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ROLE OF FLOW DEPENDENT AND FLOW INDEPENDENT VISCOELASTICITY ON TIME DEPENDENT BEHAVIOUR OF VISCO-POROUS SCAFFOLDS

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Summary: Three dimensional scaffolds can provide a controlled in vitro model for mechanobiological studies. However, determining the local mechanical environment surrounding cells is complicated due to the nonlinear and viscoelastic behavior of these biomaterials under loading. In particular, the mechanics of visco-porous scaffolds is influenced, among other factors, by flow-dependent and flow-independent viscoelasticity. By developing a reliable poro-viscoelastic model, we can separate flow-dependent and flow-independent mechanisms and numerically evaluate their contribution to the local mechanical environment. For this purpose, we combined experimental characterization and computational optimization to develop an accurate semi-inverse poro-viscoelastic model contrary to highly variable method of estimating flow-dependent and flow-independent contributing parameters together.

Different types of polymeric scaffold were fabricated and characterized. We developed a poro-viscoelastic finite element model using COMSOL Multiphysics to study time dependent behavior of the scaffolds. Different parameters for a poro-viscoelastic model are required including Equilibrium-Elastic modulus (Eeq), Poisson ratio (ν), strain-dependent permeability ($k(\varepsilon)$), porosity (φ) and relaxation function ($G(t)$) which is usually defined by Prony Series. Having measured Eeq, ν, $k(\varepsilon)$ & φ, we defined an optimization routine using particle swarm optimization (PSO), to estimate relaxation moduli and times (flow-independent contributing parameters) to have the same trend of stress relaxation for model and experiment. The objective function for PSO was defined to cover peak and equilibrium stresses as well as stress rate at critical time points.

The release of loading-induced fluid pressure takes a longer time in scaffolds with lower permeability contrary to the instantaneous relief in highly permeable scaffolds. By increasing the loading rate, the flow dependent viscoelasticity becomes the dominant contributing factor on transient local mechanical environment of poorly permeable scaffold. The relaxation moduli are directly correlated to crosslinking density of the scaffold, while there is an inverse correlation between relaxation times and crosslinking density of the polymeric network. We showed that the interaction and rearrangement of polymer chains under loading would be stabilized slower in a low-crosslinked scaffold compared to a constrained network. Indeed, the effective mechanism and time window for flow-dependent and flow-independent viscoelasticity can be tuned by permeability and crosslinking density of the biomaterials for different mechanobiological studies.