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Female athletes with ligament dominance exhibiting altered hip and ankle muscle co-contraction patterns compared to healthy individuals during single-leg landing

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ABSTRACT

Background: Anterior cruciate ligament (ACL) injury is one of the most serious knee injuries and occurs frequently during exercise. Altered hip and ankle muscle co-contraction patterns may contribute to dynamic knee valgus and ACL injury mechanisms. Lack of dynamic control of ground reaction force (GRF) is known to be contributing factor for ACL injury by placing excessive force on passive structures. Muscle co-contraction is a dynamic mechanism for GRF absorption. Therefore, any alterations in co-contraction might be a risk factor for ACL injury. Ligament dominance is a term to define individuals who rely more on ACL ligament for GRF control.
Research question: This study aimed to compare the muscle co-contraction patterns of distal and proximal knee muscles during single leg landing in female athletes with and without ligament dominance.
Methods: This is a cross-sectional study. A total of 54 female athletes were assigned to the healthy ($n = 27$) and ligament dominance ($n = 27$) group based on their Tuck Jump test scores. The electromyography activity of the gluteus medius, adductor longus, tibialis anterior, peroneus longus, medial and lateral gastrocnemius was measured by an electromyography in drop down a 30-cm-high stair. A Multivariate Analysis of Variance (MANOVA) was used for statistical analysis ($p \leq 0.05$).
Results: The two groups demonstrated an overall significantly different muscle co-contraction patterns ($P < 0.05$). There was a decreased in co-contraction of proximal group and an increased co-contraction in the distal muscles in ligament dominant group.
Significance: The findings have provided evidence to support the notion of neuromuscular imbalances in ligament dominance deficit. These findings can be useful for the coaches and experts to design preventive exercises and modify the current programs for the people affected by ligament dominance.

1. Introduction

In the United States, knee injuries constitute about 60% of high school sports injuries [1] and anterior cruciate ligament (ACL) injuries constitute more than 50% of the total knee injuries [2]. About 250,000 cases of ACL tear occur annually in America of which 100,000 cases lead to reconstructive surgery [3]. In general, female athletes (18–35 years old) [4] are 4–6 times more prone to ACL injury than male athletes [5]. Most non-contact ACL injuries occur during sudden deceleration or while jumping down [6]. This injury is more severe in single-leg landing than double-leg landing. The force absorption by passive structures such as the ligament during landing is a risk factor for the occurrence of primary and secondary ACL injuries, MCL injury, patellofemoral pain syndrome, and Iliotibial band syndrome [7]. Ligament dominance occurs when the neuromuscular control strategies adopted by the athlete do not provide adequate dynamic stability for the knee joint. As a result, a major part of the ground reaction force (GRF) is absorbed by ligaments during sports activities, leading to knee valgus [8]. Excessive knee valgus has been shown to contribute to the mechanism of injury which could be due to the imbalance in the neuromuscular control of the lower extremity [9]. Knee valgus angle and abductor torque are the main predictors of ACL injury [8]. Previous studies have reported that a 5° increase in the valgus angle leads to higher loads (up to six times) on the knee joint [10].

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Neuromuscular control is one of the modifiable factors in preventing ACL injury [11]. Changes in synergistic and antagonistic muscle strategies during landing may be a potential factor in the lower extremity and ACL injuries in female athletes [12].

The muscles around the knee joint (such as the hamstrings and quadriceps) play a crucial role in ACL strain. Previous studies have focused on the co-contraction patterns of hamstrings and quadriceps [13]. However, some researchers believe that the muscles which stabilize the hip and ankle joints could also contribute to knee stability [14].

Padua et al. [15] reported that the increased co-activation of the gluteal and adductor muscles during the double-legged squat task may lead to hip adduction and internal rotation that can finally result in medial knee displacement (dynamic knee valgus). In contrast, Mauntel et al. reported that the co-contraction ratios of the gluteal and hip adductor muscles during single-leg squat are lower in individuals with dynamic knee valgus than in those of the control group [16].

In addition to the proximal segments of the knee joint, the distal segments can also alter knee mechanics and cause knee injury. Previous studies have shown that changing the mechanics of each segment of the lower extremity can cause injuries to other segments [17]. In this regard, Bell et al. [18] reported that the muscle imbalance between the plantar flexor and the dorsiflexor of the ankle joint increases muscle stiffness which limits dorsiflexion. The results of a meta-analysis provided evidence that a reduced ankle dorsiflexion range of motion correlates with dynamic knee valgus [19]. Smith et al. [20] showed that the co-activation of medial/lateral gastrocnemius during daily activities is higher in individuals with knee osteoarthritis.

Because of the close connection of the lower extremity segments due to the kinetic chain, each segment transmits forces and movements to the neighboring segments in a predictable pattern. Therefore, when abnormal mechanics occur in a particular joint, the movement impairment will be transmitted to the adjacent joints in sequence [21]. However, it is unclear how the muscular control of the hip and ankle joints affects knee mechanics during functional activities. Screening and muscle testing procedures are accepted clinical tools for determining the weakness and tightness of muscles. In a functional task such as single-leg landing, examining the co-contraction of muscles provides a better insight into muscle function [22] as this mechanism provides dynamic stability during functional tasks [23]. The purpose of the current study was to compare the co-contraction patterns of distal and proximal knee muscles during single-leg landing in female athletes with and without ligament dominance. In this study, the co-contraction patterns of agonist-antagonist muscles and the synergistic heads of gastrocnemius muscles were investigated. It was hypothesized that the co-contraction patterns of distal and proximal muscles during single-leg landing would be different in athletes with and without ligament dominance. Moreover, it was hypothesized that the co-contraction (agonist-antagonist and synergist) ratios would be more in the ligament dominance group than in the control group.

2. Methods

2.1. Study design

This study is cross-sectional. Based on previously published studies [15], the desired sample size was calculated using G*Power 3.1 software (power = 0.95, α = 0.05, effect size = 0.95) and it was determined that 27 cases were needed for each group (healthy and ligament dominant).

2.2. Participants

In this study, to find 27 individuals with ligament dominance, 16- to 26-year-old female athletes from volleyball and basketball clubs were extensively examined using the tuck jump test (explained in detail later). In addition, a group of age-matched individuals was used as the control (healthy) group. The recruitment procedure is shown in Fig. 1.

The other inclusion criteria were as follows: having at least a two-year experience of regular sports activity, having a normal body mass index (BMI) (20–25), attending specific sports (basketball and volleyball) for three sessions a week on average, having no fracture or record of surgery on the lower extremity over the past one year, and having the preconditions of plyometric exercises for the tuck jump assessment. The following were the exclusion criteria: meniscus and ligament injuries in the knee, a history of serious injury over the past six months resulting in absence from the training sessions, neurological diseases reducing balance and proprioception [16], lower extremity deformities, a history of delivery, mechanical back pain, and participation in training programs aimed at preventing ACL injuries. It should be mentioned that another exclusion criterion for the healthy group was ligament dominance in the knee. The subjects were homogenized in terms of height, weight, age, BMI, and history of sports activity. The tests were performed in the sport sciences laboratory of XXX University. All participants were informed about the tests, the research goal, and the research procedures before attending the study. Subsequently, they filled in the informed consent form to participate in the study. This research was approved by the Ethics Committee of XXX University of Medical Sciences (#XXX) and followed the guidelines of the Declaration of Helsinki.

2.3. Screening procedure

The tuck jump test was used for screening the athletes. This test has inter-rater reliability of 0.93 and intra-rater reliability of 0.87 [24].

The tuck jump test began in the squat position with the hips below the knees and the feet about shoulder-width apart. During jumping up, the subjects were asked to bring their knees as close to the torso as possible and to keep jumping for 10 s. Two cameras (Fujifilm HS55;

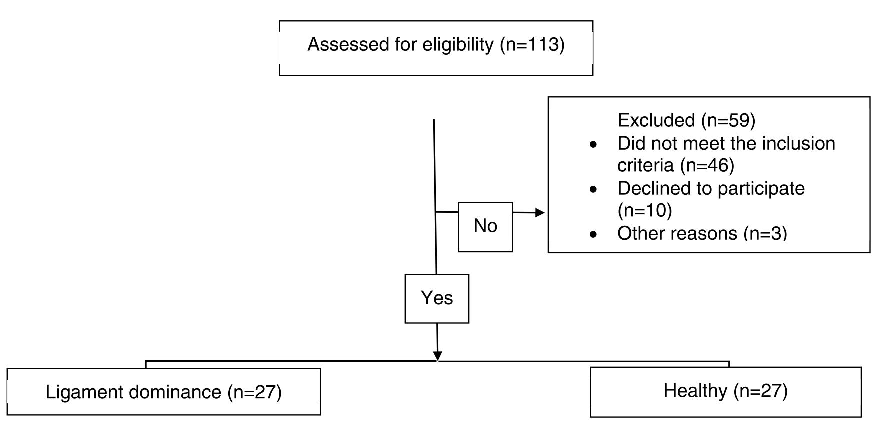

Fig. 1. The flow chart of the participants in the stud.

resolution: 20 megapixels; made in China) were used to record the tuck jump from the sagittal and frontal views and to score it [25]. The subjects who showed a positive sign of landing with knee valgus, the distance between whose feet was more or less than their shoulder-width after landing, and received a total score of 6 or above were classified as individuals with ligament dominance [26].

2.4. Laboratory assessments

The primary assessment was done by recording the subjects' demographic information (age, height, and weight), medical history, and sports history using a questionnaire. The electromyographic (EMG) activity of the dominant leg was recorded by an 8-channel wireless surface EMG system (Biometrics Ltd., Newport, UK). The data were collected at a sampling rate of 1000 Hz. The dominant leg was considered as the leg which the subjects would use to kick a ball [13]. To decrease skin impedance, the desired areas were shaved using a disposable razor and cleaned with 70% isopropyl alcohol. The surface electrodes (LE230, 42 × 24 × 14 mm, with a center-to-center electrode distance of 2 cm and the input impedance of > 100 Mohms) were placed on the bulk of the following muscles aligned with the muscle fibers: the gluteus medius muscle (GMed): the electrode was placed at 50% of the distance between the iliac crest and the greater trochanter [27]; the adductor longus muscle (AL): the electrode was placed four cm below the pubis in the medial hip area [28]; the medial gastrocnemius muscle (MG): 20% of the distance between the fibular head and the central part of the heel [29]; the lateral gastrocnemius muscle (LG): one-third of the distance between the fibular head and the central part of the heel [30]; the tibialis anterior muscle (TA): one-third of the distance between the fibular head and the malleolus [30]; the peroneus longus muscle (PL): 25% of the distance between the fibular head and the lateral malleolus [31]. The maximum voluntary isometric contraction (MVIC) of each muscle was obtained and recorded before the test. Each isometric contraction was held for six seconds and repeated 3 times with one minute of rest between the contractions. Verbal encouragement was used to provoke the subjects' maximum effort.

A footswitch (Biometrics Ltd., Newport, UK, FS2) was placed under the 1st metatarsophalangeal joint to determine the time of foot-ground contact.

The subjects performed a 10-min warm-up before the test. The task entailed single-leg landing (not jumping) with the dominant leg from a 30 cm stair. The participants were asked to prevent their non-dominant leg from having any contact with the ground and to keep their balance after landing without hopping (Fig. 2). Each subject repeated the task three times with a rest interval of 30 s [32].

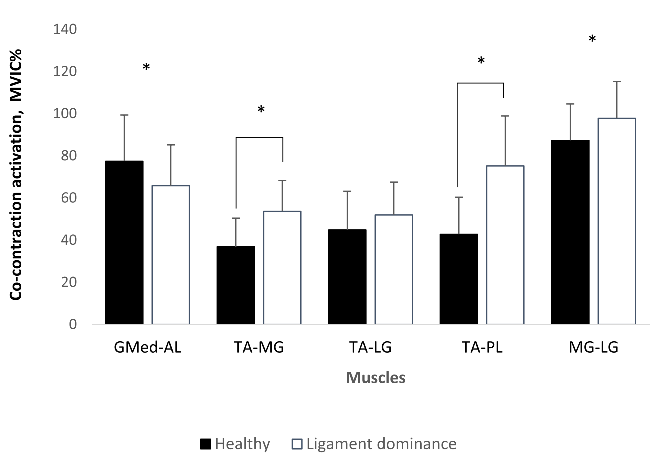

Fig. 2. Comparing the co-contraction patterns between the groups.

2.5. Data analysis

The EMG data were analyzed in MATLAB Software (Mathworks, Inc., Natick USA). A 10–500 Hz band-pass filter and a 60-Hz notch filter were used to suppress the motion artifact and the other unwanted signals. Then, a 50 data point moving window root mean square (RMS) of the filtered data was calculated 100 ms before landing [33]. The percentage of muscle activity was calculated by dividing the activity of each muscle by the MVIC value and multiplying the result by 100. The co-contraction was calculated based on the average muscle activity in the three landing tasks using the following equation [34]:

$$CI = 2 * \frac{EMG_{ANT}}{EMG_{AG} + EMG_{ANT}} * 100 \tag{1}$$

where the antagonist is the muscle with a lower EMG activity and the agonist is the one with a higher EMG activity.

2.6. Statistical analysis

The results were analyzed in the SPSS software (version: 26). The normality of data distribution was checked using the Shapiro-Wilk test, while the homogeneity of the demographic data in the two groups was checked using the independent t-test. Furthermore, the co-contraction activities of the two groups were compared using multivariate analysis of variance (MANOVA) at the significance level of 95% ($P < 0.05$).

3. Results

3.1. Demographics

The two groups did not show any significant differences in their demographic characteristics. Table 1 presents the mean and standard deviation of the subjects' demographic information.

3.2. Electromyography

These data did not violate the statistical assumptions of the MANOVA model. The results of the MANOVA test which were used for comparing the co-contraction activities of the two groups showed a significant difference between them ($P < 0.05$) (Table 2).

The MANOVA analysis showed significant differences between the groups (Wilks' lambda = 0.519, $p < 0.001$). The comparison of the two groups showed a significant difference in the GMed-AL ($F_{1,52} = 4.22$, $p = 0.045$), TA-MG ($F_{1,52} = 19.25$, $p < 0.000$), TA-PL ($F_{1,52} = 32.64$, $p < 0.000$), and MG-LG co-contraction patterns ($F_{x,y} = 9.95$, $p = 0.003$). However, there was no significant difference between the two groups regarding the TA-LG co-contraction ($F_{1,52} = 2.38$, $p = 0.129$) (Fig. 2).

4. Discussion

The purpose of this study was to compare the co-contraction patterns of distal and proximal knee muscles during single-leg landing in female athletes with and without ligament dominance. The results of the

Table 1
The demographic characteristics of the healthy and ligament dominance groups.

Variable	SD ± Mean				
	Ligament dominance	Healthy	df	t	P
Age (years)	19.59 ± 2.13	20.18 ± 2.81	52	-0.871	**0.388**
Height (cm)	165.51 ± 6.78	166.44 ± 8.31	52	-0.448	**0.656**
Mass (kg)	60.04 ± 11.11	60.32 ± 8.03	52	-0.100	**0.921**
BMI (kg/m^2)	21.89 ± 3.67	21.83 ± 3.01	52	0.680	**0.946**
Sport history (years)	5.44 ± 2.66	7.03 ± 3.99	52	-1.723	**0.092**

Table 2
The results of the MANOVA test comparing muscle co-contraction in the healthy (n = 27) and ligament dominance (n = 27) groups.

Variable	Wilks' lambda	F	df	P	Partial Eta Squared
Co-contraction (MVIC %)	0.519	912.8	5	0.000[a]	**0.481**

MVIC: maximum voluntary isometric contraction.
[a] Significant interaction ($P < 0.05$).

current study showed that the co-contraction patterns of the TA-PL, TA-MG, and MG-LG muscles were higher in the ligament dominance group than in the healthy group 100 ms before foot-ground contact. However, the co-contraction of the GMed-AL muscle was lower in the ligament dominance group than in the healthy group 100 ms before foot-ground contact.

The results of the present study showed that the co-contraction index of the GMed-AL muscle was lower in the ligament dominance group than in the healthy group. This result is in line with previous studies (Mauntel et al. [16], Mansourizadeh et al. [35], Goto et al. [36], and Rostami et al. [37]). Rostami et al. [37] reported that the co-contraction of the GMed-AL muscles following contact with the ground was less in individuals with ACL injury (ACLR and ACLD) than those in the control group. The relative co-contraction between the GMed-AL muscles may contribute to dynamic knee valgus. The greater activity of the AL muscle which is not balanced by that of the GMed muscle may result in hip adduction and internal rotation. A larger co-contraction index demonstrates that the GMed muscle is more active than the AL muscle. Conversely, a lower co-contraction index indicates reliance on the AL muscle. It is generally believed that dynamic knee valgus may be due to the inadequate activation of the gluteal muscle [38].

The results of the present study showed that the ligament dominance group had a higher distal co-contraction pattern than the healthy group. The increased co-contraction activity of the distal muscle can be due to the stiffness of the posterior leg muscle and can restrict the ankle range of motion in the sagittal and frontal planes [39]. The restricted ankle dorsiflexion range of motion can increase the intense forces applied to the tissues around the joints and disturb the joint proprioception. Disturbance in the joint proprioception and the afferent nerves can affect processing in the central nervous system, the efferent nerves, and the functionality of the joint [40]. With restricted ankle dorsiflexion, the subject may try to compensate for this lack of range of motion in the sagittal plane by moving in the frontal or transverse plane through the kinetic chain [41]. This compensatory reaction can be done by increasing foot pronation, tibia internal rotation, hip internal rotation, and adduction and can cause ligament dominance [42]. Muscle stiffness increases with the increased co-contraction of the plantar flexor and dorsiflexor muscles. This is an indicator of the inefficiency and excessive energy intake of the muscles which can lead to muscle fatigue [43]. Padua et al. [15] found that the increased co-contraction of the TA-MG muscles is related to the increased ankle muscle stiffness and decreased ankle dorsiflexion which can lead to medial knee displacement in the frontal plane. Other studies have shown that the increased stiffness of the distal muscles can decrease the ankle joint function, the angular velocity, and the mechanical torque during the concentric phase [44]. These conditions can threat the final performance of the joint. In the study of Li et al. [45], the individuals with chronic ankle instability (CAI) exhibited more TA-LG and TA-PL co-contraction during the landing phase on a tilted surface compared to the healthy group.

In summary, the imbalance of the (agonist-antagonist and synergist) muscles can affect the function of the lower extremity by increasing hip adduction, knee abduction, tibia internal or external rotation, eversion, pronation, and restricted ankle dorsiflexion. In addition, this can increase dynamic knee valgus and the amount of loads on the ACL ligament. The normal co-contraction of the muscles can improve their coordination and prevent joint instability and lower extremity injuries.

One limitation of the current study was that it did not have a thorough kinematic and kinetic assessment of landing. It is recommended that the muscular activity of the trunk muscles be examined since it could provide a better insight into the pathophysiology of injury.

5. Conclusions

The findings of this study provided clinical evidence for the neuromuscular imbalances which are considered as modifiable risk factors in ACL injury. The results of this research corroborated the notion that muscle imbalance does contribute to ligament dominance. This imbalance is related both to agonist/antagonist coupling and synergistic muscles. Accordingly, it is recommended that new rehabilitation protocols and preventive exercises be designed to address both types of muscle imbalance in ligament dominant athletes.

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Conflict of interest

The authors have no conflict of interests.

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