Multi-scale Models of Coronary Perfusion

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Recent developments of both models and imaging are now providing a rapidly advancing set of tools with which to focus on the analysis of the structure function relationships central to coronary perfusion.

On the structural side ongoing advances in medical image acquisition and processing technologies across a range of modalities are now providing increasingly rich data sets from which detailed anatomically accurate models of coronary anatomy can be extracted. The complex structure of vascular networks inevitably imposes the requirement that this type of extraction is automatic which in turn often necessitates customizing the image processing techniques to the specific imaging modality focused on characterizing structure at a given spatial scale. At the whole organ scale an example this approach is the detailed model of the full coronary tree extracted from μCT data using iterative 2D sampling and boundary extraction using active contours. Comparison with high resolution scans from sub regions of the same sample indicate vessel radii can be accurately estimated using this approach down to ~20μm to form a network of ~2000 connected vessel segments. To complete the anatomical characterization at the microvascular scale we have recently tailored a different region growing approach to extract capillary beds from extended volume confocal imaging data.

The flow models applied on these geometries aim to decrease computational cost by reducing three dimensional Navier-Stokes equations to one dimension by assuming a radial velocity profile. Through coupling vessel radius to vascular pressure the nonlinear elastic properties of the coronary vascular wall can be characterized. By adding the force exerted on the vascular tree calculated from finite deformation models of cardiac contraction the coupling between coronary blood flow and myocardial contraction can be incorporated. While in large feeding vessels blood can be well approximated as a Newtonian fluid at the scale of microvascular perfusion viscosity reduces with vessel radius due to the Frahraeus-Lindqvist effect which significant affects the temporal and spatial dynamics of flow at this scale. To account for these non Newtonian effects, this one dimenenional framework has recently been extended to simulate blood flow within the microcirculation. On going work is now currently underway to integrate both the anatomical and functional models at the whole organ and microvascular spatial scales to provide a full multi-scale model of coronary flow.