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CHARACTERIZATION AND COMPARISON OF UNLOADER (ABDUCTION) KNEE BRACE STIFFNESS

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SUMMARY
This study characterized the stiffness of three off-the-shelf knee braces as a function of brace deflection angles using a relatively simple experimental method and equipment commonly available in motion capture laboratories. The resulting stiffness function can be used to compute the moment applied to a subject's leg, given a measured brace deflection angle. Thus, it is possible to apply these brace abduction moments to a more detailed musculoskeletal model to investigate changes in medial contact loads. Brace unloading (abduction) moment was primarily a function of adduction deflection; however, the abduction stiffness decreased with increased range of motion.

INTRODUCTION
For subjects with medial knee osteoarthritis, unloader (abduction) knee braces may be prescribed to reduce pain [1], improve function [2], and possibly reduce loading [3] on damaged joint surfaces. Load reduction can occur if the brace applies abduction moment to the knee [4] or if the brace alters the subject's gait or neuromuscular patterns [5]. However, the magnitude of the unloading abduction moment provided by off-the-shelf braces varies greatly between designs [6]. Furthermore, while studies often report frontal plane brace deflection angles of four to ten degrees as a surrogate for unloading moment [7], these angles cannot be directly compared between braces of different stiffness. Therefore, the purpose of this study was to develop a simple method for comparing the abduction stiffness of knee unloader braces throughout their ranges of motion.

METHODS
Brace stiffness was quantified for three off-the-shelf knee braces: "OAactive" (VQ Orthocare, Irvine, CA, USA), "Unloader XT" and "Unloader Lite" (Ossur, Reykjavic, Iceland). First, each brace was attached to a "shank" segment (Figure 1) that was rigidly bolted to a 6 degree of freedom force platform (AMTI, Massachusetts, USA). Three-dimensional motion of three retro-reflective tracking targets affixed to each of the thigh and shank brace segments was recorded using a 12-camera passive motion capture system (Qualysis, Gothenburg, Sweden). A functional flexion axis between thigh and shank brace segments was computed using the helical axis method, and the joint centre was located at half of the knee width along this axis. The anatomical shank coordinate system was defined using this mediolateral flexion axis, an anterior-posterior adduction axis mutually perpendicular to the flexion axis and lab vertical axis, and an inferior-superior axis mutually perpendicular to flexion and adduction axes. The anatomical thigh coordinate system was defined in the neutral pose (Figure 1) using the same shank adduction axis, an inferior-superior axis mutually perpendicular to the adduction axis and an axis through the lateral thigh markers, and a mediolateral axis perpendicular to the adduction and inferior-superior axes. The primary outcome measures for the study were brace adduction moment and brace adduction angle; therefore, a Cardan angle sequence YXZ (adduction-flexion-internal rotation) was used to compute the deflection between the thigh and shank brace segments. Brace deflection was defined as a change in adduction, flexion, or internal rotation angle relative to the neutral brace pose.

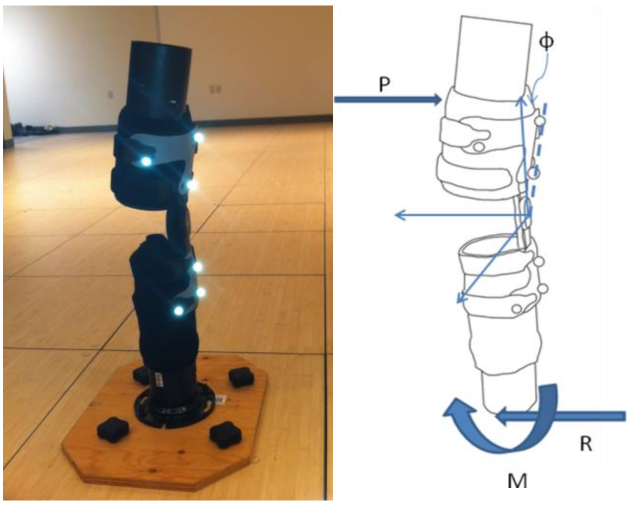

Figure 1: Left: VQ Orthocare "OAactive" knee brace rigidly fixed to a six degree-of-freedom force platform with retro-reflective motion tracking markers applied to thigh (top) and shank (bottom) segments**. Right:** Illustration of measured reaction force, R, and reaction moment, M, brace adduction angle, ϕ, and applied load, P. Flexion and internal rotation deflection angles are not shown.

Schmalz et al. [7] computed brace stiffness by simultaneously measuring an applied load and brace deflection. In this study, a quasi-static load, roughly aligned with the functional flexion axis, was manually applied to the proximal end of the thigh brace segment. This load generated a three-dimensional brace deflection angle and a three-dimensional reaction force and moment at the force platform. The net joint reaction moment was computed about the brace joint centre, and expressed in the anatomical shank coordinate system.

Three stiffness trials were performed for each brace at flexion angles of approximately 0, 45, and 90 degrees, respectively. For each trial, the brace was initially unloaded then the deflection load was slowly applied until a significant deflection angle (greater than 20 degrees) was achieved, then slowly unloaded to zero. Brace deflection during patient use typically does not exceed 10 degrees [7]. A fourth trial of longer duration was performed by applying loads at intermediate angles throughout the brace flexion range of motion.

Finally, the unloading (abduction) moment about the shank anatomical adduction axis was interpolated as a function of the brace flexion and adduction deflection angles. During human gait, peak compressive medial joint loads occur during mid-stance when knee flexion angles range between 0 and 20 degrees. Therefore, brace stiffness as a function of only adduction angle, averaged between 0 and 20 degrees of flexion, was compared between braces.

RESULTS AND DISCUSSION

For a given flexion angle, the unloading brace moment was a linear function of brace deflection about the shank adduction axis (Figure 2). The "Unloader XT" brace was the stiffest, followed by the "OAactive" and the "Unloader Lite". Each brace could achieve an unloading abduction moment of 6 Nm, given a brace adduction deflection angle greater than 12 degrees.

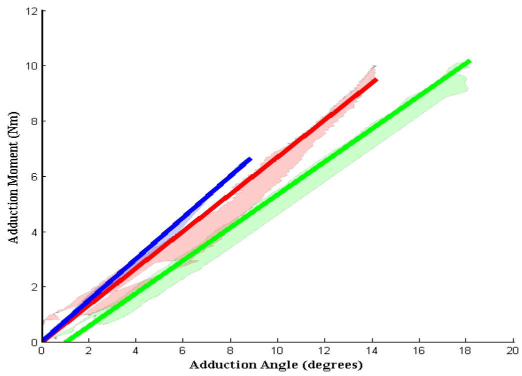

Figure 2: Brace abduction moment as a function of brace adduction angle, averaged for each brace for 0-20 degrees of brace flexion to represent the stance phase of gait. Red: "OAactive" (VQ Orthocare), Green: "Unloader Lite" (Ossur), Blue: "Unloader XT" (Ossur).

It has been estimated that, independent of changes to gait kinematics or muscle forces, the brace will reduce medial loads by roughly 1% of body weight for each Nm of applied unloading abduction moment [4]. Thus, each of these braces could conceivably reduce medial contact loads by 6% of body weight if the user could withstand the discomfort of such a large force.

Brace abduction stiffness was not constant throughout the range of motion (Figure 3). Each brace was stiffest, and provided the largest magnitude of unloading abduction moment, when it was close to zero degrees of flexion.

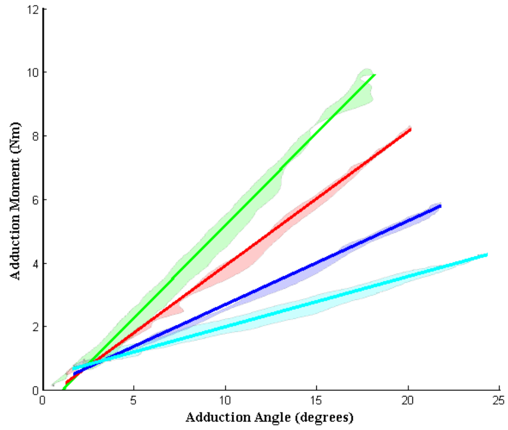

Figure 3: Brace abduction moment as a function of both adduction and flexion angles for the "Unloader Lite" (Ossur) knee brace. Decreased stiffness (slope) with increased flexion angle was observed for all three braces. Green: 0-20 degrees flexion angle, Red: 20-40 degrees flexion angle, Blue: 40-60 degrees flexion angle, Cyan: 60-80 degrees degrees flexion angle.

CONCLUSIONS

This study characterized the stiffness of three knee braces as a function of brace deflection angles. The resulting stiffness function can be used to compute the moment applied to a subject's leg, given a measured brace deflection angle. Thus, it is possible to apply these brace abduction moments to a more detailed musculoskeletal model to investigate changes in medial contact loads. Brace unloading (abduction) moment was primarily a function of adduction deflection angle; however, the abduction stiffness decreased with increased range of motion. Future work should use these reaction moments to better understand the effectiveness of knee braces for medial osteoarthritis in both gait and more demanding functional activities.

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