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The effect of eight weeks of core stability training on the lower extremity joints moment during single-leg drop landing

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The effect of eight weeks of core stability training on the lower extremity joints moment during single-leg drop landing

Abstract

Background: Biomechanical factors are the main mechanism of load applied on the anterior cruciate ligament (ACL). The aim of this study was to evaluate the effect of eight weeks of core stability training on the lower extremity joints moment during a single leg drop landing task. Material and methods: Thirty basketball athletes were randomly assigned into training and control groups. The training group performed core stability training for 8 weeks, but the control group did not perform these exercises. Lower extremity kinetics and kinematics variables during a single leg drop landing test were collected by a motion analysis system and a force plate in a pre- and post-test. Data were analyzed using a mixed repeated measure ANOVA test ($p \leq 0.05$). Results: The results showed there was a significant reduction in the moment of flexion, adduction and rotation of the hip and the moment of the knee and subtalar joint in the training group ($p < 0.05$), while there was no significant reduction in the ankle moment ($p > 0.05$). Conclusions: Core stability training that was used in this study can reduce the forces exerted on the lower extremity joints during single leg drop landing. So, this study provides evidence that core stability training reduces lower extremity joints moment and may reduce the risk of ACL injury in athletes.

Keywords

core stability, lower extremity, joint moment, ACL injury, single leg drop landing

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Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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INTRODUCTION

Anterior cruciate ligament (ACL) injury has been considered as one of the most common knee ligament injuries not only in athletes but also in active non-professionals [1]. ACL injury causes long-term disability and high costs [2]. This injury greatly threatens children and adolescents [3]. Athletes who participate in jumping, cutting and rotating sports, such as basketball and volleyball, are often 4 to 6 times more at the risk of ACL injury [4]. At least 70% of ACL injuries are non-contact [3]. Evidence suggests that lower extremity condition during high risk activities, such as running, cutting, rotating or landing maneuvers, may be predisposing factors for tearing the anterior cruciate ligament [5, 6]. It is believed that the condition of the lower extremity that directly affects ACL loading plays a significant role in increasing the risk of ACL injury. Most non-contact ACL injuries occur during sport activities involving single leg drop landing [7]. Several theories have been presented to explain the mechanisms of the ACL injury. These theories include external and internal variables [8]. There are also outer factors, such as knee braces and athlete's shoes [9]. A number of studies have focused on anatomical and anthropometric values, such as thigh length [10], articular lameness [11], and the width of the intercondylar fossa of femur [12]. Anatomical factors include increased Q angle, size and shape of the femoral intercondylar fossa, and severe foot inflammation. Biomechanical factors include muscle activation patterns and changes in articular angles and imposed forces on the lower extremity [9, 13], which shows that biomechanical and neuromuscular patterns are moderately responsive to the training program [14, 15].

In an overview of non-contact ACL injury mechanisms, researchers found that multi-axial forces (sagittal, frontal, and transverse) on the knee are the main mechanism of the ACL injury [16]. The combination of these forces often occurs during sports movements, including acceleration, redirection and jump-landing. It is believed that the biomechanical and neuromuscular factors of the trunk and lower extremity during these movements are the most likely causes of the high rate of ACL injury in athletes [17]. Some researchers have reported that descent from jump is one of the most important mechanisms of ACL injury in basketball and volleyball players [18, 19]. Evidence suggests that many risk factors can be corrected with interventional training and can improve athletic performance [20, 21]. One of the factors that have recently been used as an intervention to prevent ACL injury is the core stability exercises. There is a close kinetic relationship between the movements of the proximal part of the lower limbs and the knee. Therefore, changes in the kinematics of the proximal region and their muscle activity patterns may affect the forces on the lower limb joints.

While the core muscles do not act directly on the knee joint, their activity can have an effect on the lower extremities alignment and the load bearing capacity of the knee. Evidence shows that core muscle training is effective in reducing ground reaction forces. Araujo et al. [22] argued that the exercise of core muscles reduces the vertical reaction force and improves kinetics and may reduce the risk of lower limb injury in female athletes [22]. Dynamic stability of the trunk and a lower extremity is based on the neuromuscular control of the lumbar-pelvic-hip complex. This complex includes the trunk, the pelvis and the hip joint as well as muscles covering the joints [23–25]. Core muscles training improves the stability and endurance capacity of the core muscles [26–28], which could explain performance improvement and also the forces acting on the body during endurance activities [29].

During activities which require the body to withstand its weight, muscles are largely responsible for the ability of the body to absorb shock and reduce the force on the body when it comes to contacting with the ground [30]. Increasing the amount of force on the joints indicates the body's ability to absorb shock and is an indicator of excessive pressure on the body in a short time. The shock resulting from the onset of a jump is absorbed by the musculoskeletal system; however, when the external body loads are too high to be absorbed by the body, the risk of injury increases [31]. Therefore, recognizing the factors that affect the body's ability to absorb these forces may be effective in preventing lower extremity injury and improving athletes' biomechanical performance [30]. One of the muscle roles is reduction of the forces imposed on the body [32]. Thus, it can be assumed that strong muscles effectively contribute to the prediction and absorption of shock, and hence, they can better reduce the amount of charge imposed on the body compare to weak muscles [32]. Greater strength of the muscles and the prediction of impact during the landing can increase the internal torque on the joints and thereby absorb the forces of the body. From this perspective, a detailed torque analysis is very important in the study of body movements and in preventing lower limb injury.

Understanding whether the implementation of core exercises can reduce the moment of lower extremity joints during single leg drop landing is quite essential in preventing the injury. According to the researcher's study, no study could be found that evaluated the effect of eight-week core stability training on the lower extremity joints. Therefore, the aim of this study was to determine whether intervention of eight-week core muscle training could reduce the torque of lower extremity joints during landing.

MATERIAL AND METHODS

PARTICIPANTS

This study is a quasi-experiment with pre–post testing design and selective sampling. Based on previous studies and due to the fact that in quasi experiment studies usually 20 or 30 samples are used [29], 30 professional basketball players were recruited for this study. Subjects were randomly divided into a training group (n = 15) and a control group (n = 15). All 30 athletes were enrolled voluntarily and before entering the study, the test and training protocols were explained to the subjects, and they all signed the consent form. Ethical approval for this study has been granted by the ethics committee of Musculoskeletal Research Center of Isfahan University of Medical Science. The selection criteria were: free of any musculoskeletal disorders such as neuromuscular disorder, previous ankle sprain, pes planus, and pes cavus. Lower extremities injuries were defined as injuries which lead to the absence of more than one day of physical activities [33]. All tests were conducted in Musculoskeletal Disorders Research Center of Isfahan University of Medical Sciences.

DATA COLLECTION INSTRUMENTS

Triaxial Force Plate (Kistler Model, 5 × 60 × 50 cm, made in Switzerland) was used to measure the initial contact of the foot on the ground and the kinetic data. The initial contact of the foot on the ground is defined as the moment in which the vertical reaction force becomes more than 30 N [34]. The information regarding ground reaction forces was recorded with a sampling frequency of 1000 Hz. Also, the motion analysis system (Qualysis motion capture systems, Sweden 2.7 "build 771") was used to measure the kinematic data at 200 Hz [35]. Finally, the forces were normalized to be unbiased based on the subjects' weights and then the lower extremity joint kinetics and kinematics were calculated using OpenSim (v.3.0.2, Stanford University) software.

Procedure

After some orientations, the subjects were invited to the laboratory for evaluation of the pre-intervention (first week) landing performance and measuring the body height and weight. Eight weeks later, the same procedure was repeated after completing the intervention. 34 reflecting skin markers with 4 mm diameter were placed on two sides of the body based on the Visual 3D marker set [36] over the first and the fifth metatarsal, the medial and lateral malleolus, the heel, the lateral and medial epicondyle, the great trochanter, the anterior and posterior superior iliac spine (ASIS and PSIS, respectively), the iliac crest, the sacrum, the wrist, the elbow joint, the acromioclavicular joint (AC), the sternum, C7 and on the vertex of the head. Also, four rigid plastic clusters containing three markers on each cluster were placed on the shin and thigh to trace the segmental movements, which was adapted from kinetic and kinematic studies [37]. The 3D position of each marker was recorded using a 7-camera optoelectronic motion capture system (Proreflex, Qualysis, Savedalen, Sweden). Data were filtered by using a low-pass filter (fourth-order zero-lag Butterworth filter) with the cut-off frequency of 6 Hz.

After standard warm-up, subjects performed 3 tests of landing from a wooden box with a height of 40 cm. The box was put on the ground, 10 cm in front of the force plate. The participant stood in a balanced position close to the edge of the box in a way that the dominant leg be placed in suspension (heel in contact with the edge of the box). This situation limits the horizontal movement of the body with the control of center of gravity. For each landing, the subjects received an oral countdown and were taught to land directly on the force plate while keeping their hands on the outer side of the hips to remove any change that is attributed to the hand. Subjects were asked to perform one landing from a 40-cm high box to the force platform with single leg [34]. Each landing task was performed 3 times, and there was 1 minute of rest between each jump in order to eliminate neuromuscular fatigue [38].

Kinetic and kinematic data was saved simultaneously on a computer. Tests taken from the participants were converted to a 3D file using Qualisys Track Manager (Qualysis motion capture systems, Sweden 2.7 [build 771]) and then an output file was taken from using Mokka as an ASCI file (3D Motion kinematic and kinetic analyzer, version 0.6.2) in order to determine ground reaction forces. Next, the mean data from 3 successful landings was used to calculate variables.

To calculate the lower extremity joints moment, the inverse dynamics method was used in OpenSim (v.3.0.2, Stanford University) software.

Exercise program

The training protocol included 8 weeks' (3 sessions a week with each session of 25–50 minutes) core stability training under the supervision of researchers for the training group and ordinary training for the control group. In this study, the training protocol of Willardson et al. and Araujo et al. [22, 39] were employed.

The experimental and control groups were allowed to carry out their normal activities. All training sessions were supervised by the researcher who attended all practice sessions to ensure that the subjects were performing the exercises correctly. Each subject participated in three training sessions every week. The subjects of the experimental group had to attend at least 21 sessions out of 24 training sessions and they were not allowed to be absent for 3 consecutive training sessions; otherwise, they were excluded from the study. At the beginning of each training session, general warm-up exercises (including jogging, warm-up exercises for upper extremities, the body, and lower extremities) were conducted for 5 minutes. Training intervention activities are presented in Table 1.

Table 1. Structure of the eight-week training program

	Weeks 1 and 2	Weeks 3 and 4	Weeks 5 and 6	Weeks 7 and 8
Plank	Holding 3×30 seconds	Holding 3×45 seconds	Holding 3×45 seconds	Holding 3×45 seconds
Medicine ball overhead throw	3×20 repetitions	3×30 repetitions	3×45 repetitions	3×45 repetitions
Supine bridge	Holding 3×30 seconds	Holding 3×45 seconds	Holding 3×45 seconds	Holding 3×45 seconds
Abdominal crunch	3×20 repetitions	3×30 repetitions	3×45 repetitions	3×45 repetitions
Medicine ball pullover pass	3×20 repetitions	3×30 repetitions	3×45 repetitions	3×45 repetitions
Medicine ball underhand throw	3×20 repetitions	3×30 repetitions	3×45 repetitions	3×45 repetitions
Medicine ball seated chest pass	3×20 repetitions	3×30 repetitions	3×45 repetitions	3×45 repetitions
Medicine ball rotation throw	3×20 repetitions	3×30 repetitions	3×45 repetitions	3×45 repetitions
Split leg scissors	3×20 repetitions	3×30 repetitions	3×45 repetitions	3×45 repetitions

STATISTICAL ANALYSIS

The whole data were statistically analyzed using SPSS v22.0. For data distribution analysis the Shapiro-Wilk test was used. Moreover, the mixed repeated measure ANOVA test was employed to compare the main variables of the study. Assessment assumption was done with 95 percent significance and $p \leq 0.05$.

RESULTS

Demographical variables obtained from 30 professional basketball players are presented in Table 2.

Table 2. Subject characteristics (Mean ±SD)

	Training group	Control group	p
Age (year)	16.6 ±0.9	16.8 ±0.7	0.79
Height (cm)	185.25 ±3.4	186.45 ±4.3	0.48
Weight (kg)	69.5 ±6.3	70.2 ±5.3	0.43

The results of mixed repeated measure ANOVA test are presented in Table 3; these results indicated that after 8 weeks of core stability training there was a significant effect of time (before intervention and after intervention) in the moment of flexion, adduction and rotation of the hip joint and also in the knee and subtalar moment ($p < 0.05$). However, the results of mixed ANOVA test on the ankle torque variable showed that the within-group effects were not significant (F = 2.8, p = 0.10). In addition, the results showed that there was a significant difference between the two groups for hip flexion, hip rotation, ankle and subtalar moment ($p < 0.05$); while the between-group effects for the hip adduction and knee torque variable were not significant (F = 0.19, p = 0.660 & F = 0.001, p = 0.980). The results of the test also showed that there was a significant interactive effect of time and group in all lower limb joints except for the ankle torque ($p < 0.05$). This means that the lower limb joints of the subjects have significantly changed under the influence of core stability training. These results are presented in Table 3.

Table 3. ANOVA with repeated measure lower extremity joints moment for each group before and after training time (mean ±SD)

Variable		Training group	Control group	Within group	Between group	Interaction
Hip flexion (Nm/kg.m)	Pre-test	49.2 ±12.8	49.2 ±12.8	p = 0.001	p = 0.010	p = 0.001
	Pro-test	28.6 ±10.3	50.4 ±9.0			
Hip adduction (Nm/kg.m)	Pre-test	40.6 ±13.0	41.1 ±8.8	p = 0.002	p = 0.660	p = 0.002
	Pro-test	24.4 ±9.4	42.1 ±8.7			
Hip rotation (Nm/kg.m)	Pre-test	40.6 ±7.6	46.0 ±7.4	p = 0.006	p = 0.001	p = 0.020
	Pro-test	30.2 ±9.0	44.8 ±7.2			
Knee (Nm/kg.m)	Pre-test	153.8 ±37.9	141.6 ±38.0	p = 0.001	p = 0.980	p = 0.001
	Pro-test	108.8 ±21.6	141.5 ±37.9			
Ankle (Nm/kg.m)	Pre-test	2.8 ±1.1	3.6 ±1.9	p = 0.100	p = 0.045	p = 0.690
	Pro-test	2.3 ±0.8	2.9 ±1.0			
Subtalar (Nm/kg.m)	Pre-test	40.6 ±10.4	40.4 ±8.0	p = 0.001	p = 0.040	p = 0.004
	Pro-test	29.1 ±5.0	48.9 ±11.4			

DISCUSSION

The results of this study showed the 8 weeks of core stability training affect the torque of lower extremity joints during the single leg drop landing task. These results indicated that after 8 weeks of training, there was a significant change in flexion, adduction and rotation torque of the hip, and also in the knee and subtalar torque between pre-test and post-test ($p < 0.05$). However, there was no significant difference in ankle torque after 8 weeks of training ($p > 0.05$). In this study, an appropriate dynamic model was developed to examine some of the kinetic parameters of lower extremity joints during the single leg drop landing task. The ability of the muscles to produce more internal torque during landing will result in a greater ability to absorb shock during landing and thus reduce the reaction force to the joints [40]. Opensim software was deployed to examine the joint torque. Opensim is biomechanical analysis software that can predict joint external loads and muscle contact loads [41]. Detailed contact loads show more accurately the incidence of soft tissues and consequently the risk of injury [42]. In the first step in the investigation of detailed contact loads, the researcher assumed that the opensim software was able to predict external torques of the joints. It has been shown that opensim software modeling is a suitable method for calculating the joint torque [43]. In this study, the external torque was calculated, which is due to the forces exerted on the body. To calculate the external torque, the inverse dynamics method and the dynamic musculoskeletal model were used to calculate the torque of the joints. Using the inverse dynamic of net force, all forces and torques were calculated for different joints. Direct measurements of forces in motor activity, such as jump-landing, are almost impossible.

On the other hand, the force estimation is a necessity to quantify the forces that cause movements. In this study, the forces imposed on the lower limbs joints during the jump-landing motion were quantified by the inverse dynamics method. Earlier, researchers such as Nunome et al. [40], and Dorge et al. [44] calculated the torque in the joints using a dynamic model; they investigated the torque during a football shoot. In this study, they examined the torque of the lower limb joints using a reverse dynamic model during a jump.

The production of muscular energy causes positive internal momentum around the lower limb joints in most movements [44]. The positive moments of force in these joints indicate that the muscles attempt to open the hip and knee joint and bring the ankle joint to the plantar flexion. Just a little before touching the ground, it is possible to observe a negative muscular momentum [45]. This muscular torque is likely to act as a preventative mechanism of injury, but external forces on the joints produce external torque in the body. In the present study, the external torque of the knee joint was larger than the torque of the other joints in both of the pre-test and post-test, which seems logical, since during the practice of landing, the knee-opening muscles struggle to strengthen the knee joint. On the other hand, the knee joint is the largest joint in the body. Therefore, greater force and torque are needed to move it, especially in dynamic movements, such as landing jumps. The ankle joint torque was the lowest, probably because the ankle joint had high bone strength and did not require much muscle effort. On the other hand, compared with the knee joint, it supports fewer muscles, and it is normal that less internal torque is created on this joint. Studies have shown that defect in neuromuscular control during dynamic movements is considered as the main cause of ACL injury [46]. Extreme knee loads, especially increased knee abduction moments, predict ACL injury in athletes with high sensitivity and specificity. Pre-season screening for athletes and follow-up of ACL injuries proves that athletes who had ACL injuries had a greater incidence of 8-degree valgus loss than healthy subjects [5]. The displacement of the frontal plane of the trunk [47] as well as the reduced proprioception of the core [48] both predict an initial ACL injury in athletes [5]. A defect in the neuromuscular control of the trunk during landing and cutting may result in non-control of the trunk in the lateral movement; this defect may include movement and torque of knee abduction through mechanical and neuromuscular mechanisms [5].

The joint torque is a significant sign of the load applied on the joint and is the main predictor of load distribution through the structures surrounding the joint during the movement [49]. Torque magnitude is an important variable for evaluating the joint function [49]; and so, increasing knee joint torque can increase severity [50], pain [51] and the rate of knee injury, including osteoarthritis [52]. By increasing the torque, the load increases and can lead to the destruction of the articular cartilage. Studies have shown that these torque variables are associated with chronic pain in the joint [53] and bone destruction [54]. Maly et al. (2015) reported that increased torque increases joint injury [55].

The association between ACL injury and neuromuscular control of the trunk and proximal limb of the lower limb is well defined [56]. Hewett et al. [5] stated that people who are prone to ACL injury have an increased knee abduction external torque, which is related to the external torque of the hip abduction. According to these materials, the risk of non-ACL injury is related to knee forces that are affected by reduced neuromuscular control in the trunk and hip;

therefore, if muscle torso control increases, the external torque in the knee will decrease. Chappell et al. [14] stated that neuro-muscular and biomechanical control patterns are moderately responsive to exercises. Previous training programs that led to favorable changes in biomechanical models included balance composition, lower extremity strength, and plyometric to show all aspects of neuromuscular control [57, 58]. These comprehensive programs often involve long training sessions and the use of equipment that was not readily available. Researchers examined specific muscle involvement during trunk and lower limb exercises, but little information was available on how core stability training affects the biomechanics of the trunk and lower extremities during dynamic descent tasks [59]. Pfile et al. [59] examined the effect of the core stability training on the flexion and internal rotation torque of the thigh and the abduction and flexion torque of the knee. The results of the study showed that the core stability training reduced the hip-flexion and hip internal-rotation moments, but these exercises did not alter the abduction and knee flexion torque. In the present study, the core stability training caused changes in the external torque of the lower limb joints (except for the ankle joint torque), which confirms the assumption of the research. In this study, the external torque of the knee fell due to the external torque of the extensors. It is believed that the domination of the quadriceps muscle is dangerous to ACL injury. The predominance of this muscle increases the internal torque of the knee extensor compare to internal torque of the knee flexor, which potentially results in prolonged imbalance in strength and coordination of muscle activity [60]. Thus, it is believed that the decrease in the external torque of the knee flexion changes to show a more balanced neuromuscular pattern [59]. Additionally, excessive reliance on quadriceps can mean that people attach excessive anterior pressure to ACL during dynamic activities, which increases the risk of non-contact injury. Ligament dominance occurs when the ligament (not the articular muscles around it) is used to reduce the energy generated by the ground reaction force [61]. Ligament dominance causes more knee movement inward, resulting in greater knee abduction torque and ground reaction force [62]. Decreased torque of knee abduction may indicate that core stability training interventions have been effective in reducing individual reliance on static stability to reduce the force during landing operations. The results of this study probably indicate that increased neuromuscular coordination of the trunk and hip muscles during the exercise protocol may reduce the athlete's reliance on the quadriceps muscle function. It is reported that participants with greater external rotational strength had less knee flexor torque during single-legged landing, and this attributed to less need for quadriceps activity during landing [62]. Specific exercises in the core may increase neuromuscular control and squinting power of the quadriceps muscle, but in the present study no information was given on the strength or activity of the quadriceps muscle to confirm whether a change in the muscle strength was created after the exercises or not. Muscle activation can contribute to the control of knee joint stability. In addition to proximal muscles, neuromuscular features and various knee joint activation strategies may result in different loads on ACL [63]. Increasing the activation of quadriceps and reducing the activation of hamstrings may alter the absorption of muscular energy during landing, and increase the ground reaction forces and moments associated with increased risk of the ACL injury [64].

In addition to the above findings, with significance of the main effects of the groups, the results showed that the lower limb joint torque was significantly lower in the training group than in the control group after 8 weeks of training.

Exercise can improve the core stability, activation of the muscle patterns, increasing the trunk flexion and possibly the eccentric strengthen of the quadriceps muscle. Therefore, it would be expected that after 8 weeks of training, the torque of lower limb joints in the training group would be significantly more than the control group which did not do specific training.

CONCLUSIONS

Summing up, it can be concluded that functional core stability training reduces the torque of the lower limb joints during single-legged landings. This demonstrates the effect of these exercises on improving knee muscle activation in athletes.

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