Modeling Fluid-Induced Porous Scaffold Deformation

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Abstract

Utilization of bioreactors to regenerate tissues outside the body has been intensely investigated in functional tissue engineering. Various studies have been performed using computational fluid dynamics (CFD) to understand fluid flow within bioreactors while assuming porous scaffold as a rigid structure. However, the physical and mechanical properties of most tissue engineering scaffolds suggest otherwise. The objective of this study was to analyze the effect of fluid-induced stress on scaffold structure and nutrient consumption. The scaffolds were examined in a flow-through bioreactor configuration. Experiments were performed to evaluate the mechanical properties of chitosan-gelatin and polycaprolactone (PCL) scaffolds. Poisson's ratio of chitosan-gelation was higher than many isotropic materials and decreased with freezing temperature of the solution. PCL scaffold had a Poisson's ratio of 0.3. Simulations were performed by coupling fluid flow with structural mechanics using a moving mesh in COMSOL Multiphysics version 4.2a. Increasing in flow rate beyond 5 mL/min increased the deformation. The deformed mesh predicted a lowered pressure drop compared to the original mesh at flow rates beyond 5 mL/min. The effect of mechanical properties on pressure drop and deformation was also evaluated. A scaffold with higher Young's modulus and higher Poisson's ratio was recommended. Density of the scaffold did not show a significant influence on pressure drop or deformation. To examine the effects of fluid-induced stress on nutrient consumption, the consumption kinetics of oxygen and glucose were added to the simulation. There was decrease in nutrient consumption with the deformed mesh. A 3D geometry of parallel-flow and axial-flow bioreactors was designed. Free and Porous Media physics, Solid Mechanics physics, and Moving Mesh physics was added to the setup. The physical and mechanical properties, and boundary conditions was setup. The Free and Porous Media physics and Solid Mechanics physics was coupled using the two-way coupling method through Moving Mesh physics. To perform two-way coupling, fluid stress and strain calculated from Free and Porous Media physics was used in Solid Mechanics physics to predict deformation in the mesh, the Moving Mesh physics created a new deformed mesh; this new mesh was used by Free and Porous Media Physics to predict the new pressure drop.