THE RELATIONSHIP BETWEEN FORCE PRODUCTION DURING ISOMETRIC SQUATS AND KNEE FLEXION ANGLES DURING LANDING

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The current study quantified the relationship between force production during isometric squats performed at different external knee flexion angles (40, 60, 80, and 100 degrees) and initial and peak knee flexion angles during landing. A total of 18 male and 18 female recreational/collegiate athletes completed a jump-landing-jump task and four maximal isometric squats at different knee flexion angles. Significant correlations were observed between peak force production during isometric squats and initial and peak knee flexion angles during landing for females, but not for males. For females, decreased isometric strength during squats was associated with decreased knee flexion during landing. For males, isometric strength alone may not be sufficient to explain differences in knee flexion during landing. Future studies are warranted to study the effect of postural-specific strength training on landing mechanics in females.

KEY WORDS: ACL, kinematics, kinetics, biomechanics, jump-landing

INTRODUCTION: Anterior cruciate ligament (ACL) loading has been shown to be affected by knee flexion angle, and studies have demonstrated that ACL loading decreases when knee flexion angle increases (Dai, Mao, Garrett, & Yu, 2014). Consequently, studies have investigated how knee flexion angle could be increased during landing in an attempt to reduce ACL injury risks (Ericksen, Gribble, Pfile, & Pietrosimone, 2013), but the underlying mechanism associated with small knee flexion angles during landing is still unclear.

Previously, investigators have quantified the relationship between lower extremity strength and knee flexion angle, but the findings have been inconclusive. Some studies have found significant correlations between lower extremity strength and landing mechanics (Lephart, Ferris, Riemann, Myers, & Fu, 2002), while other studies have not found such correlations (Beutler, de la Motte, Marshall, Padua, & Boden, 2009). The inconsistent findings may be explained by two factors. The first factor is the body positioning during testing. Wilson, Murphy, & Walshe (1996) highlighted the importance of posture in determining the transfer effect between training exercises and strength testing protocols. Assessing lower extremity strength at postures that are not similar to landing may not truly represent the dynamic strength utilized during lading. The second factor is the measure of lower extremity strength at a single knee flexion angle, as opposed to a range of knee flexion angles. Researchers have demonstrated that posture and training can affect the force producing abilities of the musculature by altering the force-length relationship (Ullrich, Heinrich, Goldmann, & Bruggemann, 2010). Assessing lower extremity strength at a single knee flexion angle may ignore the potential interaction between muscle force-length relationship and dynamic movement patterns.

Therefore, the purpose of the current study was to quantify the relationship between force production during isometric squats performed at different external knee flexion angles (40, 60, 80, and 100 degrees) and knee flexion angles during landing. It was hypothesized that force production during isometric squats performed at deep knee flexion (80 and 100 degrees) would be positively correlated with initial and peak knee flexion angles during landing.

METHODS: A total of 18 male and 18 female recreational/collegiate athletes (age: 20.5 ± 1.8 years; height: 1.74 ± 0.12 m; mass: 71.5 ± 17.0 kg) participated in the current study. Participants were physically active, had experience in sports that involved jump-landing tasks, and had no history of major lower extremity injuries. Participants completed a warm-up protocol before data collection. The testing leg was randomly selected and 26 retroreflective markers were placed on the participants' bony landmarks on the torso and selected leg. Marker positions were captured using eight Bonita 10 cameras (Vicon Motion Systems Ltd, Oxford, UK) at a sampling frequency of 160 Hz. Ground reaction force (GRF) data were collected using two FP4060-10-2000 force platforms (Bertec Corporation, OH, USA), sampling at 1600 Hz.

Participants completed a jump-landing-jump task and four maximal isometric squats. For the jump-landing-jump task (Boling et al., 2009), participants jumped from a 30-cm high box to a distance of 50% of their height forward from the box with the foot of testing side landing on one force platform, and then immediately performed a countermovement and vertical jump for peak height. Participants performed 3 recorded trials, with a 30-second rest between jumps to allow for energy system recovery.

The testing environment was then prepared for the four maximal isometric squats (Figure 1) at four different knee flexion angles. The four knee flexion angle ranges (35-45, 55-65, 75-85 and 95-105 degrees) were achieved by manipulating the locations of the bar catch pins within the squat rack. Knee flexion angle was identified using the greater trochanter, lateral femoral condyle, and lateral malleolus markers of the testing leg and calculated in real-time using the Vicon Nexus 1.8.2 software. Participants performed a number of primary trials with a plastic bar without maximum contraction to obtain the necessary knee flexion angles for different heights of the pins. Once the pins for the requisite knee flexion angles were identified, weights were added to the squat rack itself to provide resistance, and the participants performed the maximal contractions against a metal barbell in a random order. During the isometric squats, the participants stood with feet shoulder-width apart, one on each force platform, and held their hands on the bar. The participants extended the lower extremities and trunk with peak effort. Knee flexion angles were monitored during each trial to ensure participants achieved the desired angle. Participants were coached to use 2 seconds to reach peak force and then maintain that force for three more seconds. Three minutes of rest was provided between each trial.

Figure 1. Squat rack and barbell with a participant positioned at different knee flexion angles (40, 60, 80, and 100 degrees).

For the landing trials, the knee flexion angle at initial ground contact and the peak knee flexion angle during landing were calculated as the 2-dimentional external angle defined by the greater trochanter, lateral femoral condyle, and lateral malleolus markers. For the isometric squatting tasks, the peak vertical GRF during a period of 1 second was extracted. Pearson correlation tests were performed between the peak force during the isometric squats at knee flexion angles of 40, 60, 80, and 100 degrees and the initial and peak knee flexion angles during landing for all combined participants, males, and females. Type I error rate was set at 0.05 for statistically significant correlations. Statistical tests were performed using IBM SPSS Statistics 21 (IBM Corporation, Armonk, NY, USA).

RESULTS: For females (Table1), most correlations were statistically significant ($p<0.05$). No significant correlations were observed for combined participants or males (Table 1).

Table 1. Pearson product-moment correlation coefficients (p values) between peak force production during squats and knee flexion angles during landing for combined participants, males, and females

		Peak force during squat with 40º knee flexion	Peak force during squat with 60º knee flexion	Peak force during squat with 80º knee flexion	Peak force during squat with 100º knee flexion
Initial Knee Flexion during Landing	Combined	0.224 (0.189)	0.247 (0.146)	0.331 (0.052)	0.274 (0.106)
	Males	−0.062 (0.806)	0.070 (0.783)	0.152 (0.561)	0.053 (0.853)
	Females	0.445 (0.064)	**0.483 (0.042)**	**0.518 (0.011)**	**0.538 (0.021)**
Peak Knee Flexion during Landing	Combined	0.231 (0.175)	0.170 (0.323)	0.068 (0.699)	0.153 (0.373)
	Males	0.120 (0.635)	−0.028 (0.912)	−0.155 (0.552)	−0.049 (0.847)
	Females	**0.530 (0.024)**	**0.709 (0.001)**	**0.554 (0.020)**	**0.672 (0.002)**

DISCUSSION: The purpose of the current study was to quantify the relationship between peak force production during isometric squats and knee flexion angles during landing. The similarity in body postures between squat and landing provided a better representation of the dynamic strength utilized during landing. The range of knee flexion angles during isometric squats allowed an assessment of the relationship between angle-specific strength and knee flexion angles during landing. The results supported the hypothesis for females that force production during isometric squats performed at deep knee flexion would be positively correlated with initial and peak knee flexion angles during landing, but not for males.

A number of studies have investigated the relationship between lower extremity strength and lower extremity biomechanics, however, these studies have found inconsistent results. Boling et al. (2009) found that decreased lower extremity strength and decreased knee flexion angle have been associated with increased risk of patellofemoral pain. Lephart et al. (2002) found that females landed with smaller knee flexion angles than males and had relatively weaker quadriceps and hamstrings when normalized to body mass compared with males. In contrast, Beutler et al. (2009) observed that muscular strength and anthropometric factors did not predict poor landing technique in military cadets. Mizner, Kawaguchi, & Chmielewski (2008) found that lower extremity strength did not affect the athlete's ability to alter their landing mechanics following instruction and that lower extremity strength was a poor predictor of ACL injury risk factors. Herman et al. (2008) showed that strength training alone may not be sufficient to modify jump-landing patterns in females. A recent study by Carcia, Kivlan, & Scibek (2011) proposed that using closed kinetic chain exercises to quantify lower extremity strength could more closely represent lower extremity kinematics during a landing task compared with open kinetic chain strength measures. In this study, a seated leg press position with a knee flexion angle of 25° was used. However, no relationship was found between lower extremity strength and sagittal plane knee kinematics during landing.

Different from previous studies, strength was assessed during squats in the current study. The similar involvements of muscle groups and movement patterns during squats compared with landing may allow for better assessment of dynamic strength utilized during landing. Interestingly, significant correlations were only observed for females. The sex disparity between males and females in the incidence of ACL injuries has been well established, however a definitive reason for why females are at a greater risk has yet to be identified. In the current study, females with weaker strength during squats landed with less knee flexion during the drop-jump task, which has been identified as a risk factor for ACL injury. Improving postural-specific strength at relatively deep knee flexion may provide a strategy to improve the landing mechanics of female athletes. However, future intervention studies are warranted to test this hypothesis. On the other hand, the non-significant correlations in males may be due to increased strength in males compared with females as well as other factors that may affect jump-landing mechanics. Other factors such as the utilization of muscle stretch-shortening cycle may contribute to the changes of knee flexion angles during landing. The selection of knee flexion in individual performances may also be affected by motor control programs. Weaker individuals may land with a greater knee flexion angle because they had learned this motor control pattern from previous experience or instruction. On the other hand, stronger individuals may land with a smaller knee flexion angle simply because they had not learned this motor control pattern. The study by Herman et al. (2009) has shown the importance of both strength and movement training in modifying lower extremity biomechanics during landing.

CONCLUSION:

Significant correlations were observed between the peak force production during isometric squats at different knee flexion angle and both the initial knee flexion angle and the peak knee flexion angle during landing for females, but not for males. Future studies are warranted to study the effect of postural-specific strength training on landing mechanics and ACL injury risks in females. For males, other factors such as the utilization of muscle stretch-shortening cycle and learning of motor control programs may have a greater contribution to knee flexion angles during landing compared to strength.

REFERENCES

Beutler, A., de la Motte, S., Marshall, S., Padua, D., & Boden, B. (2009). Muscle strength and qualitative jump-landing differences in male and female military cadets: The jump-acl study. *Journal of Sports Science & Medicine, 8*, 663-671.

Boling, M. C., Padua, D. A., Marshall, S. W., Guskiewicz, K., Pyne, S., & Beutler, A. (2009). A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: The joint undertaking to monitor and prevent ACL injury (JUMP-ACL) cohort. *The American Journal of Sports Medicine, 37*(11), 2108-2116.

Carcia, C. R., Kivlan, B., & Scibek, J. S. (2011). The relationship between lower extremity closed kinetic chain strength & sagittal plane landing kinematics in female athletes. *International Journal of Sports Physical Therapy, 6*(1), 1-9.

Dai, B., Mao, D., Garrett, W. E., & Yu, B. (2014). Anterior cruciate ligament injuries in soccer: Loading mechanisms, risk factors, and prevention programs. *Journal of Sport and Health Science, 3*(4), 299-306.

Ericksen, H. M., Gribble, P. A., Pfile, K. R., & Pietrosimone, B. G. (2013). Different modes of feedback and peak vertical ground reaction force during jump landing: A systematic review. *Journal of Athletic Training, 48*(5), 685-695.

Herman, D. C., Onate, J. A., Weinhold, P. S., Guskiewicz, K. M., Garrett, W. E., Yu, B., & Padua, D. A. (2009). The effects of feedback with and without strength training on lower extremity biomechanics. *The American Journal of Sports Medicine, 37*(7), 1301-1308.

Herman, D. C., Weinhold, P. S., Guskiewicz, K. M., Garrett, W. E., Yu, B., & Padua, D. A. (2008). The effects of strength training on the lower extremity biomechanics of female recreational athletes during a stop-jump task. *The American Journal of Sports Medicine, 36*(4), 733-740.

Lephart, S. M., Ferris, C. M., Riemann, B. L., Myers, J. B., & Fu, F. H. (2002). Gender differences in strength and lower extremity kinematics during landing. *Clinical Orthopaedics and Related Research,* (401), 162-169.

Mizner, R. L., Kawaguchi, J. K., & Chmielewski, T. L. (2008). Muscle strength in the lower extremity does not predict postinstruction improvements in the landing patterns of female athletes. *The Journal of Orthopaedic and Sports Physical Therapy, 38*(6), 353-361.

Ullrich, B., Heinrich, K., Goldmann, J. P., & Bruggemann, G. P. (2010). Altered squat jumping mechanics after specific exercise. *International Journal of Sports Medicine, 31*(4), 243-250.

Wilson, G. J., Murphy, A. J., & Walshe, A. (1996). The specificity of strength training: The effect of posture. *European Journal of Applied Physiology and Occupational Physiology, 73*(3-4), 346-352.