EFFECTS OF FOOT PLANTING POSITIONS ON KNEE JOINT IN DROP LANDING

Ji-Yong Joo[1], Young-Kwan Kim[1], Jin-Kyu Lee[2], and Choongsoo Shin[2]

Department of Physical Education, Chonnam National University, Gwangju, Korea[1]

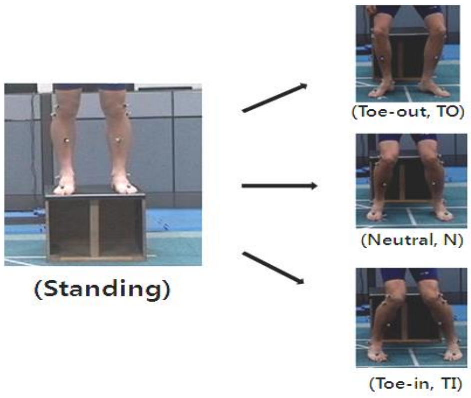
Department of Mechanical Engineering, Sogang University, Seoul, Korea[2]

The purpose of this study was to investigate the effect of three different foot placement positions at the moment of foot-ground contact on the knee joint kinematics and kinetics in drop landing in an attempt to estimate the risk of non-contact anterior cruciate ligament (ACL) injury. Three foot placement positions were toe-in (TI), neutral (N), and toe-out (TO) positions according to the heading direction of toes relative to femur. Seventeen college students participated in this study and motion capturing system with force-platforms was used to assess the drop landings. Toe-in (TI) position should be avoided due to the highest combined loading of valgus and internal rotation. The neutral foot landing position is recommended to minimize the risk of non-contact ACL injury.

KEY WORDS: drop landing, ACL injury, kinematics, kinetics

INTRODUCTION: The landing is a mandatory action immediately after jumping and is very important in many sports circumstances. There are a lot of landing studies associated with the injury mechanism. It is well known that improper landing postures cause lower limb injuries, especially non-contact anterior cruciate ligament (ACL) injuries (Boden et al., 2000).
Non-contact ACL was attributed to inefficient cushioning process at joints such as ankle, knee, and hip in responding to the ground reaction force as a result of landing. The mechanism of non-contact ACL injury, attributed to extreme valgus moment and/or extreme tibial anterior force in the situation of near-extended knee (0~25° flexion). is well known (Chappell et al., 2002). However, the review paper noticed that the combined loading condition such as valgus moment plus internal/external moment together would be much harmful to the risk of non-contact ACL injuries (Shimokochi and Shultz, 2008).
Therefore, this aim of this study was to investigate how the foot placement positions on landing would give effects on the kinematics and kinetics of the knee joints and whether they would cause the risk of non-contact ACL injury. The different foot placement positions were divided into toe-in (TI), neutral, and toe-out (TO) positions according to the direction of toe heading relative to the femur. These different positions were assumed to induce internal or external rotational angles intentionally at the instant of foot contact and consequently would drive the combined loading on the knee.

METHODS: Seventeen healthy collegiate male students (age of 20.5±1.1 years; height of 1.75±0.06m; mass of 68.8±5.8kg) having no neuromuscular injuries within last six months participated in this study as volunteers.
Eight High speed cameras (Eagle®, Motion Analysis, Santa Rosa, CA, USA) with sampling rate of 120 Hz and two force-platforms (Type 9281E, Kistler, Amherst, NY, USA) with sampling rate of 1,200 Hz were used to collect motion and ground reaction force data. Nineteen reflective markers were placed on major anatomical positions in order to create the local coordinate axes of the body segments. All data collection and post-processing were performed using Cortex 4.0® (Motion Analysis, Santa Rosa, CA, USA).
All participants performed a drop landing from a box of 0.35 m height. Three different planting-foot positions were assigned depending on the heading of the toes. Neutral (N) position was defined as the parallel lines of feet with the width of participant's shoulder space between mid-feet. Toe-in (TI) position was 30° inward turn (adduction) of the feet with respect to N position and toe-out (TO) position was 30° outward turn (abduction) with the distance of participant's shoulder space between mid-feet (Figure 1). In an attempt to create consistent feet positions, the guide tape was attached on the floor.



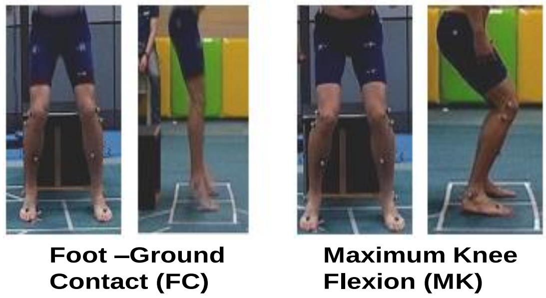


Figure 1: Standing position on the box and three different feet placements on the floor.

Figure 2: Definition of events.

The landing motion was divided into two events such as foot-ground contact (FC) and maximal knee flexion (MK). Down-phase period was between FC and MK (Figure 2). Right knee only was considered for analysis due to the symmetric motion of landing. The distance between knees, knee joint angles, peak ground reaction force, and peak knee moment were calculated and compared by three foot placement positions and events. One-way or two-way repeated measured ANOVA was used with a significance level of 0.05.

RESULTS: Figure 1 represented a significant interaction by foot placement positions and events ($F(2,32)=58.7$, $p<.01$). TI position induced the decreased distance between knees, while TO position produced the increased distance of knees. N position did not induced changes in the distance between knees.

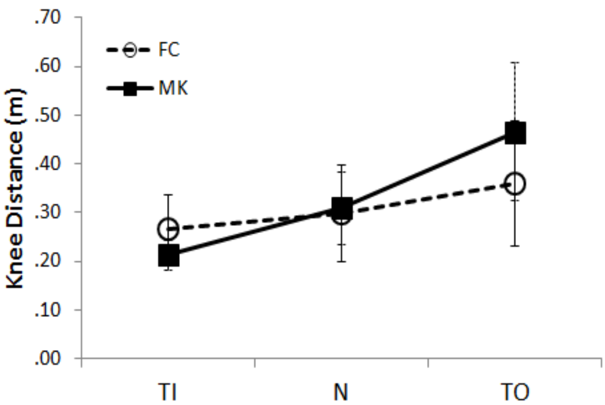


Figure 3: Chages in the distance between knees according to three differerent foot placement positions and two events (TI=toe-in; N=neutral; TO=toe-out; FC=foot-ground contact; MK=maximum knee flexion).

Table 1 indicated changes in knee joint angles according to foot placement positions and events. Significant interactions were detected in changes in flexion angle ($F(2,34)=10.8$, $p<.01$) and varus angle ($F(2,34)=3.76$, $p<.05$). Regarding internal/external angles, only main effect according to foot placement position ($F(2,34)=8.94$, $p<.01$). TI position significantly flexed knee less than N and TI positions after landing. All foot placement positions induced varus angle of knee but TO position produced significantly larger increases in varus angle than any other position. TO position demonstrated a significantly larger internal rotation angle after landing.

Table 1
Changes in knee joint angle accoding to foot placement positions and event (unit: °)

	TI	N	TO	*F*	*P*
Flexion (+)					
FC	15.7±5.7	12.0±4.0	10.6±3.7	10.8	<.01* (TI<N, TO)
MK	52.4±18.2	60.5±19.2	64.5±10.6	(F×E)	
Varus (+)					
FC	4.1±9.0	3.4±5.7	0.4±10.2	3.76	.04* (TO<N<TI)
MK	-3.9±10.2	-7.8±8.9	-14.0±5.5	(F×E)	
Internal(+) Rotation					
FC	-8.5±7.6	0.6±6.4	29.1±4.3	8.94	<.01* (TI,N<TO)
MK	2.3±11.0	14.4±6.7	40.8±4.5		

*p<.05, FC=foot-ground contact, MK=maximum knee flexion, TI=toe-in, N=neutral, TO=toe-out, F×E=interaction by foot placement positions and events

Table 2
Changes in peak ground reaction force according to foot placement positions (unit: BW)

	TI	N	TO	*F*	*P*
Posterior	0.24±0.03	0.23±0.04	0.20±0.04	14.0	<.01* (TO<TI,N)
Medial	0.21±0.07	0.08±0.05	0.11±0.02	60.8	<.01* (N<TO<TI)
Vertical	1.94±0.34	1.89±0.44	2.02±0.43	3.13	ns

*p<.05, FC=foot-ground contact, MK=maximum knee flexion, TI=toe-in, N=neutral, TO=toe-out.

Table 3
Changes in peak joint moment according to foot placement positions (unit: Nm)

	TI	N	TO	*F*	*P*
Flexion	17.2±4.2	16.9±4.6	16.1±4.5	1.44	Ns
Varus (+)	-36.5±43.7	15.5±51.7	101.1±44.6	46.9	<.01* (TI<N<TO)
Internal(+) rotation	28.6±7.3	26.1±7.4	22.3±6.7	7.20	<.01* (TO<TI, N)

*p<.05, FC=foot-ground contact, MK=maximum knee flexion, TI=toe-in, N=neutral, TO=toe-out.

Table 2 showed three directional peak ground reaction force (GRF) immediately after landing prior to maximum knee flexion. Different foot placement position did not induce any difference in vertical direction but produced significantly different mean differences in posterior and medial directions. TI position revealed the highest medial peak GRF and TO position did the lowest posterior peak GRF.
Table 3 showed peak joint moment immediately after landing for three directions. Main effects of foot placement positions were detected in only flexion and varus/valgus moments. TI position showed peak valgus moment, while TO position did peak varus moment immediately after landing. In addition, TO position demonstrated the smallest peak internal rotation moment prior to maximum knee flexion position.

DISCUSSION: Non-contact ACL injury is mainly attributed to very extreme anterior joint force with high knee extension moment around fully extended knee position, which tends to minimize the role of hamstring muscles to reduce the anterior knee force (Chappell et al., 2002). This injury occurred in extreme valgus moment condition primarily. However, Shimokochi and Shultz (2008) noticed the importance of the combined loading (valgus moment plus internal/external moment together) to the risk of non-contact ACL injury as well.

This study intentionally let participants have the combined loading on the instant of foot-ground contact with three different foot placement positions in order to find which foot placement position would be harmful to the non-contact ACL injury. From the perspective of combined loading, TI position was the most harmful position because of peak valgus moment and internal rotation moment together immediately after landing. The main cause of this was attributed to the decreased distance between knees after landing. Noyes et al. (2005) found untrained females demonstrated the reduced distance between knees in landing. They noticed this position was vulnerable to the non-contact ACL injury and increased the distance between knees by the help of neuromuscular training.

TO position did not showed valgus moment immediately landing but it is not a recommendable position neither. Since TO position induced the largest varus angle and internal rotation angle with the largest varus moment finally, it has potential risk of non-contact ACL as well. Biomechanically neutral position showed decent kinematics and kinetics of the knee. Therefore, with intention or with the help of balanced training the neutral foot position on landing is recommended to minimize the risk of non-contact ACL injury.

CONCLUSION: In many sports situations of landing, people should avoid toe-in landing posture because it is very likely to have peak valgus moment plus internal rotation moment. This could be the harmful combined loading to the non-contact ACL injury. Therefore, the practice toward neutral foot placement position is recommended to reduce the risk of non-contact ACL injury.

REFERENCES:

Boden, B.P., Dean, G.S., Feagin, J.A., & Garrent, W.E. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopeadics,* 23, 573-578.

Chappell, J.D., Yu, B., Kirkendall, D.T., & Garrent, W.E. (2002). A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *American Journal of Sports Medicine,* 30, 261-267.

Noyes, F. R., Barber-Westin, S. D., Fleckenstein, C., Walsh, C., & West, J. (2005). The drop-jump screening test: Difference in lower limb control by gender and effect of neuromuscular training in female athletes. *American Journal of Sports Medicine,* 33, 197-207.

Shimokochi, Y. & Shultz, S.J. (2008). Mechanisms of noncontact anterior cruciate ligament injury. *Journal of Athletic Training,* 43, 396-408.