A Theoretical Framework for Modeling Arterial Tissue Equivalent Evolution

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There is a pressing need for arterial replacements for treating myriad vascular diseases in the coronary and peripheral circulations. Despite recent advancements in biocompatibility, patency, and burst pressures in arterial tissue equivalents (TEs), the resulting constructs possess dissimilar biomechanical properties as compared to native arteries and are thus unable to carry out the specialized functions of healthy native vessels. Furthermore, we lack clear knowledge on how and why TEs attain their properties, making it difficult to rationally improve these constructs. Naturally, bioengineers aim to discover the fundamental mechanisms by which evolving chemomechanical conditions affect remodeling. Towards these ends, we employ a growth and remodeling (G&R) theory build upon well-understood principles in continuum mechanics and accounting for biological processes including cellular proliferation and apoptosis, turnover of extracellular matrix proteins, and the reorganization of structurally-important collagen networks.

We have adapted our previously published thick-walled computational model of arterial growth and remodeling to match the conditions of the in vivo host remodeling of a polymeric graft. The simulation initializes with an elastomeric tube of known geometry and mechanical properties and subjected to physiological pressures, blood flows, and an axial stretch imposed by the proximal and distal arterial segments. The model predicts remodeling timecourses, geometries, and evolving mechanical properties resulting from varying turnover rates and accumulation of elastin, collagen, and smooth muscle. These predictions compare favorably to experimentally-observed 'neoarteries' from rat hosts. Moreover, results suggest that the coupled effects of polymer degradation and rates of collagen turnover can strongly influence bounded and unbounded growth in the early remodeling process.

Computational models cannot yet comprehensively capture the complex biological processes involved in tissue equivalent evolution, thus we must employ them alongside animal models to investigate various interventional cardiovascular procedures. However, theoretical frameworks founded upon hypothesized cellular behaviors and continuum mechanics have borne considerable progress and promise to continue to aid in the elucidation of complex biomechanical systems, the design of rational experiments, and the development of improved clinical interventions. We expect that such enabling and interpretive models will guide the development of improved arterial TEs.