A NOVEL APPORACH TO DESIGN KNEE IMPANTS FOR WEAR AND STRESS SHIELDING PERFORMANCE

Ryan Willing [1] Anthony G Au [2] Il Yong Kim [1] and A. Amirfazli [2]

[1] Queen's University, Kingston, ON, Canada; iykim@me.queensu.ca
[2] University of Alberta, Edmonton, AB, Canada; a.amirfazli@ualberta.ca

INTRODUCTION

Total knee replacement (TKR) has long been the standard operation to relieve pain and restore range of motion to knee joints damaged by osteoarthritis. TKR frequency has been steadily increasing, and has been forecasted to increase to over 3.5 million primary and 270 thousand revision surgeries per year by 2030 [Kurtz et al., 2006]. The need for revision surgery can be the product of a number of factors, which include wear of the implant components, especially the ultra high molecular weight polyethylene (UHMWPE) bearing, and bone weakening caused by stress shielding, a bone remodeling process caused by stiff implant components "shielding" neighboring bone from load. While patient specific characteristics greatly influence success or failure of TKR, implant design is primarily related to these failure modes.

Wear of the UHMWPE insert in TKR is an issue because wear particles released into the body can cause an adverse tissue reaction, called osteolysis, which leads to density loss in neighboring bones. Previous work has shown that optimizing implant design for reduced wear results in lower conformity between the femoral component and UHMWPE insert [Willing and Kim, 2006].

Such reduced conformity can be detrimental to the bone as recent results have shown that, in addition to stiff implant materials, loading conditions as a result of altered condylar geometry can themselves cause stress shielding [Au et al., 2007]. Stress shielding will lead to bone resorption adjacent to the implant, potentially compounding the effects of osteolysis, and ultimately leaving inadequate bone stock for TKR support.

Whereas it is clear that some design characteristics play significant roles in determining the wear and stress shielding performance of an implant individually, it is unknown whether or not any of these characteristics are shared and, more importantly, would be considered competing factors. For example, a design factor that is beneficial for wear would be detrimental for stress shielding performance. In this research we have used a novel approach which combines the finite element (FE) methods for load and stress calculations with design optimization techniques to answer the above question.

METHODS

A parametric FE model of a TKR has been developed, where design variables such as frontal and sagittal femoral condyle radii can be modified to simulate different implant designs *in-silico*. Wear simulation is performed within the commercial FE package ANSYS (Swanson Inc., Houston, PA). A wear model based on Archard's law estimates wear at the contact surface of the UHMWPE during simulations of ISO-14243-1, a set of load and displacement waveforms for force controlled wear

simulators. This study has focused on the femoral component and the UHMWPE insert.

Following the wear simulation, the contact pressure contours are mapped onto an identical FE UHMWPE insert assembled to a titanium tray and tibia. The validated tibia FE model features 25 different material properties to represent heterogeneous bone. Quasi-static loading is applied to the TKR model to determine the stress shielding effects within the bone. A parameter study is performed after the computational framework has been completed. Parameters governing the shape of the implant components are modified in order to observe the impact on the wear rates and patterns at the contact surface, as well as the stress levels within the tibia. Design optimization follows, where TKR designs are optimized to reduce UHMWPE wear. Pre- and post-optimization stress levels within the tibia are then compared to wear results to determine if stress shielding is elevated with reduced wear levels.

RESULTS

Preliminary results include the development of the FE models and optimization for wear. It was found that the radius of curvature of the femoral condyles in the sagittal plane, as well as the conformity with the UHMWPE insert in this plane, carried the highest impact on expected wear rates. The radius of curvature is minimized, and the conformity in this plane is minimized as well, which results in smaller contact patches with higher contact stresses. Wear rates, however, decrease as the contact patch between the two components decreases (Fig 1). Preliminary results using the tibia FE model show that bone stresses decrease when load is concentrated on a smaller area. Thus, it is anticipated that reducing wear rates would potentially increase stress shielding.

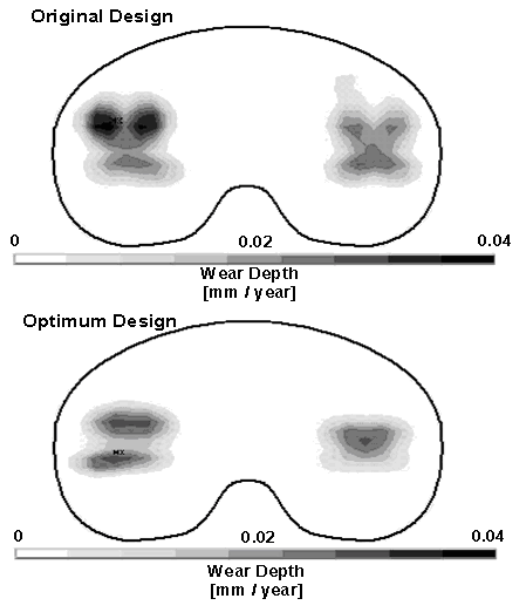

Figure 1: Initial wear pattern (above) compared to optimized wear pattern (below) shows reduction in patch size and depth

CONCLUSIONS

For the first time, the relationship between TKR design considering wear and stress shielding simultaneously is being studied. The study investigates whether there is a coupled relationship between wear and stress shielding, and discusses its consequences to improve TKR implant design. A wear-optimized design has been completed; its impact on stress shielding in the bone will be analyzed shortly.

REFERENCES

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