The application of the Lattice Boltzmann method to the one-dimensional modeling of blood flow in elastic vessels

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The models for the blood motion in the cardiovascular system range from the 0-D lumped models, 1-D pulse propagation equations to 3D viscous flow equations [1]. In many cases the 3D approach based on the solution of the Navier-Stokes equations is too detailed while 0D lumped models are oversimplified and applicable only for the distal vasculature. In the case of the 1D models it is assumed that the radial velocity is negligible [2]. Then, integrating the Navier-Stokes equations over the radial variable the 1D nonlinear system of equations (depending only on one spatial variable, axial coordinate) for the luminal area change and the axial blood velocity is derived. The common way to solve this equations is locally conservative Galerkin (LCG) method.

I will present an alternative way to model 1D blood dynamics based on the kinetic equations, namely, using the Lattice Boltzmann approach [7]. This method describes the motion of particles on Cartesian spatial lattice (advection part), the collision of the particles in spatial nodes is modeled by assuming that the velocity distribution of the particles tends to some local equilibrium state (trend to Gaussian distribution). The Lattice Bolzmann (LB) method correctly reproduces low-Mach incompressible flows like blood motion and can be used in the modeling of the cardiovascular network. The details about 3D modeling with LB approach can be found in several papers [3]-[5].

We start with two-dimensional model D2Q9 applied to the flow in the two-dimensional elastic tube with periodic boundary conditions with pressure variations at the vessel inlet and outlet and Dirichlet boundary conditions for the moving vessel wall. Next, we sum over all spatial points perpendicular to the flow and reduce the system to the three velocity model (D1Q3) supported by the additional equation accounting for the luminal area response to the blood pressure. From this pressure-area relation we evaluate the correction coefficients for the lattice distribution densities at the each time step. This correction is necessary since it accounts for the vessel geometry (luminal) change which could not be captured by the one-dimensional LB model.

The presented method is simpler than the finite-difference methods for the nonlinear 1D blood equations [6]. The method correctly describes the change in shape of the initial pulse wave and moreover can be applied for the assessment of the forward and the backward blood pressure-velocity wave (reflected wave) superposition. The blood velocity waveforms can be obtained for the different elastic area-to-pressure responses of the vessel wall, the wall viscoelastic effects can be also potentially implemented.

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