FINITE ELEMENT ANALYSIS OF STEM DIMENSIONS IN A REVISION TOTAL KNEE ARTHROPLASTY USING VISIBLE HUMAN COMPUTED TOMOGRAPHY DATA

J Schmidt [1*], A Henderson[2], H Ploeg [1], K Deluzio [2], M Dunbar [2,3]
[1]Department of Mechanical Engineering, University of Wisconsin-Madison, Madison, WI
[2]School of Biomedical Engineering, Dalhousie University, Halifax, NS [3]QEII Health Science Center, Halifax, NS
** 1550 University Avenue, Madison, WI 53706,Tel: 608-263-6692, Fax: 608-265-2316, jschmidt1@wisc.edu*

INTRODUCTION

The Orthopedic Network News reported that 171,335 primary knee and 16,895 revision total knee arthroplasties were performed in 2001 alone [1]. Due to the additional bone loss that accompanies revision surgeries, stemmed implants are used to achieve a well-fixed and stable implant. Yet, evidence-based surgical guidelines for stem selection are not available. Finite element (FE) modeling from computed tomography (CT) data has been previously used to provide a better understanding of bone mechanics when orthopedic implants are inserted [2, 3]. A pilot study, using composite tibia bone, was performed to establish a protocol to create a FE model from CT data using commercial software, and validated with mechanical testing [4]. A more realistic model is needed to accurately determine the effect of stem diameter and stem width of the tibia component in a revision total knee arthroplasty. Therefore, the current project created FE models from cadaveric CT data to test the hypothesis that the diaphyseal contact of the distal stem of a tibial component decreases micromotion and promotes healthy bone remodeling to increase long term implant fixation.

METHODS

Four FE bone models were created for this study from the left and right tibias of the Visible Human male and female data sets (United States National Library of Medicine, Bethesda, MD). The protocol used to create FE models from CT data is outlined in **Figure 1**.

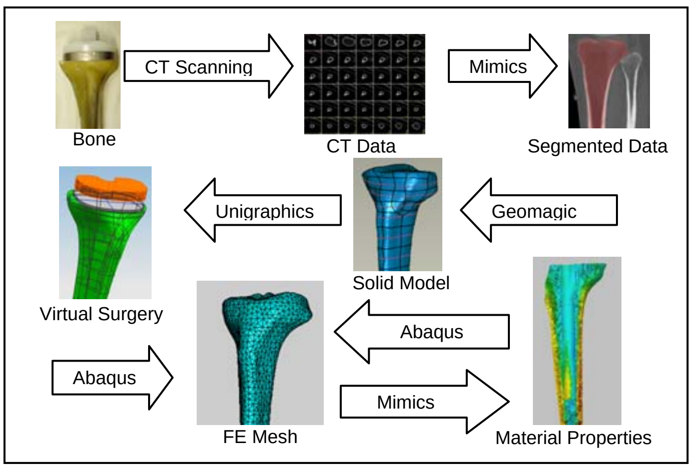

Figure 1 *Flow chart showing the protocol established to create FE models from CT data using material properties assigned on an element by element basis using the Housfield unit form the CT data.*

Specifically, the bones were CT scanned to provide information about the geometry and material properties of the bones. The CT data were segmented using Mimics 9.0 (Materilise, Ann Arbor, MI) software and data were exported in a binary stereolithography (stl) format to Geomagic Studio 6 (Raindrop Geomagic, Inc., Research Triangle Park, NC) where solid models of the normal bone were created. Virtual surgery was performed on the solid models using Unigraphics NX 2.0.0.21 software (UGS, Plano, TX) to implant models of the tibial components (Zimmer, Warsaw, IN). A mesh was then created in Abaqus 6.4 (Abaqus Inc., Providence, RI) and exported back into Mimics where material properties were assigned on an element by element basis (**Figure 1**) using previously defined relationships between Hounsfield unit and elastic modulus [5, 6] (**Figure 2**). Additional material properties were defined as in **Table 1**. Each tibia was inserted with four different stem lengths (75, 125, 155, 175 mm) and three stem diameters defined as under reamed, normal, and over reamed. Over and under reaming were defined as a stem ± 2mm from the normal stem which created initial contact with the cortical region of the bone. In addition, two different medial to lateral loading cases of 2kN were applied (100:0, 60:40).

Material	Elastic Modulus (GPa)	Poisson's Ratio
Cement	2.0	0.23
Polyethylene	1.0	0.45
Titanium	110	0.3

Table 1, above
Material properties assigned to implant within the FE model.

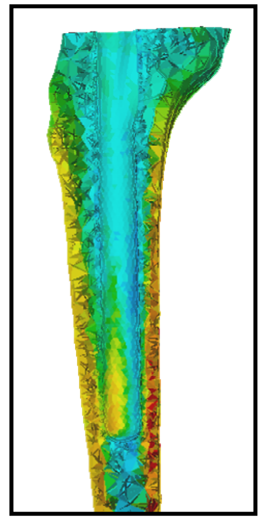

Figure 2, right
Sagittal view of material properties distribution in bone, shown without implant. Elastic modulus for bone was determined from CT data and Poisson's ratio was 0.3.

ANALYSIS

The FE results were analyzed to determine the micromotion between the stem and bone at the stem tip, along with the maximum von Mises stress at the proximal and distal ends of the implant. Results were analyzed to determine the effect of stem length and stem diameter. Results were also compared to the initial pilot study, using the composite bone, results from FE analysis and mechanical testing [4].

DISCUSSION

The method of creating FE models from CT data has not yet been standardized. Previous studies have created semi-automated [2] and automated [3] methods while the current study has applied a method using commercially available software. This approach allows for easier comparison between inter-laboratory studies.

The current study provides initial results relating stem length and diameter to micromotion and stress in bone. This provides a basis for development for models which include additional FE boundary conditions and bone remodeling algorithms. These more advanced models will provide evidence based surgical guidelines for both pre-operative and operative stem selection guidelines to encourage healthy bone remodeling for patients.

REFERENCES

1. Orthopedic Network News. *CMS Med Par*. 9/8/03. www.OrthopedicNetworkNews.com.
2. Cattaneo, P.M., M. Dalstra, and L.H. Frich. Proceedings of the Institution of Mech Eng. Part H, 2001. **215**(2): p. 203-13.
3. Keyak, J.H., et al. in *35th Annual Meeting, Orthopaedic Research Society*. 1989. Las Vegas, Nevada.
4. Henderson A, Schmidt J, Ploeg H, Deluzio K, Dunbar M submitted to *14th Annual Symposium on Computational Methods in Orthopaedic Biomechanics*. 2005. Chicago, IL.
5. Hvid, I., et al. J Biomech, 1989. **22**(8-9): p. 837-44.
6. Rho, J.Y., M.C. Hobatho, and R.B. Ashman. Medical Engineering & Physics, 1995. **17**(5): p. 347-355.