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KNEE UNLOADER BRACE EFFECTIVENESS USING A DETAILED MUSCULOSKELTAL MODEL: A PILOT STUDY

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SUMMARY
This study presents a pilot investigation into the effectiveness of unloader knee braces for osteoarthritis subjects. The unloading effect of the brace was modeled by applying a knee abduction moment as a function of the brace deflection angle, eliminating the need for load sensors on the knee brace. The use of a detailed musculoskeletal model provided the means to evaluate the relative importance of external moments and individual muscle contributions to changes in the joint contact force. Preliminary results from our pilot study suggest that the majority of the medial contact load reduction due to brace use was a result of changes in ground reaction and muscle forces, not of the actual unloader moment applied by the brace.

INTRODUCTION
Many knee braces for patients with painful medial knee osteoarthritis are marketed as "medial unloaders", suggesting that medial tibiofemoral contact loads will be reduced by wearing a brace. While it has been shown that unloader knee braces effectively relieve pain and improve function, the magnitude of medial load reduction during gait can vary greatly between subjects and brace types [1]. In order to evaluate brace effectiveness, it is necessary to compute not only the unloading moment applied by the brace to the knee joint, but also changes in external joint loads and muscle co-contraction [2]. Previous modeling studies have been limited either in their musculoskeletal detail [3] or incorporation of altered external joint moments and forces [4]. Therefore, the purpose of this study was to develop a detailed musculoskeletal model capable of evaluating the effectiveness of knee unloader braces.

METHODS
For this pilot study, a single healthy male subject (height 1.94m, weight 100kg) performed gait trials at self-selected speed with and without an off-the-shelf medial unloader knee brace (VQ Orthocare, Irvine, CA, USA). Bilateral trajectories of thirteen anatomical landmarks and twenty markers on rigid tracking clusters were recorded at 200Hz using a 12-camera passive motion capture system (Qualysis, Gothenburg, Sweden). For trials where the subject was wearing the unloader brace, six additional markers were used to track the thigh and shank brace segments. Synchronized ground reaction forces were recorded at 1000Hz from a series of five force platforms arranged in tandem along a 20m walkway (AMTI, Massachusetts, USA). Marker positions and ground reaction forces were low-pass filtered at 6Hz and 20Hz, respectively.

A detailed bilateral musculoskeletal model [5] was modified to remove arm segments and include a frontal plane knee degree of freedom, resulting in a 14-segment, 25-degree of freedom model. Each knee joint thus consisted of two degrees of freedom, flexion and adduction, with three translations and internal rotation derived as functions of the flexion angle [5]. The model was actuated by 94 Hill-type musculotendon actuators. Additionally, each knee adduction degree of freedom was actuated by an ideal torque actuator.

Functional joint centres were computed using spherical optimization for hip and shoulder joints, and using the helical axis method for knee and ankle joints. The model was scaled in OpenSim [6] using a least-squares method to align the subject's experimental functional joints and anatomical marker positions with corresponding joint centres and anatomical landmark within the model. The mass of the generic bilateral model (72.1kg) was uniformly scaled to match the subject's mass, and virtual tracking markers were added to model to match experimental marker positions from a static calibration trial.

An inverse kinematics algorithm solved for joint angles that minimized the least-squares difference between tracking markers fixed on the model and experimental marker positions. Residual Reduction Analysis (RRA) was used in OpenSim to compute the joint moments required to track the subject's motion while minimizing dynamic inconsistency between kinematics and measured ground reaction forces. Static optimization, minimizing the sum of the squared muscle activations, was used to estimate muscle forces that would generate the computed joint moments.

Medial and lateral contact locations were fixed on the tibial plateau at one quarter of the joint width (~3cm) medial and lateral to the joint centre [7]. In accordance with the knee joint model, these contact locations translated and internally rotated with respect to the femur as a function of flexion angle. Muscle moment arms about each condyle, and condylar locations, were exported from OpenSim using the MuscleAnalysis and BodyKinematics analyses, respectively. The axial component of medial and lateral knee joint contact forces, directed along the long axis of the tibia, was computed in Matlab (Mathworks, Natick, Massachusetts, USA) using the summation of muscle and ground reaction force moments about each of the medial and lateral condyles [7].

The unloading (abduction) moment applied by the brace to the subject's knee joint was experimentally determined as a function of brace flexion and abduction angles. Briefly, the brace was rigidly fixed to a force platform and deflected in the abduction and flexion directions. Inverse dynamic computations about the functional brace joint centre yielded a solution manifold of abduction moment as a function of brace angles. At each instant during the gait trials, brace flexion and abduction angles (Figure 1A) were computed in Matlab from marker trajectories, and the abduction moment applied to the shank and thigh segments was interpolated from the manifold (Figure 1B).

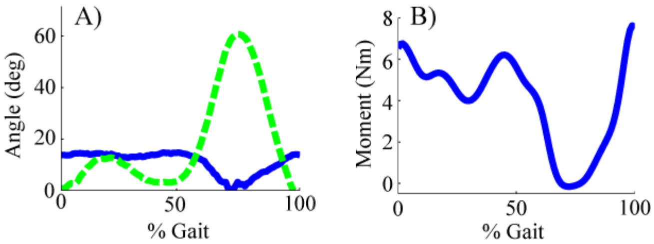

Figure 1: A) Brace flexion (dashed, green) and adduction (solid, blue) angles throughout the gait cycle. The brace was deflected roughly 14 degrees in the adduction direction throughout most of stance. B) Abduction moment applied to the knee by the brace throughout gait. The brace applied between 4 and 7Nm of unloader abduction moment to the knee during stance, and was highly sensitive to the brace flexion angle.

For gait trials in the "braced" condition, the unloader knee brace was worn by the subject with a subjectively perceived large abduction moment to exaggerate its effect on the model. This moment was applied as an external load in equal and opposite directions to the model's shank and thigh segments, respectively, during residual reduction, static optimization, and joint contact computations. Additionally, a mass of 300g was added to the left thigh and shank segments to account for the mass of the brace.

RESULTS AND DISCUSSION

Medial contact forces are presented for two gait trials to show the effect of the knee brace. The subject walked at 1.42 and 1.45m/s for the un-braced and braced conditions, respectively.

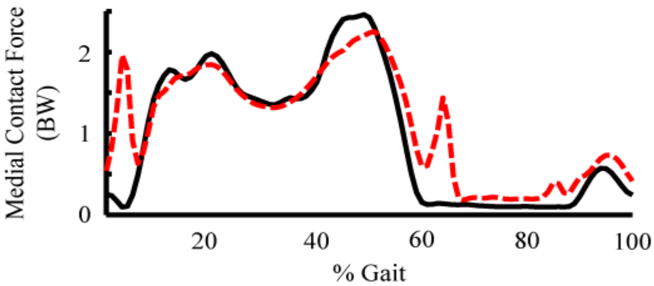

Figure 2: Medial contact force for unbraced (black, solid) and braced (red, dashed) gait trials.

The peak medial knee contact force during stance was reduced by wearing a knee brace from 2.46 times bodyweight (BW) to 2.25BW (Figure 2). These values are slightly higher than medial loads reported in literature [7]. However, for both braced and un-braced the medial compartment accounted for roughly 90% of the total axial knee contact force during the stance phase of gait. While this medial ratio approaches the upper limit found in literature [7], it also indicates that the total knee contact force around 2.5BW is within a reasonable range.

A previous modeling study estimated that, in the absence of any changes in external joint loads or kinematics, the reduction in medial contact load should be approximately 0.01BW (1%BW) for each newton-metre (Nm) of unloader moment [4]. In this study, the brace unloader moment was roughly 5Nm, which means the expected reduction in medial contact load solely due to the brace would be roughly 0.05BW. However, our model estimated a 0.21BW reduction in peak medial contact force due to wearing the brace. This additional reduction in medial load is due to changes in the external ground reaction force, net joint moments, and muscle forces. For example, late in the stance phase at the location of the overall peak contact force (Figure 2), estimated gastrocnemii forces were reduced for the braced relative to the un-braced trial.

CONCLUSIONS

This study presents a pilot investigation into the effectiveness of unloader knee braces for osteoarthritis subjects. The unloading effect of the brace was modeled by applying a knee abduction moment as a function of the brace deflection angle, eliminating the need for load sensors on the knee brace. The use of a detailed musculoskeletal model provided the means to evaluate the relative importance of external moments and individual muscle contributions to changes in the joint contact force. It has been suggested that knee braces are equally, or more, effective for reducing pain in neutral and unloading settings [3]. Preliminary results from our pilot study support this claim; the majority of the medial contact load reduction was a result of changes in ground reaction and muscle forces, not of the actual unloader moment applied by the brace. Future work will compare estimated muscle forces with EMG measurements to evaluate the accuracy of the optimization solution, and expand the investigation to multiple subjects and knee braces. The results of this study could have a significant impact on guidelines for brace use and design.

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REFERENCES

1. Hunter D, et al., *Ann.Rheum.Dis.* **71:** 1658-65, 2012.
2. Ramsey D, et al., *J.B.J.S.Am.* **89:** 2398-2407, 2007.
3. Pollo F, et al. *Am.J.Sports Med.* **30:** 414-21, 2002.
4. Shelburne K, et al., *Clin.Biomech.* **23:** 814-21, 2008.
5. Arnold E, et al., *Ann.Biomed.Eng.* **38:** 269-79, 2010.
6. Delp S, et al., *IEEE Trans.Bio.Eng.* **54:** 1940-50, 2007.
7. Winby C, et al., *J.Biomech*. **42:** 2294-300, 2009.