PREDICTED GAIT MODIFICATIONS TO REDUCE THE PEAK KNEE ADDUCTION TORQUE

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INTRODUCTION

High tibial osteotomy (HTO) is a more conservative surgical procedure than is total knee replacement for treating medial compartment knee joint osteoarthritis (OA). Following HTO surgery, patients with a low peak knee adduction torque during gait tend to have the best long term clinical outcome [1]. As an alternative to HTO surgery, this study uses inverse dynamic optimization of a patient-specific full-body gait model to predict gait modifications that could reduce the peak knee adduction torque.

METHODS

Kinematic and kinetic gait data were collected from a single highly functional knee OA patient with 5º varus alignment and grade 2 medial OA in both knees. The subject walked at a speed of approximately 1 m/sec and also performed isolated joint trials to determine the position and orientation of each lower extremity joint [2]. One complete gait cycle (left heel strike to left heel strike) with clean surface marker and ground reaction data was selected as the nominal data set for the optimization study.

A dynamic, three-dimensional full-body gait model was developed using SIMM. The model possessed 27 degrees of freedom (DOFs) composed of gimbal (3 DOFs), universal (2 DOFs), and pin (1 DOF) joints. External forces and torques acting on the pelvis were calculated from a 6 DOF joint between the ground and pelvis. Since no external loads act on the pelvis in real life, non-zero external force or torque components at any time frame represent error in the model and/or experimental data.

Joint and body segment parameters in the model were tuned via optimization to match the nominal gait data as closely as possible. The cost function simultaneously minimized errors between model and experimental marker locations in the laboratory reference frame, external pelvis forces and torques, and changes in body segment parameters away from their initial values. Design variables were joint positions and orientations in the body segments, body segment parameters, and parameters defining joint translations and rotations (see below). Final root-mean-square (RMS) errors were 1.9 cm in surface marker positions and 3.6 N and 2.8 Nm in external pelvis forces and torques, respectively.

Inverse dynamic optimizations were performed to predict novel gait motions that minimized the left knee adduction torque subject to several reality constraints: follow the prescribed path of each foot, follow the experimental trunk orientation, eliminate external forces and torques on pelvis, and keep the center of pressure under each foot. The 500 design variables were motion and ground reaction torque curves parameterized using a combination of a cubic polynomial and eight Fourier harmonics [3]. Ground reaction forces, shoulder and elbow rotations, and pelvis horizontal translations were prescribed to match the experimental data. The optimizations were performed with and without penalty terms to minimize changes in the leg control torques.

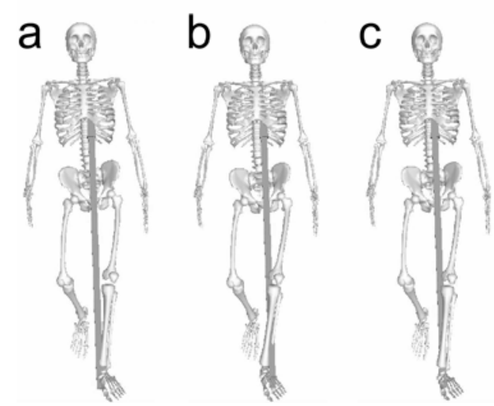

Figure 1: a) Experimental gait motion, b) gait motion predicted without control torque tracking, and c) gait motion predicted with control torque tracking. Arrows indicate line of action of ground reaction force vector.

RESULTS AND DISCUSSION

The optimizations predicted realistic gait motions that reduced the peak knee adduction torque by 72% without control torque tracking and 45% with it (Fig. 1). The optimizations drove the left knee inward in part through increased hip, knee, and ankle flexion, causing the ground reaction force vector to pass more laterally to the knee center than in the experimental situation. These kinematic changes were produced primarily by an increase in knee extension and ankle inversion torque. Predicted changes with control torque tracking were similar but decreased in amplitude compared to those found without control torque tracking.

The optimization results suggest that gait modifications may be able to reduce the peak knee adduction torque by as much as HTO surgery, which has been reported to produce an average 34% reduction [1]. Due to their synergistic effects, even small gait modifications had a large influence on the peak knee adduction torque. If the predicted gait modifications can be achieved in practice, they could help define new rehabilitation strategies for knee OA patients either apart from or in conjunction with HTO surgery.

REFERENCES

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ACKNOWLEDGEMENTS

This work was funded by the Whitaker Foundation.