Research Paper: The Effect of 8 Weeks of Core Stability Muscles Training on Kinetics of Single-Leg Landing

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ABSTRACT

Purpose: Core stability training (CST) has increased among athletes. The study hypothesis is that neuromuscular training and exercises of central area of trunk, pelvis and hip can reduce injury risk, and specifically peak vertical ground reaction forces in drop landing task. Therefore, the objective of this study was to evaluate kinetics during single leg drop landing test following a CST intervention.

Methods: The present research was a quasi-experimental study with pretest/posttest and a control group. After giving their informed written consent, 30 athletes (15 in the experimental group, and 15 in the control group) volunteered to participate in the training program consisting of CST sessions, 3 times per week for 8 weeks. Training group was performed the CST during 8 weeks but control group did not perform these exercises. Kinetics variables in pretest and posttest during single-leg drop landing were measured by motion analysis and force plate device. To compare the obtained data, mixed ANOVA repeated measure at significance level of $P<0.05$ was used. All analyses were done by SPSS 22.

Results: The results revealed that the peak vertical ground reaction forces, loading rate, and average loading rate significantly reduced following 8 weeks CST intervention ($P<0.05$).

Conclusion: This study shows evidence that core stability training improves landing kinetics, and may reduce lower extremity injury risk in athletes.

1. Introduction

Central stability refers to muscle control of waist-pelvic surrounding area aimed at maintaining functional stability in neutral positions and assist in the production and transmission of energy from the trunk to the limbs [1, 2]. Core stability is important for athletes and also those who are active for pleasure; because it provides proximal stability for distal mobility, especially in movements which the stability of the spine is involved [3, 4]. Although core stability exercises are widely used in injury prevention and rehabilitation; re-

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cently it is more used as a way to enhance athletic performance [1, 5, 6].

Training and numerous sports activities involve landing and need appropriate jump-landing technique. Jump-landing techniques and the peak landing forces are considered the potential risk index of lower extremity injuries during a jump test [7, 8]. Landing is a dynamic movement which is often used to identify biomechanical properties attributed to the increased risk of injury in athletes [9]. High vertical reaction forces created in a short period (high impulse) during landing practice are associated with increased risk of injury [10]. These forces that are exerted on the lower limbs may cause more damage [11].

This mechanical impacts must be reduced through the musculoskeletal system. Increased impact forces during landing and repetition of these forces provides grounds for damaging soft tissue structures around the joint [12]. One of the most important factors involved in the injuries is the forces exerted on the joints of the lower limb [7, 13]. The increasing influence of the loading implies poor shock absorption and imposing high level of pressure on lower limb in a short time [14]. Factors that affect the load volume include speed of movement, landing height, type of shoes, trunk weight, location and level of the landing as well as landing strategy [15]. Vertical ground reaction forces are parameters that describe a person's landing in terms of the severity [13].

Ability to control and appropriate absorption of the forces during dynamic activities can reduce the damage; therefore, understanding the factors affecting the body's ability to absorb these forces, might be effective in preventing lower extremity injuries and improving the biomechanical performances [14]. Evidence shows that core muscle training is effective in reducing ground reaction forces. Araujo et al. (2015) in a pilot study investigated the effect of core muscles exercise on the second phase of the kinetic landing on women. They stated that core stability training would reduce vertical reaction force and improve the landing kinetics and might reduce the risk of lower extremity injuries in female athletes [16]. Dynamic stability of the trunk and lower extremity is based on the neuromuscular control of lumbar-pelvic-hip complex. This complex include trunk, pelvis and hip joint as well as the muscles covering the joints [17-19]. Core muscles training improves the stability and endurance capacity of the core muscles [20-22] which could explain performance improvement and also the forces acting on the body during endurance activities [5].

The association between poor stability of the core body and injuries has been already described [23-25]. Particularly, weak neuromuscular control over core muscles may increase knee valgus torque and hip external adduction during the landing [24], which increases the load on the anterior cruciate ligament [26]. Landing in sports like basketball is very common and causes a lot of damages, which may be due to the ground reaction force observed during this activity [27]. In this move, a contact force with the size of 2 to 12 times the body weight is produced often associated with lower extremity injuries [28].

Researchers have suggested that dynamic stability of the knee depends on the core body control [2]. Epidemiological evidence shows the relationship between weak control of trunk neuromuscular system and the anterior cruciate ligament (ACL) injury [25]. In addition, Meier et al. (2006) reported that neuromuscular training program, including balance training and essentially dynamic core stability exercises for trunk and pelvis significantly reduce the contact forces of landing while plyometric exercises do not reduce these forces [29].

As the evidence suggests, core stability exercises can reduce the maximum landing forces and may also lead to improvement of the performance, but the effectiveness of specific interventions in the trunk and particularly of core stability training is not determined [16]. While previous studies investigated the landing forces, but it is suggested that the core trunk muscles may affect the landing technique, too [16]. In this study, impact of core stability on the kinetics of the landing will be considered. Therefore, this study aims to determine that whether intervention of 8 weeks of core muscles training can improve the kinetics of landing.

2. Materials and Methods

The current research design was quasi-experimental with pretest-posttest design and the control group. A total of 30 professional basketball athletes which were selected by convenient and purposeful sampling method participated in this study. Subjects were randomly assigned in the experimental (n=15) and control groups (n=15). The experimental group and the control group did routine basketball practices. In addition, the experimental group performed 8 weeks of core muscles training, while the control group did not do any special training in this regard. Exclusion criteria included history of cardiovascular or nervous disease over the past year, history of abdominal injury, lower back or limb pain in the past year; limitation of physical activity or surgery in the last two years; untreated injuries or pain in the spine, abdomen or lower extremity limb or absence of more than two sessions during the exercise protocol. All tests were conducted in the Ergonomics Laboratory of Musculoskeletal Disorders Research Center, Faculty of Rehabilitation, Isfahan University of Medical Sciences. Before participation, test and training protocols were explained to the subjects and they all signed the consent form.

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, peak vertical ground reaction forces, loading rate, and the average loading rate. The initial contact of the foot on the ground is defined as the moment in which the vertical reaction force becomes more than 10 N. The loading rate is the amount of force during landing and is a measure of the pressure on the tissues. This variable is defined as the maximum reaction force when a person hits the ground until reaches the peak force. But the average load is the peak reaction force minus reaction force at the moment of contact with the ground divided by the time between these two forces and the average amount of load should be less than amount of the load. Information regarding ground reaction forces was recorded with force plate with sampling frequency of 200 Hz [30].

Single-leg landing protocol and measuring the reaction force

After some orientations, the subjects were invited to the laboratory to evaluate the pre-intervention (first week) landing performance and measuring height, body weight and the reaction force. Eight weeks later, the same procedure repeated after completing the intervention. After standard warm-up, subjects performed 3 tests of landing by barefoot from a wooden box with a height of 40 cm [31]. The box was put on the ground, 10 cm in front of the force plate. The participant stood in 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 jump, the subjects received an oral countdown and were taught to land directly on the force plate while keeping their hands on thighs to remove any change that is attributed to the hand. Landing techniques for each jump was instructed to the subjects and between each jump a minute break was given to relieve neuromuscular fatigue and consistency between subjects be ensured. The peak landing force is defined as the most vertical ground reaction force observed following the landing from the box [16]. Before the test, participants practiced landing 3 times. Three successful trials were recorded for each subject. If the subject lost the balance, had no bilateral landing, his hands moved from the hips, or could not land on the force plate after a vertical jump, the jump would be repeated.

The information regarding ground reaction forces on force plate was registered from the moment the foot contacted the force plate in line with internal-external, anterior-posterior and vertical positions for 20 seconds. This information was saved on a computer connected to the force plate. 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 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. The relative maximum landing force was calculated by dividing vertical reaction force of peak landing (N) by the subject's Body Weight (NBW). The amount of load was obtained in the form of normalized peak vertical force divided by the time it reached the maximum force from the moment of first contact of leg with the ground (Eq. 1) [32]. The average load volume was calculated through Equation 2 [16].

Equation 1: Loading rate

$$\text{Loading rate}=\left[\frac{\text{peak}F_z\,(\text{N})/\text{body weight (N)}}{\text{time to peak }F_z}\right]=\frac{\text{BW}}{\text{ms}}$$

Equation 2: Average amount of load

$$x=\frac{\text{peak VGRF-VGRF at first foot contact}}{\text{time interval}}$$

Exercise program

Subjects of the experimental group conducted exercises of core muscles 3 times a week for 8 weeks. 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 must 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

Table 1. Core muscles training intervention.

Sport	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 rotational 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

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session, general warm up exercises (including jogging, warm up exercises for upper extremity, body, and lower extremities) were conducted for 5 minutes. Training intervention activities are presented in Table 1.

Statistical analysis

All data analyses were performed using SPSS 22. To examine data distribution in two groups, Shapiro-Wilk test used. Also, mixed ANOVA repeated measure test was used to compare the relative peak landing, the average load amount, and anterior shear force. The hypothesis testing also conducted at the significant level of 95% with α took less than or equal to 0.05.

3. Results

Significant differences were not observed between subjects in their demographic data which included age, weight, and height (Table 2). Table 3 presents the peak reaction force, amount of load and the average amount of load in experimental groups during the single-leg landing at the moment of foot contact with the ground.

The peak relative reaction force in the experimental group decreased 0.64 N • N_{BW} and after participating in stabilization training 0.02 N • N_{BW} in the control group (Table 3). Mixed ANOVA repeated measures test results showed significant differences between pretest and posttest results (F=43.28, P=0.012); furthermore, the results showed a significant difference between two groups (F=1.88, P=0.032).

Test results also showed that interactive effects of time (preintervention and postintervention) on the groups (experimental and control) is significant (F=14.22, P=0.029). Mixed ANOVA repeated measures test results on the amount of load variable and the average amount of load showed significant differences between pretest and posttest (P=0.03, F=27.42 and P=0.038, F=17.88, respectively). Furthermore, no significant difference was found between the two groups (P=0.03, F=4.53 and P=0.04, F=3.76, respectively). The results also showed that interactive effects of time (before and after the intervention) on the groups (experimental and control) was significant (P=0.031, F=15.66 and P=0.036, F=19.88, respectively).

Table 2. Demographic information of subjects (Mean±SD) of studied groups.

	Exercise Goup (Mean±SD)	Control Group (Mean±SD)
Age (y)	16.6×0.9	16.6×0.9
Height (cm)	185.25×3.44	186.45×4.3
Weight (kg)	69.5×6.3	70.2×5.34

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Table 3. Analysis of variance with repeated measures for study variables.

Variable	Group	Pre-Intervention	Post-Intervention	Within Group Comparison	Between Group Comparison	Interaction
The maximum vertical ground reaction force N/N_{BW}	Exercise (experimental)	2.55±0.73	1.91±0.57	F=43.28 P=0.012*	F=1.88 P=0.032*	F=14.22 P=0.029*
	Control	2.81±0.63	2.79±0.68	F=23.54 P=0.114		
Amount of load N/N_{BWs}	Exercise (experimental)	207.31±70.31	123.42±45.76	F=27.42 P=0.0.03*	F=4.53 P=0.03*	F=15.66 P=0.031*
	Control	209.56±65.87	207.12±54.42	F=10.22 P=0.312		
Average amount of load N/N_{BWs}	Exercise (experimental)	35.42±12.11	21.17±9.1	F=17.88 P=0.038*	F=3.76 P=0.04*	F=19.88 P=0.036*
	Control	34.64±14.02	33.61±43	F=7.28 P=0.23		

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4. Discussion

This study aimed to investigate the effect of 8 weeks core stabilization training on the kinetics of landing in the basketball player athletes. The results of this study showed significant decrease in the peak reaction force during landing after the training intervention. Studies have shown that muscle contraction before and during the initial ground contact help to spread the load and reduce stress on the joints [35]. This reduction of load amount and the force exerted on the joints needs a strong control of musculoskeletal system [36, 37]. It has been shown that in various landing conditions, the core muscles are alternatively involved in the energy absorption and the forces exerted on the trunk [24, 33, 34].

Iida et al. (2013) reported that landing training program for 2 weeks contributed to 19% significant reduction of the landing force per kilogram of body weight, in the first phase of landing, compared to 1.4% reduction in the control group [35]. Because the trunk segment makes up more than 35% of the body [36] its movement and/or status during the landing is influential on the reaction force of the ground [37]. Strong and stable lumbopelvic region facilitates effective transfer of power from the ground to create movements and/or torque in the limbs [38]. When the forces of reaction resulting from limb movement challenges trunk sustainability; some muscles are contracted before limb agonist muscles to compensate for the effects of turbulence on the posture [39].

This coordination takes place with a group of synergistic muscles as well as the interaction between the agonist and antagonist muscles, which requires sensory, biomechanical strategies, and moving processes learned during responses from previous experiences and changed anticipation [39]. Central nervous system uses different strategies for postural control during the movements. Trunk muscles act by feedforward mode and are activated to reduce the torque created by turbulence before or in a combination with the main organs [40]. Increasing the rigidity of the trunk center provides proximal stability for upper and lower extremity movements, keeping the center of gravity at the level of reliance and effective absorption of created distal forces [24].

Previous studies showed preactivation of the lower extremity [42-44] and trunk muscles [37, 44] before contacting with the ground during landing. Okubo et al. (2013) investigated abdominal muscles activities during the jump landing. They mentioned that abdominal muscles are activated before landing. The researchers also reported that abdominal muscles are used in an orderly way (from the deep muscles to surface muscles) during this operation [33]. Kulas et al. (2006) [37] reported that abdominal muscles are activated during the landing operation before contact is made with the ground. It was recently reported that rectus abdominis, external oblique muscle and gastrocnemius are activated during landing before initial ground contact. These muscles get activated to prepare landing hit by increasing the stiffness of the ankle joint and intra-abdominal pressure and operate as a postural predictive control to absorb energy [44].

These studies and their results show importance of trunk muscles during the landing. Previous studies have shown that stability training can lead to change in muscle recruitment patterns. Ekström et al. (2007) evaluated EMG in planck and side planck and concluded that the exercises create sufficient activity of trunk muscles like the rectus abdominis, Multi-head and external oblique muscles in order to stimulate compatibility in muscular endurance of these muscles [20]. Imai et al. (2014) reported that in the young football players, stabilization training would lead to significant improvements in jumping practice (time during a jump/contact time) and suggested that these exercises improve trunk position control during landing contact [45]. Stevens et al. (2006) [46] investigated the effect of lumbar stabilization exercises on the muscle recruitment patterns in healthy individuals and their results showed increased level of activity of the abdominal muscles. The researchers found that muscle recruitment patterns can be changed in healthy people using a training program that focuses on neuromuscular control. Therefore, regarding to what was mentioned, we conclude that stabilization exercises used in this study improves feedforward muscle activity in this area through increasing core stability that leads to the adoption of the better power absorption strategy.

While we cannot explain a mechanism through which core stability training interventions reduces peak vertical reaction force during landing jump, previous studies have shown that weak trunk neuromuscular control is accompanied by the increase in valgus, torque and motion in the knee adduction [47] and the more prevalence of lower extremity injuries [25] and the kinematic changes are accompanied by peak vertical reaction force [48]. On the contrary, neuromuscular training, including trunk exercise, decreases knee adduction torques and inclination to valgus fall during landing [29]. Trunk muscle activity which has priority over the lower extremity muscles activity and position and movement of the trunk during the landing, have a significant impact on reaction force [37]. Increased intra-abdominal pressure before contact with the ground is observed and trunk muscles are activated in feedback controlling of the posture in preparation for contact absorption of landing [37].

Co-Contraction of flexor and trunk extensor muscles and lower extremity muscle increases rigidity and protection of lower extremity joint structures in a way that magnitude of many contact forces during landing increase trunk stiffness [41]. Iida et al. (2011) reported that contact force has positive relationship with maximum voluntary contraction of rectus abdominis. The findings of this study may also be influenced with changes in the trunk power creating changes in landing posture, which determines the reaction force of vertical landing [35]. Based on previous evidence, a reduction in the peak landing force observed in the present intervention can reduce the risk of knee injury [29].

Peak vertical reaction force has strong association with the knee adduction and abduction torques [48]. Besides the relationship between landing forces and the risk of impact damage, it was suggested that repeated landing with the vertical reaction force can lead to pressure damage due to high contact load [48]. The results of the current study showed that core muscle training, which is an isometric trunk exercise, may be an important component in prevention programs of lower extremity injuries and may contribute to the kinetics of professional landing, which were seen in previous multi-components programs. Previous evidence has shown that the landing kinetics is associated with ACL load [47]. These changes may imply a prevention readiness programs plan for non-impact ACL injuries in athletes.

In this study, only male subjects were recruited. Also, psychological conditions and motivation of subjects were not controlled. Skill level of participants was not also controlled which could affect the results. Other researchers are recommended to investigate the effects of core muscles exercises on lower extremity and trunk kinematics and improvement of muscle recruitment of central segment of the body by using valid devices such as motion analysis system and electromyography device. It is also recommended that other sport activities such as jump-landing and shear movements be to assess the effect of core muscles training and determining the effect of these exercises on the frontal plane kinematics.

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Conflict of Interest

The authors declared no conflict of interests.

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