INTRODUCTION

Static optimization has been the method of choice for estimating muscle and joint contact forces during gait (Brand et al, 1994). Although the relatively small computational demands of this approach have allowed very detailed musculoskeletal models to be used, static optimization has been criticized in several respects: 1) the method is highly dependent on the accurate collection and processing of experimental data, 2) the physiological properties of muscle have typically not been included in the problem, and 3) the performance criterion is required to be time-independent (Hardt, 1978; Patriarco et al., 1981). Dynamic optimization addresses these shortfalls, but it incurs enormous computational cost. As a result, dynamic optimization solutions for gait have been few and have lagged behind their static optimization counterparts in terms of model complexity (Yamaguchi and Zajac, 1990), so much so that a meaningful comparison of the two methods as they apply to gait has not been possible. In this study, a dynamic and a static optimization problem for gait were solved. The musculoskeletal model used was similar in complexity to previous static optimization models and considerably more detailed than previous dynamic optimization models. A direct comparison of the two methods was made possible by using as inputs to the static optimization problem the joint moments computed from the dynamic optimization solution.
taken into account by limiting muscle force in accordance with the force-length-velocity property of muscle; however, muscle activation dynamics was neglected. The performance criterion was the minimization of the sum of the square of muscle activations. For the dynamic optimization problem, the performance criterion was the minimization of the total amount of metabolic energy expended per unit distance traveled.

RESULTS

In general, the time histories of muscle force predicted by the static and dynamic optimization solutions were very similar. Consequently, the contact forces at the hip, knee, and ankle were also similar (Fig. 2).

![Figure 2: Resultant joint contact force at the hip normalized by body weight.](image)

DISCUSSION

The striking similarity between the dynamic and static optimization solutions provides strong evidence that static optimization is entirely adequate for predicting joint contact forces during gait, provided that the net joint torques exerted by the muscles are known with confidence. Similarity between the two solutions implies that 1) activation dynamics may be neglected in the static optimization problem for gait and 2) there is a functional equivalence between minimizing metabolic energy over the entire gait cycle (a time-dependent performance criterion) and minimizing the sum of muscle forces squared at any instant (a time-independent performance criterion). Accurately estimating the net joint torques exerted by the muscles remains a critical element of the static optimization approach (Patriarco et al., 1981). It is suggested that dynamic optimization should be used when 1) accurate experimental data cannot be obtained, 2) activation dynamics is suspected to play a significant role during the activity, or 3) one would like to use simulation as a tool for predicting how changes in musculoskeletal structure might affect function.

REFERENCES


ACKNOWLEDGEMENTS

Supported by The Whitaker Foundation, NASA Grant # NAG5-2217, NASA-Ames Research Center, and The University of Texas Center for High Performance Computing.