Abstract

Mechanical loosening of the uncemented acetabular components has been mainly attributed to bone resorption and excessive generation of wear particle debris. The precise relationship between the cause and effect of mechanical loosening and the extent to which mechanical factors play a role in the process are not clearly understood yet. This study is aimed at investigating the load transfer and the effect of implant-induced bone adaptation, and its relationship with the failure risk, using numerical and experimental techniques. A new experimental set-up was developed, with specially designed fixtures and supporting mechanisms, in order to validate reasonably accurate three-dimensional (3-D) finite element (FE) models of intact and implanted composite pelvises. Measurement of full-field and discrete strains at various locations on the intact and implanted hemi-pelvises and implant-bone micromotions along three orthogonal directions were undertaken and validated using equivalent FE models. Subject-specific 3-D FE models of intact and implanted pelvises were developed using CT-scan data. The most appropriate method of application of the hip joint force on the intact pelvis was investigated. Application of hip-joint force through an anatomical femoral head having a cartilage layer was found to be more appropriate than a perfectly spherical femoral head, thereby leading to more accurate stress-strain distribution in the acetabulum. The musculoskeletal loading condition included twenty-one muscle forces and hip joint force of a normal walking cycle. The effects of different implant materials (CoCrMo alloy, alumina ceramic, CFR-PBT with UHMWPE liner and CFR-PEEK), implant design and implant-bone interface conditions on bone remodelling were investigated. Strain shielding and bone resorption were considerably higher for bonded implant-bone interface condition as compared to debonded implant-bone interface condition. Since bone remodelling for the ceramic components was not much worse than the metallic components and considering the improved wear properties of the alumina ceramic, the alumina ceramic appeared to be viable alterative to CoCrMo alloy. In case of composite cups, the stiffness of the acetabular component (e.g., design, material, thickness) played a crucial role in bone remodelling process. Compared to the horseshoe-shaped design, the hemispherical design exacerbated bone resorption. The horseshoe-shaped CFR-PEEK acetabular cup with 3 mm thickness seemed to be a promising alternative bearing surface considering bone deformation, stress shielding and bone remodelling. A mixed-integer multi-objective optimization problem was formulated and solved using genetic algorithms to obtain optimal design parameters that would minimize bone resorption as well as volumetric wear. Thickness of the acetabular component played a predominant role in bone adaptation and volumetric wear. A combination of suitable implant material and corresponding optimal thickness was obtained from the Pareto-optimal front of solutions. The CFR-PEEK material appeared to be the most suitable bearing material as compared to other bearing materials, such as CoCrMo alloy, ceramic, UHMWPE.

Keywords: hip, pelvis, finite element analysis, acetabular component, *in vitro* testing, strain rosette, digital image correlation, implant-bone micromotion, strain shielding, bone remodelling, bone density, wear, multi-objective optimization, genetic algorithm.