TWO-DIMENSIONAL DYNAMIC NUMERICAL MODEL OF THE AORTIC VALVE OPERATION

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Hemodynamics within vessels are an important factor in the development of various vascular complications, such as the formation of atherosclerotic plaques and aneurysms [1]. These complications pose a serious risk to human life, especially in cases involving the aorta. Mechanical properties of the blood vessel as well as the position and structure of the aortic valve play a significant role in blood flow and the pressure exerted by the blood on the vessel walls. The purpose of this work is to study the dynamic processes occurring in the aortic root through mathematical modeling.

To create a mathematical model, various initial data is required. These are the dimensions of the aortic root and aortic valve leaflets, the position of the aortic valve relative to the outflow tract of the left ventricle and the angle between the axes of the ascending aorta and the outflow tract of the left ventricle. Another factor influencing hemodynamics inside a blood vessel, in addition to the size of the vessel, is the structure of the leaflet and vessel wall at the tissue level. Collagen is the major load-bearing component of the aortic valve and can transfer load from the leaflets to the aortic wall when the valve is closed. Changes in the structure of the aortic wall and leaflets can be incorporated into the mathematical model using the Young's modulus.

The main method in modeling this interaction was the method of finite-difference integration of the Navier-Stoke equation and the conditions of mechanical equilibrium of the vascular wall for the related problems of viscous fluid flow and deformation of the elastic medium at the junction of the vertebral arteries into the basilar artery.

The fluid flow can deform the wall, so to numerically simulate the flow profile in a continuously deformable geometry, it is necessary to use the arbitrary Lagrange-Euler (ALE) method. The ALE method uses the dynamics of deforming geometry and moving boundaries using a moving mesh [2]. The vessel wall is a deformable material that can elastically deform under load. Consequently, the fluid flow also follows a new path, so the flow in the original geometry will be different from the flow in the deformed geometry.

As a first step, a two-dimensional geometric model of the aortic root was developed. The thickness of the valve leaflets was taken as 0.3 mm, the internal diameter of the aorta as 2 cm, the thickness of the aortic wall as 0.8 mm, and the initial angle between the aortic axis and the valve leaflet as 60º. The cardiac output had a duration of 0.1 s. The Young's modulus of the valve leaflet was 10^5 Pa and the Young's modulus of the aortic wall was $5 \cdot 10^5$ Pa. Blood was assumed to be a Newtonian fluid with a viscosity of 5 mPa·s. The dynamic calculation was performed in the interval 0–1.5 s with a step of 0.1 s changing the angle of the aortic valve relative to the centerline of the aorta.

As a result of the simulation, the stress-strain state of the aortic wall and valve leaflet, the flow velocity field were calculated and it was shown that the movement of the valve leaflets has a flutter (oscillatory) character, manifested in a two-stage ejection of blood into the aorta.

References

1. *Safar M. E.* Systolic blood pressure, pulse pressure and arterial stiffness as cardiovascular risk factors // Current opinion in nephrology and hypertension. 2001. Vol. 10, iss. 2. P. 257–261.

2. Large deformation fluid-structure interaction–advances in ALE methods and new fixed grid approaches / W. A. Wall [et al.] // Fluid-structure interaction: modeling, simulation, optimization. 2006. P. 195–232.

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