COMPARISON OF INTERFACE STRESSES AND STRAINS FOR ONLAY AND INLAY UNICOMPARTMENTAL TIBIAL COMPONENTS

1,2Peter S Walker, 1Dhiraj S Parakh, 1,3Miriam E Chaudhary, 4Chih-Shing Wei

1Laboratory for Minimally Invasive Surgery, NYU Hospital for Joint Diseases, New York, NY

2Department of Mechanical and Aerospace Engineering, NYU-Poly, Brooklyn, NY

3Department of Chemical and Biological Sciences, NYU-Poly, Brooklyn, NY

4Cooper Union for the Advancement of Arts and Science, New York, NY

INTRODUCTION

There are two main designs used for unicompartmental tibial components. The first design, an all plastic component called an inlay, preserves bone on the outer edge of the tibia which is feasible using a robotically-controlled burring tool. Also, the depth of resection is small, preserving the strongest cancellous bone which is near the surface. The second design, called an onlay, resects the entire condyle and includes a metal backed plate which rests on the resected tibia. This component requires more bone removal but metal-backing has previously been shown to distribute the load more uniformly. The purpose of this study was to investigate the hypothesis that while inlay components require less bone removal, the peak stresses and strains at the surface of the bone will be greater when compared to onlay components.

METHODS

Preoperative CT scans were obtained from 4 patients who later were treated with UKA using the MAKO surgical system. The scan data was processed using Mimics software (Materialise, Leuven, Belgium). Tetrahedral elements were generated and material properties for each element were obtained from the Hounsfield numbers of the CT scan. The modulus of elasticity values are shown graphically in Figure 1. The stiffest bone is close to the surface with a rapid diminution of stiffness below. All four tibias showed a similar pattern.

The plastic inlay was dimensioned to be 6mm thick. The metal-backed component consisted of 6mm plastic and 2mm metal bonded together. The plastic component (UHMWPE) and metal-backed onlay were assigned material properties1,2,3,4 (Figure 1).

The magnitudes of the force and the medial-lateral force ratio were taken from data of instrumented knee replacements5,6,7. The 1500N load on the plastic was applied centrally over a circle of diameter 7.1mm a typical contact area for metal-on-plastic components. On the lateral side the 750N load was applied over an area of 450mm2 based on a typical contact area determined experimentally on knee specimens8. The 2250N force in the patella tendon was applied over the tibial tubercle. The loads were the same for both the inlay and onlay components. The base of the tibia was constrained in all directions.

The analysis was carried out using Abaqus finite element software (Dassault Systems, Concord, MA). Von Mises stresses and strains were calculated at the surface of the bone immediately below the components (Figures 2 and 3).

Analyses were first carried out on the inlay and onlay components for the 4 tibias. Following that, an analysis was also carried out on one tibia with a metal backed onlay component which had 2 anterior pegs and one posterior keel, resembling the commercially available component (MAKO Surgical Corp, Lauderdale, FL).
RESULTS

The Von Mises stresses on the interface surface of the bone are shown for all 4 tibias in Figure 2. For the plastic inlay component, the concentration of stress beneath the applied load is apparent with no apparent matching to the underlying bone stiffness. In contrast, the metal-backed onlay component distributed the load over a larger area, with the highest stresses being generally in the areas of stiffest bone.

The stresses were in the region of 20MPa and 3MPa for the inlay and onlay components respectively with a mean ratio of 6.12 (Figure 4). The strains for the inlay were consistently higher than for the onlay (Figure 5). For the onlay, we disregarded the high values on the inner edge due to the corner of the metal baseplate. Hence we adjusted the scale of the plot to more clearly show the strain distribution of the main surface. The mean inlay/onlay ratio was 13.51. Because of the consistency between the results for the 4 tibias, and the large difference between the peak stresses and strains for the inlay and onlay components, the results are considered significant.

For the onlay component with 2 pegs and 1 keel, there were regions of higher stress and strain values, around the ends of the projections when compared to the flat component. However, on the interface surface around the projections, there was evidence of reduced stresses and strains.

DISCUSSION

One factor which was not accounted for in our analysis was the effect of the cement layer. Varying cement thickness in our analysis would likely cause a change in stress and strain values due to the stiffer material properties of the bone-cement composite beneath the plastic components, though the effect would be small for metal-backed components.

The stress patterns showed the ability of the component to spread the load over the surface. The strain values were an indication of the susceptibility of bone failure, based on the finding that there was a linear relation between modulus and ultimate strength, for trabecular bone. Based on the stress criterion, the inlay component produced stress concentrations beneath the load, due to the combination of the modulus of the plastic and its thickness. The metal-backed onlay component showed more favorable distribution of load, with lower peak stress values. Using the strain criterion, the onlay component again showed much lower values than the inlay. Hence the data supports the hypothesis that the metal-backed onlay component will have reduced stress and strain values at the interface bone surface, and less likelihood of migration and bone resorption.

In essence, a metal-backed uni-component produced more favorable bone stresses and strains compared with an all-plastic component, but the extra bone resection could be a disadvantage should a revision be necessary.

Lastly, this discussion has prompted a further investigation into this study. Tetrahedral meshes with a smaller element size of 2mm are being generated for each of the four bones analyzed. Furthermore, based on the preliminary results mentioned above, metal-backed onlays will be replaced by all-metal onlays of a 2mm thickness and undergo a similar analysis, to determine if a further reduction of bone resection is an advantage.

ACKNOWLEDGMENTS

This study was funded by MAKO Surgical Corporation, Fort Lauderdale, FL and the Department of Orthopedic Surgery, New York University, Hospital for Joint Diseases. We thank Professor Nikhil Gupta (New York University-Polytechnic Institute) for advice on the Mimics methodology.

REFERENCES