ABROAD

A MODEL OF THE HUMAN CIRCULATORY SYSTEM
WITH AN EXTENDED PULSE SIMULATOR AS A BASIS
FOR ARTIFICIAL HEART MONITORING

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Current progress in emergency care significantly decreases the death rate from heart attacks. However, surviving patients commonly suffer from cardiac insufficiency. Some of the patients are seriously handicapped and even bedridden. Because heart transplantation is severely restricted because of short supply of donor material, the development of alternative approaches to the problem is quite urgent. The artificial heart is an alternative approach to the problem.

Evaluation and study of the functional changes induced by the use of an artificial heart in the human circulation system, i.e., in physiological and pathological parameters of the human body, provide valuable diagnostic information. This requires comprehensive simulation of the interaction between the human circulatory system and an artificial heart.

The goal of this work was to describe a model of the human circulatory system that allows simulation of cardiac insufficiency and its compensation with an additional blood pump (BP) (artificial heart).

Model

Mean value simulation is a basis of the model considered in this work. This allows special long-term simulation of changes of the hemodynamic parameters to be implemented. This model uses a complex circulation control mode. Thus, the effects of both short-term and long-term regulation failure of cardiac activity and circulation can be simulated. The model consists of a central unit, which simulates the circulation dynamics (CD), and peripheral units, which simulate an autonomous system of local circulation control, stress-induced vascular relaxation, and the renin-angiotensin system. Other peripheral elements are electrolytes, cell water, erythrocytes, etc.

Mean value simulation is able to simulate physical load and abrupt movements of patients with cardiac insufficiency. However, a significant disadvantage of mean value simulation is its failure to take the pulse character of hemodynamics into account. To provide adequate simulation of cardiac activity and circulation in patients with CD insufficiency (CDI), the dynamics of systole and diastole and independent parameters of circulation should be taken into account to synchronize the CDI characteristics with healthy heart dynamics.

It is obvious that only the model of CDI with a pulse component may be physiologically sensible. Thus, mean value simulation alone is inappropriate for this purpose. The main idea of the modification of mean value simulation implemented in this work was to use pulse simulation only where it is absolutely necessary, i.e., to simulate the heart and functionally close elements of circulatory system. Therefore, mean value simulation was supplemented with pulse simulation of CD. However, to reduce the complexity of the model and to decrease the required time of computation, we used mean value simulation as much as possible.

The simulation model described in this work is shown in Fig. 1. All the elements inside the frame represent mean value simulation. The elements outside the frame represent pulse simulation.

The peripheral elements of the complex model of CD simulation can be considered invariable. Therefore, their simulation does not require pulse mode. The CD unit represents pulse extension, which is a new element of CD simulation. The other elements of the CD unit were borrowed unchanged from a mean value simulation system. Adequate compatibility between mean value simulation elements and pulse extension unit is provided by two interfaces (see Fig. 1).
Because pulse extension is mainly provided by the CD unit alone, a modular structure of the pulse extension function was implemented.

The function of correlation between cardiodynamics and inertia of blood is a major parameter of each pulse model of human circulation. The processes in the ventricles and atria of the heart are determined with adequate blood supply and state of cardiac muscle. The time dependence of cardiac muscle relaxation during the diastole is not linear and it cannot be easily interpreted in terms of analytical description. The systolic component of the function can be expanded into Fourier series, and this allows the diastolic relaxation during systole to be described.

The contribution of blood inertia into the model can be accounted for by the aortic pressure parameter called insisur. This phenomenon appears as a result of instantaneous hydrostatic head induced by the aortic valve closure. Insisur is widely used as a diagnostic criterion in physiological models. The pulse model of human circulation is presently extensively updated, and new principal model elements are in progress.

Reproduction

The CD dynamic simulation by mean value models will be replaced by the pulse models described above. The interfaces are designed to take into account the parameters essential for other elements and units, e.g., peripheral resistance, local circulation control, stress-induced vascular relaxation, etc. The other parameters will be brought into correspondence with the requirements of newly developed CD units. For example, cardiac productivity and systolic volume of left or right chambers of the heart will not be varied together with pulse extension any longer because they are under control of the contractile capacity of the