A NUMERICAL INVESTIGATION INTO THE APPLICATION OF AN ORTHOTROPIC POROUS STRUCTURE FOR A FEMORAL STEM MANUFACTURED USING LASER MELTING TECHNOLOGY

Kevin Hazlehurst, Chang Jiang Wang, Mark Stanford
Department of Engineering, University of Wolverhampton, United Kingdom

Introduction

Following total hip arthroplasty the load transfer into the host bone can be reduced by the insertion of stiff femoral stems that exhibit homogeneous and isotropic behaviour. Bone resorption caused by stress shielding can promote premature implant loosening and the need for revision surgery [Whiteside, 1989]. Through using additive layer manufacturing techniques it is now possible to match the stiffness characteristics between the implant and host bone [Murr, 2010]. Numerical studies have shown that more flexible implants with a non-homogeneous structure have the potential to preserve periprosthetic bone stock following surgery [Gong, 2012]. However, utilising porous structures with orthotropic properties for a cementless femoral stem that could be manufactured using laser melting technology appears to have been overlooked. This work compares the stress distribution in the periprosthetic femur when implanted with Cobalt Chrome Molybdenum (CoCrMo) stems of varying stiffness and material behaviour.

Methods

ANSYS finite element modelling software was used to determine the orthotropic material properties of a porous cellular CoCrMo structure with a strut size of 0.50 mm. The orthotropic structure was designed in order to emulate the mechanical properties of femoral cortical bone. The fully dense CoCrMo and cortical bone were both modelled as linear isotropic materials. The elastic modulus was 210 GPa and 17 GPa, with Poisson's ratios of 0.3 and 0.33 respectively. The stress distribution in the periprosthetic bone was analysed using a simplified three dimensional model of a cylindrical tapered femoral stem inserted into cortical bone. The distal end of the femur was constrained and a 3000 N resolved point load was applied at thirty degrees to the vertical axis at the proximal end of the stem [Gong, 2012]. The models were meshed with solid eight node hexahedral elements. Fully bonded surface to surface contact conditions were created to simulate ideal fixation at the bone-implant interface.

Results

The isotropic and orthotropic stems with cortical bone properties showed increased levels of stress in both proximal and distal regions. The fully orthotropic stem produced increased stress values in the central region and proximal rim of the bone, Figure 1c. Using a porous core improved the stress distribution when compared to the solid stem. There was no obvious difference observed in the stress distribution between the isotropic and orthotropic graded stems, Figures 1d and 1e.

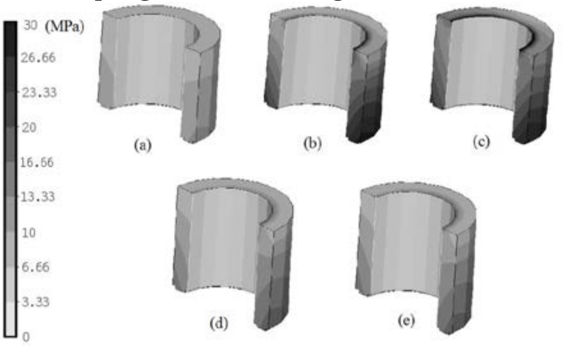

Figure 1: Sectional view of the von Mises stress in the proximal bone, (a) Solid CoCrMo stem, (b) Stem with isotropic cortical bone properties, (c) Fully porous orthotropic stem, (d) Graded stem with a porous isotropic core, (e) Graded stem with a porous orthotropic core.

Discussion and Conclusions

This work considers that the stress value in the bone can be used as a basis for predicting bone remodelling. The results then show that orthotropic material behaviour and using a porous core could potentially help to preserve periprosthetic bone stock. The introduction of a CoCrMo outer skin to the stem appeared to negate the benefits of using orthotropic material properties. Therefore, the adoption of using orthotropic material properties in conjunction with a functionally graded cementless femoral stem does not appear to be beneficial based upon the results from this work.

References

Gong *et al*, J Bionic Eng, 9:66-74, 2012.
Murr *et al*, Phil Trans R Soc A, 368:1999-2032, 2010.
Whiteside, Clin Orthop, 247:138-147, 1989.