

## CFD SIMULATION OF BLOOD FLOW THROUGH ARTIFICIAL HEART VALVES

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**Summary:** *Artificial valve replacement is a common procedure in case of heart valve disorders treatment. The main task of this prosthesis is to generate blood flow similar to flow generated by natural, human valve. Velocity distribution depends mainly on the geometry of the valve. That is why it should be analysed and modified in case to obtain the best results. The objective of this study was to numerically investigate how geometry of valve (the maximal opening angle) influences velocity distribution behind a valve in terms of potential negative effect on blood components. For this purpose seven 2D models of artificial heart valves (AHV) with different maximal opening angle were created in Gambit. The blood flow was simulated in Ansys Fluent. This paper demonstrates the effectiveness of CFD method in artificial heart valves design process. Using Ansys Fluent, it is possible to simulate flow thorough AHV and analyze blood distribution in a region close to the valve, where physical measurements are very difficult to conduct.*

**Keywords:** *CFD, artificial heart valve, blood flow simulation*

### 1 Introduction

The most common valve defects are: valve stenosis and mitral regurgitation. In case of the above-mentioned disorders, the most common procedure is an artificial valve replacement. Thanks to the development of biomedical engineering for 50 years, there is the possibility to perform such operation [1, 2, 3]. Although many companies are working on improving geometry of AHV, there is still no perfect prosthesis which could replace the natural valve. The main problem faced by developers is to ensure adequate blood flow, as close as possible to the natural. Researches show that AHV produce higher velocity gradients than natural heart valves. That, create undesirable shear stress acting on the surfaces of blood cells. This can lead to changes in the membranes of these cells. Changes in membrane lipid fluidity of red cells may decrease their deformation abilities, and increase the platelet aggregation, what consequently influence the rheological properties of the blood and increase probability of thrombus formation [4]. That is why it is necessary to analyze how velocity is distributed in area close to the valve, and to modify it by improving geometry of valve, in case to achieve the best velocity distribution [5, 7, 7, 9]. Formed flow should be uniformly distributed, to prevent creating zones in which the liquid is stationary and zones where it moves at a high speed. Both of these zones are harmful to our circulatory system. Congestive zone conduct to platelet aggregation and thrombus formation, while in the zone of strong turbulence, deformation and destruction of blood cells is more likely to appear [10].

### 2 Material and methods

#### 2.1 Geometric model - Gambit

Two different kinds of artificial heart valves were designed: tilting disc valve and bileaflet valve. Main valves dimensions: external suture ring diameter: 28 mm, flange diameter: 19 mm, disc thickness: 0.5 mm. Cross sections and all dimensions are shown in figure 1.

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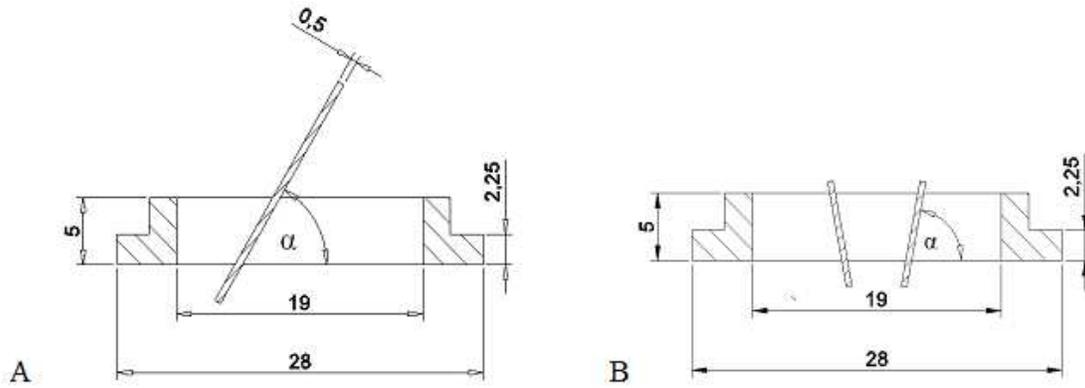


Figure 1: Cross sections and dimensions [mm] of designed valves. A - titling disc valve, B - bileaflet valve.

Four 2-D models of titling disc valve, and 3 models of bileaflet valve with different maximal opening angles were created in Gambit software. Disc positions for tilting disc valve were:  $\alpha = 60^\circ, 70^\circ, 80^\circ, 90^\circ$ . For bileaflet valve:  $\alpha = 70^\circ, 80^\circ, 90^\circ$ ,

## 2.2 Simulation - Fluent

Simulations of blood flow through prepared models were proceed by using Ansys Fluent software. It was steady, turbulent and Newtonian flow. K-epsilon model was used. For this study, the elasticity of vessel walls was neglected, valve and aortic walls were assumed rigid. Models represent situation when disks are fully open.

**FLOW PARAMETERS** Simulations were performed for the intensive flow of blood, when volumetric flow rate  $Q = 25\text{ l/min}$ , that corresponds to the peak physiological flow through the human aorta. Velocity of blood flow in simulations was  $1.6\text{ m/s}$ . The Reynolds number was 12057. Calculations are performed for the continuous flow with constant velocity at the inlet, and for a constant position of the valve disk.

**BLOOD MODEL** Blood was modeled as isotropic homogeneous, Newtonian liquid with the following parameters: density  $\rho = 1055\text{ kg/m}^3$ , dynamic viscosity:  $\nu = 0.0035\text{ kg/m} \cdot \text{s}$ .

## 3 Results

The analyzed parameter was velocity distribution. Figure 2 shows velocity fields generated by seven different valves simulated in Ansys Fluent.

## 4 Discussion

Velocity profile generated by tilting disc valve is unsymmetrical. The major stream is skewed towards one side of the aorta in the direction in which disc opens. Width and speed of this stream is directly connected with opening angle of the valve. The bigger opening angle, the wider is the stream and the lower is the speed. The fact that the whole flow and pressure is focused in one side of artery may have negative influence on aortas walls. It may lead to unnecessary aorta fatigue. Another characteristic feature of tilting valves connected with unsymmetrical flow is fact that two main zones are created. First zone covers area of main stream, it is a zone where blood flows with high speed. The second one is a zone where blood flows slower. It can be seen very clearly, especially when maximal opening angle is small. In case of valve with opening angle  $60^\circ$ , speed amplitude between zones is very high, which is something that must be avoided. By increasing the opening angle, velocity amplitude between both zones can be decreased and that improve the flow of the blood.

Bileaflet valves, unlike tilting disc valves generate symmetrical blood flow. Two main streams on both sides of aorta, and one smaller in a centre of artery can be distinguished. It can be assumed that this flow

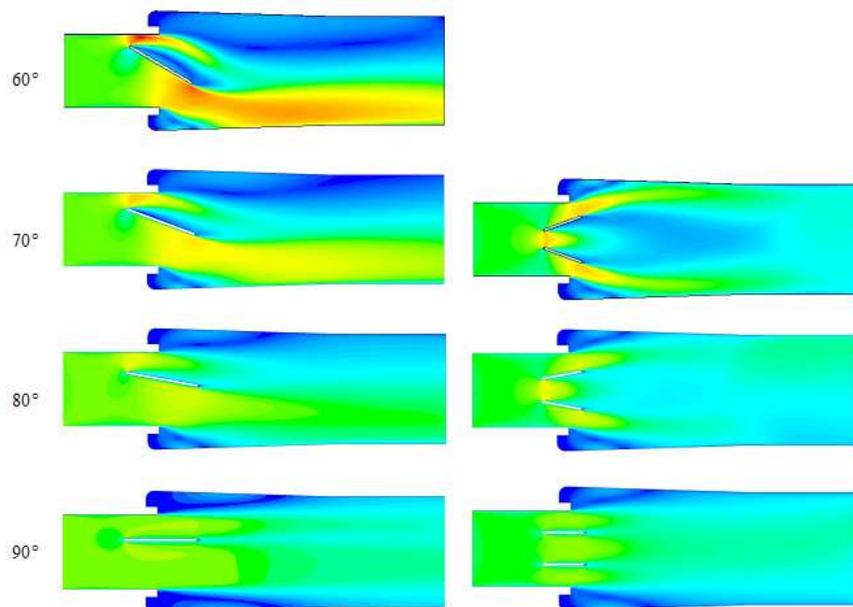


Figure 2: Velocity distribution.

profile is better than asymmetrical flow generated by single disc valves, because it affects aortas walls equally, but still it is not similar to the flow generated by natural heart valve, because in human valve main stream is focused in the middle of aorta.

The study confirmed that the larger opening angle, the better the flow distribution. The best results were obtained for models with a maximum valve opening angle  $\alpha = 90^\circ$ , for both, tilting disc valve and bileaflet valve. When  $\alpha = 90^\circ$ , maximum flow velocity generated by these valves was observed in the central portion of the aorta. This is similar to the flow through a natural human valve. Moreover, for every valve, regardless of the type and disc position, in the area close to the valve ring very slow blood flow was observed. This is the area where platelet aggregation and thrombus formation are most likely to appear.

To sum up, performed simulations provided qualitative and quantitative information about velocity distribution, without preparing expensive and complicated experimental model. The results were used to compare different valves and select the best one in terms of generated flow. It was shown that blood flow distribution can be improved by changing valve geometry.

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