RISK FACTORS RELATED TO ANTERIOR CRUCIATE LIGAMENT INJURY OF FEMALE BASKETBALL PLAYERS DURING STEPPING MOVEMENTS

Heng-Ju Lee, Tung-Hsi Tseng and Chia-Yin Liang

Department of Physical Education, National Taiwan Normal University, Taipei, Taiwan

The purpose of this study was to compare the biomechanical factors related to anterior cruciate ligament injury during unanticipated movements after landing and immediately applied in stepping movements. Four healthy female basketball players were recruited in this study. All subjects were asked to perform five successful trials at each stepping movements after jump landing. Results of the current study showed that different step movements may result in different biomechanical factors to cause different ACL injury risk levels. Future studies should focus on investigating the best jump landing and stepping strategy, and analyzing better ways to coordinate lower extremity joints to reduce non-contact ACL injury risks.

KEY WORDS: anterior cruciate ligament, injury risk, cross over step.

INTRODUCTION: The jump landing is an integral skill for athletes in basketball, volleyball, and handball. Many knee injuries could occur during this motion. For example, anterior cruciate ligament (ACL) injury is a common injury in jump landings. The maneuvers most likely to cause ACL ruptures include an axial impulsive loading of the knee joint combined with a valgus knee moment as well as internal or external tibial rotation. This may occur during a plant-and-cut maneuver or single leg landing with fully extended knee (Boden, Dean, Feagin, & Garrett, 2000; Olsen, Myklebust, Engebretsen, & Bahr, 2004; Krosshaug, & Bahr, 2005).

It is interesting to note that roughly 70% of ACL ruptures are non-contact injuries. In addition, females are two to eight times more likely to sustain a non-contact ACL injury than males. Previous studies have found several biomechanical factors associated with non-contact ACL injury and these include; peak values for vertical ground reaction force (VGRF), knee flexion and valgus angles, moments of external knee valgus and hip flexion (Hewett et al., 2005). The function of the ACL is to prevent excessive anterior translation of tibia. If an excessive anterior tibial shear force appeared, it would increase the rate of ACL injury. In the past, many studies have investigated effects of landing height and gender in lower extremity injuries while performing jump landings. The purpose of this study was to determine ACL injury risk factors between direct and cross over step maneuvers in female basketball athletes. We hypothesized that cross over steps would cause different levels of ACL injury risks when compared to direct step movements.

METHODS: Four healthy female basketball players (19.0 ±1.0 y, 1.70 ±0.07 m, 62.5 ±5.07 kg, Jumping height: 34 ±3.92 cm) were recruited in this study. The starting location for the subjects to perform the jump landing was 70 cm away from the force plates. While jumping, subjects were asked to touch a target which was placed at 50% of their maximum CMJ jumping height with both hands and to land with both legs onto separate force plates (Wikstrom, Power, & Tillman, 2004; Wikstrom, Tillman, & Borsa, 2005) (Figure 1).

Subjects were asked to perform stepping movements to the right or left immediately after landing. Step direction and mode (direct step or cross over step) were randomly assigned by a signal light which was located 360 cm in front of the subject. Symbols 1 and 4 indicated direct step movement to right and left. Symbols 2 and 3 indicated cross over step movement to right and left (Figure 2).

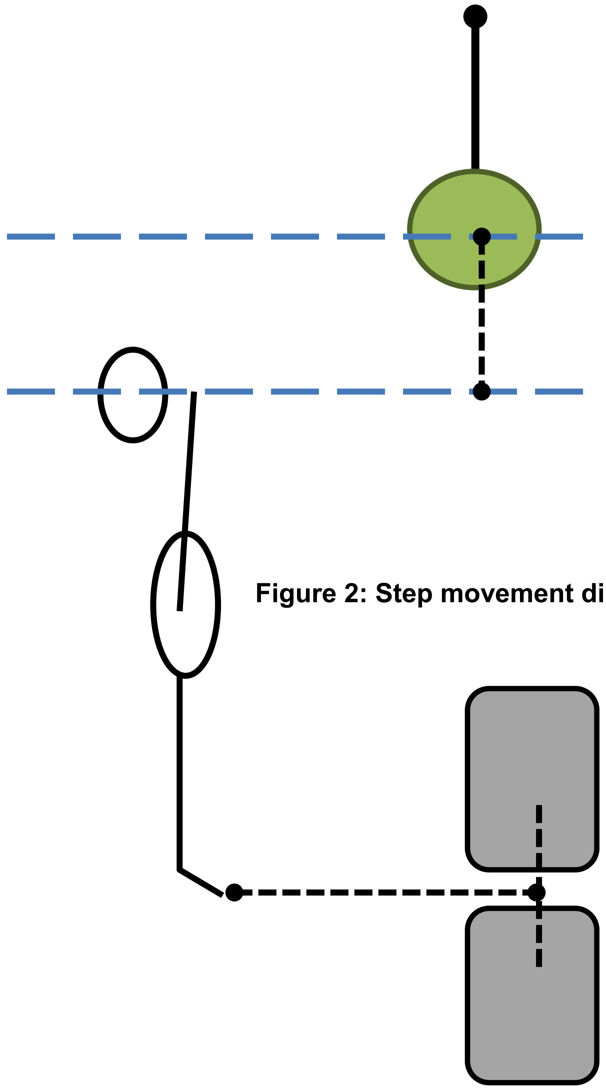

Figure 2: Step movement directions and singal light design.

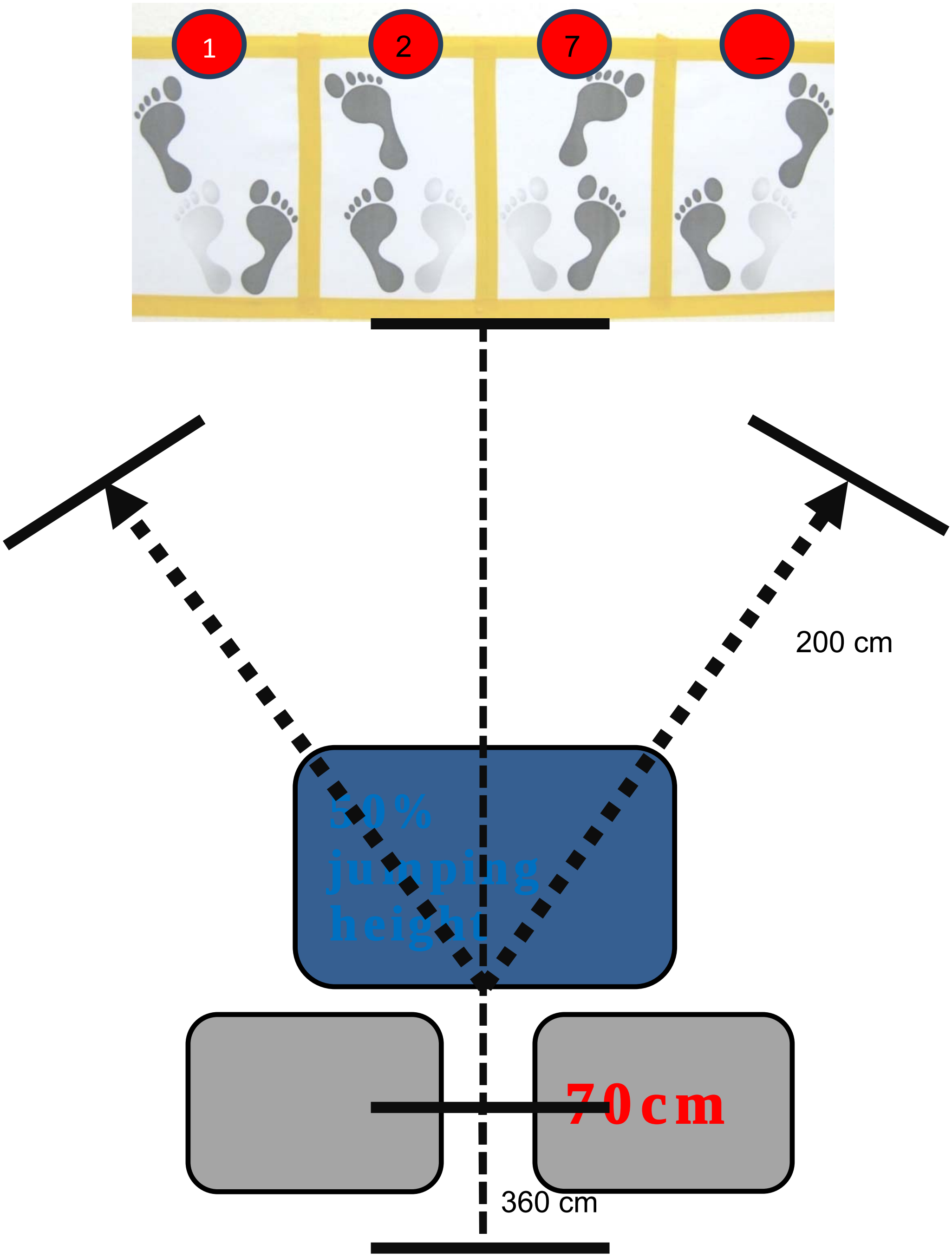

Figure 1: Experimental design.

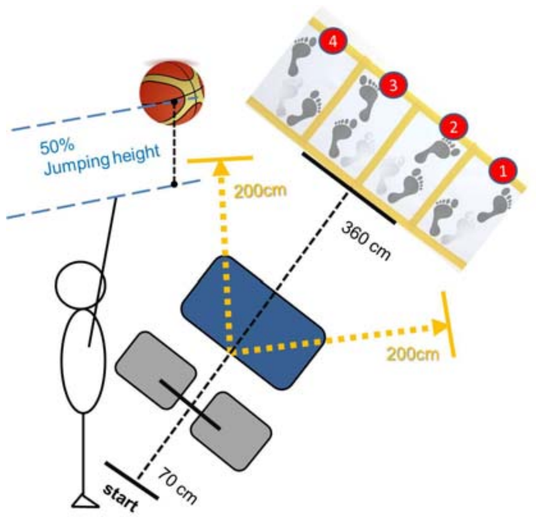

Figure 3: Experimental design.

During landing, if the subject performed an unstable landing posture or had an extra jump action upward or forward, the data was voided. Subjects were required to complete five successful trials for each step movement. Kinetic data were collected by 3 force plates (Kistler, Germany) at 1000 Hz. Kinematics data were collected by 10 camera motion capture system (Vicon, UK) at 200 Hz. Both kinetic and kinematics data were synchronized by the Nexus software (Vicon, UK). Friedman two-way analysis of variance by ranks was used to compare biomechanical factors of ACL injury during different step movements. Post hoc comparison was used by rank sums. A significance level of 0.05 was set for all statistical tests.

RESULTS: Means and standard deviations for peak values of VGRF, anterior tibial shear force, knee flexion angle, knee valgus angle, knee valgus moment and hip flexion moment of supporting and stepping legs are presented in Table 1.

The peak VGRF of cross over step stepping leg was significantly greater (*p*=.001) than cross over step supporting leg. The peak anterior tibial shear force of the direct step supporting leg was significantly greater (*p*=.006) than the cross over step supporting leg. There were no significant differences in peak knee flexion angle or valgus angle among the four stepping movements. The peak knee valgus moment of direct step supporting leg was significantly greater (*p*=.003) than direct step stepping leg. The peak hip flexion moment of cross over step stepping leg was significantly greater (*p*=.028) than cross over step supporting leg.

Table 1: The biomechanical factors during stepping movements.

ACL injury risk factors	Stepping movements (mean ±SD)			
	Direct Step		Cross over step	
	Supporting leg	Stepping leg	Supporting leg	Stepping leg
VGRF (BW)	1.52 ±0.15	1.73 ±0.06	1.30 ±0.08 [b]	1.86 ±0.09 [b]
ATSF (N/kg)	5.55 ±1.87 [c]	5.73 ±0.68	3.64 ±1.19 [c]	5.29 ±1.09
knee flexion angle (deg)	52.48 ±6.93	53.98 ±6.22	51.86 ±7.58	49.03 ±5.93
knee valgus angle (deg)	8.21 ±5.20	5.80 ±2.75	8.24 ±4.04	7.39 ±3.51
knee valgus moment (Nm/kg)	0.64 ±0.21 [a]	0.08 ±0.03 [a]	0.22 ±0.08	0.16 ±0.08
hip flexion moment (Nm/kg)	0.79 ±0.62	1.56 ±0.44	0.52 ±0.33 [b]	1.50 ±0.37 [b]

ATSF – Anterior Tibial Shear Force

[a] indicates significant differences between Direct step Supporting leg and Direct step Stepping leg ($p < .05$).

[b] indicates significant differences between Cross over step Supporting leg and Cross over step Stepping leg ($p < .05$).

[c] indicates significant differences between Direct step Supporting leg and Cross over step Supporting leg ($p < .05$).

[d] indicates significant differences between Direct step Stepping leg and Cross over step Stepping leg ($p < .05$).

DISCUSSION: Results of the current study demonstrated that peak VGRF of the cross over step stepping leg (1.86 BW) was significantly greater than the cross over step supporting leg (1.30 BW). Greater GRF could cause greater impact force onto lower extremity joints while performing dynamic tasks, which could lead to possible higher injury rates. Cadaver studies have shown that quadriceps force could generate anterior tibial shear force and apply stress and strain to the ACL when the knee is near fully extension. Conversely, the hamstrings provide posterior tibial shear force, subsequently reducing the force placed on the ACL (Li, Rudy, Sakane, Kanamori, Ma, & Woo, 1999). If anterior tibial shear force generated by the eccentric quadriceps contraction was excessive, the hamstring may not provide adequate force to counter anterior tibial shear force. Therefore, the ACL might be at risk of injury. In our results, the peak anterior tibial shear force of the direct step supporting leg (5.55 N/kg) was significantly greater than the cross over step supporting leg (3.64 N/kg). Previous research has suggested that increased knee flexion angle during landing may reduce knee injury risk, because more knee flexion could increase muscle activation of hamstring which could reduce anterior tibial shear force on the ACL (Brazen, Todd, Ambegaonkar, Wunderlich, & Peterson, 2010). When the knee angle was greater than 30° of flexion, there would be less strain applied onto the ACL. Our results showed that the knee flexion angles of four stepping movements were either over 30° of flexion and there were no significant difference among different stepping movement. It was shown that either of the four stepping movements would result in less strain applied onto the ACL. But it takes into consideration only the option of the knee flexion angle. Bendjaballah,et al. (1997) found that load applied on the ACL could be six times greater when the peak knee valgus angle was greater than 5°. Our data showed that knee valgus angle of all movements were all greater 5°. In addition, Markolf et al. (1976) defined as the maximum sustainable axial force (Fmax) that the limb could sustain before the joint opened medially or laterally more than 8°. This value of 8° was based on the maximum opening of the joint found in cadaver studies. In our results, supporting leg of direct step and cross over step were both over 8°, but they were no significant difference in stepping leg of direct step and cross over step.
The results of this study showed that the knee valgus moment of supporting leg of direct step (0.64 Nm/kg) was significantly greater than the direct step stepping leg (0.08 Nm/kg). Markolf et al. (1995) examined valgus knee moment loading usually combinations of other forces and moments in cadaveric knees. A quasi-static valgus knee moment loading of 10 Nm was found to increase ACL strain in the flexed knee. Knee valgus angles and moments were the primary predictors of ACL injury risk. Additional valgus loading could increase strain level of ACL. The hip flexion moment of stepping leg of cross over step (1.50 Nm/kg) was significantly greater than cross over step supporting leg (0.52 Nm/kg) in this study. The increased hip and knee motion in sagittal plane have been shown to decrease joint motion in frontal plane to reduce the possibility of ACL injury during landing (Pollard, Sigward, & Powers, 2010).

CONCLUSION: Knee anterior tibial shear forces and valgus moments are the primary predictors of ACL injury risk. Physiologic valgus moments on the knee can increase anterior tibial translation and loads on the ACL by several-fold. The current findings indicate that female basketball players might have higher risk of knee injury during direct step than cross over step maneuver. Future studies should focus on investigating the best jump landing and stepping strategy, and on analyzing better ways to coordinate lower extremity joints to reduce non-contact ACL injury risks.

REFERENCES:

Bendjaballah, M. Z., Shirazi-Adl, A., & Zukor, D. (1997). Finite element analysis of human knee joint in varus-valgus. *Clinical Biomechanics, 12*(3), 139-148.

Boden, B. P., Dean, G. S., Feagin, J., & Garrett, W. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopedics, 23*(6), 573-578.

Brazen, D. M., Todd, M. K., Ambegaonkar, J. P., Wunderlich, R., & Peterson, C. (2010). The effect of fatigue on landing biomechanics in single-leg drop landings. *Clinical Journal of Sport Medicine, 20*(4), 286-292.

Hewett, T., Myer, G., Ford, K., Heidt, R., Colosimo, A., McLean, S., et al. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes. *The American Journal of Sports Medicine, 33*(4), 492-501.

Krosshaug, T., & Bahr, R. (2005). A model-based image-matching technique for three-dimensional reconstruction of human motion from uncalibrated video sequences. *Journal of Biomechanics, 38*(4), 919-929.

Li, G., Rudy, T., Sakane, M., Kanamori, A., Ma, C., & Woo, S. L. Y. (1999). The importance of quadriceps and hamstring muscle loading on knee kinematics and in-situ forces in the ACL. *Journal of biomechanics, 32*(4), 395-400.

Markolf, K. L., Burchfield, D. M., Shapiro, M. M., Shepard, M. F., Finerman, G. A. M., & Slauterbeck, J. L. (1995). Combined knee loading states that generate high anterior cruciate ligament forces. *Journal of Orthopaedic Research, 13*(6), 930-935.

Markolf, K., Mensch, J., & Amstutz, H. (1976). Stiffness and laxity of the knee--the contributions of the supporting structures. A quantitative in vitro study. *The Journal of bone and joint surgery. American volume, 58*(5), 583-594.

Olsen, O. E., Myklebust, G., Engebretsen, L., & Bahr, R. (2004). Injury mechanisms for anterior cruciate ligament injuries in team handball. *The American Journal of Sports Medicine, 32*(4), 1002-1012.

Pollard, C. D., Sigward, S. M., & Powers, C. M. (2010). Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments. *Clinical Biomechanics, 25*(2), 142-146.

Wikstrom, E. A., Powers, M. E., & Tillman, M. D. (2004). Dynamic stabilization time after isokinetic and functional fatigue. *Journal of Athletic Training, 39*(3), 247-253.

Wikstrom, E. A., Tillman, M. D., & Borsa, P. A. (2005). Detection of dynamic stability deficits in subjects with functional ankle instability. *Medicine & Science in Sports & Exercise, 37*(2), 169-175.