# EFFECT OF SKI BOOT TIGHTNESS ON SHOCK ATTENUATION TIME AND JOINT ANGLE WITH ANTERIOR-POSTERIOR FOOT POSITIONING IN DROP LANDINGS

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Eight recreational skiers performed drop landings barefoot and wearing ski boots. The purpose of this study was to examine if different ski boot tightness affects the shock attenuation time, and minimal joint angles during landings. Shock attenuation time and joint angles were obtained via an AMTI force plate and video analysis of subjects' drop landings. Repeated Measures Analysis of Variance (ANOVA) was used to analyze differences between means for the dependent variables. Our results indicate that differences in ski boot tightness do not affect shock attenuation time during landing. Results also indicate that minimal ankle joint angle can be affected by different ski boot tightness. This implies that a tighter ski boot condition can restrict dorsiflexion of the ankle during landing.

**KEYWORDS**: anterior cruciate ligament, ski boot, knee, ankle, alpine skiing

**INTRODUCTION:** Alpine skiing is one of the most popular winter sports in the world. Despite the popularity of the sport, a large number of injuries occur each year. In past decades, injuries to the lower extremities excluding anterior cruciate ligament (ACL) have been reduced as the quality of ski bindings and ski boots have been improved (McConkey, 1986). In contrast, the incidence of ACL injuries have increased (McConkey, 1987; Pujol & Blanchi, 2007).

Several mechanisms have been suggested as causes of an ACL injury during skiing. According to McConkey (1987), a small balance disturbance during the landing phase following a jump in alpine skiing can easily cause the skier to fall backwards. Once skiers fall backward, quadriceps muscles contract forcefully to regain balance. This large quadriceps contracture pulls the tibia anteriorly via the patellar tendon (Geyer & Wirth,1991; McConkey, 1986). This anterior movement of tibia can create strong enough tension of the ACL to rupture it (McConkey, 1987).

Previous researchers have also noted that off-balance conditions such as backward falling can create an impact force that drives the ski boots anteriorly with respect to the femur, resulting in rupturing of the ACL (Hame *et al*., 2002; McConkey, 1986; 1987). This is termed "boot induced" mechanism of injury.

Despite the fact that many studies were conducted to find correlations between ACL injuries and movements involved in alpine skiing, the effect of ski boot tightness (by changing the number of hooks on the buckles) on ACL injury has not yet been examined. Therefore, the main aim of this study was to examine if different ski boot tightness can affect shock attenuation time in drop landings. The secondary purpose of this study was to observe if differences in ski boot tightness can alter minimum knee and ankle joint angles during recovery time.

**METHODS:** Eight recreational skiers volunteered as subjects (three female and five male; mean ± SD: 23.3±4.0 years; height = 172.6±11.3 cm; body mass = 69.1±8.9 kg). Subjects completed a Physical Activity Readiness Questionnaire and were excluded if they reported previous history of lower extremity injury or disorder. Approval for the use of Human Subjects was obtained from the Institutional Review Board prior to commencing the study. Informed consent forms were read and signed by each subject prior to data collection.

Warm-up prior to the test criteria via a sledge drop landing consisted of at least 3 minutes of low intensity work on a cycle ergometer. This was followed by static stretching including one exercise for each major muscle group with static stretches held from 12-15 seconds. Following the warm-up and stretching exercises, the subjects were allowed at least 5 minutes rest prior to beginning the test.

The subject was placed into the chair of the 30° inclined sledge (Figure1). Each subject was instructed to land on the platform from drop of a height of 70 cm (perpendicular to the sledge). Two practice jumps were performed to allow the subject to become accustomed to the test criteria. Following the two practice jumps, the subject was asked to perform the drop landings with four foot conditions with three landing locations; anterior, neutral, and posterior locations (Figure1). Foot conditions were barefoot, ski boots loose (none of hooks of the top two buckles of the ski boots were engaged), ski boots medium (one to two hooks were engaged), and ski boots tight (subjects were asked to engage as many hooks as possible). A total of twelve landings were performed by each subject: barefoot at anterior (BA), neutral (BN), and posterior (BP), ski boots loose at anterior (LA), neutral (LN), posterior (LP), the medium at anterior (MA), neutral (MN), posterior (MP), and tight at anterior (TA), neutral (TN), posterior (TP). The landings using ski boots were randomly ordered except the barefoot conditions were always performed first. A one minute rest interval was maintained between each landing.
A force platform (OR6-5-2000, AMTI, Watertown, MA, USA) was mounted on the 60° inclined landing plate (Figure 1). Ground Reaction Force data were collected at 2000 Hz to measure shock attenuation time, real time displayed and saved with the use of computer software (NetForce 2.0, AMTI, Watertown, MA, USA) for later analysis. The shock attenuation time was measured as time expressed in milliseconds between initial contact of the landing and the first minimal vertical reaction force following the peak vertical reaction force after initial contacts.

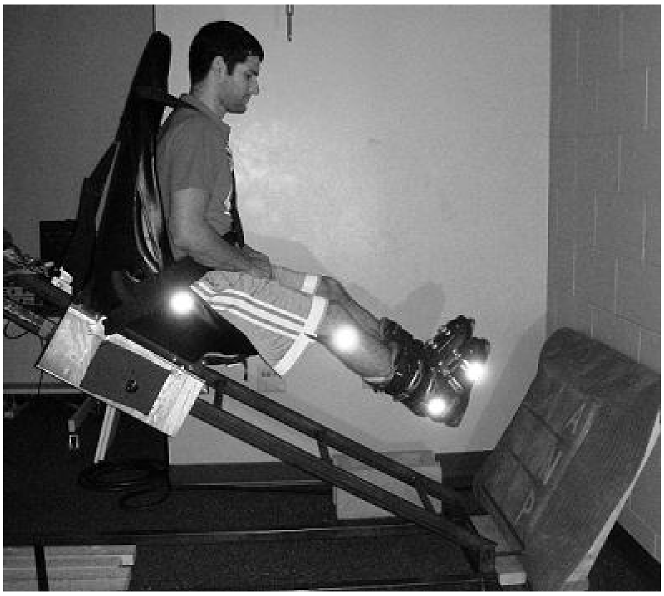

**Figure 1: Subject Performing the Sledge Drop Landing.**

Video of the landings was obtained at 60 Hz from the right side using 1 cm reflective markers placed on the seat near the greater trochanter, fibular head, lateral malleolus and the fifth metatarsal for the barefoot condition, the tip of the lowest buckle of the ski boot, near the fifth metatarsal for three ski boot conditions. Markers were digitized using automatic digitizing software Motus 8.5 (Vicon/Peak, Centennial, Co, USA) and minimal knee, and ankle joint angles were determined after data were smoothed using a fourth order Butterworth filter (Winter, 1990). Relative angles for knee and ankle were measured with a smaller joint angle value indicating more flexion of the knee and more dorsiflexion at the ankle.
Kinetic and kinematic data were matched using a synchronizing signal to determine the initial contacts. A cubic spline data interpolation program was written (using Matlab 6.5) to time normalize the data files.
Shock attenuation time and minimal knee and ankle joint angles were the dependent variables studied. A Two-Way 4 (type of boot condition) x 3 (foot landing condition) Repeated Measures Analysis of Variance (ANOVA) was used to analyze differences between means for the dependent variables. An alpha level of 0.05 was used to determine significance for all comparisons. In the case of significance, follow-up comparisons were made using the

Bonferroni adjustment. Statistical analysis was completed using SPSS version 16.0 (SPSS Inc., Chicago, IL).

**RESULTS**: As shown in Table 1, there were no differences ($p>0.05$) in the shock attenuation time. Table 2 shows that Min Knee angle at all landing locations, Anterior, Neutral and Posterior were different from each other ($p < 0.05$). As shown in Table 3, minimal (Min) ankle joint angle with ski boots loose condition at all three landing locations were significantly different ($p < 0.05$) from all other foot and other landing conditions.

**Table 1 Shock attenuation time (millisecond), minimal (Min) joint angles (Mean ± SD) for the Knee, and Ankle (N=8).**

| | Barefoot | Loose | Medium | Tight |
|---|---|---|---|---|
| Anterior | 559±216 | 519±220 | 550±186 | 517±208 |
| Neutral | 561±260 | 475±160 | 419±98 | 390±139 |
| Posterior | 476±123 | 393±34 | 402±37 | 372±55 |

Shock attenuation time was measured in

**Table 2 Minimal (Min) Knee angle (degree) (Mean± SD) (N=8).**

| | Barefoot | Loose | Medium | Tight |
|---|---|---|---|---|
| Anterior [a] | 104.8±19.93 | 94.3±16.09 | 95.7±15.08 | 92.5±15.92 |
| Neutral [b] | 110.8±24.18 | 108.3±10.19 | 111.6±15.66 | 117.8±17.05 |
| Posterior [c] | 127.4±14.96 | 127.1±18.38 | 135.5±9.01 | 136.2±10.55 |

[a] Indicates significant difference from Neutral and Posterior ($p < 0.05$).
[b] Indicates significant difference from Anterior and Posterior ($p < 0.05$).
[c] Indicates significant difference from Anterior and Neutral ($p < 0.05$).

**Table 3 Minimal (Min) Ankle angle (degree) (Mean± SD) (N=8).**

| | Barefoot | Loose [a] | Medium | Tight |
|---|---|---|---|---|
| Anterior [b] | 97.4±5.82 | 88.3±6.53 | 92.1±4.06 | 93.1±2.46 |
| Neutral | 87.3±6.44 | 81.4±3.21 | 87.6±3.93 | 89.3±3.44 |
| Posterior | 87.0±4.54 | 79.3±2.62 | 83.9±2.85 | 86.0±2.66 |

[a] Indicates significant difference from barefoot, medium, tight ($p < 0.05$).
[b] Indicates significant difference from Neutral and Posterior position ($p < 0.05$).

**DISCUSSION:** The first objective of this investigation was to study if the different ski boots' tightness can affect shock attenuation time in drop landings. Our results showed that there are no differences in the shock attenuation time between the different foot conditions with three landing locations. This indicates that ski boot tightness has no impact on the shock attenuation time during the landing phase in alpine skiing. This result could be explained by the lack of involvement or interactions between ski boots, bindings, and skis. Thus, this limitation of our study suggests further investigation of the effect of the ski boot tightness on the shock attenuation time should involve the ski bindings and skis.

Hame *et al*. (2002) and McConkey (1986) reported that hyperflexion of the knee with the additional tibial torque appear to be mechanisms of injury for the ACL in alpine skiers. The results of our study showed there are no differences in Min Knee angles between different landing locations. This indicates that ski boot tightness may not affect the range of motion of the knee during the landing in alpine skiing. However, Min Knee angle at the Anterior location differed from two other locations. It has been suggested that the ACL is at risk of rupture when the skiers fall backward with knees flexed (Gerritsen *et al*., 1996; McConkey, 1986; 1987). Since our results showed that subjects flexed their knees more at anterior location than at two other locations, this indicates that landings at anterior location may lead the skiers falling backward by increasing knee flexion.

Malliaras *et al*. (2006) found that patellar tendinopathy was associated with a reduced range of ankle dorsiflexion and restricted dorsiflexion may alter lower limb landing biomechanics. Our data suggested that engaging more hooks of the ski boot buckles restricts dorsiflexion of the ankles during the landing. Noé *et al*. (2007) found that wearing ski-boots induced changes in a skiers' postural strategy. Thus, tightening the ski boot buckle may influence balancing techniques during landings due to restriction of dorsiflexion at the ankles.

**CONCLUSION:** As suggested by previous researchers, backward falling may increase the chance of the ACL injuries. Our data indicates that landing at the Anterior location can increase knee flexion, which likely will result in backward falling. Although our results showed that different ski boot tightness does not affect the shock attenuation time, tightening ski boots can restrict dorsiflexion of the ankle during landing. Further research should involve ski bindings and skies to examine if the ski boot tightness with skis can affect shock attenuation time.

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