MECHANOBIOCHEMICAL BASED ORTHOTROPIC BONE REMODELING AROUND UNCEMENTED ACETABULAR COMPONENT

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Introduction

Aseptic loosening of acetabular component is often associated with the adverse effect of periprosthetic bone remodeling owing to stress/strain shielding. An earlier study proposed a thermodynamic-based model that could incorporate the coupling between the mechanical loading and biochemical reactions associated with bone adaptation [1]. Although mechanobiochemical (MBC) model was considered in a few studies, bone anisotropy was ignored in the algorithm [1, 2]. The objectives of the study were: (1) to develop a novel framework incorporating MBC model with the orthotropic bone remodeling algorithm, and (2) to further compare the predictions with those of orthotropic strain-based remodeling [3].

Methods

The patient-specific 3-D finite element (FE) models of intact and implanted hemipelvises were developed following the procedure as reported in our previous study [4]. The implanted model comprised of pelvic bone and a component resembling Zimmer Trilogy^{TM} acetabular cup having outer diameter of 54 mm with Ti-alloy metal-backing (5 mm thickness) and UHMWPE liner (6 mm thickness). The newly developed framework considered a thermodynamic-based bone adaptation along with the orthotropic material property determination based on the strains along the principal directions. The standard law of mass action was modified as Eqn. 1, to achieve the coupling between the concentrations of the constituents in the biochemical reactions (biochemical affinity of the reactions) and the mechanical stimulus [1].

$$r_\alpha = k_{+\alpha} \prod_{i=1}^{n} [N_i]^{v_{\alpha i}} - k_{-\alpha} \prod_{i=1}^{n} [N_i]^{v'_{\alpha i}} + l_{\alpha v} d_{(1)} \quad (1)$$

Where r_α and A_α represents the rate and affinity of the α^{th} biochemical reaction (α = 1 to 5), l and k represents the phenomenological and reaction rate coefficients, respectively, $d_{(1)}$ represents the rate of dilatation (rate of volume variation). $v_{\alpha i}$ and $v'_{\alpha i}$ are the stoichiometric coefficients of the mixture of N_i entering and leaving the α^{th} reaction, respectively [1].

Results

The changes in bone density distribution, after equilibrium in bone remodeling, corresponding to orthotropic strain-based model (Figure 1b) and orthotropic MBC model (Figure 1c) were compared. The orthotropic strain-based model predicted an appreciable bone resorption (~78%) in the region of interest (ROI) 1, whereas the orthotropic MBC model predicted a slightly lesser reduction in average bone density (~73%) in the ROI 1. The sectional plots of Figures 1b and 1c indicated similar trends of high bone resorption (70-80%) by the both models. However, more volume of bone elements (10-20%) were subjected to bone resorption in the orthotropic MBC model.

Discussion

Bone apposition was observed near the acetabular rim for orthotropic strain-based model and the orthotropic MBC model (Figure 1). However, bone resorption was more predominant in the orthotropic MBC model (Figure 1). Despite similarities, notable deviations in periprosthetic bone density distributions were observed (Figure 1). These results corroborated well with clinical studies. Hence this novel framework, combining biochemical and the mechanical stimuli along with bone anisotropy, adequately predicted bone adaptation around an uncemented acetabular component.

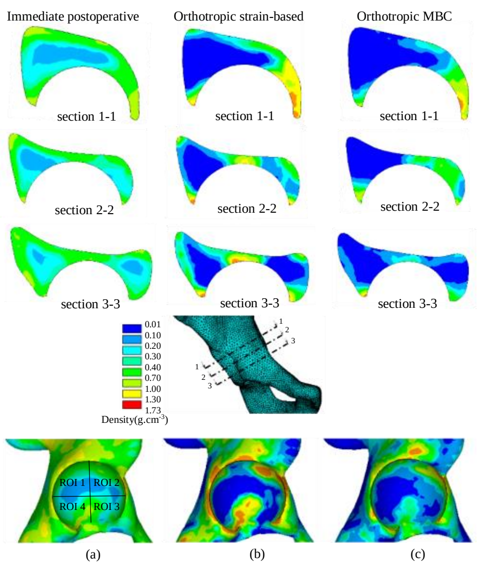

Figure 1: Changes in bone density distribution owing to implantation, sectional and lateral views: (a) immediate postoperative; (b) orthotropic strain-based model predictions; (c) orthotropic MBC predictions.

References

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