Robust Optimization of Total Joint Replacements Incorporating Environmental Variables

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Direct search techniques for the optimal design of biomechanical devices are computationally intensive requiring many iterations before converging to a global solution. This along with the incorporation of environmental variables such as multiple loading conditions and bone properties make direct search techniques infeasible. In this study, we introduced new methods that are based on the statistical design and analysis of computer experiments to efficiently account for environmental variables. Using data collected at a relatively small set of training sites, the method employs a computationally inexpensive predictor of the structural response that is statistically motivated. By using this predictor in place of the simulator (e.g. finite element model), a sufficient number of iterations can be performed to facilitate the optimization of the complex system. The applicability of these methods was demonstrated through the design of a femoral component for total hip arthroplasty incorporating variations in joint force orientation and cancellous bne properties. Beams on elastic foundation (BOEF) finite element models were developed to simulate the structural response. These simple models were chosen for their short computation ime. This allowed us to represent the actual structural response surface by an exhaustive enumeration f the design and environmental variable space, and provided a means by which to validate the statistical predictor. We were able to accurately predict the structural response and the optimal design using only sixteen runs of the computer code. The general trends predicted by the BOEF models were in agreement with previous three-dimensional finite element computer simulations, and experimental and clinical results, which demonstrated that the important features of intramedullary fixation systems were captured. These results indicate that the statistically based optimization methods are appropriate for optimization studies using computationally demanding models.