EFFECT OF MECHANICAL AORTIC VALVES ON CORONARY ARTERY FLOW IN A PATIENT SUFFERING FROM ISCHEMIC HEART DISEASE

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Introduction

One of the most common diseases of the cardiac system is ischemic heart disease (IHD). It remains the leading cause of mortality worldwide [1]. To detect ischemia caused by artery stenosis and quantify its severity fractional flow reserve (FFR) method is commonly carried out.

In our study, we aim to assess the difference in FFR values in patients with a mechanical valve implanted. The study determines the effect of blood flow through artificial valves: trileaflet (TRI), bileaflet (BIL) and natural valves, on flow in stenosed coronary arteries and the value of the FFR index.

Methods

The geometrical model of blood was generated in Mimics software from CT images of a 50-year-old man with coronary artery stenosis. The model consisted of the aortic root with Valsalva sinuses and coronary arteries. We considered two types of mechanical valves, i.e. BIL and TRI valve and natural aortic valve (Figure 1). The design of the mechanical valve rings and BIL valve discs was modelled in our previous study [2].

Figure 1: Aortic valves: a) TRI, b) BIL, c) natural.

The dynamics of blood circulation were determined using ANSYS 2020 R2 software. Flow velocity at maximum valve opening was determined from a Doppler ultrasound examination. The value of 0.97 [m/s] was determined at the inlet of the system. The zero gauge pressure was described at the aortic outlet and coronary arteries outlets.

Results

Using data from the results of pressure distribution, the FFR ratio was calculated and compared with the results of coronarography (Table 1). The FFR is defined as the ratio of mean pressure measured distally behind the stenosis location (P_d) to mean pressure measured proximally (P_a). The pressure (P_d and P_a) was calculated at a distance of five stenosis diameters from the maximum coronary artery stenosis as it is measured during the examination. Figure 2 shows the flow velocity change in the aortic root and ascending aorta.

	E_{OA}	Geometric flow area [cm^2]	FFR [%]
natural valve	2.85	3.74	83
BIL valve	1.53	2.88	78
TRI valve	0.73	1.61	77

Table 1: E_{OA}, geometric valves flow area and FFR ratio.

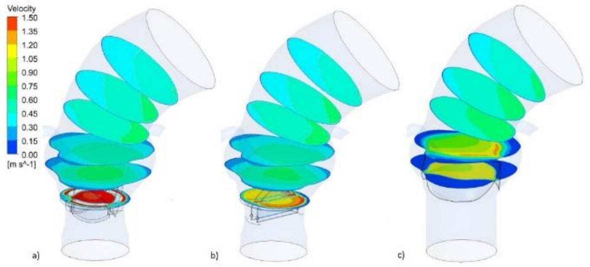

Figure 2: Flow velocity change in aorta induced by the valve: a) TRI, b) BIL, c) natural.

Discussion

The value of the FFR ratio for the natural valve (83%) is equal to the FFR value from coronarography (83%). The FFR values for BIL and TRI mechanical valves are 78% and 77%, respectively. The differences in the results may be due to the smaller E_{OA} of the mechanical valves. Although the E_{OA} for the TRI valve (0,73 [cm^2]) is smaller than the BIL valve's (1,53 [cm^2]), the FFR value differs slightly. This is probably due to the shape of the TRI valve leaflets, which point toward the sinuses of Valsalva at the maximum opening and allow unobstructed blood flow into the coronary arteries.

Studies suggest that geometric parameters of the coronary artery are essential in the final hemodynamic results of the simulations. Defining distal boundary conditions is particularly challenging, as circulatory conditions in the coronary microcirculation are heterogeneous in health and disease. The values of pressure in a coronary artery, and consequently those of FFR, strongly depend on boundary conditions, especially those defined in the truncated ends of the arteries at the outlets [3].

Analysis of fluid behaviour indicates that implanting the valve before the aortic root does not cause vortices in the sinuses of Valsalva and reduces turbulent flow. However, this may have a negative effect on the closure of the valve leaflets.

References

1. Fossan FE et al, Cardiovasc Eng Technol, 9:597-622, 2018.
2. Pawlikowski M et al, Acta Bioeng Biomech, 24:141-152, 2022.
3. Taylor CA et al, Annu Rev Biomed Eng, 11:109-134, 2009.