CHANGES IN LOWER-LIMB MUSCLE FORCES WITH PROPHYLACTIC KNEE BRACING DURING LANDING AND STOP-JUMP TASKS

Katie Ewing[1], Rezaul Begg[2], Peter Lee[1]

Department of Mechanical Engineering, University of Melbourne, Melbourne, Victoria, Australia[1]
Institute of Sport, Exercise and Active Living, Victoria University, Melbourne, Victoria, Australia[2]

Prophylactic knee braces are designed to prevent knee injuries, which often occur during sports such as basketball and volleyball, but their efficacy is debated. The purpose of this study is to calculate and compare lower-limb muscle forces in braced and unbraced recreational athletes during landing and stop-jump tasks. Experimental motion capture and ground reaction force data were collected from five participants with and without a knee brace. Subject-specific musculoskeletal models were created in OpenSim and were used to calculate muscle forces. Preliminary results indicated that knee bracing altered both the magnitude and timing of muscle actions. This study provides insight into the likely role of prophylactic knee bracing and muscle function in knee protection.

KEY WORDS: injury, prevention, landing, musculoskeletal modeling, muscle forces

INTROUDCTION: Anterior cruciate ligament (ACL) injuries, which account for the majority of sports-related knee injuries, are painful, costly, and debilitating to the injured athlete. Non-contact ACL injuries occur during landing and stop-jump related tasks, which are frequently performed in sports such as basketball, volleyball, and soccer. ACL injury prevention programs have focused on modifying neuromechanical deficiencies through plyometric exercises and strength training. Prophylactic knee braces were introduced to protect the knee joint against unmodifiable risk factors, such as extreme anatomical alignments and severe impact loads. However, several large epidemiologic studies provide conflicting evidence on the prophylactic efficacy of bracing, with some even suggesting that bracing may have negative consequences (Grace, 1988; Sitler, 1990).
Several biomechanical studies have investigated the effect of knee bracing on lower-limb kinematics and on muscle function during dynamic activities. Yu et al. (2004) found that a prophylactic knee brace significantly increased knee flexion angle at landing, but had no effect on peak ground reaction forces. Electromyography (EMG) was used to find differences in the magnitude of muscle activity during running between braced and unbraced subjects (Osternig, 1993), but no differences were observed in muscle timing during cutting (Branch, 1989). These studies suggest that a knee brace can alter neuromuscular control, but it is unclear if bracing works by providing mechanical stability to the knee or by changing limb position.
Computer-based musculoskeletal models provide a means to quantify muscle contributions to complex movements in more detail compared to EMG. Model-predicted muscle forces allow us to understand how individual muscles contribute to human movement without having to conduct invasive experimental measurements. During impact loading, muscle forces could explain the resulting tension on the ACL that can lead to rupture (Pflum, 2004), thus providing critical information for improved injury prevention methods.
The purpose of this study is to use experimental motion capture and rigid-body musculoskeletal modeling to calculate and compare lower-limb muscle forces in braced and unbraced recreational athletes during landing and stop-jump tasks.

METHODS: Five participants who regularly participate in a landing sport have been enrolled in this study thus far. Eligible participants were between the ages of 18 and 30 and were free from lower extremity injury or disease. Testing was conducted in the Gait Analysis

Laboratory at Victoria University (Melbourne, Australia). All participants provided informed consent in accordance with the relevant human ethics committees. Prior to testing, each participant was fit with a commercial knee brace that is designed to help protect the knee joint. A total of 54 retro-reflective markers (14mm diameter) were attached to specific locations on the participant's lower limbs, trunk, and arms (Figure 1A). A motion analysis system consisting of ten optical infra-red cameras (500 Hz; VICON Mx, Oxford Metrics, UK) collected the three-dimensional kinematic data, while two synchronized force plates (1000 Hz, AMTI, USA) simultaneously recorded ground reaction forces. The dominant limb was defined as the preferred leg for kicking a ball. Following a standardized warm-up, the participant was instructed to step off a 60 cm platform with his or her dominant leg and land barefoot onto the force plate using either both legs (double-leg landing) or the dominant leg (single-leg landing), the order of which was randomized. Participants also performed a vertical stop-jump task, which consists of an approach run and a double-footed landing followed by a take-off for maximum height. These landing tasks were repeated while the participant wore the knee brace.

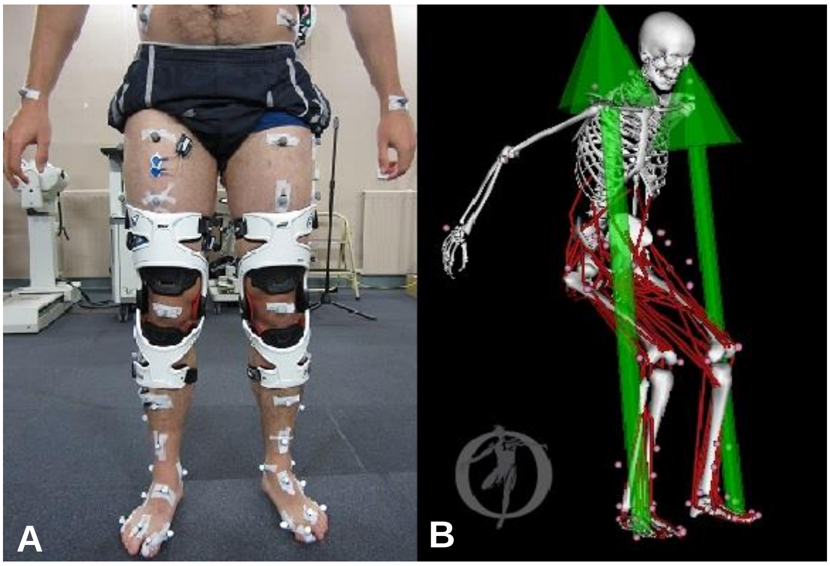

Figure 1. A) Custom marker set and prophylactic knee brace used in this study. B) Stop-jump simulation of a subject-specific musculoskeletal model in OpenSim.

Marker trajectories and ground reaction force data were filtered at 20 Hz using a fourth order Butterworth filter (Bisseling, 2006). Subject-specific musculoskeletal models (31 degrees-of-freedom, 92 musculoskeletal tendon units) were developed and simulated in OpenSim, an open-source 3D musculoskeletal modeling software (Figure 1B) (Delp, 2007). Inverse kinematics calculated the joint angles that best matched the experimental marker trajectories, while inverse dynamics computed the net joint moments at each joint. A unique solution of individual muscle forces was solved via static optimization by minimizing the sum of the squares of muscle activations. It was assumed that the effect of bracing was expressed in the experimental data and thus knee brace forces and elements were not included in the simulations. The average of three trials for each task and condition was used for analysis. The landing phase was defined as the duration from foot strike to maximum knee flexion angle.

RESULTS: Preliminary kinematic and kinetic data are presented in Table 1. Prophylactic knee bracing slightly increased the mean peak vertical ground reaction force (GRF) during all landing tasks. Mean peak vertical GRF was greatest during the single-leg landing and smallest during the stop-jump task. Bracing resulted in different trends in maximum knee flexion angle depending on the task condition. Mean maximum knee extension moment also slightly increased with knee bracing during all landing conditions.

Table 1. Descriptive statistics (mean ± standard deviation) of peak vertical GRF (normalized to body weight (B.W.)), peak knee flexion angle, and peak knee extension moment (normalized to body mass) for all landing tasks with and without a knee brace.

	Double-Leg Landing		**Single-Leg Landing**		**Stop-Jump**	
	No Brace	*Brace*	*No Brace*	*Brace*	*No Brace*	*Brace*
Peak GRF (B.W.)	2.07± 0.34	2.13 ± 0.40	2.95 ± 0.24	3.01± 0.18	1.58 ± 0.18	1.66 ± 0.19
Peak Knee Flexion Angle (Deg)	100.14 ± 16.49	97.84 ± 12.60	74.14 ± 8.43	72.27 ± 2.95	84.78 ± 13.06	87.19 ± 8.33
Peak Knee Flexion Moment (N-m/kg)	1.85 ± 0.51	1.90 ± 0.35	2.20 ± 0.25	2.42 ± 0.32	1.63 ± 0.44	1.81 ± 0.69

Musculoskeletal modeling results indicated that prophylactic knee bracing qualitatively altered both the magnitude and timing of muscle forces (Figure 2). Generally, slight increases in peak forces of the hamstrings, quadriceps, and soleus muscles were observed with bracing across all landing conditions. However, muscle force results between bracing conditions varied amongst participants. Furthermore, there was no consistent trend in the timing of muscle activations. In some instances, peak muscle forces occurred later in the landing phase under the brace condition.

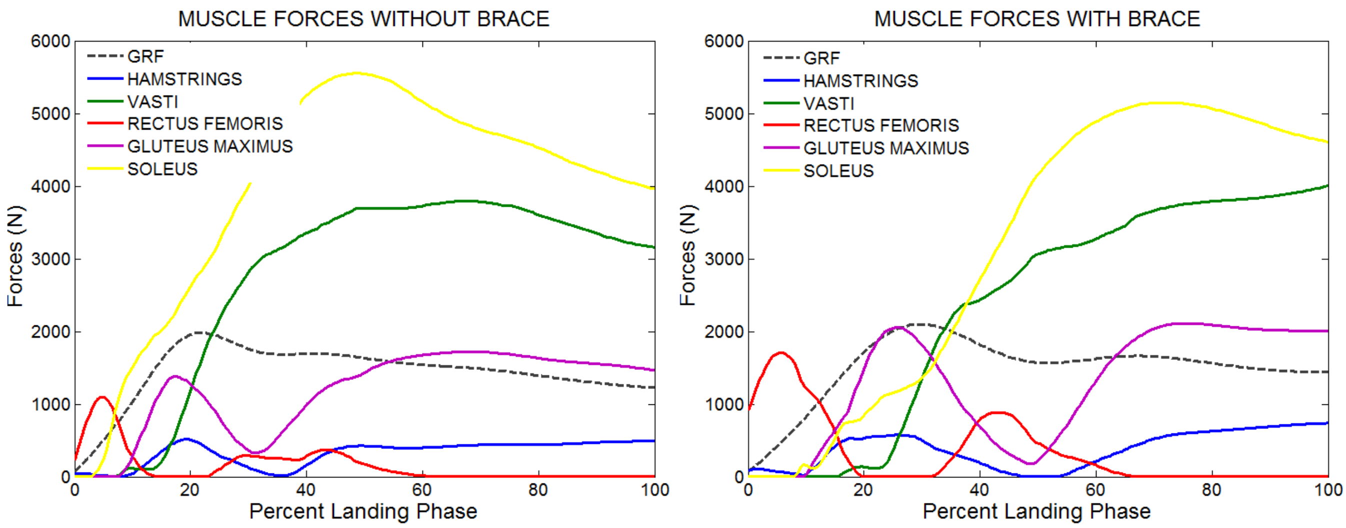

Figure 2. Representative plot of vertical GRFs and muscle forces during a single-leg landing from 60cm with and without bracing for a 66.2 kg participant.

DISCUSSION: Prophylactic knee bracing increased the mean maximum knee flexion angle during the stop-jump task, which may help protect knee joint structures such as the anterior cruciate ligament (ACL). The force on the ACL depends on the anterior shear force applied on the tibia, which is reduced with increased knee flexion angle. However, bracing decreased the mean maximum knee flexion angle during the double-leg and single-leg landing tasks, suggesting that knee bracing may better protect the ACL during realistic maneuvers that occur in game situations compared to during controlled movements.

To our knowledge, no previous studies have calculated knee muscle forces using simulations during landings with and without with a knee brace. Preliminary results from this study indicate that knee bracing altered the magnitudes of force produced by the lower-limb muscles, which could have significant implications as the load on the ACL primarily depends on the force of the hamstrings and quadriceps. The simultaneous activity of these muscles, known as co-contraction, plays an important role in maintaining the stability of the knee joint during high-impact tasks (Hewett, 2008). The quadriceps muscles, which can increase stresses in the ACL, produce much greater force than the hamstrings. The trend towards larger muscle forces with bracing reflects on the increases found in knee extension moments. Furthermore, knee bracing delays the onset of hamstrings activation. This may have negative consequences on the knee joint during landing because the hamstrings are the primary knee flexors, which inhibit anterior tibial translation and thus protect the ACL. Delayed activation with respect to peak GRF, which is the instance most closely associated with injury, may place the ACL at greater risk of rupture. Future comparison with electromyography activation patterns will validate these findings.

An important finding from this study is the large magnitude of force produced by the soleus muscle. Although the soleus does not cross the knee joint, it contributes to the GRF and generates a posterior tibial force, which could help protect the ACL during landing (Mokhtarzadeh et al., in press). The large soleus forces observed later in the landing phase suggest that the ankle plantarflexors may play a role in stabilizing the knee joint. These muscles should be considered when designing training programs for ACL injury prevention regardless of knee bracing.

Experimental limitations of this study include the potential motion of the brace during the landing tasks and the immediate results of wearing the knee brace without a longer training period. Although the order of the landing tasks was randomized within each condition, the braced condition was always tested after the unbraced condition, which may result in a sequence effect. There are also a number of limitations associated with musculoskeletal modeling, such as using a common generic model for scaling and the lack of activation dynamics in the static optimization problem. This preliminary study had a small sample size and thus statistical analysis was not performed. Another potential concern is the influence of bracing on the comfort and performance of an athlete during sporting activities, but these factors are out of the scope of this study.

CONCLUSION: The usefulness of prophylactic knee braces during sporting activities remains under debate. This preliminary study provided a quantitative assessment of the effectiveness and mechanism of knee bracing by examining changes in lower-limb kinematics and muscle forces during landing. Understanding the role of lower-limb muscles is crucial to developing appropriate injury prevention programs, which can help athletes improve muscle coordination strategies. To further investigate the significance of bracing on muscle function, a total of twenty participants will be tested, followed by rigid body modeling and statistical analyses. Future investigation will aim to calculate ACL and joint reaction forces to elucidate the effect of knee bracing on internal knee structures.

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