Relationship between Hip and Knee Strength and Knee Valgus Angle during Drop Jump in Elite Female Athletes

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ABSTRACT

Purpose: The purpose of this study was to investigate the relationship between hip and knee strength with knee valgus angle during drop jump in elite female athletes.

Methods: Forty female athletes (mean ± SD age, 21.5 ± 1.99 years; height, 169.08 ± 8.25 cm; body mass, 61.05 ± 10.06 kg) participated in this study. Isometric hip and knee muscles strength were evaluated using standard clinical procedures and a handheld dynamometer. Knee valgus angle was assessed using a 6-camera motion analysis system during a drop jump task. Pearson correlation analyses were performed to determine the relationship between hip and knee muscles strength and knee valgus angle at initial contact (P≤0.05).

Results: Hip abductor strength and knee flexor-extensor ratio were found to be negatively correlated with knee valgus angle (r = –0.229, P = 0.04 and r = –0.446, P = 0.002, respectively).

Conclusion: No relationship between measure of hip external rotation strength and knee valgus angle was observed (P = 0.39). Strength training of the hip and knee musculature may still need to be addressed in prevention programs, but it also should be combined with teaching proper neuromuscular control through balance, plyometrics and sport-specific exercise.

1. Introduction

Anterior cruciate ligament (ACL) injury occurs with a 2 to 10 fold greater incidence in female athletes compared to males playing the same landing and cutting sports [1]. This increase in ACL injuries in the female athletes has fueled intense examination of the mechanisms responsible for the gender disparity in these debilitating sports injuries [2-4]. Furthermore, ACL rupture is costly, with conservative estimates of surgery and rehabilitation at $17,000-$25,000 per injury [5, 6]. Additionally, potential loss of entire seasons of sports participation, decreased scholarship funding; lowered academic performance, long-term disability, and significantly greater risk of radiographically diagnosed osteoarthritis have been reported [7].

The mechanism underlying gender disparity in ACL injury risk is likely multifactorial in nature. Several theories have been proposed to explain the mechanisms underlying the gender difference in ACL injury rates. These theories including related extrinsic (physical and visual perturbations, bracing, and shoe-surface interaction) and intrinsic (anatomic, hormonal, neuromuscular, and biomechanical differences between genders) variables [8]. It seems that identification of the neuromuscular and biomechanical risk factors associated with the ACL injury

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mechanism could provide direction for targeted prophylactic interventions for high risk individuals.

Excessive frontal plane motion of the lower extremity during sport activities is thought to be a contributing factor in many traumatic and overuse injuries of the knee [9-11]. Such motion can contribute to dynamic knee valgus; thereby, stressing the medial joint capsule and medial collateral ligament [9]. In addition, dynamic knee valgus has been identified as a predictor of ACL injury in a prospective study [10]. Furthermore, excessive frontal plane motion of the lower extremity can lead to repetitive strain of the pes anserine complex and contribute to patellofemoral joint pain [12]. On the other hand, the control of knee motion in the frontal plane (varus / valgus) is achieved via three stabilizing mechanisms including tibiofemoral joint contact, as well as passive and active restraint systems. The active restraint system refers to the muscles that activate to control or produce motion [13]. While muscular control of the knee in the sagittal plane has been well documented, it remains unclear what muscles contribute to varus and valgus control during functional weight bearing activities. Furthermore, dynamic control of the knee in the frontal plane, particularly in the valgus direction, has practical relevance with regards to injury prevention. A valgus knee angle not only places strain on the passive medial restraint system of the knee, but also in combination with anterior tibial translation, strain on the anterior cruciate ligament is increased significantly [14]. Consequently, understanding muscle contribution to the frontal plane active restraint system of the knee may have practical applications in strength training for sport and injury prevention.

Excessive frontal plane motion of the lower extremity has been attributed to abnormal motion at the hip and ankle, including hip internal rotation and adduction, as well as foot pronation and external rotation [11, 15]. Another factor thought to contribute to the inability to maintain frontal plane control of the lower extremity while performing dynamic tasks is diminished proximal strength [13, 15, 16]. Female athletes have been shown less absolute strength than their male counterparts, suggesting a potential link between insufficient muscular strength and noncontact ACL injuries in female athletes [17-19]. Researchers have speculated that decreased strength of the hip musculature may be a major contributor to control the lower extremity during dynamic tasks [20, 21]. Individuals with PFP are reported to have decreased strength of the hip musculature, which may lead

to a lack of lower extremity dynamic control [22, 23]. Clinicians are increasingly prescribing hip strengthening exercises to patients [24]. However, it is not yet well understood whether these exercises should be applied for injury prevention and rehabilitation, or both. It is also unclear whether the mechanism of influence might be directly a result of the action of the hip abductors and external rotators or via a synergistic effect on the larger thigh muscles or gluteus maximus.

Decreased hip strength has been associated with increased frontal plane knee excursion during a single leg squat. To date, researches have been focused on the relationship between lower extremity strength impairments and single limb tasks. Given that the demands placed on the lower extremities may differ during double and single limb activities, the predictors of frontal plane knee excursion during a drop jump task may differ as well. Understanding of the factors that influence frontal plane knee excursion during a drop jump task will interpret such screening assessments. Previous studies have produced conflicting evidence to support this proposed relationship between strength of the hip, knee musculature and faulty lower extremity mechanics in healthy individuals. Cliborn et al. have been shown significant negative relationship between the concentric hip abductor torque and frontal motion of knee during single leg squat [13]. While Hoolman et al. have been reported significant positive relationship between isometrics hip abductor strength and frontal plane knee motion during single leg squat tests [25]. There are some studies that reported no significant correlation between hip abductor and external rotator with knee valgus angle [24, 26]. Therefore, the purpose of this study was to investigate the relationship between hip and knee strength and knee valgus angle during drop jump in elite female athletes.

2. Methods

2.1. Subjects

Forty elite female volleyball and basketball players between the ages of 18 and 25 participated in this study. All subjects were healthy, with no current complaints of lower extremity injury. Participants were excluded from the study if they reported any of the following: [1] history of previous trunk and lower extremity surgery, [2] history of previous ACL surgery or repair [3], presence of any medical or neurologic condition that would impair their ability to perform athletic maneuvers and [4]

presence of any lower extremity malalignment. These malalignment include hip anteversion, Q angle, tibio-femoral angle, knee recurvatum, tibial torsion and foot pronation that evaluated by standard clinical methods [27-29]. First, height and weight of subjects were measured. Then, participants were evaluated for strength and landing mechanics after first being familiarized to all testing procedures. Subjects were tested during the first 6 days of menses to control any potential hormone effects on strength or resulting knee joint neuromechanics [30]. The dominant stance limb (defined as the stance leg

when kicking a soccer ball) was measured. Before examination, all procedures were explained to each subject, then all subjects signed a written consent form approved by University of Tehran.

2.2. Strength Testing

Peak isometric force was calculated for the following muscle actions: hip abduction, hip external rotation, knee extension, and knee flexion (Figure 1).
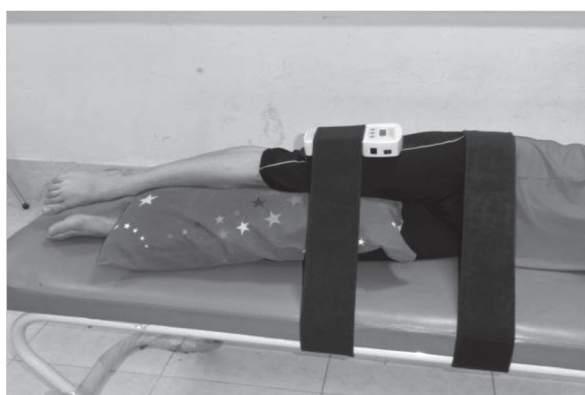
A Hip Abduction

B Hip External Rotation

C Knee Flextion

D Knee Extension

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Figure 1. Participant positioning and HHD location using a non-elastic strap for strength testing; (A) Hip abduction: participants were side-lying with a pillow between their legs and the test hip at approximately 0° of abduction; the HHD was placed 5cm proximal to the lateral condyle. (B) External hip rotation: participants were seated with knee and hip flexed at 90°; the HHD was placed 5cm proximal to the medial malleolus. (C) Knee flextion: participants were prone; the HHD was placed proximal to the posterior aspect of ankle. (D) Knee extension: participants were seated with knee and hip flexed at 90°; the HHD was placed proximal to the anterior aspect of ankle (16, 31).

All test positions were based on those identified in the literature [16, 31]. Also, straps were used to stabilize the subject and handheld dynamometer [Micro Manual Muscle Tester; North Coast) to eliminate the influence of tester strength on these measurements. For each test, one practice and three experimental trials were performed for five seconds, with 15 seconds of rest between contractions [16]. Furthermore, strength measurements have been normalized to subject body weight to facilitate the comparison of results with previous studies. The average normalized peak force values produced during the three trials was used for analysis. Before testing, within rater reliability was determined for the principal investigator. Intraclass correlation coefficients ranged from .91 to .99 for each test.

2.3. Kinematic during Drop Jump Task

Subjects performed a series of drop jump maneuvers after all clinical measures were done. Three-dimensional trajectory data were obtained using a 6-camera motion analysis system (Vicon 460 Motion Capture). Trajectory data were sampled at 200 Hz and digitally recorded. Furthermore, ground reaction forces were collected at 1000 Hz using a calibrated and leveled force plate (Kistler; 9286A) embedded in the floor. Reflective markers were placed on anatomical landmarks according to the Kadaba marker set [32]. Knee joint adduction-abduction was quantified for each subject over a series of drop jump trials. The drop jump consisted of the subject starting on top of a box (50 cm in height) with her feet positioned 35 cm apart (distance measured between toe markers) [33]. Then, subjects were instructed to drop directly down off the box and immediately perform a maximum vertical jump, raising both arms as if they were jumping for a basketball rebound. Also, a trial was discarded and subjects were asked to repeat the trial, if we observed subjects to step or jump off the box, if they lost their balance, if they did not land bilaterally, or if they failed to land back onto the force plate following the maximal vertical jump. Three successful trials were recorded for each subject. It is worth mentioning that, drop jump has been shown high within session reliability with intra-class

correlation coefficients of greater than 0.93 [34]. The first contact on the platform (ie, the drop from the box) was used for analysis. Vertical GRF was used to identify the time at initial contact with the ground. Initial ground contact was defined as the instant at which the vertical ground reaction force exceeded 10 N [10].

10 retro-reflective markers were placed on the right and left anterior-superior iliac spines, mid-thigh, medial and lateral femoral epicondyles, mid-shank, medial and lateral malleoli, heel and 2th metatarsal, of each subject. First, a stationary trial was taken with each subject in a neutral (standing) position to align her with the global laboratory coordinate system. Each subject's local joint coordinates were aligned to her standing position to control for intersubject variation in anatomical alignment (ie, zero-position valgus alignment) during the static trial. Then, medial knee and ankle markers were removed before the dynamic trials. Raw marker coordinates were recorded with Workstation software. Furthermore, marker trajectories were filtered through a low-pass Butterworth digital filter at a cutoff frequency of 10 Hz. The data convention for knee adduction/abduction was denoted as positive and negative, respectively. Knee abduction-adduction angles at initial contact demonstrated during the landing phase were subsequently recorded for each trial.

2.4. Statistical Analysis

All data analyses were performed using SPSS version 20. The Kolmogorov–Smirnov test was used in order to indicate a normal distribution of the data. Furthermore, relationships between each strength variables and knee valgus angle were assessed using a Pearson correlation analyses. Statistical significance was accepted at the level of a≤ 0.05.

3. Results

Descriptive information of subjects is presented in Table 1. Table 2 includes the means and standard deviations for the strength and knee valgus data. The results

Table 1. Descriptive information of subjects.

Variable	Mean± SD
Age (year)	21.15±1.99
Height(cm)	169.08±8.25
Weight(kg)	61.05±10/06
Athletic Experience (year)	8.84±2.29

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Table 2. Means and standard deviations for the strength and knee valgus data

Variable	Mean± SD
Hip Abductor Strength (%body weight)	2.74±0.53
Hip External Rotator Strength (%body weight)	1.83±0.43
Knee Flexor-extensor Ratio (%body weight)	0.76±0.95
Knee Valgus Angle (Degree)	-1.07±6.02

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Table 3. Correlation (r) between strength and knee valgus angle

	Hip Abductor Strength	Hip External Rotator Strength	Knee Flexor-extensor Strength Ratio
Knee Valgus Angle	r = -0.299*	r = -0.133	r = -0.446*
	P- value = 0.049	P- value = 0.391	P- value = 0.002

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of Pearson correlation showed a statistically significant relationship between hip abductor strength (P = 0.049), knee flexor- extensor strength ratio (P = 0.002), and knee valgus angle. Additionally, no significant relationship was observed between hip external rotator strength and knee valgus angle (P = 0.391) (Table 3).

4. Discussion

The results of this study show that there is a significant relationship between hip abductor strength and knee valgus angle at initial contact. These data suggest that individuals with greater strength of hip abductor muscle tend to demonstrate a lower amount of knee movement in the valgus direction. Females showed greater hip adduction and internal angular rotations during single-leg weight bearing movements compared to males, which may produce a greater external knee valgus moment [11, 15, 35]. This finding suggests that the gluteal muscles function eccentrically in controlling excessive hip internal rotation and the strength of these muscles can reduce motion at the knee [36]. Hip abductor weakness may predispose the body to injury by altering trunk or lower extremity kinematics, resulting in increased mechanical stresses on various joints and soft tissues. Lateral trunk lean in subjects with weak hip abductors has been cited as a potential kinematic compensation that could lead to low back pain and injury [37]. Our findings are in agreement with previous investigations demonstrating a significant contribution of hip abductors in control of valgus motion at the knee [13, 16] and in contrast with

two previous studies [12, 26]. Such discrepancy could be due to the method of valgus measurement. Sigward et al. and Bary defined valgus angle as the difference between the distance of right and left lateral knee markers at initial contact and maximum knee flexion during the deceleration phase of landing. But in the present study, we calculated valgus angle as the angle between thigh and shaft in dominant leg at initial contact.

No correlation was found between isometric hip external rotation strength and knee valgus angle at initial contact. Previous authors have suggested that the ability to land correctly depends less on muscular strength of the lower extremity and more on an individual's skill at landing. The lack of correlation between frontal plane knee excursion and isometric hip external rotation strength in the current study is consistent with a recent publication by Mizner et al. [38]. In their study, it was reported that individuals could improve their landing kinematics (ie, increase knee flexion and decrease knee valgus) after a very brief instruction period, and the extent of correction was independent of hip muscle strength. . Both Synder et al. and Fredericson et al. have found that six-weeks of a hip strengthening program decreases knee valgus and patellofemoral pain [39, 40]. Similarly, Earl et al. showed that 8-weeks of progressive core and hip strengthening, as well as technique instruction during stabilization and functional exercise improves lower extremity biomechanics including knee valgus [26]. These findings suggest that the observed pattern prior to instruction is more reflective of a "choice" or "learned motor pattern" rather

than actual hip strength [12, 38]. Furthermore, the results are in contrast with some previous studies that reported a relationship between hip external rotation and knee valgus angle during single leg drop landing [36, 41]. One reason for this discrepancy may be the nature of the task evaluated. A single-limb task requires greater control of the hip in the frontal and transverse planes than an inherently more stable double-limb activity such as the drop jump task. Perhaps the demands associated with a double-limb drop jump task have not been of sufficient magnitude to elicit meaningful alterations in lower extremity kinematics resulting from decreased hip muscle strength.

Interestingly, some studies suggest individuals with knee medial displacement (KMD) that are actually stronger than individuals without KMD. Bell et al. and Bandholm et al. have reported that individuals with KMD have greater hip abductor and external rotator strength, suggesting that people with KMD may actually develop increased hip rotation external strength over time [42, 43]. When individuals go into KMD they contract concentrically their hip abductors and external rotators to move themselves out of KMD. Therefore, these muscles will strengthen over time. While we did not observe an increase in hip external rotation strength as knee valgus angle, our findings are consistent with the latter studies.

The results also showed that there is significant relationship between knee flexor- extensor strength ratio and knee valgus angle at initial contact. It was observed that female athletes had less absolute strength than their male counterparts, suggesting a potential link between insufficient muscular strength and noncontact ACL injuries [17-19]. On the one hand, regarding the knee-extensor muscles contract eccentrically to control knee flexion during landing, researchers have suggested that less initial contact of knee flexion angle might be related to weak knee extensor strength [17]. On the other hand, weak knee flexor strength has been implicated as a potential risk factor for noncontact ACL injuries [44, 45]. Salci et al. have reported that knee extensor and flexor strengths are positively correlated with knee flexion excursion in male volleyball players [19]. It is worth mentioning that women use preferentially the quadriceps more than males in order to stiffen and stabilize the knee joint [8]. Therefore, if an athlete uses preferentially 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 with using the group of posterior chain muscles that possess multiple muscles with various tendon insertions that can be selectively utilized to control the limb during functional tasks. In the condition termed ligament dominance, muscles do not sufficiently absorb the ground reaction forces, so the joint and the ligaments must absorb high amounts of force over a brief time period [8]. Additionally, high amounts of force that sustained over a short period of time lead to higher impulse forces resulting in ligament rupture. On the other hand, deficits in knee flexor strength during landing may lead to excessive extension torques that increase stress on knee joint passive stabilizers, and provide enough torque to cause injury. The hamstrings are considered synergist with the ACL and are able to pull the tibia posteriorly. Thus, the stress on the ACL decreases. Finally, the hamstrings have tendons on both sides of the joint that could provide frontal plane control of motion at the knee.

It is important to remember that lower extremity kinematics may be influenced by many factors other than hip abductor, hip external rotator, knee flexors and knee extensor strength. Ankle pronation/eversion, bony anatomy, coactivation synergistic effects with other muscles, neuromuscular training, movement strategy instruction, sagittal-plane kinematics, movement anticipation, ground–shoe friction, incline of landing surface, and other external distractions have all been cited as potential influences on lower extremity frontal plane kinematics. On the other hand, researchers have described a highly reproducible technique using a hand-held dynamometer and stabilizer straps to measure hip abduction and external rotation strength in the clinical setting. The reliability of this measurement technique gives the clinician an efficient way to screen a group of athletes to determine which of them may be at risk of suffering knee injuries and subsequently may benefit from muscular strengthening.

5. Conclusion

The findings of this investigation support an association between strength of the hip and knee musculature and frontal plane knee motion at initial contact. These data suggest that increased frontal plane knee motion toward valgus direction may occur when hip abductor and knee flexor-extensor ratio strength values are relatively low. Further research should be done about additional biomechanical variables, such as neuromuscular control for better understanding of the multiple factors that in-

fluence faulty mechanics. Gaining a clear understanding of all biomechanical factors influencing lower extremity mechanics during dynamic tasks will help clinicians to develop more effective intervention programs.

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