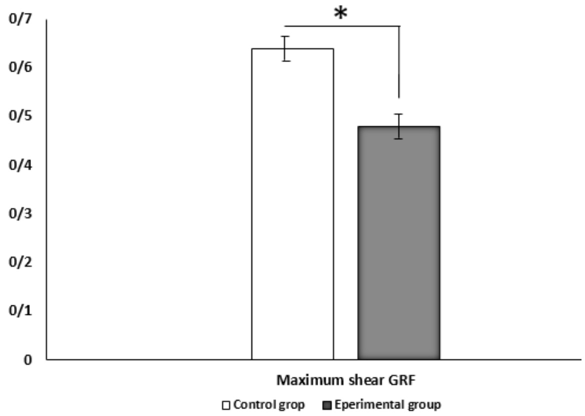


Figure 2. Comparing the intra-group variations of the vertical and shear GRF

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Table 5. Results of the analysis of covariance for time variations of McGill trunk tests

Dependent Variable	Sum of Square	Sum of Square	df	Mean of Squares	F	P	Effect Size
Pre-test	346412.47	346412.47	1	346412.47	71.309	0.001	
Group	131715.04	131715.04	1	131715.04	27.113	0.001*	0.564
Error	102016.64	102016.64	21	4857.92			

* The means difference is significant.

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Considering the significance of the F test, the differences in the time of reaching the maximum vertical GRF, the maximum vertical GRF, and the maximum shear GRF were investigated. An independent t-test was used for the intra-group comparison.

As shown in Figures 1 and 2, the results of the independent t-test showed a significant difference between the control and experimental groups concerning the mentioned variables (P≤0.05). Thus, performing four weeks of the core stability training caused significant changes in the variables of the time to peak vertical GRF, maximum vertical GRF, and maximum shear GRF.

Table 5 reports the results of the univariate ANCOVA test that was used to investigate the intra-group differences of the time variables of the McGill trunk endurance test.

The results of the ANCOVA test ($F_{1,1,21}$= 27.113) with the significance level of more than 0.05 showed a sig-

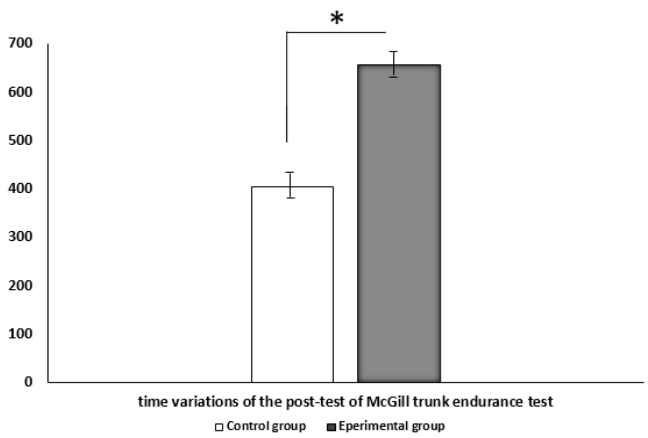

Figure 3. Intra-group comparison of time variations in McGill Trunk Endurance Test

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nificant difference in the time variations of McGill trunk endurance test between the experimental and control groups, in the post-test. The effect size (0.564) indicated that the difference between the two groups after the adjustment of the post-test score was caused by the independent variable.

Given the significance of the F test, the differences between the variables were investigated. Figure 3 shows the intra-group comparison of the McGill trunk endurance test using the LSD test.

As can be seen, there was a significant difference between the two groups in the time variations of the McGill trunk endurance test in the post-test. Particularly, the two groups significantly differ in the time variations of the performing of the McGill trunk tests (P<0.01). Therefore, the 4-week core stability training program significantly improved the performance of the McGill trunk endurance test.

Discussion

The purpose of this study was to investigate the effect of a 4-week core stability training program on the maximum vertical GRF, the maximum shear GRF, and the time to peak vertical GRF, in individuals with functional ankle instability during the single-leg drop landing task. After four weeks of the core stability training, the results showed that the maximum amount of the vertical and shear components of GRF significantly decreased (P<0.05) in the experimental group, during the single-leg drop landing task. Also, the time to peak amount of the vertical GRF significantly increased in the experimental group (P<0.05).

Few studies have examined the effect of the core stability training on the reaction force applied to the ankle. According to our literature review, only four articles have examined the effect of the core stability training on the kinetic variables of the lower extremity. Here, we review these articles and discuss their results with regard to those of the present study.

The results of Sato and Mokha (2009) who examined the effect of six weeks of the core stability training on the GRF during running were the only inconsistent results with those of our study. Results showed no significant effect on the mentioned study. The authors declared that the lack of significant results was originated from the increased running speed in the post-test (3.08 m/s), compared with the pre-test (2.99 m/s): The faster the running the faster the reaction force [25]. Indeed, the results of that study cannot be compared with those of the present study because the investigated tasks were different.

Araju et al. (2015) and Fatahi et al. (2016) have shown that core stability training improves the landing kinetics in healthy individuals. These researchers have suggested the reasons for these changes: performing the core stability training may cause changes in one's posture during landing. Moreover, they have suggested that changes in the kinematics of the lower extremity may also help to explain the changes in the landing kinetics after the core stability pieces of training [21]. Besides, the researchers showed that the core stability part of training improved the activity of the feed-forward of the core muscles and led to a better adaptation to force absorption [22]. However, both studies have been conducted on healthy people, thus, the results of these studies cannot be compared with that of the present study because of the differences in the study samples.

The study of Gage et al. (2009) is very close to the present work. This study investigated the effect of an 8-week abdominal exercise program on the kinetics and electrical activity of transverse abdominal, the internal and external oblique and gluteus medius, the vastus medialis, and the peroneus longus, during the single-leg drop landing task in the participants with ankle instability. The results showed that eight weeks of abdominal exercises altered the GRF and reduced the maximum vertical component of the GRF. Also, the exercises reduced the activity of all muscles with significant changes in the transverse abdominal, external oblique, vastus medialis, and fibularis longus muscles.

The authors concluded that a decrease in muscle activity in the group with instability (vastus medialis and fibularis longus muscle) and the healthy group (vastus medialis muscle) indicated that the abdominal exercises could transfer muscle activity toward the lower part of the kinetic chain. As the abdominal exercises reduced proximal and distal muscle activities, it was suggested that these exercises could improve the neuromuscular function of the lower part of the kinetic chain. This improvement is caused by enhancing the feed-forward mechanism, therefore, it reduces the maximum reaction force after eight weeks of exercise [7].

As stated above, the results of the present study showed a decrease in both vertical and shear components of the GRF and the loading rate.

The central nervous system uses a variety of strategies for postural control during movement. The trunk muscles act as a feed-forward mode and are activated before or in conjunction with the main limb to reduce the torque created by perturbation [26]. The postural prediction setting provides proximal stability for distal mobility. The increased stiffness of the core trunk stabilizes the proximal segment to improve the distal movement, keep the center of gravity at the base of support, and effectively absorb the created distal forces [27].

The abdominal muscle complex that includes the transverse muscle, the external and internal oblique, and the rectus abdominis stabilizes the vertebral column by contracting and provides stronger support for lower extremity movements [14]. As the transverse abdominal muscle contracts, intra-abdominal pressure, and the tension of thoracolumbar fascia increases; these contractions provide strong support for the movement and muscle activation before the limb movement [14, 28].

Based on the previous studies, it can be stated that the core stability as a part of training potentially improves the neuromuscular function of the lower kinetic chain by improving the ability of the feed-forward mechanism, which in turn leads to better compatibility to force absorption. Based on the abdominal muscle activity before the ground contact, Kolas et al. (2006) reported the feed-forward control of trunk muscles during landing [29]. Past studies have shown the pre-activation of the lower extremity muscles [26, 30, 31] and trunk muscles 30 before initial contact during landing. Okobu et al. (2013) showed that the abdominal muscles are activated before jump-landing. Researchers have also demonstrated that muscles are activated regularly, from the deep to the superficial muscles [32].

The trunk muscle activity before the activation of the lower extremity muscle and trunk position during landing significantly affects the GRF [29]. Iida et al. (2011) reported that the contact force was positively correlated with the percentage of the maximal voluntary contraction of the rectus abdominis muscle. The authors suggested that the increased activity of rectus abdominis muscle and the contraction of trunk extensors during landing would increase intra-abdominal pressure and trunk stiffness that leads to the reduction of the GRF. They also showed an increase in the activity of the external oblique, rectus abdominis, and gastrocnemius muscles before initial contact during landing. Therefore, the activation of these muscles, the increase of the ankle joint stiffness, and the rise in the pressure of the intra-abdominal prepare the body for landing trauma and act as the postural predictors of force absorption [30].

Although the kinetic variables have not been studied in the present study, another reason for the change in kinetic variables may be the improvement in the kinematics of the lower extremity after landing. The decreased knee flexion has been reported in the participants with functional ankle instability during the jump-landing exercise, compared with the healthy individuals [33]. Also, it has been reported that individuals with chronic ankle instability and healthy individuals use different landing strategies [34-36]. During the landing, individuals with ankle instability use ankle strategy to maintain postural control, while healthy individuals use hip or combined strategy. The ankle strategy is defined as less joint rotation or stiff landing, whereas the hip strategy represents a larger joint rotation in the lower limb joints.

The ankle landing strategy adds more reaction force to the ankle, the foot muscular structures, and the surrounding muscles of the ankle. This strategy absorbs more energy than the hip and knee strategies do. However, the hip and combined strategies transfer more energy upward in the kinetic chain, thereby, reduce the energy absorption by the ankle and surrounding muscles, and impose less stress on these structures [34]. The peak of the GRF can be reduced by increasing the range of the motion of the hip and knee joints during a static landing task [37]. Haddas et al. (2016) investigated voluntary vertebral column stability on the lower extremity kinematics and kinetics as well as the electromyographic activity of the trunk and lower extremity muscles during a drop-jump task [38]. The results of the study showed an increase in the hip and knee flexion angle at the heel contact, these changes subsequently reduced the maximum vertical force during landing [38]. It can be concluded that the core stability training changed the landing strategy, and subsequently, improved the landing kinetics. However, these variables have not been examined in the present study.

Conclusion

This study demonstrates the importance of proximal muscle training to reduce ankle re-injury. Therefore, after the ankle sprain, not only the leg muscles and lower leg but also the whole of the kinetic chain should be trained.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of University of Tehran (Code: IR.ut.Rec.1395023).

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Authors' contributions

All authors were equally contributed in preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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