Modeling and Simulation of Blood Flow and Hemolysis in LVADs

Motivation:
• heart disease as most frequent death cause for adults worldwide
• 50,000 persons could benefit from heart transplant (US)
• donor hearts available for only 2,500 patients each year (US)
• artificial hearts in use since 40 years
• total (TAH) or partial (LVAD) replacement of heart function

Mathematical Modeling and Numerical Solution:
• flow in the blood pump governed by incompressible Navier-Stokes equations of mass and momentum conservation
• blood modeled as Newtonian fluid
• in-house finite element solver XNS
• use of mesh-update techniques
• stabilized space-time Galerkin/Least-Squares (GLS) formulation

Simulation of the Flow Field:
• each revolution of the impeller divided in 200 time steps
• velocity and pressure data storage up to 30 GB for a revolution
• good correlation with experimental data, especially at low rpm

Challenges:
• required flow performance: 5 liters per minute
• pump size should be as compact as possible
• risk: damage of blood cells due to high shear in mechanical pumps
• risk: thrombosis due to recirculation areas in the flow field
• LVAD pumps oxygen-rich blood from left ventricle into aorta

Quantitative Blood Damage Prediction:
• red blood cell undergoes deformation under shear
• sublethal hemolysis: hemoglobin release through pores of stretched red blood cell membrane
• at constant shear hemolysis is a function of time and shear

Project DeBakey LVAD:
• axial blood pump, diameter ~1 cm, 7500–11500 rpm
• development at MicroMed Cardiovascular in Houston, Texas
• numerical analysis of the flow field at CATS
• typical mesh composed of 5 million elements
• 6 million unknowns per time step

Project GYRO LVAD:
• centrifugal blood pump, diameter ~6 cm, 2000–3000 rpm
• development at Baylor College of Medicine in Houston, Texas
• numerical analysis of the flow field and cumulative damage in terms of hemolysis at CATS
• grid with 1 million finite elements
• pressure distribution and pathlines
• high shear regions

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