Clinical data assimilation and uncertainty quantification in cardiovascular simulations

Alison Marsden, Daniele Schiavazzi, Tain-Yen Hsia

Patient-specific cardiovascular simulations require a combination of uncertain assumptions and inputs from clinical, physiologic, and imaging data. Current methods often require users to accept deterministic simulations as ``truth'' with no associated confidence intervals and offer no way to compare the reliability of simulation outputs. In addition, models often require laborious hand tuning to match boundary condition assignments to clinical data. We present a suite of efficient and automated tools for 1) assimilation of uncertain clinical data into lumped parameter networks, and 2) propagation of uncertainty to assign confidence intervals to simulation predictions. Bayesian parameter estimation with adaptive Metropolis sampling is used to identify the posterior distribution of boundary conditions generating model results compatible with the uncertain clinical data. These methods are designed to be fully automatic and to provide optimal physiological estimates in systems characterized by practical multimodality in the posterior. Three-dimensional unsteady finite element simulations of blood flow are performed using the SimVascular flow solver (simvascular.org). The solver is interfaced with stochastic collocation methods to propagate uncertainties to simulation outputs, compute associated confidence intervals and quantify parameter sensitivities. We illustrate the use of these tools in two clinical examples: single ventricle congenital heart patients, and coronary artery bypass graft surgery. This work is a step towards establishing quantitative metrics by which to judge cardiovascular simulation reliability, enabling future adoption in clinical practice.