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Patient-specific simulation and data analysis for diagnosis and treatment of heart valve disease

Johan Hoffman[1] **and Joel Kronborg**[1]

[1] KTH Royal Institute of Technology, Lindstedtsvägen 5, 114 28, Stockholm, Sweden,
{jhoffman,joelkro}@kth.se, kth.se/profile/{jhoffman,joelkro}

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We present our work on mathematical modeling and patient-specific simulation of the blood flow in the heart. Such simulations have the potential to be part of the standard workflow in the clinic, for example, to support diagnosis and treatment of heart disease. Through simulation, the blood flow can be investigated in great detail and properties of the blood flow can be computed which cannot be measured by imaging techniques, such as the local blood pressure and mechanical stresses. Here we focus on predicting adverse effects from treatment of left ventricle heart valve disease.

The mathematical model of the intraventricular blood flow and its interaction with the mitral and aortic valves presents challenges in terms of a complex geometry, turbulent flow, a deforming domain, and fluid-structure interaction with contact. The numerical method is based on an Arbitrary Lagrangian-Eulerian approach [2], where the blood and the valve tissues are modelled in one single computational mesh, and the implementation of the method is designed to be efficient on massively parallel computing platforms.

To analyze the mechanical stresses in the blood we use the triple decomposition of the velocity gradient tensor [1], by which shear flow can be separated from straining flow and rigid body rotational flow. The level and extent of different types of mechanical stresses can lead to an elevated risk for thrombosis events. Hence, a detailed analysis of simulation data could contribute to the risk assessment of clinical interventions.

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