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THE EFFECT OF SHOES ON KNEE KINETICS AND ANTERIOR TIBIAL TRANSLATION DURING SINGLE-LEG LANDING

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The purpose of this study was to compare how knee kinematics and kinetics are influenced during single-leg landing in shod condition compared to barefoot condition. We hypothesized that the anterior tibial translation (ATT) and utilized coefficient of friction (uCoF) are greater in shod landing. Ten male subjects performed single-leg landing from a 0.3-m-high platform using their self-selected dominant lower limb under shod and barefoot condition. A force plate and a motion capture system were used for measuring ground reaction force and capturing kinematics data, respectively. The shod condition showed a significant higher ATT ($p = 0.011$) and uCoF ($p = 0.022$) at 30° flexion than barefoot condition. These findings would be considered as one of evidence that high shoe-surface friction increase ACL injury risks due to high ATT at extended knee position.

KEY WORDS: shod, barefoot, anterior cruciate ligament injury, landing

INTRODUCTION: In sports, single-leg landing is common task that involves large movements of the knee joint within a short time. Because of these sudden movement and large impact loading on the lower extremities, it can lead to knee joint injuries (Dufek and Bates, 1991). In many case of knee joint injuries, the anterior cruciate ligament (ACL) injury is very common. The ACL is a vulnerable soft tissue of the knee joint, especially among participants of sports involving single-leg landing and rapid stopping, such as soccer, basketball, and tennis (Hewett et al., 2005). More than 70% of ACL injuries occur in noncontact situations, and ACL injuries cause functional disability and premature degenerative changes in the articular cartilage (Lohamander et al., 2007). Therefore, the mechanisms of ACL injury have been widely studied. In particular, single-leg landing experiments have often been conducted for investigating knee injuries (Hrysomallis, 2007).
Different types of sports shoes have been made for reducing risk of injury or enhancing sports ability. Some research already investigated the types of sports shoes related to injury and the effect of barefoot and shod conditions on joint kinematics and kinetics. However the effects of these conditions on lower extremity kinematics and kinetics during single-leg drop landing are unclear (Shultz et al., 2012; Webster et al., 2004; Yeow et al., 2011).
The purpose of this study was to compare how knee kinematics and kinetics differ during single-leg landing in shod condition compared with barefoot condition in order to provide meaningful information for future studies towards ACL injury risks. We hypothesized that the anterior tibial translation (ATT) and utilized coefficient of friction (uCoF) are greater in shod versus barefoot landing.

METHODS: Ten active male college students (age: 24.2 ± 1.4 years, mass: 66.8 ± 5.9 kg, and height: 1.74 ± 0.04 m) were tested after signing an informed consent form approved by university's Institutional Review Board prior to participating in the study. Only subjects who do not have any current pain or injury or a history of lower limb musculoskeletal injuries requiring surgery were included. All analyses were completed on the dominant limb, defined as the preferred limb when kicking a ball. No restriction was imposed on the shod condition. The subjects were asked to wear their own running shoes during the test.

Subjects were instructed to perform single-leg drop landing by stepping off a 0.3-m-high platform using their self-selected dominant limb under shod conditions and barefoot condition. The subjects fold their arms across their chest and step off the platform without jumping up or stepping down and land as naturally as possible. Following the warm-up, the subjects practiced landing task and three single-leg landings were recorded under each shod and barefoot condition. A trial was considered successful if a participant stepped off the platform and adopted a stable landing posture while maintaining his balance. Initial contact was defined as the first frame at which the vertical ground force exceeded 20N. The subjects rested for three minute between trials. The two considered types of landing were randomized. Three-dimensional lower limb kinematics of the dominant limb was recorded for each subject during landing. Marker sets defining a three-segment rigid link model of the lower limb were captured at 400 Hz using a motion analysis system equipped with five infrared cameras (Eagle; Motion Analysis Corp., Santa Rosa, CA). A force plate (9260AA6; Kistler, Winterthur, Switzerland), embedded onto the floor, was used to obtain GRF at 1200 Hz, while five infrared cameras were used to obtain kinematic data. Before the landing trials, the force plate and motion capture system were calibrated based on the manufacturers' recommendations, and kinematic data were synchronized with GRF data. For the barefoot condition, 10 retro-reflective markers (12.5 mm) were placed on bony landmarks (bilateral greater trochanter, thigh, lateral and medial femoral epicondyles, lateral and medial edges of the tibial plateau, shank, lateral and medial malleoli, and second metatarsal head) according to the modified Helen-Hayes marker set for measuring the six-degrees-of-freedom knee joint motion. The same marker placement was adopted for the shod condition, with the exception that the second metatarsal head marker was placed on the shoe.
The kinematics and GRF data were digitally smoothed using a zero-lag fourth-order Butterworth low-pass filter at a cut-off frequency corresponding to 15 Hz (Bisseling and Hof, 2006). Knee joint angles were calculated using Euler angle rotations of the tibia relative to the femur (Andriacchi et al., 2003). Anterior tibial translation (ATT) was calculated as the distance between the origins of the femoral and tibial coordinate systems in the sagittal plane. Also, the utilized coefficient of friction (uCoF) was introduced to represent the shear resistance to foot sliding. The uCoF was calculated as the ratio of the shear force (anterior-posterior force and medial-lateral force) to vertical ground reaction force (Tsai and Powers, 2009). Data pertaining to barefoot and shod conditions were compared using a paired one-tailed Student's t test at a 95% level of confidence. All statistical analyses were performed using MATLAB version R2011a (Mathworks, Natick, MA).

RESULTS: Anterior tibial translation (ATT) at 30° of knee flexion was significantly higher during shod (5.39 ± 2.04mm) landing compared with barefoot (4.59 ± 2.38mm) landing (p = 0.011, Figure1), but ATT at 25° of knee flexion or at higher flexion were not different.
The utilized CoF was significantly higher during shod landing at 25°, and 30° of flexion ($p < 0.05$, Figure 2), but was not different at 35° or higher flexion angle between two conditions. The utilized CoF was approximately 50% and 55% higher in shod condition at 25° and 30° of knee flexion was not different.
For all the axes, peak GRF and peak knee joint force were not significantly different between the shod and barefoot conditions (p>0.05, Table 1).

Table 1: Group mean and standard deviation of peak medial, anterior and vertical ground reaction forces (N/BW) and knee joint forces (N/BW) between shod and barefoot condition.

Axes	Peak ground reaction force (N/BW)			Peak knee joint force (N/BW)		
	Barefoot	Shod	p-value	Barefoot	Shod	p-value
Medial(+): Lateral(-)	0.28±0.11	0.27±0.13	p = .816	0.29±0.12	0.30±0.14	p = .941
Anterior(+): Posterior(-)	0.22±0.27	0.35±0.33	p = .126	0.26±0.27	0.37±0.32	p = .197
Superior(+): Inferior(-)	3.50±0.42	3.57±0.36	p = .725	3.29±0.40	3.35±0.32	p = .750

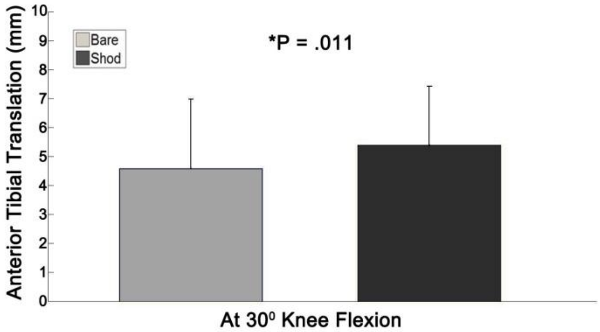

Figure 1: Comparison of anterior tibial translation (ATT) at 30° of knee flexion during single-leg landing. ATT at 30° of knee flexion was significantly higher during shod landing(p=0.011).

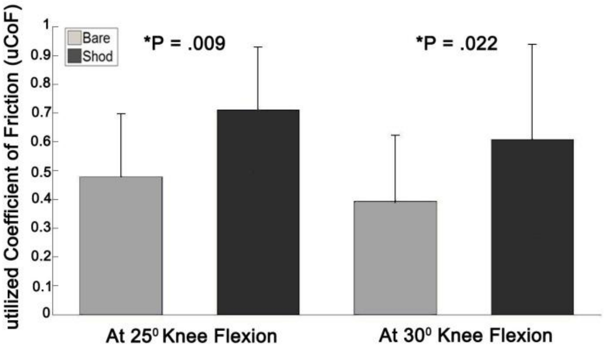

Figure 2: Comparison of utilized coefficients of friction (uCoF) between shod landing and barefoot landing at 25° and 30° of knee flexion.

DISCUSSION: The result shows that the anterior tibial translation (ATT) is significantly higher at 30° of knee flexion under shod landing than under barefoot landing. This increased ATT seems to be result from the higher shoe-surface uCoF, and it would cause an increase in ACL injury risk (Myers et al., 2012). Also the uCoF was significantly higher during shod landing. A high uCoF implies that shoes can provide adequate shear resistance relative to the vertical resistance from the ground compared to the barefoot condition (Tsai and Powers, 2009).

ATT was significantly higher under shod (5.39 ± 2.04mm) landing than that under barefoot (4.59 ± 2.38mm) landing at 30° flexion. This 0.8-mm difference between shod and barefoot landing corresponds to an approximately 2.7%-3.2% increase in strain on the ACL given that the ACL length is 31-38 mm (Smith et al., 1993). Although the actual stain on the ACL is not known, we could assume that shod landing causes more tension on the ACL than barefoot landing. Our observed ATT was similar to the previous research that reported 5.2 mm ATT measured in vivo using KT-1000 arthrometer (Daniel et al., 2003).

At 30° flexion, a statistically significant increase in ATT was noted due to increase in the uCoF. This holds the theory that increased shoe-surface friction could be an ACL injury risk factor. Furthermore, higher playing surface friction is known to increase ACL injury risk (Dowling et al., 2010; Dragoo and Braun, 2010). Some studies suggest that the biomechanical changes observed under the high CoF condition are associated with an increased ACL injury risk. Orchard and Powell (2003) reported that the risk of knee sprains is significantly lower on grass than on indoor synthetic turf. Also, Oslen et al. (2003) found that the incidence of ACL injuries among handball players was higher on synthetic, rubberized indoor floors than on wooden floors. Therefore, our study that increased ATT under a high shoe-surface uCoF at the small knee flexion angle could explain the higher incidence of ACL injuries under high shoe-surface friction.

It should be noted that we did not control the type of shoes. The use of self-selected shoes may have affects our result because of different shoe-surface traction. However, large deviations in the measured shod condition data were not observed across measurements and did not prevent us from identifying meaningful differences between shod and barefoot landing.

CONCLUSION: This study shows that both the ATT and uCoF are higher under the shod condition for knee flexion angles at 30°. The observed ATT (5.39 ± 2.04mm) was similar to the previous study that reported 5.2 mm ATT measured in vivo using KT-1000 arthrometer (Daniel et al., 2003). Furthermore, Higher playing surface friction is known to increase ACL injury risk (Dowling et al., 2010; Dragoo and Braun, 2010). Therefore, our results would be considered as one of evidence that high shoe-surface friction may increase ACL injuries due to high ATT at extended knee position.

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