NUMERICAL EVALUATIONS OF FUNCTIONALLY GRADED POROUS INTERBODY CAGE FOR SPINAL FUSION

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Introduction

Functionally graded porous (FGP) interbody cages might offer a trade-off between porosity-based reduction of implant stiffness and mechanical properties. Although earlier studies have investigated the influence of graded porosity on the stress-strain related failure mechanisms, the effect of graded porosity on an interbody cage for spinal fusion has scarcely been investigated [1, 2]. A novel design of an FGP interbody cage is hypothesized to yield favourable bone remodelling owing to graded porosity and offer sufficient stiffness to restrict the Range of Motion (RoM), necessary for primary stability. The study aims to investigate the deviations in load transfer and associated potential failure of FGP interbody cages and to evaluate peri-prosthetic bone remodelling around various FGP interbody cages. A comparison with a cage model with 78% uniform porosity (P78 model) has also been undertaken.

Methods

The patient-specific FE models of the intact and implanted lumbar spine were developed following the procedure reported earlier [3]. The effective orthotropic mechanical properties of the porous structure were calculated using homogenization of a tetrahedron-based unit cell. The Porosity 1 (P_1) and Porosity 2 (P_2) of an interbody cage element are defined by volume fractions V_1 and V_2, which correspond to the porosity in the inferior/superior regions and the central region of the cage. Three different porosity levels of 48%, 65%, and 78% were considered for P_1, which corresponds to FGP models A, B, and C, respectively. A P_2 value of 0% was assumed, which corresponds to solid-Ti alloy in the central region of the cage. The gradation of porosity within the cage is governed by the following equations:

$$\boldsymbol{V_1} = \left[\mathbf{1} - \left(\frac{|z|}{h/2}\right)^{m}\right] \quad (1); \qquad \boldsymbol{V_2} = \left[\left(\frac{|z|}{h/2}\right)^{m}\right] \quad (2)$$

Here, h is the cage height, m is the gradation exponent which controls the distribution of materials along the gradation direction (z). The applied loading conditions included a compressive follower load of 280 N, followed by a moment of 7.5 N-m to simulate flexion, extension, lateral bending, and torsion.

Results

The RoM of the implanted model was reduced by 81 – 88%, as compared to the intact model, for all physiological movements. Variations in stiffness affected strain distribution and bone remodelling around the cages. Peak strains of 0.5–1% were observed in less number of peri-prosthetic bone elements for the FGP cages as compared to the solid-Ti cage. For the FGP model C, bone apposition of 11–20% was predicted in the L4 and L5 regions of interest (ROIs) for the FGP model C. The deviations in bone density change between FGP Model C and P78 model were 3–8% for L4 and L5 ROIs (Figure 1). FGP resulted in a reduced average micromotion (~70–106 μm) as compared to solid-Ti (116 μm) for all physiologic movements.

Discussion

Implantation with cage led to an increase in peak strains and bone density around the interbody cage. However, the adverse effect of bone remodelling was less for the FGP cages as compared to solid-Ti cage. Although the P78 model offers almost similar mechanical behaviour and bone remodelling trends, the FGP Model C offers reduced RoM thereby improved primary stability. Compared to solid-Ti and uniformly porous cages, the FGP cage seems to be a viable alternative considering the conflicting nature of strength and porosity.

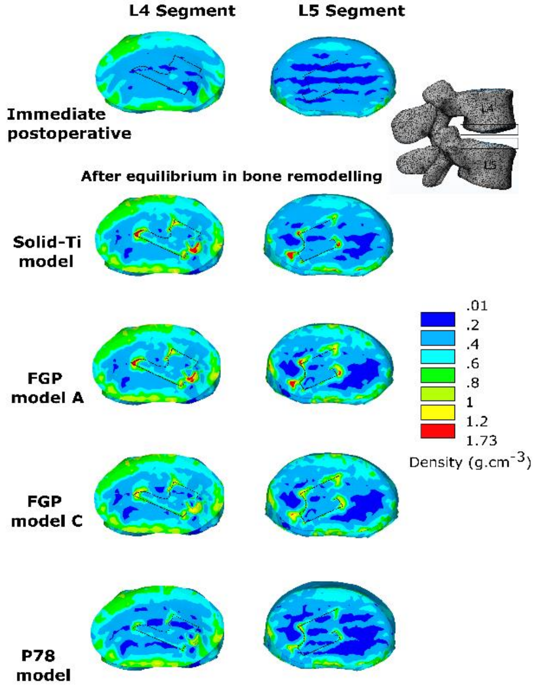

Figure 1: Bone density distribution in the L4 and L5 ROI for different cage models.

References

1. Bahraminasab et al., Mater. Des. 52: 441-451. 2013.
2. Moussa et al., J Med Eng. 1-10. 2017.
3. Talukdar et al., J Biomech Eng. 144(10). 2022.