A STRAIN MAP OF THE HUMAN DISTAL TIBIA DURING THE STANCE PHASE OF WALKING: A COMBINED APPROACH USING DYNAMIC CADAVER SIMULATIONS AND FINITE ELEMENT ANALYSES

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INTRODUCTION

Lanyon, et al. (1975) and Burr, et al. (1996) have reported *in vivo* human bone strains during activity, using strain gages attached to the tibia. Peterman, et al. (2001) produced similar results at multiple sites using a dynamic *in vitro* model described by Sharkey and Hamel (1998). In the present study, the *in vitro* technique was expanded via finite element modeling (FEA) to produce a three-dimensional map of the strains experienced by the distal tibia during walking. The model is unique in that it was driven entirely by measured strain data, requiring no assumptions (apart from those inherent to the gait simulation) about the loading environment giving rise to the strains.

METHODOLOGY

One left extremity was amputated at mid-shank from a fresh frozen female donor (estimated body weight of 380N, 69 years of age at time of death). The cadaver extremity was prepared and installed in a dynamic gait simulator apparatus, which simulates the kinematics and kinetics of walking. Nine triple-element stacked strain gage rosettes (WA-06-060WR-120, Measurements Group, Raleigh, NC) were adhesively fixed to the distal third of the tibial shaft and sampled at 5Hz as the foot was advanced through the stance phase of gait. Data were collected over multiple walking trials, filtered, averaged, and combined to form 27 time-based strain plots, where each of the nine rosette sites yielded three plots. The specimen was removed from the apparatus, gage locations were marked on the bone, and the distal tibial shaft was isolated from the foot. The shaft was then fixed, embedded in MMA, sectioned via registered serial milling, and digitally captured. Endosteal and periosteal contours were digitized from planar sections and lofted to create a solid model of the cortex.

An 8-node block finite element mesh was fit to the cortical geometry using Truegrid software (XYZ Scientific Applications, Livermore, CA) and appropriately optimized. Correspondence between element faces and gage locations were noted and hard-coded into controlling algorithms, such that strains on particular element faces could be compared with rosette data from the cadaver simulations. An arbitrary 3-force, 3-moment load state was applied to the distal end of the model, and a fully clamped boundary was prescribed at the proximal end. A numerical routine was written whereby three-dimensional strains were resolved using strain data from the 27 discrete rosette sites. The routine used a least squares optimization algorithm to estimate experimental loading at each time increment, deforming the model to reproduce the empirically determined strains. At each increment, strain results from the arbitrary load state were compared to the measured strains and the arbitrary state was automatically adjusted until a pre-determined error tolerance was achieved. The full-field strains were then stored and the model was advanced to the next time increment, using initial conditions from the prior step. In this analysis, MATLAB (Mathworks, Natick, MA) was used for optimization and data management, together with the ABAQUS (HK&S, Pawtucket, RI) finite element solver.

RESULTS AND CONCLUSIONS

Dynamic, three-dimensional strain data were compiled as animations of axial, maximum principal, minimum principal, and shear strain over the stance phase of gait. Animations of variation in the neutral axis of bending over stance were also created. These animations will be presented.

The present study is limited in that only one specimen was analyzed, the medical history of the donor was not known, nonlinearity and inhomogeneity of the bone tissue were not considered, and the analysis was a time-scaled version of gait. Despite these important issues, the strains predicted are in agreement with those reported in the literature, and may provide boundary conditions for more detailed models of local phenomena within actively loaded bone tissue.

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