Abstract

Quantitative evaluation of peri-acetabular bone ingrowth and bone remodelling is necessary to assess failure of uncemented acetabular component. However, there is a scarcity of studies investigating the combined influences of bone ingrowth and remodelling on fixation of acetabular component. Quantitative predictions of bone ingrowth and remodelling call for FE-based numerical study combining the mechanoregulatory tissue differentiation and adaptive bone remodelling algorithms. Since both these processes depend on the mechanical environment, a detailed description of the loading history, implant geometry and bone quality is necessary for FE-based pre-clinical analysis. Using patient-specific FE models of intact and implanted pelvises, a numerical study was performed to investigate the influence of simplifications in loading regimes on numerical evaluation of acetabular component. Results indicated that consideration of eight load cases representing the entire gait cycle was required for a thorough evaluation of mechanically induced implant failure. In order to account for the macroscale regional variations in host bone material properties and implant-bone relative displacements within the 3-D microscale model of implant-bone interface, a novel mapping framework has been developed. This framework was found useful in predicting the spatial variation in progressive peri-acetabular tissue differentiation. A close agreement between the predicted trends and the previous findings provided confidence in the use of this framework for numerical predictions of bone ingrowth. The efficacies of phenomenological and cell-phenotype specific mechanoregulatory algorithms in predicting bone ingrowth were quantitatively compared. The phenomenological algorithm was found computationally faster, however, the cell-phenotype specific algorithm was particularly useful in investigating the influences of cellular activities on bone ingrowth. The influences of implant surface texture designs on bone ingrowth were investigated through a full-factorial design of experiment (DOE) based statistical method along with sequential phenomenological algorithm. Results indicated that the bone ingrowth process was inhibited due to an increase in inter-bead spacing from 200µm to 600µm and bead diameter from 1000µm to 1500µm and a reduction in bead height from 900µm to 600µm. The bead height (amongst the main effects) was found to have a predominant influence on bone ingrowth. Thereafter, a multiscale framework has been developed to simulate the combined effect of bone ingrowth and remodelling around an acetabular component. The results indicated that for an uncemented acetabular component made of CoCrMo, there was hardly any effect of bone ingrowth on bone remodelling. However, bone remodelling was found to have considerable influence on bone ingrowth.

Keywords: acetabular prosthesis, uncemented, bone ingrowth, bone remodelling, tissue differentiation, mechanobiology, implant-bone micromotion, phenomenological, cell-phenotype specific algorithm, finite element analysis, design of experiment, multiscale framework.