An effective closure model for computational hemodynamics

Paris Perdikaris, Brown University; Leopold Grinberg, IBM T. J. Watson Research Center; George Em. Karniadakis, Brown University

The aim of the present work is to address the closure problem for hemodynamics simulations by developing a flexible and effective model that accurately distributes flow in the downstream vasculature and can stably provide a physiological pressure outflow boundary condition. We model blood flow in the sub-pixel vasculature by using a nonlinear 1D model in self-similar networks of compliant arteries that mimic the structure and hierarchy of vessels in the meso-vascular regime (radii 500μm – 10μm). In contrast with linearized impedance models, this approach overcomes cut-off radius sensitivity issues by introducing a monotonically decreasing artery length-to-radius ratio across different generations of the fractal tree and lacks dependence on the resistance/capacitance parameters typically required for outflow conditions. Our model accounts for wall viscoelasticity and non-Newtonian flow effects in small arteries and arterioles, and convergences to a periodic state in two cardiac cycles regardless of the initial condition used. The resulting fractal trees typically consist of thousands to millions of arteries, posing the need for efficient parallel algorithms. To this end, we have scaled up a Discontinuous Galerkin solver that utilizes the MPI/OpenMP hybrid programming paradigm, and is capable of computing near real-time solutions. The proposed model is extensively tested on a large patient-specific cranial network with 50 arteries and 21 outlets, returning physiological flow and pressure wave predictions without requiring any parameter estimation or calibration procedures.