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Permeability and fluid flow-induced wall shear stress of bone tissue scaffolds: Computational fluid dynamic analysis using Newtonian and non-Newtonian blood flow models

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Abstract

Among the factors that are important in successful bone tissue regeneration through scaffolds are permeability and fluid flow-induced wall shear stress (WSS) because of the direct contribution of these factors to cell bioactivities. The permeability of scaffolds is usually measured using fluids such as water, which are characterized as Newtonian materials with constant viscosity. However, using the fluid properties of blood as bases in measuring permeability can lead to more realistic results given that scaffolds are implanted in the body, where the only flowing fluid (i.e., blood) is a non-Newtonian fluid. Moreover, the linear relationship of WSS with fluid viscosity challenges the use of Newtonian fluids in determining WSS magnitude. With consideration for these issues, we investigated permeability and WSS through computational fluid dynamics (CFD) analyses of lattice-based and gyroid scaffold architectures with Newtonian and non-Newtonian blood flow properties. With reference to geometrical parameters and the pressure drops derived from the CFD analyses, the permeability levels of the Newtonian and non-Newtonian models were calculated by exploiting the classic and modified Darcy's equations, respectively. Results showed that both scaffold architectures were several times more permeable in the Newtonian blood flow models than in their non-Newtonian counterparts. Within the scaffolds, the non-Newtonian flow of blood caused almost twice the magnitude of WSS originating from Newtonian blood flow. These striking discrepancies in permeability and WSS between the two blood models were due to differences in their viscosity behaviors.