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Blood-flow simulations in three-dimensional aneurysms using LBM: From risk-assessment to follow-up treatment decisions

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Cardiovascular diseases, such as cranial aneurysm or arterial stenosis, rank among the top global causes of death. Therefore, their genesis and treatment are subject of active, interdisciplinary research ranging from medical science via biology, chemistry and physics through to mathematics. Since experimental in-vivo observations are limited and risky for the individual, mathematical modeling and computational analysis facilitate the in-silico assessment of various treatment methods such as stenting or coiling with patient specific data [3]. For this purpose, we developed a three-dimensional, high-performance computational model for blood-flow simulations through realistic vessel and aneurysm geometries, which are reconstructed from actual MRI-scans. The hemodynamic flow equations include non-Newtonian flow properties for blood characterization and are coupled via the in- and out-flow boundary conditions to a one-dimensional circulatory network simulation [1]. We solve the blood-flow model based on the lattice Boltzmann method [2]. Furthermore, we simulate a treatment by coiling using a mechanical wire model to obtain a detailed structural representation. Instead of fully resolving the structure during the flow-simulations, we propose to surrogate it by a porous medium within the aneurysm cavity, so that the interior Darcy-flow is coupled to the vessel's free flow by a generalized Navier-Stokes model. This improves the efficiency of the flow-simulations by allowing for limited resolution. The parameters of the heterogeneous and possibly anisotropic porous medium are found by averaging. We analyzed uncertainties in the parameters and model conditions for relevant quantities of interest. Our numerical results show good agreement between the different approaches. The computational analysis can be directly applied for the risk assessment of aneurysm rupture by evaluation of the resulting wall shear stresses. While the vessel walls are considered to be rigid in previous studies, we aim for a full fluid-structure interaction simulation coupling the blood-flow model to an elastic deformation model of the pulsating vessel wall. Additionally, we envisage the incorporation of a multi-phase thrombosis model on a multi-timescale basis, which could predict the aneurysm occlusion under different treatment regimes.

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Participation

In-Person

References

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