

A PARAMETRIC APPROACH FOR ESTIMATING A RANGE OF PHYSIOLOGICAL TIBIOFEMORAL CONTACT FORCES DURING GAIT

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INTRODUCTION

The tibiofemoral contact force generated by muscular contraction at the knee during ambulation is an important component in understanding joint function, injury, and disease. However, determining the individual muscle forces required to balance the external joint loads remains a challenge due to the indeterminate nature of the joint. Various optimization techniques [Taylor 2004] are typically used to solve the muscle redundancy problem yet they often fail to elucidate potential antagonist muscle activity which may play an important role in pathologic, and even healthy, gait.

The purpose of this study was to apply a previously developed parametric hip model [Hurwitz 2003] to the knee joint. This model allows one to systematically study the effect of different levels of muscle force combinations on the tibiofemoral contact forces. The primary objective of this study was to compare the effect of antagonist muscle activity during walking with actual *in vivo* contact force measurements measured with an instrumented knee implant.

METHODS AND PROCEDURES

Experimental data were collected from a single patient with an instrumented knee implant (male, right knee, age 80, 68 kg, 1.7 m). The instrumented knee transmitted the tibiofemoral compressive load from 4 uniaxial

load cells embedded in the tibial component at 70 Hz.

The subject performed walking trials at a self-selected normal speed (1.5 m/s). Kinematic and kinetic data were collected during walking using an optoelectronic system and force plate. The point cluster technique was used to calculate the kinematics of the lower limbs [Andriacchi 1998]. Inverse dynamics was used to calculate the 3-dimensional external joint moments.

The marker positions in the gait trials were used to scale and determine the kinematics of a lower-limb musculoskeletal model in SIMM (Musculographics, Inc., [Delp 1990]). The model was then used to determine the maximum isometric force, the moment arm (flexion-extension and varus-valgus), and orientation of each of the 13 muscles crossing the knee at every point in the gait cycle.

The parametric model predicts a range of knee contact forces at each time point by parametrically varying the combinations of physiologically feasible muscle forces for each muscle crossing the joint. The muscle force combinations that balance the external flexion-extension moment are collected and the medial contact force is calculated to balance the external knee ab/adduction moment and the sum of the frontal-plane muscle moments about the lateral compartment (the patient had a valgus knee angle during gait and thus the model assumed

a frontal-plane rotation about the lateral compartment). The lateral contact load is then the difference between the total and medial contact force. The maximum antagonist muscle activity was examined at a level of 5% for this study. The range of predicted tibiofemoral contact loads with the parametric model was then compared to the actual tibiofemoral compressive forces measured during the walking trials in the instrumented knee.

RESULTS

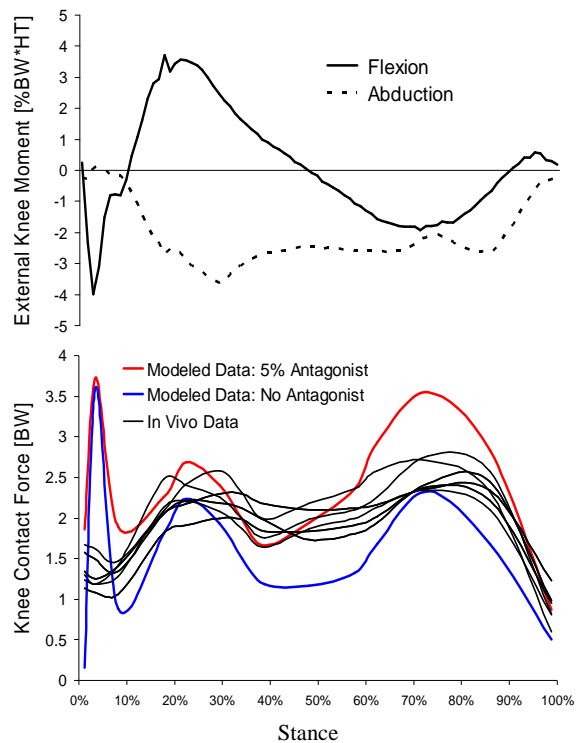


Figure 1. (Top) The pattern of external flexion and abduction moments during the stance phase of normal level walking. (Bottom) The range of parametrically estimated (colored lines) and *in vivo* (black lines) knee contact forces. The blue line represents the minimum possible contact force (no antagonist activity) and the red line represents maximum contact force with 5% antagonist activity.

The shape, magnitude, and timing of the contact force predicted by the parametric model were similar to those measured *in vivo* (Fig. 1). With antagonist activity set at 5%, the maximum parametric contact force (Fig. 1

red line) increased by an average of 0.78 BW from the minimum contact force possible (Fig. 1 blue line)

DISCUSSION

The parametric knee model allows one to fully explore the effect of all possible muscle force distributions on the tibiofemoral contact force subject only to physiological constraints and not predefined muscle activity patterns or optimization criterion. This model may be particularly valuable for examining pathologic gait, such as in the osteoarthritic knee or after ACL injury, in which it is suspected that antagonist muscle activity is present and significantly contributing to increased joint contact loads. Taking the subject in the current study as an example, the *in vivo* (instrumented knee) contact loading patterns appear to display antagonist activity, or non-optimal muscle recruitment, during walking thus supporting the use of the parametric model. While it appears that the model falsely predicted a spike in the contact load after heel-strike (corresponding to the large external extension moment), this could potentially be an artifact of differences in sampling rates between the two systems.

SUMMARY

A parametric knee model is presented that provides a method to study the sensitivity of the knee contact forces to specific agonist or antagonist activations patterns.

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