FINITE ELEMENT & IN-VITRO TESTING OF TIBIAL STEM LENGTH IN REVISION TOTAL KNEE ARTHROPLASTY

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INTRODUCTION

Total knee arthroplasty (TKA) is considered the treatment of choice for candidates with severe deterioration of the knee due to osteoarthritis. However after 10 years the failure rate is between 7 %[1] and 10%[2] and a with new, larger components must be implanted. This procedure is called revision TKA.

Most revision designs use a modular intramedullary stem to transfer stress from the damaged proximal bone surface to the distal cortical bone. However no evidence-based surgical guide is available to help surgeons decide on the size of stem to use. The goal of this research is to develop such a guide using both finite element analysis (FEA) and in-vitro testing.

METHODOLOGY

Finite Element Analysis

A solid model of a tibia was created from a computed tomography (CT) scan of a composite tibia (#3301 Pacific Research Laboratories, Vashon,WA) using Mimics 8.11 (Materialise, Ann Arbor, MI) and Geomagic Studio 6 (Raindrop Geomagic, Inc., Research Triangle Park, NC). Virtual surgery was performed using Unigraphics NX 3 (UGS, Plano, TX) to implant a size 4 NexGen A/P Wedge tibial component (Zimmer, Warsaw, IN) with four different stem lengths (125, 145, 175, 200 mm) and all with a diameter of 12 mm.

ABAQUS 6.4 (Abaqus Inc., Providence, RI) was used to analyze the four different stem lengths with a small sliding contact algorithm between the stem and bone. An axial load of 2 kN was applied to the medial and lateral condyles with a medial:lateral ratio of 60:40 and 100:0. The effect of a medial defect was also investigated with two stem lengths (145 & 200 mm). Stem-bone micromotion and von Mises stress distribution were compared in all cases.

In-vitro testing

Ten composite tibias were implanted with a size 4 Zimmer Nexgen A/P Wedge tibial component and a 12 mm diameter intramedullary stem. Five of the bones were implanted with a 145 mm length stem and five with a 200 mm length stem.

A sinusoidal axial load from 0.1-2 kN was applied for 1000 cycles with an Instron testing machine (Model #8890, Norwood, MA). Each bone was tested under two load distributions (60:40 and 100:0) and three interface conditions (uncemented, cemented tray, and medial defect) while micromotion was measured with two linear variable displacement transducers (LVDT). The LVDTs were fixed to the medial and lateral aspect of the tray and connected to the bone 100 mm distal to the bottom of the tibial tray.

RESULTS

The finite element (FE) results showed increasing peak cancellous stress (von Mises) and decreasing average proximal cancellous stress with increasing stem length. The models with medial defects revealed that stem length had a larger effect on stress than defect size. Figure 1 shows cancellous stress for two stem lengths with a medium sized medial defect.

Micromotion results for both in-vitro and finite element testing were compared and are presented in Figure 2. The in-vitro micromotion was calculated by averaging the medial and lateral LVDT amplitudes and the FE micromotion was the maximum value in the anterior region 100 mm distal from the bottom of the tray. Although there was a discrepancy between the results from the FEA and the testing, both showed the same trend of decreasing micromotion with increasing stem length.

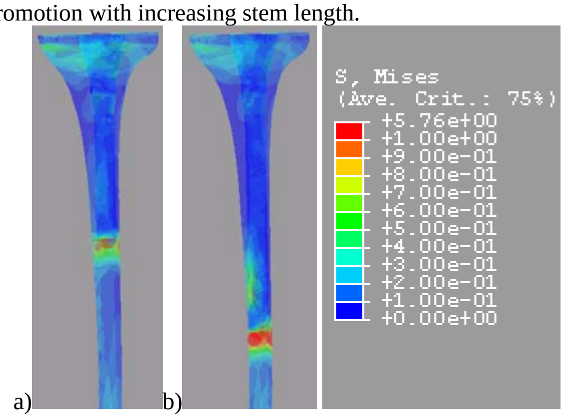

Figure 1 – Cancellous von Mises (MPa) stress for a) 145 mm stem b) 200 mm stem with a medial defect

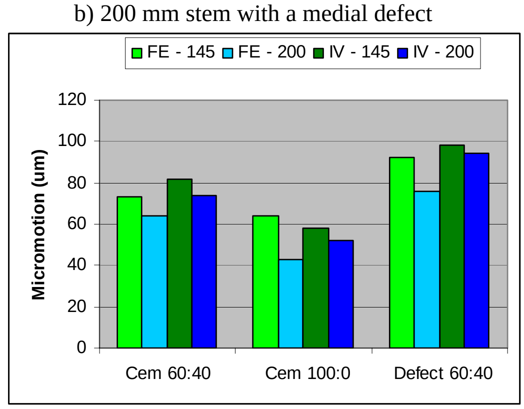

Figure 2 – Micromotion results from in-vitro (IV) and finite element (FE) testing for a 145 and 200 mm length stem

CONCLUSION

This pilot work found that an intramedullary stem successfully transfers load from the damaged proximal tibial bone to the diaphysis. A longer stem increased the load transfer and improved the stability of the implant, at 100 mm below the bottom of the tibial tray.
However, further work is required to accurately assess the tradeoff between stability and load transfer using FE models created from CT data of human tibial bones.

ACKNOWLEDGMENT

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