Math. Model. Nat. Phenom.
Vol. 9, No. 6, 2014, pp. 1–3
DOI: 10.1051/mmnp/20149601

Preface

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Blood flow modelling is a classical problem of computational fluid dynamics. It continues to attract much attention due to numerous biomedical applications. New computational methods and more powerful computers led to a considerable progress in the last decade. Continuous methods of blood flow modelling are based on partial differential equations for Newtonian or non-Newtonian fluids. Blood cells are considered in these methods in terms of concentrations with their motion described by diffusion and convection. Such methods are well developed but they are less efficient in the description of the interaction between individual blood cells in the flow. Discrete models enable description of individual cells and their interactions but they are more complex in the realization and usually require much more computation time. There is a vast literature devoted to modelling of erythrocytes behavior in blood flow.

Biomedical applications of blood flow modelling includes blood coagulation and thrombus growth in normal and pathological situations, atherosclerosis, aneurysm and some others. We witness the beginning of a new stage of this modelling where patient specific geometry of blood flows and some other properties are taken into account on the basis of medical imaging. The results of modelling can be already applied to treatment optimization and prediction of its outcome. This direction of the development of blood flow modelling will become increasingly important in the years to come tied to the applications to public health.

This issue is devoted to numerical modelling of blood flows and to its biomedical applications. It begins with a review paper by Panteleev et al. [1] on systems biology of thrombosis. It presents the state of the art in this area and among other contributions, it discusses the mechanisms of clot growth and various practical problems such as drug development, investigation of particular events underlying disease, analysis of the mechanism of drug's action, determining an optimal dosing protocols and so on. This paper is followed by two others devoted to blood coagulation. The paper by Nandu and Anand [2] concerns sensitivity analysis of clot growth and lysis. It shows that fibrin production is most sensitive to the rate constant governing activation of prothrombin to thrombin and that the rate constants for the factor VIIIa has the greatest influence on the model. The work by Sequeira and Bodnár [3] is devoted to numerical simulations of a macroscopic blood coagulation model coupled with a non-linear viscoelastic model for blood flow. The system of governing equations is solved using a central finite-volume scheme for space discretization and an explicit Runge-Kutta time-integration.

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https://doi.org/10.1051/mmnp/20149601 Published online by Cambridge University Press

One of the important applications of blood flow modelling concerns atherosclerosis. It usually leads to stenosis and arterial lesions that can affect the carotid arteries, but also the arteries of the heart (coronary), arteries of the legs (PAD), the renal arteries. It can cause a stroke (hemiplegia, transient paralysis of a limb, speech disorder, sailing before the eye). The paper by Boujena et al. [4] deals with the study the blood-plaque and blood-wall interactions using a fluid-structure interaction model. It begins with a 2D analytical study of the generalized Navier-Stokes equations to prove the existence of a weak solution for incompressible non-Newtonian fluids with non standard boundary conditions. Additional conditions due to fluid-structure coupling are proposed on the border undergoing inetraction. This coupled model includes (a) a fluid model, where blood is considered as an incompressible non-Newtonian viscous fluid, (b) a solid model, where the arterial wall and atherosclerotic plaque is treated as non linear hyperelastic solids, and (c) a fluid- structure interaction model where interactions between the fluid (blood) and structures (the arterial wall and atheromatous plaque) are conducted by an Arbitrary Lagrangian Eulerian method that allows accurate fluid-structure coupling.

Properties of blood cells and their interaction determine their distribution in flow. It is observed experimentally that erythrocytes migrate to the flow axis, platelets to the vessel wall, and leucocytes roll along the vessel wall. In the work by Bessonov et al. [5], a three-dimensional model based on Dissipative Particle Dynamics method and a new hybrid (discrete-continuous) model for blood cells is used to study the interaction of erythrocytes with platelets and leucocytes in flow. Erythrocytes are modelled as elastic highly deformable membranes, while platelets and leucocytes as elastic membranes with their shape close to a sphere. Separation of erythrocytes and platelets in flow is shown for different values of hematocrit. Erythrocyte and platelet distributions are in a good qualitative agreement with the existing experimental results. Migration of leucocyte to the vessel wall and its rolling along the wall is observed.

Gamilov et al. [6] propose a method for analysis of postsurgical haemodynamics after femoral artery treatment of occlusive vascular disease. Patient specific reconstruction algorithm of 1D core network based on MRI data is proposed as a tool for such analysis. Along with presurgical ultrasound data fitting it provides effective personalizing predictive method that is validated with clinical observations.

In [7], the authors present a fully automatic approach to recover boundary conditions and locations of the vessel wall, given a crude initial guess and some velocity cross-sections, which can be corrupted by noise. This paper contributes to the body of work regarding patient-specific numerical simulations of blood flow, where the computational domain and boundary conditions have an implicit uncertainty and error, that derives from acquiring and processing clinical data in the form of medical images. The tools described in this paper fit well in the current approach of performing patient-specific simulations, where a reasonable segmentation of the medical images is used to form the computational domain, and boundary conditions are obtained as velocity cross-sections from phase-contrast magnetic resonance imaging. The only additional requirement in the proposed methods is to obtain additional velocity cross-section measurements throughout the domain. The tools developed around optimal control theory, would then minimize a user defined cost function to fit the observations, while solving the incompressible Navier-Stokes equations. Examples include two-dimensional idealized geometries and an anatomically realistic saccular geometry description.

The last paper of the issue deals with a traceless variant of the Johnson-Segalman viscoelastic model for the blood flow simulations [8]. The viscoelastic extra stress tensor is decomposed into its traceless (deviatoric) and spherical parts, leading to a reformulation of the classical Johnson-Segalman model. The equivalence of the two models is established comparing model predictions for simple test cases. The new model is validated using several 2D benchmark problems, designed to reproduce difficulties that arise in the simulation of blood flow in blood vessels or medical devices.

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https://doi.org/10.1051/mmnp/20149601 Published online by Cambridge University Press

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