MODEL OF THE CORONARY VASCULAR BED: TRIALS IN EXPERIMENTAL PHYSIOLOGY

D. V. Borovikov and V. L. Golubykh

UDC 612.172.1:001.57

KEY WORDS: coronary blood flow; capacity of the coronary vessels; model of the coronary circulation; flow rate.

An important factor affecting movement of the blood through the coronary vessels is that contractions of the myocardium prevent the flow of blood along the vessels lying in its substance. This state of affairs is taken into account in the calculation of the total hydraulic resistance at the end of diastole, when the forces of systolic compression of the vessels are minimal, which is widely used at the present time. During detailed studies of diastolic flow characteristics in the coronary bed [1, 2, 5, 6] it was found that these relationships are determined not only by the hydraulic resistance of the vascular bed, but also by what has been called the zero blood flow pressure. More recent investigations [3, 4, 7, 9] have shown that a considerable error can be introduced into determination of the parameters of the flow characteristics by the compliance of the vascular bed.

The aim of the present investigation was to develop an adequate model of the myocardial vascular bed, taking into account influences of all the principal mechanical factors on the coronary blood flow. To describe the movement of blood along the coronary vessels, we suggested a model of the coronary bed illustrated in Fig. 1 in the form of an electrical analogy. The description of the mechanism of movement of blood along small, "collapsed" vessels was based on the model of the "vascular waterfall" suggested in [2, 6]. This mechanism is reflected by: R_1) resistance of the resistive vessels, P_{zf}) the zero blood flow pressure, the ideal diode D and E_3, symbolizing the intramyocardial pressure, acting from without on the small vessels. The parameter E_1 reflects the pressure in the aorta, R_0 the resistance of the large coronary vessels, C the compliance of the large coronary arteries, and E_2 the pressure acting from without on the large arteries. Several suggestions were used to analyze the model: 1) E_2 and E_3 are linear functions of pressure in the left ventricle, i.e., $E_2 = K_2 \cdot P_1$ and $E_3 = K_3 \cdot P_1$, where P_1 is the pressure in the left ventricle; 2) all parameters of the system (R_0, C, R_1, P_{zf}, K_2, K_3) are unchanged throughout the cardiac cycle; 3) $R_0 \ll R_1$, i.e., the resistance of the resistive vessels is high compared with that of the large vessels. The system of equations describing this particular model is as follows:

$$\begin{cases} J_1 = [(U_1 - E_3 - P_{zf})/R_1] \cdot \theta (U_1 - E_3 - P_{zf}), \\ J_2 = cd (U_1 - E_2)/dt, \\ J = J_1 + J_2, \\ U_1 = E_1 - R_0 J \end{cases}$$

where U_1, J_1, J_2, and J denote voltage and current respectively at definite points of the electric circuit (Fig. 1), and θ is the Heaviside function. The resulting differential equation is:

$$R_0 C \frac{dJ}{dt} + \left(1 + \frac{R_0}{R_1}\right) J = C \frac{d (U_1 - E_2)}{dt} + [(U_1 - E_2 - P_{zf})/R_1] \cdot \theta (U_1 - E_3 - P_{zf});$$

As an approximation $R_0 \ll R_1$:

$$R_0 C \frac{dJ}{dt} + J = C \frac{d (E_1 - E_2)}{dt} + [(E_1 - E_2 - P_{zf})/R_1] \cdot \theta (E_1 - E_3 - P_{zf});$$

Institute of Experimental Cardiology, All-Union Cardiologic Scientific Center, Academy of Medical Sciences of the USSR, Moscow. (Presented by Academician of the Academy of Medical Sciences of the USSR V. N. Smirnov.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 106, No. 10, pp. 397-399, October, 1988. Original article submitted February 19, 1988.

0007-4888/88/0010-1377$12.50

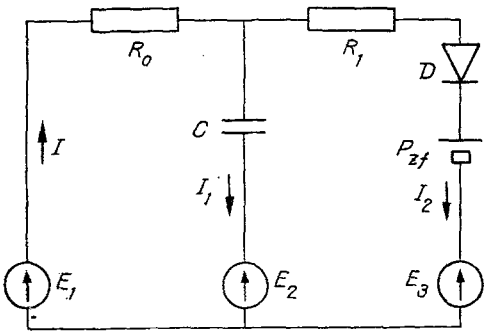

Fig. 1. Model of coronary circulation (in the form of an electrical analogy). Explanation in text.

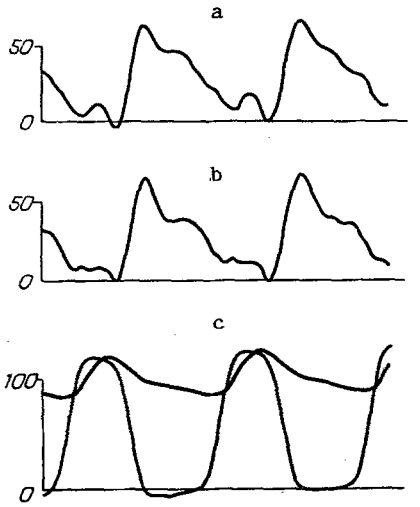

Fig. 2. Comparison of experimental curve (a) of coronary blood flow (in ml/min) with curve (b) calculated on the basis of curves (c) of arterial pressure and pressure in left ventricle (in mm Hg).

The solution of the Cauchy problem with initial conditions t = 0; I = I_0:

$$J(t) = J_0 e^{-\frac{t}{R_0 C}} + \frac{1}{R_0 C} e^{\frac{-t}{R_0 C}} \int_0^t e^{\frac{\tau}{R_0 C}} \left[C \frac{d(E_1 - E_2}{dt} + \frac{(E_1 - E_3 - P_{zf}}{R_1} \theta (E_1 - E_3 - P_{zf}) \right] d\tau. \quad (1)$$

EXPERIMENTAL METHOD

Acute experiments were carried out [6] on mongrel dogs of both sexes with an average weight of 12 kg, under hexobarbital anesthesia and droperidol premedication (75 and 5 mg/kg respectively). The transducer of an SP2201 electromagnetic flowmeter ("Statham," USA) was placed on the circumflex branch of the left coronary artery, and a catheter was passed through the carotid artery into the arch of the aorta and another was passed through its wall into the left ventricle of the heart. The HP 1280C pressure transducer was used for measurement. Curves reflecting the coronary blood flow, intraaortic pressure, and pressure in the left ventricle were recorded on an HP 7758D polygraph, and simultaneously on a TEAC R-81 tape recorder. The signals were identified and analyzed by means of a LABTAM 3015 microcomputer. On the basis of the curves of pressure in the aorta and left ventricle, the abundance (1) was calculated for assigned parameters by Newton's formula with a step of 1/100, and with a digitization frequency of 500 Hz. The results were displayed and printed in graphic form for comparison with the recorded curve of phases of the coronary blood flow.

EXPERIMENTAL RESULTS

The course of the calculated and experimental curves of coronary blood flow and pressure in the aorta and left ventricle in one experiment is shown in Fig. 2. Values of the parameters

in this case were: R_0 = 0.15 mm Hg/ml/min; C = 6.5 μl/mm Hg; R_1 = 0.85 mm Hg/ml/min; P_{zf} = 35 mm Hg; K_2 = 0.3, and K_3 = 0.35.

Analysis of the data showed that, on substitution of parameters characteristic of the coronary circulation, better qualitative agreement was obtained between the theoretical and experimental coronary blood flow curves. With fewer parameters, in models suggested previously [2, 5-8], this agreement could not be obtained.

The model suggested in [2, 6] was intended to describe the diastolic flow characteristics, whereas the behavior of the coronary blood flow during systole and some of the effects of compliance [4, 7, 9] were not fully described. Another model [7] was constructed on the basis of intramyocardial capacity. This model explains the increase in coronary blood flow during systole and certain other effects, but in principle it cannot explain the phenomenon of the linear flow characteristic and the zero flow pressure (P_{zf}).

Our suggested model is free from these disadvantages. The results obtained with it showed that it adequately describes the shape of the coronary blood flow curve. Later it is planned to study the possibility of solving the opposite problem, i.e., of finding the parameters R_0, S, R_1, P_{zf}, K_2, and K_3 of the coronary circulation from the curves of pressure in the aorta and left ventricle and of the coronary blood flow.

As a first approximation this model may enable multicomponent analysis of coronary vascular reactions. Nevertheless, it probably needs further improvements and, in particular, the possibility of allowing for nonlinearity of behavior of individual parameters.

LITERATURE CITED

1. R. F. Bellamy, Cardiovasc. Res., 43, 92 (1978).
2. J. M. Downey and E. S. Kirk, Circulat. Res., 36, 753 (1975).
3. J. M. Downey, J. Lee, and D. Chambers, Physiologist, 24, 26 (1981).
4. J. I. E. Hoffman and G. D. Buckberg, Prog. Cardiol., 5, 37 (1976).
5. E. J. Klocke, R. E. Mates, J. M. Canty, and A. K. Ellis, Circulat. Res., 56, 310 (1985).
6. S. Permuit and R. L. Rilley, J. Appl. Physiol., 18, 924 (1963).
7. J. A. E. Spaan, N. W. Breuls, and J. D. Laird, Circulat. Res., 49, 584 (1981).
8. N. Westerhof, P. Sipkema, and G. A. V. Huis, Cardiovasc. Res., 17, 162 (1983).
9. C. J. Wiggers, Circulat. Res., 2, 271 (1954).

ANTICOAGULANT AND ANTITHROMBOTIC EFFECTS OF LOW-MOLECULAR-WEIGHT HEPARIN

G. V. Bashkov, T. M. Kalishevskaya, and N. Bako

UDC 615.273.53.015.4.076.9

KEY WORDS: heparin; antithrombin III, thrombosis.

There is evidence in the literature that, besides their positive effects, commercial forms of heparin also may give rise to various side effects, such as hemorrhage, thrombocytopenia, and osteoporosis, and they may also stimulate aggregation of platelets and erythrocytes [12]. The search thus continues for heparin preparations free from the above-mentioned disadvantages. The composition of heparin, which is a mixture of glycosaminoglycans with different degrees of polymerization (mol. wt. 5-40 kD) is such that it is possible to obtain preparations with preassigned properties. The use of a low-molecular-weight heparin (LMH), with mol. wt. of under 10 kD, has been reported [5]. Compared with the commercial preparation, LMH has weaker anticoagulant activity but it is a more effective antithrombotic agent in vivo and gives rise to significantly fewer side effects [13].

Department of Human and Animal Physiology, Biological Faculty, M. V. Lomonosov Moscow University.

(Presented by Academician of the Academy of Medical Sciences of the USSR I. P. Ashmarin.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 106, No. 10, pp. 399-402, October, 1988. Original article submitted September 21, 1987.