INFLUENCE OF POLAR GRADATION ON DESIGN OF FUNCTIONALLY GRADED POROUS ACETABULAR COMPONENT

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Introduction

The stiffness mismatch between an implant and host bone causes stress/ strain-shielding in the periprosthetic bone, leading to bone resorption and eventual loosening. However, the adverse effect of stress shielding can be limited by reducing the overall stiffness of the implant. Alternatively, the implant's stiffness could be reduced by introducing porosity, thereby varying the microstructure of the implant. Variation in stiffness across an implant can also be achieved by functionally grading the porosity of the implant material. This study is aimed at a novel design of functionally graded porous metal-backed (FGPMB) acetabular components.

Methods

The patient-specific three-dimensional finite element (FE) models of intact and implanted hemipelvises were developed following the procedure reported earlier [1]. The effective orthotropic mechanical properties of the porous structure were calculated using homogenization of a tetrahedron-based unit cell. The V_1, V_2 and V_3 denoted the volume fractions corresponding to porosity levels p_1, p_2 and p_3, respectively (Figure 1). The porosity levels p_1, p_2 and p_3 were taken as 50%, 0%, and 81%, respectively. A porosity of 50% was assumed at the inner radius (θ=0°, R=R_1) of the component rim that corresponded to an elastic modulus of 30 GPa [2]. Since the cancellous bone around the dome experienced strain-shielding and eventual bone resorption [1], a porosity level of 81% was chosen at the dome (θ=90°). A porosity level of 0% was chosen at the outer rim (R=R_2, θ=0°), owing to bone apposition in the cancellous bone around the component rim [1]. The values of V_1 , V_2 and V_3 were determined as follows:

$$V_1 = V_S\left[1-\left(\frac{R-R_1}{t}\right)^{m_R}\right] \quad (1); \quad V_2 = V_S\left(\frac{R-R_1}{t}\right)^{m_R} \quad (2)$$

$$V_s = 1-\left(\frac{\theta}{\theta_0}\right)^{m_\Theta} \quad (3); \qquad V_3 = \left(\frac{\theta}{\theta_0}\right)^{m_\Theta} \quad (4)$$

Here θ_0 is equal to 90°, m_θ is the parameter that controls the gradation of porosity along the polar (θ) direction. Moreover, m_θ was assigned with five different values, such as 0.1, 0.25, 0.5, 1.0 and 5.0. The parameter, m_R controls the gradation of porosity along radial (R) direction and was taken as 1.0.

Results

Change in polar gradation exponent resulted in deviations in cancellous bone strains, average volumetric wear of polyethylene liner, implant-bone micromotion and changes in bone density distribution. Although m_θ = 0.1 exhibited a 20% increase in the volume of elements with higher strains as compared to m_θ = 0.25, a sudden change in the porosity was observed near the acetabular component rim (θ = 0°). As compared to m_θ = 0.25, more volume of bone elements, ~75% and ~100% were subjected to bone resorption for m_θ = 0.5 (section 1-1, Figure 2c) and m_θ = 5.0, respectively. An increase of ~40% in the average bone density was noted for m_θ = 0.25 in ROI 1. Only a minor increase of ~7% in average volumetric wear and implant-bone micromotion was observed with a reduction in polar gradation exponent from 5.0 to 0.25.

Discussion

A decrease in polar gradation exponent led to a reduction in bone resorption along with a slight increase in volumetric wear and micromotion. Bone resorption around the posterior-inferior region of the implanted acetabulum for different porous metal-backing was similar to that of solid backing [1]. It should however, be noted that as compared to the solid metal-backing, the bone apposition near the acetabular dome was higher for FGPMB. Hence, the FGPMB having polar gradation exponent of 0.25 appeared to be a viable alternative to the solid component.

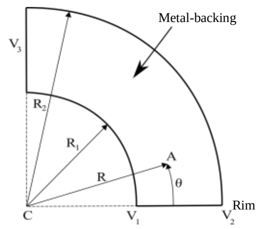

Figure 1: 2-D representative metal backing.

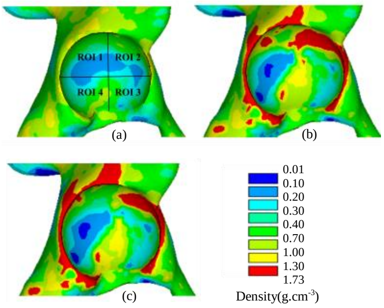

Figure 2: Changes in bone density distribution owing to implantation: (a) immediate postoperative; (b) post remodeling, m_θ =0.25; (c) post remodeling, m_θ =0.50.

References

1. Saviour et al., J Biomech Eng,145(2):021009, 2023.
2. Hedia et al., Int J Mech Mater Des, 2: 259–267, 2005.