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Effects of perturbation training on knee flexion angle and quadriceps to hamstring cocontraction of female athletes with quadriceps dominance deficit: Pre–post intervention study

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ABSTRACT

Background: Knee joint stability through co-contraction (CC) of hamstrings and quadriceps may be necessary for females with Quadriceps Dominance (Q.D) neuromuscular deficit. Unbalanced CC of medial and lateral portion of the knee can predispose women to extended knee position that exaggerate ACL injury. The purpose of this study was to determine the effects of perturbation training on knee flexion angle and neuromuscular characteristics in female athletes with quadriceps dominance deficit.
Methods: EMG data of quadriceps and hamstrings (during single limb drop-landing), and knee flexion angles (during tuck-jump test) of 29 (14 control and 15 experimental) female athletes with quadriceps dominance deficit were completed at baseline and after six weeks. Six weeks of perturbation training in the experimental group was applied over 18 sessions under the supervision of a physiotherapist.
Results: The VL-LH and VM-MH cocontraction in feed-forward and feedback phases significantly increased after perturbation training. Also peak knee flexion angle significantly increased and reaches from 26.24° ± 3.54° in pretest to 48.92° ± 6.18° in posttest due to perturbation training effects on Q.D deficit women ($p<0.01$).
Conclusions: Finally because the Q.D neuromuscular deficit is one of the important mechanisms of noncontact ACL injuries in female athletes and the effect of perturbation training in solving this problem indicated in this study, so the use of perturbation trainings is recommended to women athlete coaches to eliminate this defect and improve athletic performance (functional tuck jump test).
Clinical relevance: The balanced cocontraction ratios produced after the perturbation training may benefit in anterior cruciate ligament injury-prevention.

1. Introduction

Anterior cruciate ligament (ACL) injuries are twofold to eightfold more common in female compared with male athletes [1]. Approximately 70% of ACL tears are noncontact injuries. These noncontact injuries occur upon foot strike when the quadriceps muscle is activated to resist knee flexion. The most common mechanism of noncontact ACL injuries was pivoting or landing. At a knee flexion angle of between 0 and 30°, the quadriceps muscle load on the tibia increases anterior tibial translation and ACL strain, which may lead to ACL tear via atypical quadriceps–hamstring interactions [1,2].

Modifiable neuromuscular imbalance deficit of the quadriceps dominance (Q.D) is defined as an imbalance between knee extensor and flexor strength, recruitment, and coordination [3]. Women with Q.D deficit land with the knee at nearly full extension and this position is commonly associated mechanism of noncontact ACL injury [3,4]. Decreased hamstring strength relative to the quadriceps is implicated as a potential mechanism for increased lower extremity injuries and potentially ACL injury risk in female athletes with Q.D deficit. Q.D refers to the tendency to stabilize the knee joint by primarily using the quadriceps muscles that this deficit can alter co-contraction (CC) of hamstrings and quadriceps [3]. Women appear to preferentially use the quadriceps more than males in order to stiffen and stabilize the knee joint [4]. In addition to that, the quadriceps serves to stiffen or compress the tibiofemoral joint. If an athlete preferentially uses the quadriceps instead of the posterior chain muscles to control the limb, she uses a single muscle with a single tendinous insertion for stability and control. This is in contrast to using the group of posterior chain muscles that possess multiple muscles with varied tendon insertions that can be selectively utilized to control the limb during functional tasks.

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Joint stability through CC of hamstrings and quadriceps may be necessary when the joint experiences high quadriceps activation or when the passive structures are compromised. Authors reported that increased hamstring force during the flexion phase of simulated jump landings greatly decreased relative strain on the ACL [3,4]. To decrease the tendency toward Q.D, exercises are employed to emphasize CC of the knee flexor–extensor muscles [5]. It is difficult to develop a more appropriate firing pattern for the knee flexors while performing exercises that also strongly activate the knee extensors. If the hamstrings are adequately activated at the proper time, they can decrease ACL loading [1,3,4,6–18]. Athletes trained with deep knee-flexion jumps can learn to increase the amount of knee flexion at landing and decrease the amount of time spent in the more dangerous straight-legged position. We hypothesize that the repetitive achievement of proper positioning may facilitate increased muscle CC and possibly lead to reduced ACL loads [1,3,4, 6–18].

The quadriceps and hamstring muscles have the potential to provide dynamic knee stability. Two generalized neuromuscular activation strategies have been proposed to counter external loading at the knee during dynamic tasks [11]. One strategy involves a selective activation of muscles with the mechanical ability to counter the applied load, and the other involves an indiscriminate cocontraction without selectivity based upon mechanical advantage. Both strategies have been shown to stabilize the knee joint in the frontal plane during isometric loads [11,18]. Women appear to preferentially activate the lateral quadriceps [11] and hamstrings [6,7,11] while concurrently displaying less medial thigh muscle activation. If women land and cut with inadequate medial muscle activation (quadriceps and hamstrings), their ability to resist abduction and extension loads may be hampered, thereby promoting excessive knee abduction and extension loading and placing unnecessary strain on the ACL.

Sport medicine researchers suggested that ACL injury prevention programs should target the development of motor programs characterized by coordinated muscle activity [19–23]. Perturbation training is a specialized neuromuscular training program designed to aid in the development of dynamic knee stability among individuals with complete ACL rupture [19,20] Although the influence of perturbation training on different people was studied, this training effect on Q.D women athlete predispose to ACL injury has not been tested. Fitzgerald et al. demonstrated that a perturbation training resulted in superior return to functional activity in potential copers compared with management with a standard rehabilitation program [21]. Ihara and Nakayama and Beard et al. have similarly demonstrated improved dynamic knee stability in patients with ACL deficiency after perturbation training [21,22]. Nagano et al. reported that 5 weeks of jump and balance training program increased the knee flexion angle in female basketball athletes [9]. Also Chmielewski et al. reported that perturbation training reduced quadriceps femoris–hamstring muscle and quadriceps femoris–gastrocnemius muscle CC [5]. There are controversy between study results about the effects of perturbation training on quadriceps and hamstring CC. Also studies suggested that research on ACL injury-prevention programs should continue to investigate strategies to modify preparatory phase quadriceps and hamstring CC and decreasing quadriceps activation after ground contact [11,18]. Therefore, the purpose of this study was to determine the effects of perturbation training in the development of motor programs (quadriceps and hamstring CC) that may aid in ACL injury prevention among Q.D female athletes.

2. Methods

The design of this study was quasi-experimental. To determine sample size, a pilot study was conducted on muscle activation of 20 subjects (10 control and 10 experimental) with 3 weeks of perturbation training. Based on the formula below the sample size was calculated to be about 12 but to overcome the loss of some subjects during the training period, the 29 subjects were considered.

$$N=\left[\left(Z_{1\text{-}alpha}/2+Z_{1\text{-}beta}\right)^2\left({S_1}^2+{S_2}^2\right)\right]/(M_1-M_2)^2$$

$Z_{1\text{-}alpha}/2$ for $sig\,0.05=1.96$
$Z_{1\text{-}beta}$ for power $80\%=0.84$
$(M_1=0.70)$
$(M_2=0.48)$
$(S_1=0.25)$
$(S_2=0.09)$
$$N+\left[(1.96+0.84)^2(0.06+0.00)\right]/(0.22)^2\Rightarrow N=11.76$$

M_1 mean of muscle activation for perturbation group in posttest.
M_2 mean of muscle activation for the control group in posttest.
S_1 standard deviation of muscle activation for perturbation group in posttest.
S_2 standard deviation of muscle activation for the control group in posttest.

In total 63 females were screened and 29 Q.D females (control = 14; experimental = 15 groups) [(age = 24.32 ± 3.47 yrs); (height = 169.87 ± 8.03 cm); (weight = 65.42 ± 6.59 kg)] who were regular participants (>1.5 h/week) in jumping, cutting, and pivoting sports and were in university level sports were identified and recruited for the study. Subjects were assigned to control and experimental groups via alternate allocation.

Exclusion criteria included any history of knee ligament injury, current lower-extremity injury, recent (within 6 months) low back injury, or vestibular dysfunction. All participants signed an informed consent form before participating in the study. In performing tuck jump test if there is excessive landing contact noise and peak knee flexion angle was less than 30° the women were considered as Q.D deficit [3,24]. The Ethics approval center for this study was the Tehran Medical University and this center ethic review board previously reviewed the study protocol and then the study was done.

2.1. Electromyographic (EMG) data and CC index

The EMG data was collected from four muscles: vastus medialis (VM), vastus lateralis (VL), medial hamstring (MH), and lateral hamstring (LH) of each subject's dominant leg. The dominant leg was defined as the leg used to kick a ball for a maximum distance and was used for kinematic and EMG data collection for each person. The skin over the bellies of these muscles was prepared for electrode placement by shaving and cleaning the area with 70% isopropyl alcohol. Self-adhesive Ag/AgCl bipolar, dual surface electrodes (SKINTACT ECG Electrodes) were placed over the preparation sites in line with the muscle fibers. The electrodes were 4 × 2.2 cm with an inter-electrode distance of 2 cm.

The EMG sensor for the LH was placed over the measured midpoint (ischial tuberosity to fibular head) of the muscle belly [11,18]. The EMG sensors for the quadriceps were placed over the VL and 10 cm superior and 7 cm lateral to the superior border of the patella and oriented at approximately 10° laterally with respect to vertical; those for the VM were placed approximately 4 cm superior and 3 cm medial to the superomedial border of the patella and oriented 55° medially with respect to vertical [11,18]. The EMG sensors for the medial hamstrings (MH) were placed 36% of the distance between the ischial tuberosity and the medial side of the popliteus cavity, starting from the ischial tuberosity. A single reference electrode was positioned over the tibial tuberosity of the dominant limb [11,18]. Sensor placements and the absence of cross-talk were confirmed by evaluating the activity of each muscle with manual muscle tests. Once EMG sensor placements were confirmed, the sensors and leads were secured with prewrap and athletic tape to minimize movement artifact. EMG data were sampled at 1000 Hz [11,18].