

The Biophysical Modeling of the Hemodynamic in the Human Organism

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ABSTRACT

The circulatory apparatus has as a main function the constant maintaining of the internal environment in all the regions of the organism. The blood is a liquid tissue, being formed of a fundamental substance – plasma and blood cells. Heart is the central organ of the cardiovascular apparatus. The heart muscles have numerous biophysical properties. The cardiac muscle is never tired unless it suffered a pathological process. During the diastole, blood is aspired in the heart and during the systole it is pushed in the big and small circulation. The blood amount pushed from the heart in the vascular system in a certain time represents the blood flow. The biophysical methods are next: we administer a certain substance amount, then its passing speed will depend on its concentration; to apply the calorimetric principles for the measurement of the gastric blood flow; the diagnostic of a chronic peripheral arteriopathy we use the calorimetric method is based on measuring the heat being introduced in a certain amount of water which has known temperature; one of the most often used methods for the evaluation of the use of radioisotopes in the cardio-vascular system is the compartment method. Any attempt to apply biophysics to the life systems involves three stages. First we observe the phenomena and formulate a biophysical description in the form of equations; after to solve the equations. Finally we return to the real life system and interpret this solution in terms of reality, this interpretation may requiew experimental testing.

Keywords: biophysical modelling. hemodynamic, circulatory apparatus, calorimetric principles, arteriopathy

INTRODUCTION

The human organism behaves like a morphofunctional unit in the continuous process of adaptation to the environment. The organism's unity is not given by its homogeneity, but on the contrary, by its highest heterogeneity. From the sub-cellular structural-functional levels, step after step, to the ultimate level – the organism – heterogeneity amplifies, which requires more and more complex adjustment mechanisms, with more and more complex interrelations. [1]

The circulatory apparatus is made of a central muscular cavity organ adapted to the function of blood propulsion – the heart and a vascular system. The vascular system is a closed tubular system, made of a series of pipes, structurally adapted to the function of blood propulsion and circulation. It is represented by arteries, capillaries, veins and lymph vases. [2]

All the vases are padded internally with an endothelium which is surrounded according to certain specific mechanical and hemodynamic conditions which will form together the vascular wall. These structures are: collagen and reticulate fibres, elastic fibres, smooth muscular fibres. The vases are dynamic structures characterized by a great plasticity and adaptive capacity, their structure being partially dependent on the functional state of those organs. This fact explains the modification in biophysical limits of the vases in the pregnant uterus, in the lactating mammal gland, in the atrophic glands. The capillaries are represented by very thin canals with a diameter between 4–30 μm . These structures are present in all the organs and tissues under the aspect of variable size and form networks according to the morphofunctional features of that organ. The capillary vases as morphofunctional units have a great plastic and regenerative capacity. [3]

The capillary walls have a specific property, which is permeability. The capillary as morphofunctional unit represents a biological membrane with selective permeability. The exchanges between blood and tissues can be obtained in the following ways: a) passive transportation due to the concentration difference, this way water and small molecules can pass though; b) active transfer which is obtained through pinocytosis and endocytosis; c) the interendotelial transport at the pore level. In the composition of the vascular tree there are two circulation territories: great circulation and small circulation. [4]

The blood amount pushed from the heart in the vascular system in a certain time represents the blood flow. The blood volume that the hearts pushes in the arteries in a contraction is called systolic volume and normally it is 50–80 cm^3 . The blood volume that the heart pushes in the vessels during a minute is called minute-volume (5000 cm^3).

If we compress an artery with the finger, we can feel those rhythmical movements called pulsations. They coincide with the cardiac systoles which propagate along the arteries walls with a higher speed (5m/s) then the blood circulation speed. If we follow the pulse we can count the cardiac contractions.

BIOPHYSICAL MODELING

With modeling we usually understand the reproduction of the behaviour of a system on an analogue one especially built on the basis of certain rules. Usually, the system is modelled either on a physical one, either on a mathematical one. The mathematic model has the advantage of comfort and

economy. The mathematic dealing mode also eases significantly the discovery of the analogies between the various systems.

Generally, for the study mode of the biophysical systems, two methods are foreseen: the phenomenological methods and static methods. The phenomenological method studies the phenomena regarding a few fundamental principles that result from various experiences, leaving aside the discreet internal structure of the matter. [5]

The statistic method studies the phenomena starting from the discreet internal structure of the matter. For the study of the systems with an enormous number of particles the probability calculation is used. Hence, the measurable macroscopic properties appear like average statistic values of the properties of the individual elements.

The modeling method in biophysics consists of the creation of certain devices (models), with which processes analogue with those happening in living organism are studied. The biophysical model though abstract reasoning leads to models of the phenomena which by simplifying and isolating some aspects of the phenomena discover laws and relationships which describe with a certain approximation the behaviour or functioning of bodies or biological ensembles.

The biophysical models offer a „language” of quantitative and qualitative processing of experimental data, being compatible and adequate to the laws of biology. One of the types of modeling, the so called analogical modeling, consists of the study of a phenomena, which respects certain mathematical laws, with the help of its resemblance with another simpler phenomenon, subject to the same mathematical laws. As an example of analogies, we can quote the oscillation processes with mechanical, acoustic, thermal, optic, electromagnetic, seismic, physiologic, even economic character or the analogy between the nervous impulses and the electric impulses. [6]

The first electrograms were made by Einthoven in 1903 at Leyden, using electrodes applied in the bipolar deviation in three points on the body. The potentials collected with these electrodes represent the projections of the cardiac vectors on the exploration axes. The amplitudes of the vector at its turn is proportional with the electromotor force of the heart, whose size is a very important diagnostic mean in the medical clinic for the assessment of the heart's functioning state. At normal state the electrocardiogram presents for each cycle a sequence of five waves denoted with the letters P, Q, R, S T. Each of these waves represents the electric activity in the various phases of the cardiac cycle.

BIOPHYSICAL METHODS

Further on, we present the modelling of the blood volume, if we administer a certain substance amount, then its passing speed will depend on its concentration, hence the volume at which it spreads in the deposit. [7] This size is hard to determine. This is why post defined the amount of substance which would realise an initial concentration exactly defined in blood after the complete resorbtion and after the installation of a supposed equilibrium as dose. This initial fictional concentration in blood is denoted with c . It would be achieved at time $t = 0$, and at the time t the concentration would be c^* . Then results the analogy with the formula of c^* increase in relation of the reaction speed:

$$c^* = \frac{dc^*}{dt} = k \cdot (c - c^*)$$

and integrating:

$$c^* = c \cdot (1 - e^{-kt});$$

for the concentration decrease speed:

$$-\frac{dc^*}{dt} = k_2 \cdot c^*$$

integrate

$$c^* = c \cdot e^{-k_2 \cdot t}$$

If the two processes combine, it is mandatory that the concentration increase speed be proportional with the invasion constant k_1 , hence with the amount of substance still present in the storage:

$$c \cdot e^{-k_1 \cdot t}$$

from here:

$$\frac{dc_1^*}{dt} = k_1 \cdot c \cdot e^{-k_1 \cdot t}$$

The concentration decrease speed will be on its turn proportional with the elimination speed k_2 , hence with the present blood level:

$$\frac{dc_2^*}{dt} = -k_2 \cdot c_2^*$$

The amount of the two speeds gives the modification which is produced when the two processes take place simultaneously. For this care the relations are valid:

$$dc^* = dc_1^* + dc_2^*$$

$$\frac{dc^*}{dt} = c \cdot k_1 \cdot e^{-k_1 \cdot t} - k_2 \cdot c_2^*$$

The solution of this equation has the following expression:

$$c^* = \frac{c \cdot k_1}{k_2 - k_1} (e^{-k_1 \cdot t} - e^{-k_2 \cdot t})$$

The clinical and hemodynamic study of the vascular diseases mentioned the participation of many of the circulatory territories (cerebral, coronary, renal) in these diseases. The spleen circulation is more accessible to the hemodynamic investigation means. Further on we present a method of exploration of the gastric circulation.

In order to apply the calorimetric principles for the measurement of the gastric blood flow, we made a probe at whose end a 20 ml rubber balloon was attached. [8] Inside the probe we introduced three

thin tubes; two of them end inside the balloon and one crosses the balloon exiting it. At the end of one of the internal probes a thermistor was mounted, which can be placed in contact with a galvanometer. The external probe on whose end a clive was mounted serving at introducing in the stomach some pharmacological substances or for feeding. This way the test made can serve for the simultaneous measuring of the blood flow, the secretion and mobility of the stomach, before and after the administration of substances.

The principle lying at the base of the determination of the blood flow is the one of the calorimeter between the water in the balloon, the tissues of the stomach's walls and the blood that irrigates these tissues. Exchanges of caloric energy take place: at the beginning of the determination, the cold water from the balloon cools the organ's walls; they will be reheated by the flowing blood. Due to this heat transfer in the last analysis, the temperature of the balloon water will start to rise and it tends to equalise the one of the organ's wall.

There are two thermal systems with various temperatures: stomach (t_o) having the temperature t_o and the balloon with the temperature t_b . An unknown amount of blood of a constant temperature passes through the stomach's capillary system. Thus, at the beginning the stomach temperature and the blood temperature (t_s) are the same, but when the stomach gets in contact with the balloon, which has a lower temperature, then it tends to equalize the temperature value. [9]

In the dT interval, the stomach wall passed an amount Q_{OB} to the balloon from the blood which passed through this portion in that period of time. The heating of the balloon is directly proportional with the amount of heat absorbed and inversely proportional with the balloon's thermal capacity:

$$dt_B = \frac{Q_{OB}}{C_B}$$

On the other side, Q_{OB} is proportional with the temperature difference, with the time interval and with the thermal transmission coefficient.

We can write a similar equation for the stomach as well. The two equations can be reduced to the following forms:

$$Q_{OB} = a(t_o - t_b)dT$$

$$dt_B = \frac{a(t_o - t_b)dT}{C_B}$$

where: C_s is the blood's thermal capacity which passes in a time unit through 1 cm^2 of the stomach's surface.

$$\frac{dt_o}{dT} = \left(-\frac{a}{C_o} - \frac{C_v}{C_B}\right)t_o + \frac{a}{C_o}t_b + \frac{C_v}{C_o}t_v$$

$$\frac{dt_B}{dT} = \frac{a}{C_S} t_O - \frac{a}{C_B} t_B$$

In order to solve the problem we must find the solution of the non homogenous differential equation solutions first. So the solution of the non homogenous system will be:

$$t_O = t_S - d \cdot e^{-r_1 \cdot t} + d \cdot e^{-r_2 \cdot t}$$

$$t_B = t_S - d \cdot K_1 \cdot e^{-r_1 \cdot t} + d \cdot K_2 \cdot e^{-r_2 \cdot t}$$

The diagnostic of a chronic peripheral arteriopathy can be made from the characteristics of pain and in the presence of the trophic disturbances. [10, 11] The aggravation or the improvement of the circulation in the segment with ischemia can be also evaluated with a series of tests: pain apparition time, recolouring time, skin temperature, etc. In the physiopathology research of the circulation in arteriopathic people, when there are necessary arguments referring to the efficiency of new medicines or for the purpose of reestablishing the work capacity, the clinic diagnostic must be completed with laboratory samples: regional debt, peripheral arterial resistance, circulation time etc.

The muscular and tegument regional blood flow can be measured through several methods, some of them requiring special technical devices. The calorimetric method is based on measuring the heat being introduced in a certain amount of water which has known temperature. We know that this heat derives from arterial blood and to a very little extent, from the local metabolism. Its measuring can be made with a normal double walls calorimeter and we measure the water temperature variations. [12]

The technique has several phases: 1) the determination of the heat amount which transmits from the sick limb (it comes from the arterial blood) to the liquid environment; the calculation is made with the Fourier equation:

$$dQ = \chi \cdot \frac{dT}{dx} dS \cdot d\tau$$

where: **dQ** – transmitted heat amount; **χ** – thermal conductivity; **dT/dx** – temperature gradient; **dS** – transport surface; **dτ** – time interval. The determination of the heat amount which transmits from water to the environment is made with the formula:

$$Q = m \cdot c \cdot \Delta T$$

$$m = \frac{Q}{c \cdot \Delta t}$$

where: **Q** – heat amount; **m** – blood mass; **c** – specific heat; **Δt** – temperature difference.

Knowing the values of the previous formulas and the mass of blood circulated in that segment, we find out the segment's flow:

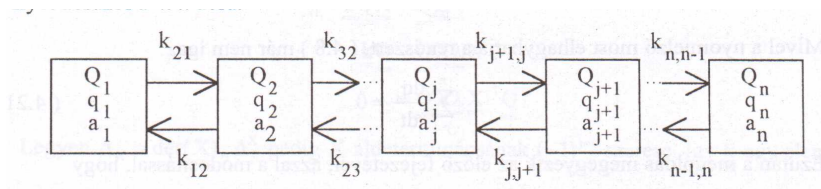
$$V_s = \frac{m}{\rho \cdot dt}$$

where: V_s – the segment volume in the time unit; m – blood mass; ρ – blood density; dt – time interval.

The explorations with radioisotopes provide data on the main factors that the functional state of the blood flow depends on: absolute blood flow, relative blood flow, circulation speed, blood mass, capillary permeability. These factors can be separated or global. The isotopic methods present the advantages of a more direct expression of the factors mentioned and the increased objectivity of the results compared to other functional exploration methods. [13]

One of the most often used methods for the evaluation of the use of radioisotopes in the cardiovascular system is the compartment method. Bellow we present this method very briefly.

We suppose that the compartments form a chain (see Figure) and the characteristic matrix of this chain will have the following form:



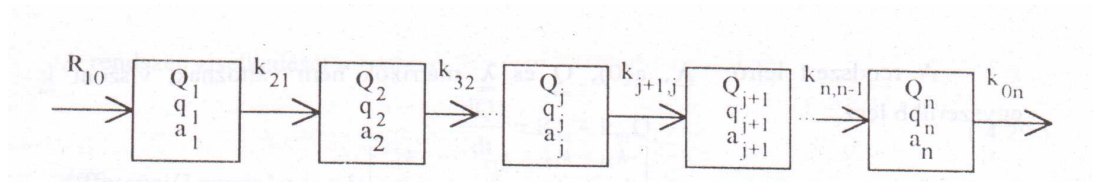
$$k = \begin{vmatrix} -k_{21} & k_{12} & 0 & \dots & 0 \\ -k_{21} & -(k_{12} + k_{32}) & k_{23} & \dots & 0 \\ 0 & k_{32} & -(k_{23} + k_{43}) & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & -(k_{n-1,n} + k_{0n}) \end{vmatrix}$$

According to Laplace's transformation, we obtain the solutions:

$$k_{21} X_{1i} - \frac{Q_2}{Q_1} k_{12} X_{2i} = \lambda_i X_{1i}$$

$$-\frac{Q_1}{Q_2}k_{21}X_{1i} + (k_{12} + k_{32})X_{2i} - \frac{Q_3}{Q_2}k_{23}X_{3i} = \lambda_i X_{2i}$$

If we introduce another simplification that each compartment has a flow only towards the neighbouring compartment ($k_{11}=k_{21}$, $k_{22}=k_{32}$, ..., $k_{nn}=k_{0n}$) then the chain's scheme will be given in figure.



In this case the radioisotope is injected only in the first compartment:

$$a_1(0) \neq 0, a_2(0) = a_3(0) = \dots = 0$$

for the matrix we obtain a simpler case

$$sI - k = \begin{vmatrix} s + k_{21} & 0 & 0 & \dots & 0 \\ -k_{21} & s + k_{32} & 0 & \dots & 0 \\ 0 & -k_{32} & s + k_{43} & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & s + k_{0n} \end{vmatrix}$$

We introduce the following supplementary relations:

$$\begin{aligned} \Delta &= (s + k_{21})(s + k_{32})(s + k_{43}) \dots (s + k_{0n}) \\ \Delta_{11} &= (s + k_{32})(s + k_{43}) \dots (s + k_{0n}) \\ \Delta_{12} &= -[-k_{21}(s + k_{43}) \dots (s + k_{0n})] \\ &\vdots \\ \Delta_{1n} &= (-1)^{1+n}(-k_{21})(-k_{32})(-k_{43}) \dots (-k_{0n}) \end{aligned}$$

And hence closer, determining the characteristic parameters for the first compartment it is possible to determine the characteristic parameters for the other compartments.

CONCLUSION

The importance on biophysics consists of the fact that a model for a simpler system gives the possibility to a certain extent to apply the same model to more complex functional systems as well (for example the organism). [14] Except for the proper mathematical modeling, biophysics also uses certain devices to help it study the processes analogue to the ones that happen in the biological systems, hence material models. This type of modeling is the cybernetic modeling. [15] Then, the

structural modeling that the bionics is based on, a science which deals with the construction of technical devices similar to the ones found in living organisms, with great perspectives in technique. Through the elaboration of models, one can achieve the prediction of normal answers of environment factors and in biophysical reactions and to detect the atypical abnormal responses.

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