TOWARD THE CHOICE OF A STRUCTURAL SCHEME FOR A MEMBRANE (CHAMBER) ARTIFICIAL HEART

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The artificial heart is a necessary part of any extra-corporeal blood handling apparatus. Generally, only pumps are implied by this term. However, it is necessary to adopt a broader viewpoint: the artificial heart consists of an instrument which is an energy source, a pump pumping the blood, and a control system regulating the pump output.

An increasing preference for the membrane (chamber) type of pump is readily apparent [1, 2]. This pump is preferred for longer perfusion periods, various optimizing mechanisms, and the variability required in synchronic operation with a sick person's heart. The comparative data on the pumps' characteristics is conclusive concerning the so-called traumatic index [3]. The mean value of the traumatic index for membrane, roller, and finger-action pumps is equal to 120, 260, and 530, respectively. In addition, the shape of blood flow profile has great significance. Relative to this, the work of E. A. Vainrib et al. [4], showing the similarity of the blood flow profile created by membrane (chamber) pumps to natural conditions should be noted. Membrane (chamber) pumps were used by essentially all of the authors trying to develop an implanted artificial heart.

The introduction of these pumps into the artificial blood handling apparatus was particularly impeded by unsatisfactory development of driving mechanisms with smoothly continuous control by the length of the pump rod's movement. Pneumatic and hydraulic drives with slide valve mechanisms did not receive a wide distribution due to the complexity of maintenance and the influence of back pressure. The work performed at our institute has served as the basis for investigations into the choice of a structural scheme for an artificial heart with membrane (chamber) pumps to be used in an extra-corporeal blood handling apparatus. A classification system was devised, based on the type of drive and transmission employed, since with a given pump many characteristics of the artificial heart depend on these elements (Fig. 1). As is evident from Fig. 1, 24 different structural schemes are possible. Each possible scheme may be coded; for example, the artificial heart with electromechanical drive, hydraulic transmission, and membrane pump can be designated by IS-1-2-M and with chamber pump by IS-1-2-C.

We will examine each group in more detail.

Group I. Electromechanical Drive. This group is characterized by high reliability, durability, simplicity of maintenance, and a high degree of technological development; it has good measurement and dynamic characteristics and is convenient for control. With this drive the sinusoidal form of the pressure curve in the main artery is easily assured. The electromechanical drive surpasses the rest in every enumerated index.

The optimal schemes of this group are IS-1-1-M, IS-1-2-M, and IS-1-2-C. The remaining schemes, for example scheme IS-1-1-C, are undesirable. This is explained by the fact that with the mechanical transmission, the dilation of the ventricle cavity of the chamber pump occurs only on account of the elasticity of its walls; and the time needed to completely fill the cavity, which is constant for each value of the stroke, is dictated by inertia. In Fig. 2 are shown curves of complete filling of the pump chamber with stroke volumes \( q_1, q_2, q_3, q_4, \) and \( q_5. \) The corresponding time required for complete filling is designated by \( t_{q_1}, t_{q_2}, t_{q_3}, t_{q_4}, \) and \( t_{q_5}. \) The time required for one operating cycle of the compressed element alone...
is $t_c$. Fig. 2 shows that $t_{q3} = t_c$. As is evident from Fig. 2, the inequality $t_c \geq t_{q_3}$ is the condition for complete filling of the pump chamber. The corresponding values of the stroke are $t_{q_3}, t_{q_4},$ and $t_{q_5}$. With the values $t_{q_3}, t_{q_4},$ a reduction of the stroke volume corresponding to $\Delta V_2$ and $\Delta V_1$ occurs. This appears as an error in the indirect measurement of the pump output.

**Group 2. Hydraulic Drive.** In our opinion, it is inadvisable to use an artificial heart of this group without a hydraulic transmission. Schemes IS-11-2-M and IS-11-2-C appear optimal. A number of inadequacies limit the possibilities of this group for an artificial heart; the complexity of maintenance in operation, and significantly lower reliability in comparison with Group 1. The use of scheme IS-11-1-M is possible; however, the idea of using a hydraulic drive is lost. Schemes IS-11-3-M and IS-11-3-C are not possible under these considerations and likewise IS-1-3-M and IS-1-3-C.

**Group 3. Pneumatic Drive.** This drive has one outstanding quality, portability. This has led to its use exclusively in artificial blood handling apparatus for regional perfusion and special assistance. Schemes IS-111-3-M and IS-111-3-C appear optimal for the given group.

**Group 4. Electric Drive.** The basic outstanding qualities are the possibility of operating the drive in a pulse mode regulated by bioelectric control signals, the absence of mechanisms for transforming rotary into translational movements, and the absence of slide valve mechanisms for control based on the pump stroke volume. As liabilities one can cite the large amount of power required and the low reliability.

The basic attempts at an artificial heart of this group use the minimal delay time between the pressure pulse in the main artery and the controlling signal (for example, R wave of an EKG). Thus it follows to consider schemes IS-IV-2-M and IS-IV-2-C as optimal. Schemes IS-IV-1-M and IS-IV-1-C give significantly higher delay times, which makes their use less desirable.

It follows to note that for structural schemes using electromechanical and hydraulic drives, such characteristics as the dependence of the stroke volume on back pressure, the linearity of the pump output determined from the number of strokes, and the choice of pumps (membrane or chamber), are limited solely by the type of transmission, mechanical or hydraulic. When pneumatic or electrical drives are used, these characteristics are determined by both the drive and the transmission.