

Stress shielding in the resurfaced femoral head

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STRESS SHIELDING IN THE RESURFACED FEMORAL HEAD

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Introduction

The development of wear-resistant bearings recently resulted in a renewed interest in resurfacing total hip arthroplasty. In the long-term, however, the success of such techniques, can be threatened by bone-implant loosening due to high interface stresses or stress shielding. In particular stress shielding of trabecular bone in the femoral head is likely to occur after placement of the stiff resurfacing implant. Although some authors have quantified stress shielding after resurfacing with conventional continuum finite element analysis [1], little is known about how, exactly, the stresses and strains in this critical femoral head region are affected.

Recently, micro- finite element (micro-FE) techniques were introduced that enable the determination of stresses and strains throughout trabecular bone regions at the level of the bone tissue [2]. The goal of this study was to analyze stress-shielding and interface stresses in trabecular bone of the femoral head after placement of a cemented resurfacing prosthesis using micro-FE analysis.

Materials and Methods

A micro-CT scanner (Scanco mCT80) was used to create high-resolution images of a normal human femur. These images were used to create a micro-FE model with brick elements of 80 microns in size. In an earlier study, stresses and strains in the femoral head of this femur were quantified for normal loading conditions [2].

For the present study, a generalized resurfacing prosthesis, consisting of a hemispherical cup with a short stem (Fig. 1) was artificially generated and added to the micro-FE model. The outer diameter of the cup was 44 mm, the thickness of the shell 1.6 mm and the length of the stem 65 mm. The femoral head was 'milled' such that a 1 mm space between the head and the inside of the cup was left. This space, and 0.6 mm of the adjacent intertrabecular space, was filled with cement, such that trabeculae would penetrate partly into the cement layer. The stem was assumed fully bonded. The complete micro-FE model consisted of over 114 million 8-node brick elements. Elements were given a stiffness of 15 GPa for trabecular bone, 22.5 GPa for cortical bone, 210 GPa for the implant and 2.28 GPa for cement.

The cup was loaded with a normal force representing the stance-phase of walking at 234% BW [3]. The distal end was fully constrained.

After solving, stress shielding within the femoral head was quantified for the regions Anteriro-Superior, Anterior-Inferior, Posterior-Superior and Posterior-Inferior.

Results

A contour plot of Von Mises stresses clearly revealed that most of the load is transferred through the stem of the implant (Fig. 2). Severe stress shielding was found in bone tissue of all regions in the femoral head, in particular in the inferior regions (Table 1). Stresses were also reduced in the neck cortical bone due to the stiffening caused by the stem.

Increased tissue stresses were found in trabeculae near the tip of the stem, at the medial side of the midstem and at some locations near the rim of the implant. Stresses in trabeculae at and near the bone-cement interface were generally low.

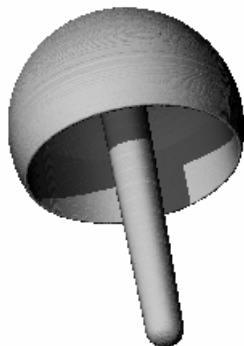


Fig. 1 The artificially created cemented resurfacing prosthesis

Discussion & Conclusion

For the implant studied here, femoral head bone loss is expected to occur in the long term due to stress-shielding. On the other hand, given the low interface stresses, interface loosening is not likely to occur.

Compared to continuum models, these micro-FE models are still challenging and require large multiprocessor computers (the present analysis took 2 weeks on 32 processors). Nevertheless, the micro-FE approach has some important advantages over continuum models. First, it fully accounts for trabecular bone volume fraction and anisotropy distribution. Second, it provides results at the level of the bone tissue, which is the level at which the cells sense the changes in loading and the level at which interface failure is initiated. Third, it enables the study of interfaces without making assumptions about their mechanical and geometrical properties. Fourth, trabecular and cortical regions are accounted for without making further assumptions. In particular, no trabecular bone density stiffness relationships need to be implemented in order to estimate the mechanical properties of trabecular bone at the continuum level. For these reasons we expect that this type of analysis can improve our understanding of stress-related failure phenomena in bone.

References

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2. van Rietbergen et al., JBMR, 18:1781 (2003)
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Acknowledgements

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region:	InfPos	InfAnt	SupPos	SupAnt
princ strain	-50%	-49%	-36%	-43%
Von Mises	-50%	-48%	-34%	-40%

Table 1: average change in trabecular bone tissue load after resurfacing in four regions within the femoral head.

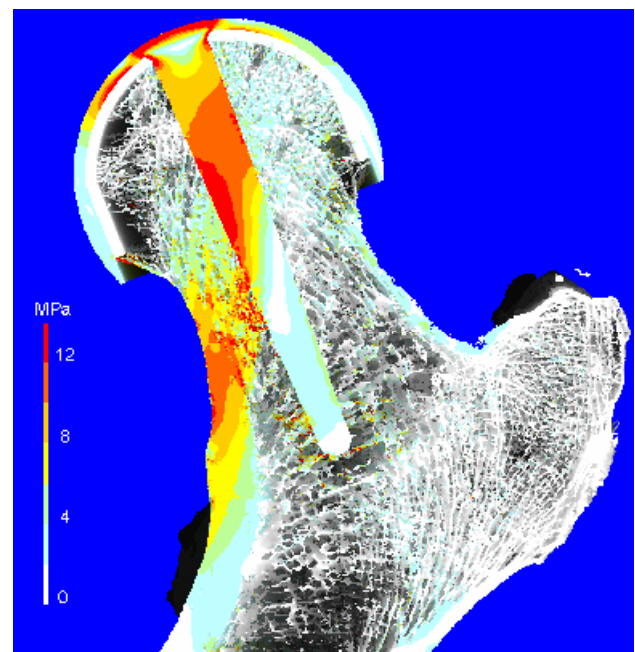


Fig. 2 Von Mises stresses in the bone tissue and implant due a hip-joint force representing the stance-phase of walking. The half-model is shown to reveal stresses in the trabeculae and stem