MODELLING OF FLUID AND STRUCTURE INTERACTION IN BLOOD VESSELS

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1. Introduction

In this extended abstract a numerical experiment of the fluid–structure interaction in blood vessels is presented. Finite Element model of the portion of the vascular system, in particular the upper part of the aorta, is build. The Navier–Stokes equations are used as the governing equations of the blood flow. The Neo–Hookean hyperelastic model is used for the description of the behavior of the vessel walls. The arbitrary Lagrangian–Eulerian ALE formulation is considered to simulate a two–way fluid–structure coupling. Change of the shape of the vessel walls influence the fluid domain and vice–versa. The FE programme COMSOL Multiphysics is employed for the simulation process.

Network of the blood vessels fulfill the important vital task supplying blood to all organs and tissues of the human body. Blood transfers nutrients and removes catabolic products from the organism. Research in blood flow has a crucial role in understanding of the behavior of the whole human system and improvement of human health. Numerical models and FE simulations has been widely used to perform biological numerical experiments [1].

The blood flow fluid dynamics was described using the time dependent Navier–Stokes equations for incompressible Newtonian fluid considering ALE formulations [2, 3]. The deformability of the fluid–structure domain was taken into account.

The governing equations take the form:

(1) $$\rho\frac{\partial \mathbf{u}}{\partial t}+\rho\left(\mathbf{u}-\mathbf{v}\right)\nabla\mathbf{u}-\mu\nabla^2\mathbf{u}+\nabla P=\mathbf{f}\ \text{ in }\ \Omega$$

(2) $$\text{div}\mathbf{u}=0\ \text{ in }\ \Omega$$

(3) $$\mathbf{u}(\mathbf{x},t_0)=\hat{\mathbf{u}}(\mathbf{x})\ \text{ in }\ \Omega$$

(4) $$\mathbf{u}(\mathbf{x},t)=\mathbf{v}_w(\mathbf{x},t)\ \text{ in }\ \Gamma_w$$

where **u** is the fluid velocity, **v** is moving reference frame velocity consistent with ALE formulation, $\mathbf{v}_w$ is the wall velocity, *P* is the pressure, **f** are the volume distributed forces, ρ is the constant fluid density and μ is the dynamic viscosity.

2. Numerical experiment

In this section results of the numerical experiment of the fluid–structure interaction in a network of the blood vessels are presented. The fluid–structure interaction problem concerning the vessel wall deformability is treated as coupled problem. Numerical simulation of the blood flow inside vessels was performed using Finite Element method. The upper part of the aorta with its branches was discretizated using 25335 tetrahedral finite elements with quadratic interpolation functions. The simulation process was carried out by COMSOL Multiphysics FE programme [4].

The blood flows into the aorta through one entry section and flows out through exit section and four aorta's branches. The blood material properties are given as: density $\rho = 1060\ kg/m^3$, dynamic viscosity $\mu = 0.005\ Ns/m^2$. The aorta material properties are given as: density $\rho = 960\ kg/m^3$, equivalent elastic modulus $E = 1.0\ 10^7\ N/m^2$, Poisson ratio $\nu = 0.45$. The pressure conditions depend on individual venal system, human health etc. In this particular case average pressure value was assumed as $P = 11160\ N/m^2$ and difference between inlet and outlet was equal $88\ N/m^2$. More results of the parametric studies with varying parameters will be presented at the conference time.

The figure 1 shows von Mises stress field inside the aorta walls, the blood velocity field and the deformation of the vessel. The blood flow has a very complex and unsteady character showing the disorders of the velocity field in the areas of the connection of the aorta and its branches, especially the second branch. This results in increasing values of the von Mises stress at the aorta–branches junctions. The high blood velocity at the beginning of the aorta is reduced after passing the third branch showing the steady velocity field values. The zone of the very low velocity at the first branch of the aorta is observed.

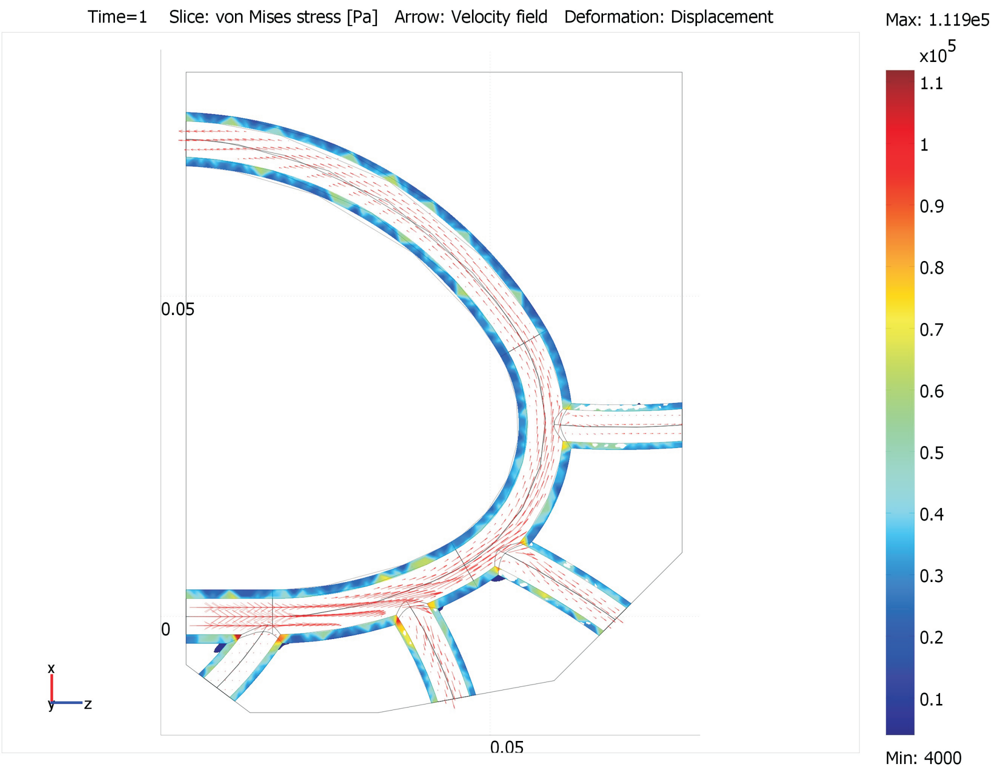

Figure 1. Von Mises stress inside the vessel walls. Blood velocity. Vessels deformation.

3. References

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