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Optimal design and uncertainty quantification in blood flow simulations for congenital heart disease

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Recent work has demonstrated substantial progress in capabilities for patient-specific cardiovascular flow simulations. Recent advances include increasingly complex geometries, physiological flow conditions, and fluid structure interaction. However inputs to these simulations, including medical image data, catheter-derived pressures and material properties, can have significant uncertainties associated with them. For simulations to predict clinically useful and reliable output information, it is necessary to quantify the effects of input uncertainties on outputs of interest. In addition, blood flow simulation tools can now be efficiently coupled to shape optimization algorithms for surgery design applications, and these tools should incorporate uncertainty information. We present a unified framework to systematically and efficient account for uncertainties in simulations using adaptive stochastic collocation. In addition, we present a framework for derivative-free optimization of cardiovascular geometries, and layer these tools to perform optimization under uncertainty. These methods are demonstrated using simulations and surgery optimization to improve hemodynamics in pediatric cardiology applications.