A study on the mechanical property and permeability of porous hierarchical bone scaffold

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Abstract

Bone repair needs porous scaffolds, which should match the natural hierarchical bone tissue and provide suitable mechanical support and permeability to allow cell activities, mass transport and bone ingrowth. Mechanical properties and permeability of scaffolds conflict as their porosity varies, then, based on one- and two-level periodic hierarchical scaffolds, the scaffolds are optimized to balance the two physical properties.

The representative volume cell (RVC) of the one-level scaffold is formed by subtracting three small cuboids from a large cuboid, and the obtained transverse (*xy*) isotropic structure is denoted by $\beta = b^{(1)}/a^{(1)}$, where $a^{(1)}$ and $b^{(1)}$ are side lengths of the pores, respectively. The RVC of the two-level scaffold is self-similarly formed by assembling 20 one-level RVCs, obtained through lengthening $l_z^{(1)}$ with $\beta = l_z^{(1)}/l_x^{(1)}$, where $l_z^{(1)}$ and $l_x^{(1)}$ are side lengths of the first-level RVCs and the self-similarity means that the first- and the second-level RVCs share a common β. Considering four transverse anisotropic structures (β = 1.00, 1.06, 1.10, 1.15), their strain-stress curves, Young's moduli, and yield stress are simulated by a commercial finite element software (Abaqus); the permeable process are simulated by a software (Fluent), and Darcy's law is employed to calculate the permeability of the structures. The normalized mechanical properties and permeability are analyzed to get the optimal structure.

For both one-level and two-level scaffolds, when β is constant, the Young's moduli is approximately negatively proportional to the scaffold porosity; when β increases, the Young's moduli and yield stress of the structure show a bigger and bigger difference in *x*- and *z*-directions, and this means that a greater β lead to a larger anisotropy. The mechanical anisotropy of the one-level scaffold is higher than that of the two-level. The permeability is opposite to the mechanical anisotropy of the one- and two-level structure, namely, when β is constant, it is quasi-linearly and positively related to the porosity in the *x*- and *z*- directions. However, the permeable anisotropy of the two-level scaffold is higher than that of the one-level, and a greater β leads to a lower anisotropy for both scaffolds. For the optimal one-level structure, $E_y^{(1)}$ is around 1300MPa ~1700MPa and $K_y^{(1)}$ is around 5000DC~6000DC, and correspondingly, the porosity is around 0.78~0.84; for the optimal two-level structure, $E_y^{(2)}$ is around 1025MPa ~1065MPa and $K_y^{(2)}$ around 8680DC~9680DC, and the optimal porosity is around 0.83~0.86.

Geometrical parameter β greatly influences the anisotropy of the mechanical properties and the permeability, and they conflict as the scaffold porosity varies. The work could be useful for the optimal design of the anisotropic scaffold used in the bone tissue engineering.

Keywords: Hierarchical scaffold, Mechanical Properties, Permeability, Anisotropy, Optimization.