RESEARCH, DESIGN, AND TECHNOLOGY

HYDRODYNAMICS OF DISK ARTIFICIAL HEART VALVES WITH DIFFERENT DESIGN PARAMETERS

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The use of mechanical artificial heart valves (AHV) to replace damaged natural valves is now a very common procedure both in our country and abroad. By 1986 more than 400,000 of the Björk–Shiley disk valves had been implanted [6]. The types EMIKS and LIKS domestic AHV's of a similar kind have been utilized in cardiac centers of the USSR since 1983, the number of implantations was over 5000, and the estimated demand is 20,000 per year. In view of this, the task of developing more perfect AHV designs having better functional parameters is both important and urgent. One of the most important of these parameters is a valve's resistance to the blood flow, which determines the energy losses in it. These losses depend mainly on the design characteristics - the angle of rotation of the disk, its shape, and the alignment with the housing. By choosing the optimal combination of these characteristics the functional parameters of an AHV can be markedly improved. The functioning of artificial valves can be studied for both a steady and a pulsating flow, and a number of investigations have indicated that the results thus obtained correlate well with one another [8, 9, 11, 12]. This is explained by the fact that for about 80% of the passage time for the flow under the actual hemodynamic conditions a valve is in the completely open condition. In a number of articles by foreign authors results are presented for AHV studies in a steady-state flow, but in these the authors either compared the resistances of the different valve designs or studied the influence on resistance of just the valve's opening angle [7]. There have been no previous domestic articles concerning the relation between the design and functional characteristics of disk-type AHV's.

The objective of the present article is to investigate the influence of design parameters in disk AHV's on their hydrodynamic resistance to a steady-state flow.

1. METHOD AND OBJECTIVE OF THE STUDIES

We chose as a basic model for the studies an AHV of the EMIKS type, which has been most widely employed in our country's cardiac centers during recent years [1-4]. The principal design parameters of these disk valves are: the rotational angle $\alpha$ of the disk, the eccentricity $e$, and the radius of curvature of the disk's input surface $R$ (Fig. 1). It is convenient to employ dimensionless parameters: the relative eccentricity $\varepsilon$ and the relative curvature $\rho$ of the surface as found from the formulas:

$$\varepsilon = \frac{2e}{D_0}; \quad \rho = \frac{D_0}{2R}.$$ 

where $D_0$ is the diameter of the passage opening in the AHV; $\varepsilon$ and $\rho$ can take on values from 0 to 1.

Thirty-eight valves of the EMIKS type with different design parameters were studied. They were all divided into three groups according to the value of the eccentricity; within

Fig. 1. Design layout of a disk-type artificial heart valve: 1) flow direction; 2, 3) large and small passages, respectively; $R$ is the radius of curvature of the disk's input surface; $\alpha$ is the rotational angle of the disk; $e$ is eccentricity.
TABLE I. Design Parameters of the AHV's Studied

<table>
<thead>
<tr>
<th>AHV parameters</th>
<th>AHV group</th>
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<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>0.50°</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.16°</td>
</tr>
<tr>
<td>$\alpha$, deg</td>
<td>61°, 64°, 67°, 74°, 79°</td>
</tr>
<tr>
<td>Number of AHV's</td>
<td>5 units</td>
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*Standard type EMIKS.*

Each group the values of $\varepsilon$ and $\rho$ were varied. In group I there were 5 AHV's that differed from the serially produced type EMIKS valves only by the rotational angle of the disk (see Table I). $D_0$ for all the AHV's was 24 mm, and the sutured size was 29 mm.

The AHV's with a lower value of eccentricity are of great interest because flow through the larger and smaller passages is more equal (see Fig. 1), which is favorable from the standpoint of preventing thrombosis. It is well known that clotting occurs mostly at a small passage where the flow velocity is reduced [10]. Shown in Fig. 2 are photographs of three AHV's having the same values of $\alpha$ and $\rho$, but different values of $\varepsilon$ (0.50; 0.40; 0.25). The values of $\rho$ and $\alpha$ for these AHV's were chosen so that they covered the range of values for the several models of modern clinical AHV's.

2. EXPERIMENTAL PROCEDURE

A steady-state flow of liquid was produced with a centrifugal pump, the input was measured with a flow meter, and the pressure drop in the valve by means of piezoelectric meters at distances of 65 mm before and 140 mm after the AHV. We chose as a working liquid water because it was shown in [12] that replacing it with a water-glycerine mixture having a viscosity equal to that of blood did not affect the pressure drop in the valve. The diameter of the cylindrical working channel was made equal to 20 or 40 mm, which to a certain extent simulated the working conditions in the aortal and mitral positions, correspondingly. The liquid's flow rate ranged from 10 to 25 liters/min (the Reynolds number was 5300 to 18,250). For every AHV calculations were made of the dimensionless resistance $\xi$, which is accepted in hydrodynamics for evaluations of local resistances:

$$\xi = \frac{\Delta P}{\frac{1}{2} \rho_c V^2} = \frac{\pi^2 D_k^4}{8 \rho_c} \frac{\Delta P}{Q^2},$$

where $\Delta P$ is the pressure drop in the AHV; $\rho_c$ is the density of the medium; $V$ is the average linear flow velocity; $D_k$ is the diameter of the channel; $Q$ is the volumetric flow velocity (flow rate). For each AHV with certain values of $\varepsilon$ and $\rho$ the function $\xi = \alpha$ that was obtained was approximated by a formula of the form $\xi = C \cdot \alpha^{-\beta}$, from which the values of $\xi$ were calculated at the angles $\alpha_{\text{calc}} = 60°, 70°, \text{and} 80°$. This made it possible to make comparisons among all the valves, inasmuch as the real rotational angles of a disk differed somewhat for them. These angles were measured by means of templates (beforehand) and by photographs of the AHV's in the flow during tests.

3. DISCUSSION OF RESULTS

The values of the resistance coefficients were determined for all AHV's; an analysis was made of the variation in these coefficients with the rotational angle of a disk, its shape (curvature), and its eccentricity as well as the effect of the working channel's diameter on these variations.

Incomplete Opening of the AHV. For some values the rotational design angle of the disk is not reached in the flow - the disk, while vibrating, "hovers" in an equilibrium position. This phenomenon was observed for AHV's of group III with the following relative curvatures:

- in a valve with a diameter of 40 mm: $\rho = 0, 0.06, 0.10$;
- in a valve with a diameter of 29 mm: $\rho = 0, 0.06, 0.10, 0.15$. 

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