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Reduction of stress shielding in surface replacement arthroplasty by using a biomimetic composite material

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INTRODUCTION: The short metaphyseal stem of current surface replacement arthroplasty (SRA) of the hip is designed for alignment purposes and is not bonded to adjacent bone. To prevent early femoral head loosening some surgeons suggested to cement the metaphyseal stem to allow a more distal fixation[1]. The adverse effects of this fixation method may be increased stress shielding in the femoral head[2] and possibly compromised long term results. A possible solution to this problem would be the use of a composite material with bone-matching mechanical properties to fabricate the metaphyseal stem. Such a stem could be osseointegrated and provide the same kind of stable fixation as a cemented metallic stem without increasing stress shielding in the femoral head. The objective of this study is to verify the validity of this claim using a finite element model.

METHODS: A finite element model (FEM) was constructed; the femur was obtained from CT-scans of a patient and modeled with heterogenic mechanical properties. All material properties were modeled as isotropic and linearly elastic; trabecular bone heterogeneity was also modeled. Three models of a commercially available implant were constructed: an unfixed metallic stem, a cemented metallic stem (cement mantle is 1 mm thick) and an osseointegrated stem made of composite material. All bone-cement, implant-cement and osseointegrated interfaces were modeled as perfectly bonded; bone-metal interfaces were modeled as frictional interfaces. A static load case representing healthy gait was applied to evaluate stress shielding in the trabecular bone of the femoral head. Trabecular bone underneath the spherical part of the implant was divided into four zones; the same was done with the trabecular bone in the femoral neck.

RESULTS: Maximal compressive stress (σ_3) in these zones for the cemented and biomimetic stems was compared with that of the unfixed stem. The decrease in stress varied from 1.8% to 21.5% in the femoral head of the cemented stem; the infero-posterior and infero-anterior zones were the most severely stress shielded with -16.4% and -21.5% of stress respectively (see zones B and D on table 1). The same two zones in the biomimetic stem showed decreases of 5.5% and 0.2% respectively. The femoral neck regions did not show a clear trend.

Table 1. Stress shielding in the femoral head for cemented & biomimetic stems vs unfixed stem

	Cemented vs unfixed stem	Biomimetic vs unfixed stem
Zone A	-4.7%	+3.7%
Zone B	-16.4%	-5.5%
Zone C	-1.8%	-0.2%
Zone D	-21.5%	-0.2%

DISCUSSION & CONCLUSIONS: The FE model has showed increased stress shielding in the femoral head when the metallic stem of the implant was cemented; it has also shown that this stress shielding can be reduced if a composite material with bone-matching properties is used to fabricate the stem. The main limitation of this study is that it has been done with only one patient-specific femur, which may not represent clinical situations. Also, osseointegrated interfaces were modeled with bonded contacts, which cannot simulate aseptic loosening (bonded contacts will always remain attached regardless of load, micromotions or bone resorption).
Further studies will be necessary to confirm these findings; bone remodelling simulations will have to be done in order to assess the severity of long term bone resorption resulting from stress shielding.

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