FINITE ELEMENT ANALYSIS ON THE EFFECT OF BONE STRENGTH ON PERIPROSTHETIC FRACTURE

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INTRODUCTION

Knee replacement is a well-developed treatment option and proven to be safe and cost-effective [1]. Periprosthetic fracture is one of the causes of failure with prevalences ranged from 0.3 to 2.5% [2]. Though uncommon, complications of post-periprosthetic fracture are devastating and rates from 25 to 75% were reported [3]. A majority of the fracture is associated with elderly patients with osteoporosis and rheumatoid arthritis patients receiving steroid therapy. These risk factors are related to reduction of bone stock, thus bone strength and results in stress alteration of bone. Understanding the association and mechanism can aid physicians to decide viable knee replacement. Computational method provides an efficient parametrica approach to investigate the biomechanics of bone-implant interface in a well-controlled environment. In the present study, a 3D finite element (FE) bone-implant model is developed to study the effect of bone strength reduction on periprosthetic stress failure.

METHODS

The geometry of the distal femur and proximal tibia was acquired from MRI of a normal adult female subject, processed by segmentation software, MIMICS (Materialise, Leuven, Belgium). The knee implant (Wright Medical Technology Inc. Advanced® Series, Arlington, USA) was scanned by digitizer and reconstructed using reverse engineering software, Rapidform (INUS Technology, Seoul, South Korea). The bones and implant were manipulated and aligned according to the implant protocol with Rapidform to simulate the surgical procedures. The bone-implant model was then imported into FE software, ABAQUS (SIMULIA, Providence, USA) for the creation of FE mesh.

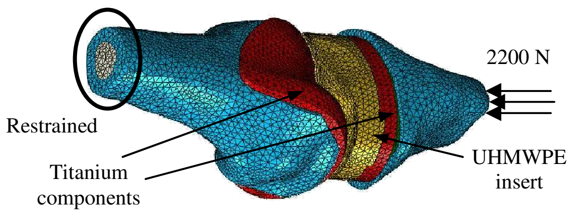

Figure 1: FE model of knee implant and bones simulating the loading response under compression.

The FE model consisting of 235828 tetrahedral elements (Figure 1) is assigned with a compressive load of 2200 N on the distal tibia with the proximal femur restrained. The material property of the cortical bone is assigned orthotropy [4]. The modulus of trabecular bone of the femur and tibia is assigned with a range of 194.5-1167 MPa and 222.5-1335 MPa respectively to study the effect of bone strength reduction. The titanium femoral component and tibia tray of the implant is assigned with elastic modulus and Poisson's ratio of 110 GPa and 0.34 respectively, while the Ultra-high molecular weight polyethylene insert is assigned values of 8.1 GPa and 0.46.

The modulus assigned in this study is converted to bone mineral apparent density (BMAD) for the sake of clinical interpretation of which BMAD is proportional to the bone yield stress [5].

RESULTS AND DISCUSSION

The predicted maximum principal stress in the trabecular femur is plotted against the BMAD as shown in Figure 2. The reported yield stress of trabecular specimens extracted from cadaveric knee with press-fit implant [5] is included for comparisons. Reduction of trabecular bone stress is predicted with reducing BMAD.

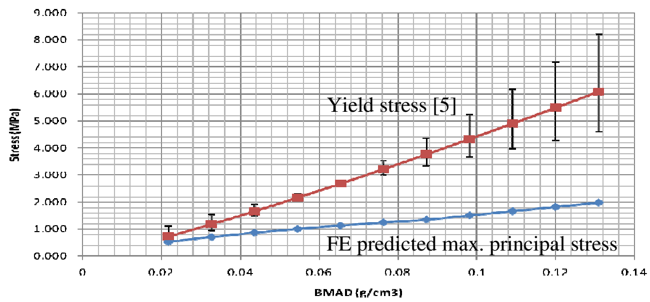

Figure 2: Predicted max. principal stress against BMAD.

For a high BMAD, the predicted maximum principal stress is far from the range of yield stress of the bone. This shows that fracture is unlikely for high bone density. Based on extrapolation, the difference between the predicted maximum principal stress and yield stress becomes smaller with reduced BMAD and starts to overlap with BMAD of about 0.02 g/cm^3, showing a high risk of fracture. In fact, the predicted maximum principal stress is expected to be higher during fall or impact and thus an even higher risk of fracture.

CONCLUSIONS

An increasing risk of fracture was predicted with reducing BMAD. The FE analysis suggested that a decline of BMAD to about 0.02 g/cm^3 may lead to a high risk of fracture. Further simulations on physiological loading conditions of higher capacity such as walking are being conducted.

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