Instantaneous Cardiac Rhythm Rate Spectrum Based on Holter Monitoring Data and its Features

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Together with frequency characteristics of instantaneous cardiac rhythm (ICR)[1-3], characteristics related to the ICR change rate *v* are of great value for studies in cardiology. According to the data from day-long Holter monitoring, we constructed the ICR change rate (*v*) distribution function *f(v)*. It was demonstrated that for different patients the function had both the unimodal and the polymodal characters. In many cases the *f(v)* is approximated accurately by the Laplace distribution $f(v)=(\varkappa/2)\exp(-\varkappa|v-v_0|)$. In general, the *f(v)* is approximated with the plenty high enough accuracy by the linear combination of Laplace's and Gaussian functions.

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[1] *A.N. Kudinov, D.Y. Lebedev, V.P. Tsvetkov and I.V. Tsvetkov*. Mathematical model of the multifractal dynamics and analysis of heart rates // Mathematical Models and Computer Simulations, 2015, v.7, №3, p.214–221.

[2] *Ivanov, A.P., Kudinov, A.N., Mikheev, S.A., Tsvetkov, V.P., Tsvetkov, I.V.* Phase space-based imaging of mass data on instantaneous cardiac rhythm (2016) CEUR Workshop Proceedings, 1787, pp. 271-274.

[3] A.P. Ivanov, A. N. Kudinov, S.A. Mikheev,V.P. Tsvetkov, I.V. Tsvetkov Phase Space of Instantaneous Cardiac Rhythm and Imaging of Big Data on It // Proceedings of the Nineteenth International Scientific Conference of DISTRIBUTED COMPUTER AND COMMUNICATION NETWORKS: CONTROL, COMPUTATION, COMMUNICATIONS (DCCN-2016). Russia, Moscow, 21–25 November 2016, under the general editorship of D.Sc. V. M. Vishnevskiy and D.Sc. K. E. Samouylov, v. 2, pp. 153-158.

Processing of results of 24-hours HM in the KT-Result program gives data set value $\{y_i\}$. Using the ratio

$$v_i = \frac{y_{i+1} - y_i}{t_{i+1} - t_i} \qquad (1)$$

we construct set $\{v_i\}$ in which i=1, 2,…N-1. Further, using the algorithm for constructing f(y), stated in the previous report, we obtain the empirical distribution function f(v).

Distribution function *f(v)* shall meet the meet the normalization requirement:

$$\int_{-\infty}^{\infty} f(v)dv = 1. \qquad (2)$$

Hereafter we will be interested in such important IHR parameters as:

$$\bar{y} = \int_{-\infty}^{\infty} f(y)ydy; \quad \bar{v}_+ = \int_{0}^{\infty} f(v)vdv;$$
$$\bar{v}_- = \int_{-\infty}^{0} f(v)vdv \qquad (3)$$

Values $\bar{y}$ $\bar{v}_+$ $\bar{v}_-$ bring a simple sense: $\bar{y}$ - average of IHR over the HM period. $\bar{v}_+$ $\bar{v}_-$, — average rate of IHR growth and decrease. They can be components of two independent nondimensional combinations:

$$\frac{\bar{v}_+ + |\bar{v}_-|}{\bar{y}^2}, \quad \frac{\bar{v}_+ - \bar{v}_-}{\bar{v}_+ + |\bar{v}_-|} \tag{4}$$

Let us compile two indices from them:

$$I_X = 6 \times 10^3 \, \frac{\bar{v}_+ + |\bar{v}_-|}{\bar{y}^2};$$

$$I_A = 10^2 \, \frac{\bar{v}_+ - \bar{v}_-}{\bar{v}_+ + |\bar{v}_-|} \quad . \tag{5}$$

They bring a simple sense. Value of I_A and its sign are indicative of a degree of dominance of rate of IHR growth or decrease. Index I_X describes a degree of IHR chaotic character and is its quantitative estimate. Coefficients 10^2 and $6 \cdot 10^3$ are chosen by us for convenience.

Let us consider IHR distribution function *f(v)* for specific patients of Tver Regional Cardiology Health Center. The results of evaluation of function *f(v)* are given in Figures 1-9.

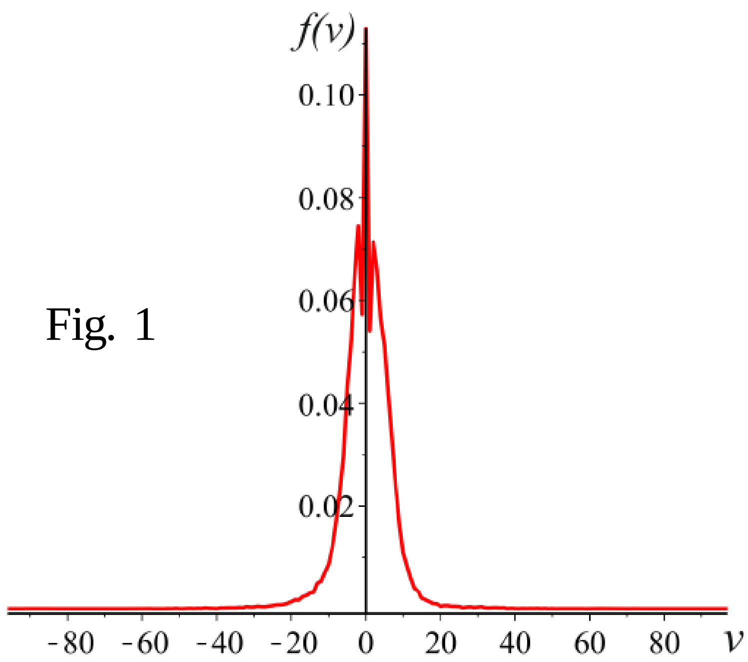


Fig. 1

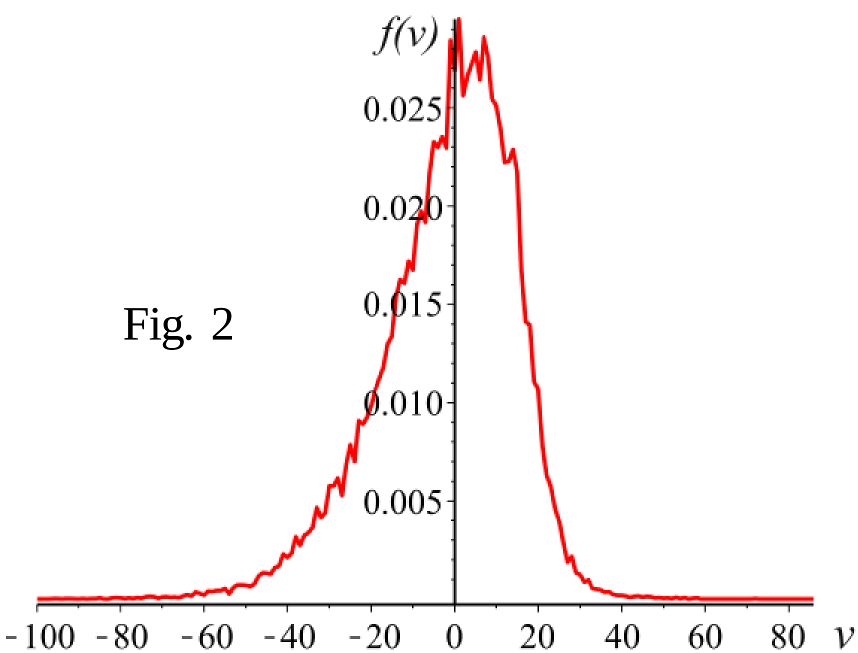


Fig. 2

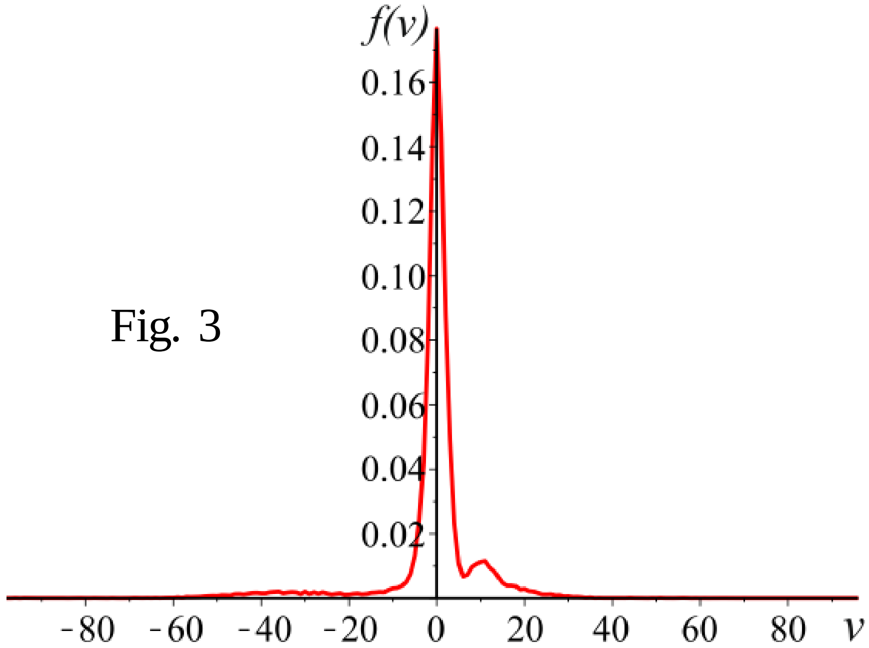


Fig. 3

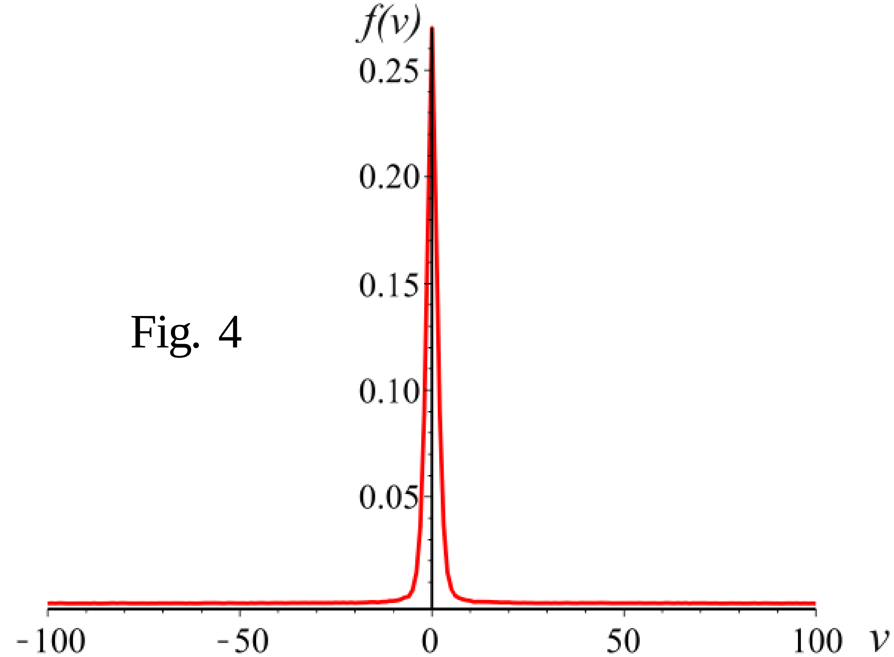


Fig. 4

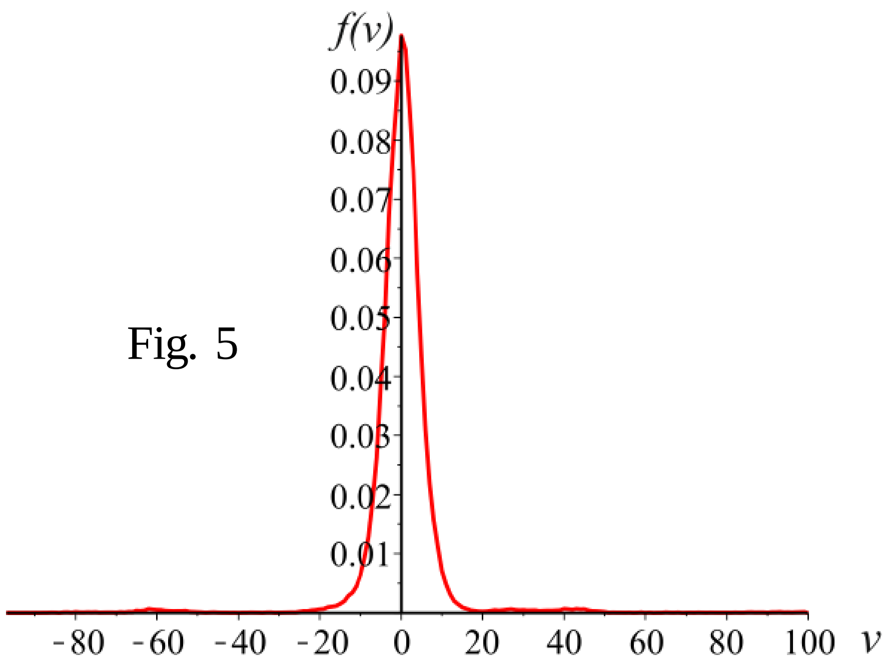


Fig. 5

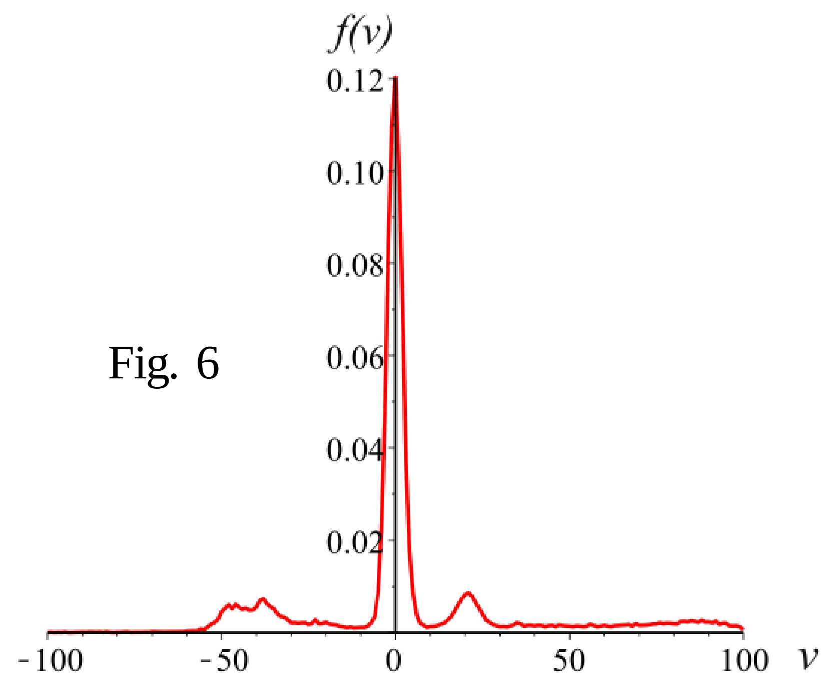


Fig. 6

Fig. 7

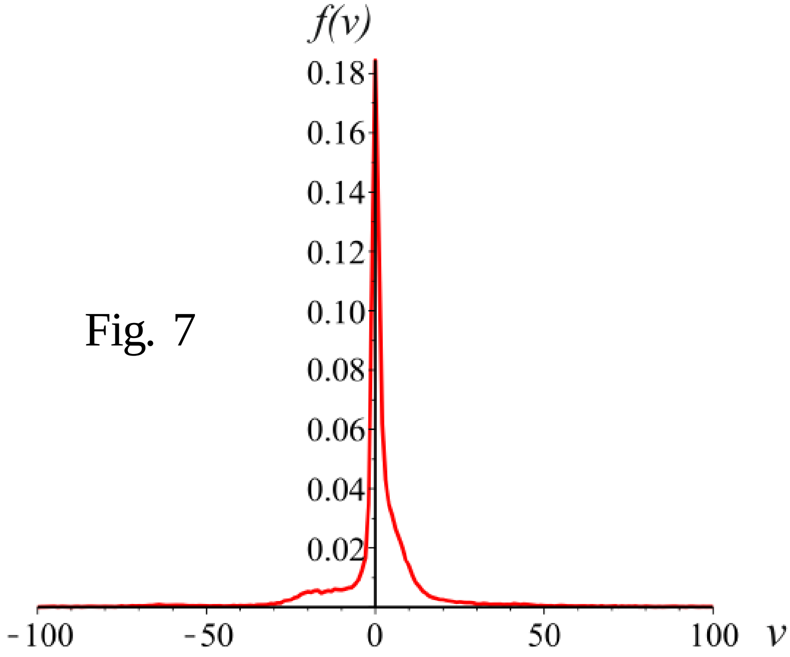


Fig. 8

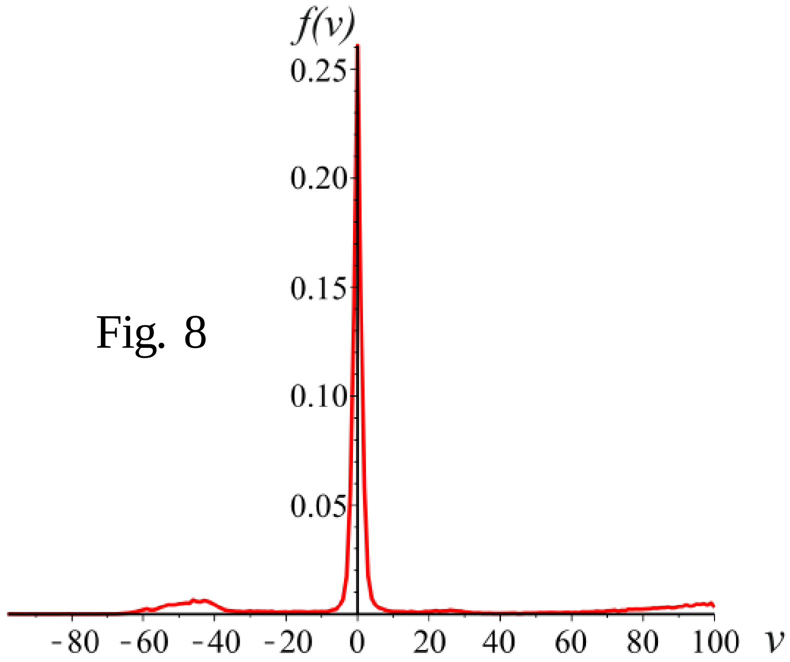
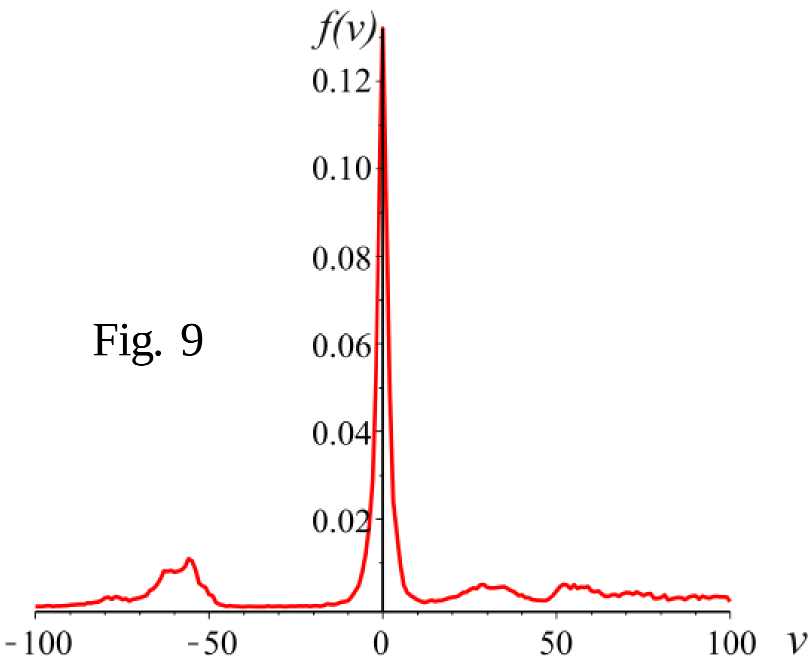


Fig. 9



The computational results of $\bar{v}_+$, $\bar{v}_-$, I_A, I_X for patients 1-9, the *f(v)* graphs of which are based on results 1-9 are given in Table 1.

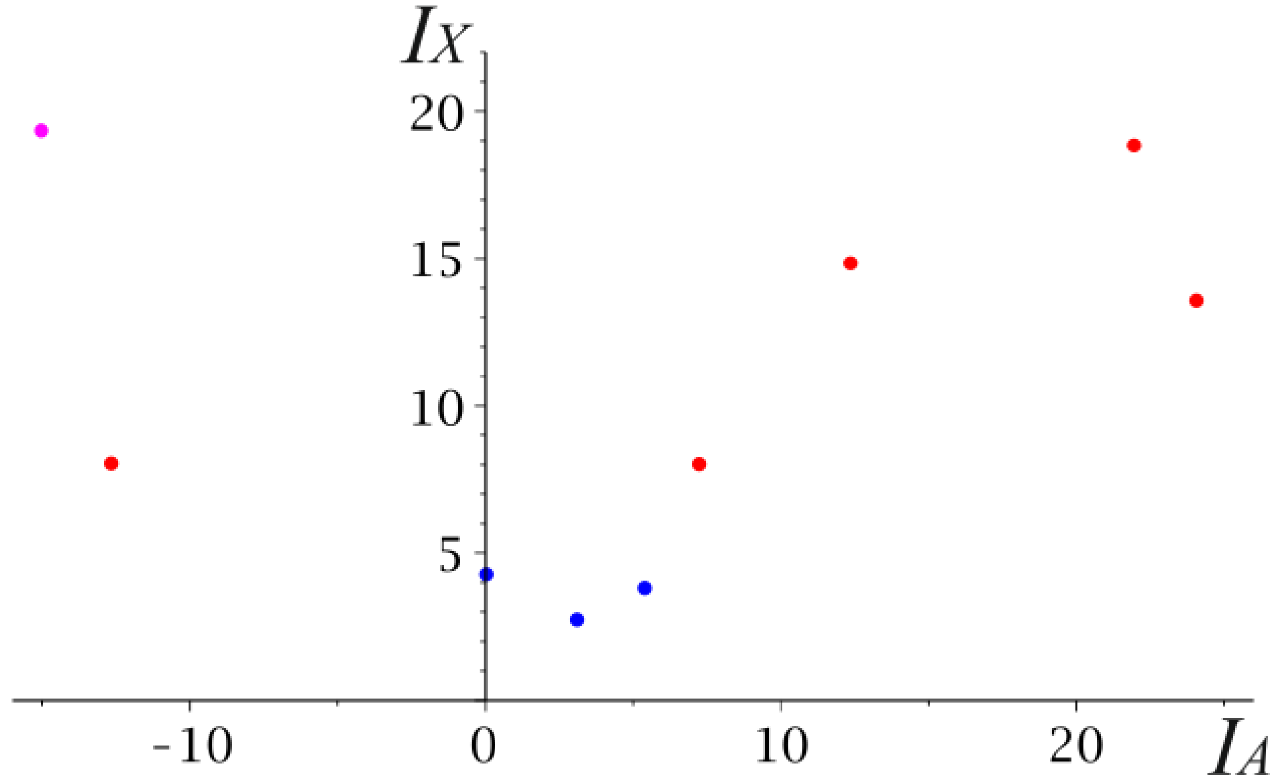
Table 1.

Patient Number	$\bar{v}_+$	$\bar{v}_-$	I_A	I_X	Diagnosis
1.	2.4817	- 2.3304	3.1429	2.6980	Norm
2.	5.3025	- 7.1727	-14.9911	19.3001	Normal bradysystolic form of atrial fibrillation
3.	2.2926	- 2.9551	- 12.6229	8.0052	Ventricular arrhythmia
4.	1.7065	- 1.7044	0.0634	4.2387	Norm
5.	2.5468	- 2.2846	5.4284	3.7750	Norm
6.	10.2151	- 6.5314	21.9966	18.7971	Ventricular arrhythmia (Grade 5, Ryan)
7.	4.1827	- 3.6156	7.2726	7.9806	Ventricular arrhythmia (Grade 4a, Ryan)
8.	10.0593	- 6.1518	24.1035	13.5361	Ventricular arrhythmia (Grade 4a, Ryan)
9.	14.2867	- 11.1338	12.4030	14.8009	Ventricular arrhythmia (Grade 4a, Ryan)

From Table 1 it follows that the values of indices I_A and I_X correspond to the patient diagnoses obtained by standard cardiological methods.

In analyzing IHR, it is possible to represent the statuses of patients in space R^2 by a point with coordinates I_A and I_X. We will call such a diagram a "two-index IHR diagram”. The diagram for test patients is shown in Figure 10.

Fig. 10



In Fig. 10 the colours of points are selected according to patient diagnoses, and this correspondence is reflected in Table 2.

Table 2.

Diagnosis	Point Color
Norm	Blue
Ventricular arrhythmia	Red
Normal bradysystolic form of atrial fibrillation	Crimson

The two-index IHR diagram plotted visualizes the IHR evolution with the course of time. The points describing the IHR statuses of patients will pass from one colour to another in the course of evolution. The issue of a process speed requires detailed follow-up study.

The empirical IHR change rate distribution functions given in Figures 1-9 can be approximated by analytical Laplace's function $e^{-\alpha_i|v-v_i|}$, Gaussian function $e^{-\beta_i(v-v_i)^2}$, $H(v-v_i)$ ($H(x)$ - Heaviside function). In particular cases, *f(v)* passes into either Laplace distribution

$$f(v) = \frac{\alpha}{2} e^{-\alpha_i|v-v_i|}, \qquad (6)$$

or Gaussian distribution:

$$f(v) = \sqrt{\frac{\beta}{\pi}} e^{-\beta_i(v-v_i)^2}. \qquad (7)$$

Presence of the Heaviside functions in approximation of empirical distribution function *f(v)* is indicative of asymmetry of this distribution in relation to their maxima of v_i. Dominance of the Gaussian function in function *f(v)* is indicative of a stochastic nature of IHR change rate distribution v at the maximum point, and dominance of the Laplace's function in function *f(v)* is indicative of a dominance of *v*-values near the maximum point. And it is none other than IHR chaotic character degree reduction. As will be shown below, in cases where the Laplace's function is dominant in *f(v)*, the chaotic character index will be lower then in cases where the Gaussian function is dominant. Let us have a look at the certain type of *f(v)* functions $f_k(v)$ (k=1,..., where 9 – test patient number):

(here $v = x$)

$$\tilde{f}_1(v) = 0.128\,e^{-0.24\,|x|} - 0.042\,e^{-2\,|x+1|} - 0.046\,e^{-1.7\,|x-1|}$$

$$\tilde{f}_2(v) = 0.03\,e^{-0.0018\,(x-5.001)^2}\,\text{Heaviside}(5.001-x) +$$
$$+ 0.03\,e^{-0.005\,(x-5.001)^2}\,\text{Heaviside}(x-5.001) - 0.004\,e^{-4\,|x-2.5|}\,\text{Heaviside}(2.5-x) -$$
$$- 0.004\,e^{-0.5\,|x-2.5|}\,\text{Heaviside}(x-2.5)$$

$$\tilde{f}_5(v) = 0.105\,e^{-0.2\,|x|} - 0.0035\,e^{-\frac{1}{12}\,|x-10|} - 0.005\,e^{-\frac{1}{12}\,|x+8|}$$