ESTIMATION OF KNEE JOINT COMPRESSION FORCE IN SUBJECTS WITH MEDIAL COMPARTMENT KNEE OSTEOARTHRITIS

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INTRODUCTION

Determination of individual muscle force contributions during walking is limited by the problem of redundancy in the motor system. While it is possible to determine external joint moments using an inverse dynamics approach, there are significant limitations to determining actual intersegmental contact forces. The role of these contact forces in pathologies such as knee osteoarthritis (OA) is not well understood, but may play a role in disease progression.

Previous authors have used optimization techniques to estimate intersegmental contact force at the knee (Anderson and Pandy 2001). We have developed a two-dimensional static optimization technique for estimating knee contact force that can be applied to pathological gait. The purpose of this investigation is to determine if the optimization technique produces results that are physiologically meaningful for individuals with knee OA, as well as to serve as a foundation on which future optimization parameters in this subject population can be established.

METHODS

Ten subjects (4 males) with bilateral knee OA voluntarily took part in the investigation. Radiographic grading of the severity of knee OA was based on the Kellgren-Lawrence scale and subjects were divided into groups based on the OA severity (Grade 1 = mild, 2-3 = moderate, 4 = severe). All data were collected on a split belt treadmill capable of collecting vertical and horizontal ground reaction forces (Bertec Corp., Columbus, OH, USA). Subjects walked at 0.8 meters/second to decrease differences in joint loading that may be associated with different self-selected walking speeds. EMG, 3D motion analysis and kinetic force plate data were obtained during 30 second walking trials.

Joint angles, external joint moments and joint reaction forces derived from kinematic and kinetic data were determined using OrthoTrak v.6.3.3 (Motion Analysis, Santa Rosa, CA, USA). Moment arms and muscle orientations for each subject were exported at each point in the gait cycle using SIMM software (Delp and Loan 1995).

Custom written Matlab code was used to determine the uni- and bi-articular muscle forces required to achieve joint moments in the sagittal plane for the ankle, hip, and knee. To overcome muscle redundancy, muscle forces to minimize net muscle stress were determined (Crowninshield and Brand 1981). Individual muscle force contributions were limited to 85% of their maximum force generating capabilities (Challis 1997).

The plots of individual muscle forces during the gait cycle for each subject were then compared to the EMG recorded during the walking trial. Bilateral maximal knee contact force was computed as the vector sum of muscle and joint reaction forces.

RESULTS AND DISCUSSION

Maximal knee contact force derived from the optimization procedure ranged from 1.69 body weight (BW) to 3.00 BW (mean = 2.15 BW). Non-normalized maximal values for knee contact force ranged from 1230 N to 2838 N (mean = 1870 N). These results correspond well to experimental measures of knee contact force by Taylor et al. (2001) who used telemetered force data from an implanted total knee device. At one year post-op, they reported walking on a treadmill at speeds similar to ours resulted in about 2.1 BW, nearly identical to our results.

When analyzed on the basis of OA grade, the severe group showed the highest averaged non-normalized intersegmental force, 1971 N (SD = 330.1). The mild group showed the lowest average force, 1621 N, a difference of 350 N (p=0.067).

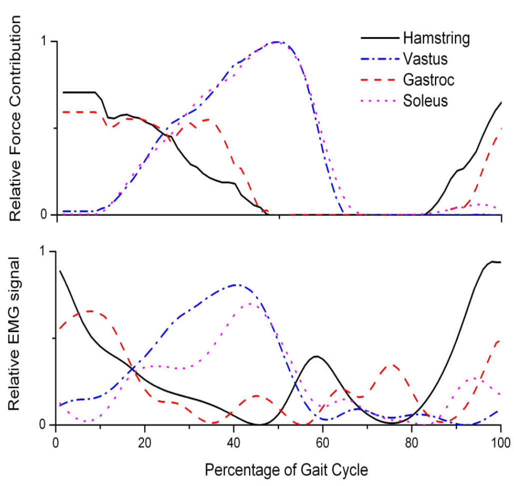

Figure 1: Theoretically derived relative force contributions (top) closely matched the relative experimentally obtained EMG signal (bottom) from a representative subject during a gait cycle (HS to HS).

When the predicted forces were compared to the EMG activation patterns (Fig. 1), the results were very similar. On/off times as well as peak activation times coincided closely with the predicted muscle forces.

SUMMARY/CONCLUSIONS

The static optimization techniques utilized here provide force data that matches the activation patterns from experimentally determined EMG. The maximal intersegmental contact forces are also similar to previous reports that have obtained the data experimentally (through instrumented knee prostheses) and mathematically (static and dynamic optimization procedures). The results from the maximal knee contact force in the mild and severe OA group suggest that differences in knee joint loading do exist depending on OA severity.

Future research using this technique will include frontal and coronal plane moments to determine differences in knee joint loading in subjects with knee OA. We will also determine whether an alternate choice of cost functions, such as minimization of joint compression, will provide even more clinically relevant information.

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