SENSITIVITY OF KNEE SIMULATOR MACHINE WEAR VOLUME TO VARIATIONS IN MOTION AND LOAD INPUTS AND COMPONENT PLACEMENTS

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INTRODUCTION

Standardized motion and load input profiles and non-standardized component placements are typically used when measuring tibial insert wear volume in a knee simulator machine [1]. However, the effect of variations in input profiles and component placements on wear volume is not well understood, mainly due to the large amount of time required to perform repeated wear tests using either physical machines or computational models.

This study uses Monte Carlo analysis to evaluate how variations in component placement (anterior-posterior tibial slope and superior-inferior location of flexion-extension axis), input loads (axial load and anterior-posterior load), and input motion (femoral flexion) affect insert wear volume in a commercial knee replacement. The analysis is performed using a novel surrogate contact modeling approach that permits extremely fast dynamic contact simulations.

METHODS

Surrogate contact modeling fits a computationally cheap contact model to data points generated by a computationally costly contact model. In this study, an elastic foundation contact model of a commercial knee replacement [2] was used as the computationally costly contact model with data points generated in the sagittal plane. Kriging models were then developed to fit the sampled axial contact force, anterior-posterior contact force, and center of pressure as a function of the relative pose between the contacting components. Finally, the Kriging-based contact model replaced the elastic foundation contact model in a multibody dynamic model of a Stanmore knee simulator machine [1] constrained to move in the sagittal plane. The accuracy of the Kriging model was confirmed by comparing with simulation results produced by the elastic foundation contact model.

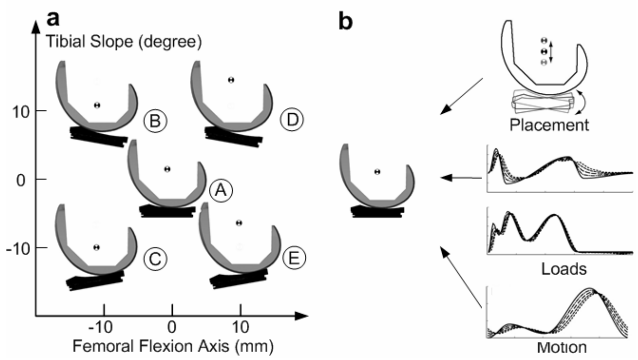

Figure 1: (a) The five nominal placements of the knee implant components. (b) For each nominal placement, the component placements, input loads, and input motion are varied locally during a Monte Carlo analysis.

To evaluate how variations in motion and load inputs and component placements affect the wear volume predicted by repeated dynamic contact simulations, we varied component placements both globally and locally. Globally, the tibial slope and the superior-inferior location of the flexion-extension axis were varied within ± 10 deg/mm, resulting in five nominal component placements (Fig 1a). At each nominal placement, we performed a Monte Carlo analysis by locally varying the motion and load inputs with principal component analysis based on curves reported in the literature [1] and varying component placements within ± 1 deg/mm (Fig. 1b). Each Monte Carlo analysis was performed on a 3.4 GHz Pentium IV PC and involved at least 1000 dynamic contact simulations, each of which required about 13 sec of CPU time, to ensure convergence of the wear predictions.

RESULTS AND DISCUSSION

We used box plots to summarize the distributions of predicted wear volume produced by the Monte Carlo analyses. Overall, variations in motion and load inputs as well as component placements had a significant effect on predicted wear volume. Globally, the predicted wear volume was affected primarily by changing the flexion-extension axis, with anterior-posterior tibial slope having a smaller effect (Fig. 2 a & b). Locally, variations in motion and load inputs caused a wider distribution of wear volume than did variations in component placements (Fig. 2 c & d).

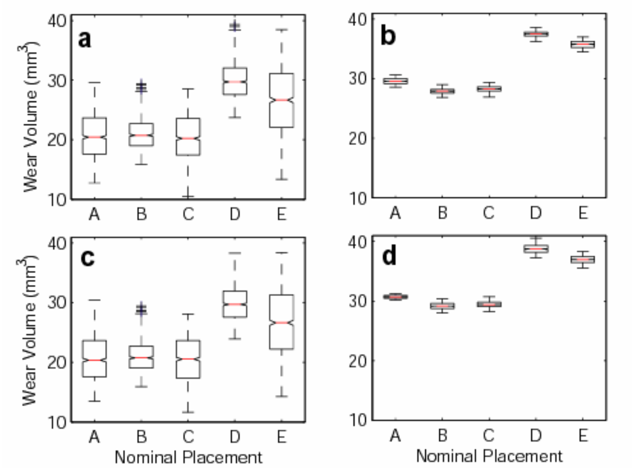

Figure 2: Monte Carlos results. Motion and load inputs and component placements and are varied together within (a) 100% or (b) 10% of their maximum ranges. (c) Motion and load inputs or (d) component placements are varied separately within 100% of their maximum ranges.

Surrogate contact modeling permits fast dynamic contact simulations as required for Monte Carlo analyses. Our results suggest that wear volume within a simulator machine may vary significantly due to variations in motion and load inputs as well as component placements. Standardization of component placements and tighter control of motion and load inputs should be evaluated. Extension of this approach to three-dimensional problems is a subject of ongoing research.

REFERENCES

1. DesJardins JD, et al. *J Biomech* **33**, 1231-42, 2000.
2. Fregly BJ, et al. *J Biomech* **38**, 305-14, 2005.