

## RHEOCARDIOGRAPHIC EVALUATION OF CARDIOHEMOKINETICS

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**Abstract.** The following values of the hemodynamics concerning the cardiohemokinetics were investigated in 20 subjects aged 30 – 59 with previous myocardial infarction, namely: 1) cardiac index, 2) physically substantiated value of kinetic energy of cardiac ejection according to V. Karpman, 3) impedance integral kinetic index developed by the authors of this article. Investigations were carried out for the purpose of comparison of these factors by their information possibilities as well as for the purpose of substantiation of the usage of the last one. Parameters for calculation of the values of the hemodynamics were determined using the thoracic tetrapolar rheography and the electrocardiography. The proposed impedance method for determination of kinetic condition of the heart has a very high correlation with physically substantiated value of kinetic energy of cardiac ejection ( $r = 0.84$ ,  $p < 0.0001$ ). It can be realised in healthy persons and in patients having blood circulation diseases as well.

**Key words:** cardiovascular biomechanics, hemodynamics, cardiokinetics, rheocardiography

### Introduction

The hemodynamic heterogeneity in healthy persons as well as in sick ones is not doubted (the cardiac index in healthy persons, which reflects blood ejection by the heart, varies from  $2.1 \text{ l/min m}^2$  to  $4.8 \text{ l/min m}^2$  and in persons with previous myocardial infarction – from  $1.4 \text{ l/min m}^2$  to  $4.8 \text{ l/min m}^2$ ). It is proved through the examination of the hemodynamics with the help of the impedance method – the thoracic tetrapolar rheography [1-4]. The thoracic tetrapolar rheography is based on the resistance of volume conductor caused by pulsating blood flow and is connected with the blood ejection by the heart where the blood has a liquid low impedance (resistance).

According to a level of the cardiac index three types of the blood circulation are distinguished: with high, moderate and low values because the volume cardiac index considers only a quantity of ejected blood but not its kinetics. It ignores the fact that the heart in itself (cardiohemokinetics) is one of the main components of the central hemodynamics. Indeed the cardiohemokinetics has a kinetic energy which ensures blood flow in the second half of the systole and the diastolic phase of cardiocycle [5, 6]. Determination of the cardiohemokinetics level according to the cardiac index – from the point of biomechanics of the blood circulation – contradicts the concept of kinetic energy, by which  $E = mV^2/2$ , where  $E$  – kinetic energy,  $m$  – mass of blood,  $V$  – blood flow rate. Karpman [7] and co-authors suggested a rational method of determination of kinetic energy of the cardiac ejection, where mass of blood stroke volume and linear blood flow rate in an initial point of the aorta are taken into consideration.

In our opinion the bioimpedance method of evaluation of the hemodynamics with the use of the thoracic tetrapolar rheography has some important advantages to determine the cardiohemokinetics. The point is that the systolic curve of the first derivative of thoracic rheogram has an index of “ohmic” ventricular ejection amplitude ( $\Delta Z / \Delta t$ ) which in physiological sense reflects the peak of maximum volumetric rate of the blood ejection into the aorta in the first half of the systole [8, 9].

Amplitudes of curves of differential rheogram consider two components of cardiac output: mass (or volume) of the blood ( $m$ ) and ejection rate of this blood volume ( $V$ ). Having these data it is not difficult to describe physical law of the kinetic energy of the cardiac ejection (cardiohemokinetics).

The purpose of this investigation was to develop and base a simple impedance method of kinetic heart condition determination.

### Materials and methods

The factors of the hemodynamics concerning the cardiohemokinetics: cardiac index, kinetic energy of ejection and integral cardiokinetic index, developed by the authors of this article, have been investigated in 20 subjects with previous myocardial infarction aged 30–59 years. For all patients the thoracic tetrapolar rheogram was registered according to a modified Kubicek method [2] with the help of multifunctional computer impedance system of blood circulation “Polyrheocardiograph” (Russia) [10]. The echocardiographic investigation to determine an aortic orifice area was conducted according to standard methods [11] using “Sigma” 21 XR (France).

Blood stroke volume and cardiac index were determined by the bioimpedance ejection for a heterogeneous model of the thorax [2, 12]. Kinetic energy of cardiac system was calculated by the formula of Karpman et al. [7]

$$E = mV^2 / 2, \quad (1)$$

where  $E$  – kinetic energy of cardiac ejection;  $m$  – mass of blood stroke,  $V$  – velocity of blood flow in initial part of the aorta. The latter was calculated with the help of division of blood stroke volume by aortic cross-sectional area (determined by the echocardiographic method) and time of left ventricular ejection. The cross-sectional area of the aortic annulus was calculated as  $\pi D^2/4$ , where  $D$  is the diameter of the aorta.

The integral cardiokinetic index was calculated by modified a Gundarov’s formula [2] of stroke volume determination.

$$V_s = \frac{0.9 K p Q^2 L T \Delta Z}{1000 Z^2 \Delta t}, \quad (2)$$

where  $V_s$  – stroke volume (litres),  $T$  – ventricular ejection time (s), 0.9 – correction coefficient dependent on the peculiarities of electrode application;  $p$  – electric resistivity of blood (Oh);  $K$  – Gundarov’s factor [2];  $L$  – distance between inner electrodes (cm);  $Q$  – perimeter of the chest on the level of the intercostal space from the front and inferior angles of the scapulae behind (cm); 1000 – index for conversion into litres,  $Z$  – basal impedance (Oh).

This formula includes the maximal amplitude of the first derivative of waveform in the systole ( $\Delta Z / \Delta t$ ). Signal reflects volume (mass) and rate of blood ejection into the aorta. The square  $(\Delta Z / \Delta t)^2$  reflects the kinetic energy of the cardiac blood ejection upon stroke. Besides, we decided to divide all values by the cardiac cycle time  $T$  (interval  $R$ - $R$  of electrocardiogram, s) and the body surface area of patient  $S$  ( $m^2$ ).

Finally formula of the integral cardiokinetic index looks like this:

Table 1. Parameters of cardiohemokinetic condition.

№	Patient	Age	Cardiac index, <i>l/min m<sup>2</sup></i>	Kinetic energy of cardiac ejection, <i>mJ</i>	Integral kinetic index, <i>Oh l/s<sup>2</sup>m<sup>2</sup></i>
1	T - n	47	2.6	3.86	0.080
2	A - v	51	2.1	2.49	0.070
3	M - n	52	2.0	2.98	0.134
4	Z - v	43	1.9	3.16	0.079
5	S - o	45	2.5	4.76	0.101
6	L - v	47	2.4	8.30	0.186
7	D - v	41	2.6	7.8	0.151
8	T - v	41	2.3	5.51	0.137
9	M - V	46	3.2	5.93	0.184
10	K - n	50	2.4	2.84	0.100
11	SH - v	40	2.6	6.49	0.122
12	K - v	56	2.9	2.74	0.070
13	M - v	41	3.2	8.03	0.148
14	R - v	46	2.9	3.34	0.090
15	G - kn	44	2.2	1.85	0.060
16	Kh - n	38	2.6	2.41	0.070
17	B - v	52	3.91	1.68	0.112
18	F - v	60	4.0	8.3	0.172
19	V - n	56	3.1	4.70	0.130
20	Z - v	50	2.1	1.49	0.060

$$I = \frac{V_s}{T S} \frac{\Delta Z}{\Delta t}, \quad (3)$$

where  $I$  – integral cardiokinetic index ( $Oh\ l/s^2 m^2$ );  $\Delta Z / \Delta t$  – maximal amplitude of the first derivative waveform in the systole ( $Oh/s$ );  $T$  – interval  $R-R$  ( $s$ );  $S$  – body surface area ( $m^2$ ).

Statistical analysis of Spearman's correlation coefficient was used for the analysis.

### Results and discussion

The values of cardiohemokinetic condition determined by different methods have a wide variation range, Table 1 (the cardiac index from 1.9  $l/min\ m$  to 4.0  $l/min\ m$ , the kinetic energy of cardiac ejection – from 1.5  $mJ$  to 8.3  $mJ$  and the integral cardiokinetic index  $I$  – from 0.06  $Oh\ l/s^2 m^2$  to 0.186  $Oh\ l/s^2 m^2$ . It is a reflection of hemodynamics heterogeneity of examined patients, because they had different classes of the heart failure (I – IV NYNA classification).

A positive and statistically reliable correlation was found: the cardiac index-the kinetic energy of cardiac ejection ( $r = 0.33$ ), the cardiac index-the integral kinetic index ( $r = 0.43$ ) and the integral kinetic index- the kinetic energy of cardiac ejection ( $r = 0.84$ ). Hence, the minimal average positive correlation is between the cardiac index and the kinetic energy of cardiac ejection, the cardiac index and the integral kinetic index but maximal correlation is between the integral kinetic index and the kinetic energy of cardiac ejection. In Fig.1 the reader can see some illustration values mentioned in the text and received in clinical practice.

Results indicate that our impedance method of cardiokinetic evaluation, Eq. (3), has a good correlation with physically substantiated Karpman's method, Eq. (1). But it is necessary to take into consideration that there are some difficulties to calculate kinetic energy of cardiac

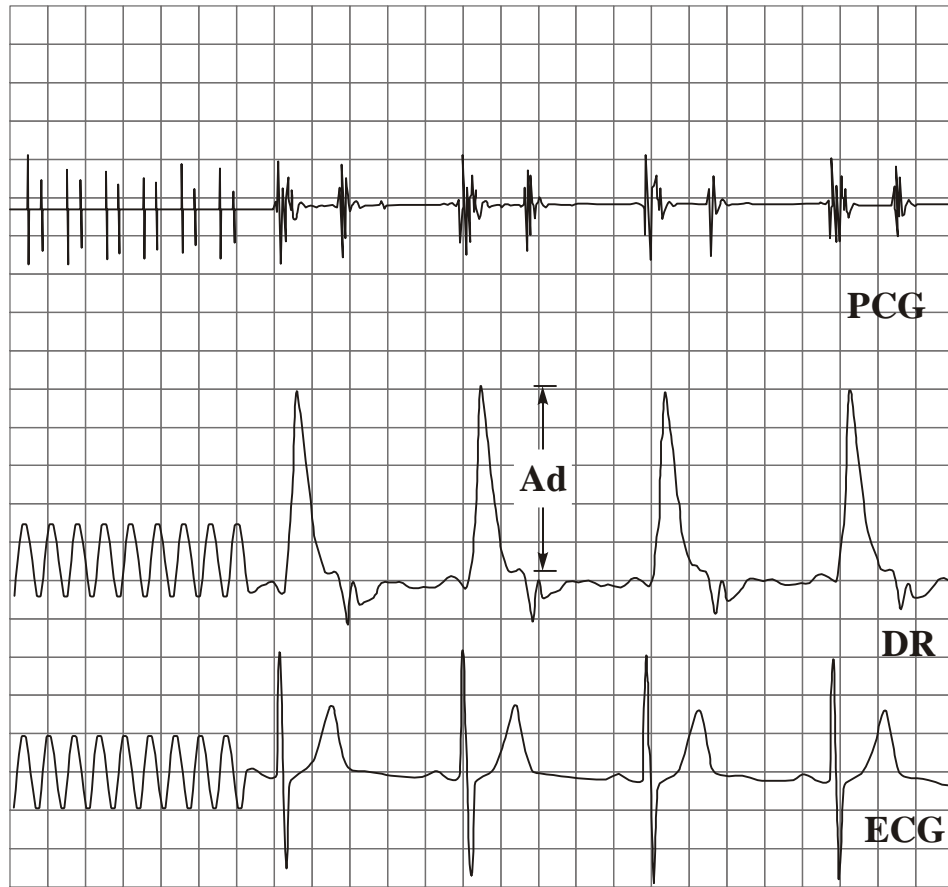


Fig. 1. Illustrations to values mentioned in text and received in clinical practice. PGG – Phonocardiogram, DR – Differential rheogram, ECG – Electrocardiogram, Ad – Maximal amplitude of the first derivative of waveform in the systole (  $\Delta Z/\Delta t$  ).

ejection because one must find time of ejection of blood stroke volume, its mass (to multiply volume and density of blood) and (it is particularly important) to find cross-sectional aortic area for determination of cardiac ejection linear velocity. The latter needs the echocardiographic method for which there are some limitations depending on the absence of examination “window” and sometimes on the patient severity (pulmonary edema, cardiogenic shock). Besides in the case of obstructive valvular diseases of the aorta the velocity of ejection is considerably increased [11] and does not reflect a true condition of the cardiohemokinetics. As to compare with impedance method the base of the echocardiography is more expensive.

### Conclusions

The proposed impedance method for determination of the kinetic condition of the heart (Equation 3) has a very high correlation with physically substantiated method of kinetic energy of cardiac ejection. When comparing the integral index method is more precise and – what is the most important – simple in use. It has no considerable limitations.

The proposed method of the evaluation of the heart kinetic condition needs further investigation for evaluation of the proposed index in healthy persons as well as in patients with different cardiovascular pathology.

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## РЕОКАРДИОГРАФИЧЕСКАЯ ОЦЕНКА КАРДИОГЕМОКИНЕТИКИ

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Под кардиогемокинетикой (кинетическое состояние сердца) понимается уровень кинетической энергии, которую получает кровь при изгнании ее во время систолы левого желудочка. Из теоретических предпосылок механики кровообращения и физических возможностей грудной тетраполярной реографии существует возможность определения кинетической энергии сердца. Ранее предпринимались попытки определения кинетики сердца на основе эхокардиографических показателей, линейной скорости кровотока в начальной части аорты и массы (объема) изгнанной крови (В.Л. Карпман с соавторами).

Целью данного исследования было разработать и обосновать простой импедансометрический метод определения кинетического состояния сердца.

У больных с постинфарктным кардиосклерозом в возрасте от 30 до 59 лет проведено исследование показателей гемодинамики, имеющих отношение к кардиогемодинамике, а именно: 1) сердечного индекса, 2) физически обоснованного показателя кинетической энергии сердечного выброса по В.Л. Карпману, 3) разработанного нами импедансометрического интегрального кинетического индекса с целью их сравнения по информативности и обоснования использования последнего.

Параметры для расчета показателей гемодинамики определялись с использованием грудной тетраполярной реографии и эхокардиографии. Предлагаемый

нами импедансометрический метод определения кинетического состояния сердца (интегральный индекс) имеет очень высокую корреляцию с обоснованным с точки зрения биомеханики показателем кинетической энергии сердечного выброса ( $r = 0.84$ ,  $p < 0.0001$ ). Этот метод прост в осуществлении и может быть использован при исследовании гемодинамики как у здоровых, так и у больных людей с заболеваниями системы кровообращения. Библ 12.

Ключевые слова: биомеханика кровообращения, гемодинамика, кардиогемодинамика, импедансная кардиография

*Received 20 September 2000*