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Use of a biomimetic composite material stem reduces stress shielding in surface replacement arthroplasty of the hip

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Objectives : A possible solution to the potential stress shielding of cemented metaphyseal stems of hip resurfacing implants is the use of a composite biomimetic material with bone-matching mechanical properties. Such a stem could be osseointegrated and procure extended fixation improving implant stability in cases where femoral head deficiencies are present (cysts, necrotic bone, osteopenia, etc.) without increasing stress shielding in the femoral head. The objective of the present study is to verify the validity of this claim using a finite element model (FEM).

Methods : A FEM was constructed based on CT-scan images of a patient who underwent surface replacement arthroplasty (SRA) . The images were segmented and a 3D reconstruction of the right femur was made; this geometrical model was then implanted with a commercially available implant. Three variants of the implant were used (the spherical part of the implant was cemented and unmodified in either case) : an unbonded metal stem, a cemented metal stem (1-mm coating thickness) and an osseointegrated stem made of composite material. Implants were positioned at 5° valgus (what is considered the optimal position for this type of implant) and the resulting geometrical models were validated by two surgeons (co-authors PAV and ML). All models were meshed with quadratic tetrahedral elements. Cancellous bone material properties were modeled as heterogenic and linearly elastic; all other material properties were modeled as isotropic and linearly elastic (with $E_{cortical\ bone}$=17 GPa, $E_{bone\ cement}$=2.07 GPa, $E_{metallic\ implant}$=210 GPa, $E_{biomimetic\ composite}$=25 GPa). All interfaces were modeled with contact elements; frictional contact was used for cement-implant and cortical bone-cement interfaces, all other interfaces used bonded contacts. A static load case representing healthy gait was applied to evaluate stress shielding in the trabecular bone of the femoral head. The trabecular bone underneath the implant was split into four zones: the maximal compressive stress (σ_3) of the cemented stem implant and biomimetic stem implant was compared with the unbonded stem implant for all four zones.

Results: Results from the FEM indicate that a cemented metal stem causes increased stress shielding when compared with the same implant having an unbonded metal stem. Stress decrease in the cemented stem implant was 16.4% and 21.5% for the infero-posterior and infero-anterior zones respectively; the same zones showed only a 5.5% and 0.2% increase for the biomimetic stem implant. The trabecular bone in the femoral neck did not present a clear trend of stress shielding. Because the stress shielding zone underneath the spherical part of the implant cannot be evaluated clinically with DEXA or QCT exams, these results cannot be confirmed clinically but seem to concur with results from published FEM and retrieval studies.

Conclusion: An osseointegrated metaphyseal stem made of biomimetic material in hip resurfacing implants seems to reduce the stress shielding effect observed in the femoral head in comparison with a bonded Chromium-Cobalt metallic stem. Such a biomimetic stem could become an interesting alternative when fixation extension is desired.