Investigation of a Reversed Materials Early Intervention Implant for Medial Osteoarthritis of the Knee

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Introduction
A recent study of 97 arthritic knees at the time of total knee (TKA) surgery showed that 21% of the cases could have been treated with a unicompartmental knee (UKA) [1]. UKA is an attractive procedure for patients with medial compartmental osteoarthritis who wish to maintain an active lifestyle. However there is an incidence of tibial component loosening due in part to the 6-10 mm bone resection. Because the principle femoral lesion is restricted to the distal end, an alternate Early Intervention (EI) design is proposed consisting of a reversed materials scheme using an inlay plastic component for the distal femur, and a thin metal plate for the proximal tibia requiring minimal bone resection and preserving the strong bone in the proximal tibia.

The purpose of this study was to investigate the potential advantages of a thin metal tibial component compared with conventional all-plastic or metal-backed UKA components. Our hypothesis was that the EI component would produce more favorable strain energy density, stress, and strain characteristics compared with the UKA components.

Methods and Materials
Preoperative CT scans with different bone densities were obtained from two patients who were later treated with UKA. Both CT scans were imported into Mimics software (Materialise, Leuven, Belgium). 10-noded tetrahedral elements of 2 mm size were assigned material properties based on equations by Rho et al. [2].

Four tibial components were considered in this study:
- An EI component of all-metal, 2 mm thick at center (EI 2 mm)
- An EI component of all metal, 3 mm thick at center (EI 3 mm)
- A UKR all-plastic inlay, 6 mm thick
- A UKR metal-backed onlay, 6 mm plastic and 2 mm metal

The EI components were placed at a 2 mm resection level, and bi-angled to minimize bone resection. The all-plastic (UHMWPE) inlay was positioned at a 4 mm resection level. The metal-backed onlay was placed at a 6 mm resection level.

The metal (cobalt-chromium) was modeled as a linear-elastic and isotropic material ($\rho = 8200 \text{ kg/m}^3$, $E = 208,000 \text{ MPa}$) [4], $\nu = 0.3$ (4). Likewise the plastic (UHMWPE) was modeled as a linear-elastic, isotropic material ($\rho = 940 \text{ kg/m}^3$, $E = 634.9 \text{ MPa}$), $\nu = 0.45$ (6).

On the medial side, a downward force of 1500 N was applied over an area of 450 mm$^2$, while on the lateral side, a downward force of 750 N was applied over an area of 450 mm$^2$. An upward force of 1500 N was applied over the tibial tubercle to simulate the force exerted by the patella tendon. In each model, the tibia base was constrained in all directions.

An intact model was also generated to compare with an implanted model. For the intact model, the same axial forces were used; however, the contact area on the medial side was increased to 554 mm$^2$ to represent loading in the arthritic knee.

All models were analyzed in Abaqus/CAE 6.10 (Dassault Systems, Concord, MA). Strain energy density below the components would indicate bone remodeling and potential pain [7]. Von Mises stresses at the bone interface indicated load distribution. The interface strains would assess possible loosening.

Results
Strain energy density (SED):
Compared to the intact model, the SED in the EI 3mm and the metal-backed UKA decreased by 46% and 34%, respectively.

Conversely, the SED in the EI 2mm and the all-plastic inlay UKA increased by 76% and 220% respectively compared to the intact tibia.

Maximum Von Mises stresses
From the stress plots of tibia 1 and tibia 2, the EI 3 mm and metal-backed onlay produced comparable stresses. However, significantly higher stresses were observed in the EI 2 mm and all-plastic inlay (Fig. 2).

Discussion
Both the all-plastic inlay and EI 2mm showed excessive SED, stresses, and strains. For the inlay, the elevated SED, stress, and strain may be associated with loosening, bone remodeling, and pain reported clinically [8-10].

An important consideration in this analysis is the required resection. While the EI 3 mm and metal-backed onlay produced comparable stresses and strains, the EI 3 mm components would require only a 2 mm resection, whereas the metal-backed onlay requires a 6 mm -10 mm resection. With the EI 3 mm, the stronger, denser bone would be preserved which is a major advantage over traditional UKA for stronger fixation and should a revision be necessary.

This study is enhanced in that two tibias were analyzed using FE methods. The material property distributions between the two tibias provided some insight into how component selection and resection level affect the stresses and strains experienced by the underlying bone. More importantly, the FEA models demonstrated the effectiveness of using an early intervention (EI) component over a traditional UKA.

Future studies aim to analyze the femoral component of this reversed materials scheme.

Significance
The early intervention component will introduce a novel approach to component design, reduce operating time for the surgeon, preserve natural anatomy for the patient, and change current practices in minimally – invasive surgery.

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References

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