Holter monitoring Data-Based Instantaneous Cardiac Rhythm Spectrum. Resonances and Antiresonances

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The report contains the instantaneous cardiac rhythm (ICR)[1-3] frequency y distribution functions $f(y)$ determined on the basis of the Holter monitoring data using MAPLE programs. There was identified a multimodal behaviour of the distribution function $f(y)$. It was shown that the ICR spectrum consisted of a solid component, resonances and antiresonances. The resonances are peaks $f(y)$ determined by peak height h and peak width Γ. The antiresonances are dips $f(y)$ determined by peak dip depth h and width Γ. The most of the time an ICR is in resonance states, and the rest of the time – in antiresonance states.

[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 $\{y_i\}$. Then we develop sets $\tilde{y}_k$ (k=1,…, K) according to ratios $\tilde{y}_k = round\ y_i$, where the round operator is an operation of rounding of values y_i up or down to the nearest whole number in Maple system.

Let denote values y_i, which are components of sets $\tilde{y}_k$, as $n(\tilde{y}_k)$, respectively. Let us consider the points of sets $\tilde{y}_k$ in the order of increasing $\tilde{y}_k < \tilde{y}_{k+1}$.Then, $n(\tilde{y}_k)$ form the IHR and IHR change rate bar charts. Approximation of $n(\tilde{y}_k)$ by piecewise-linear function n(y) with division them by N, gives empirical distribution function f(y). This construction algorithm was implemented by us on the basis of the Maple program system. The values of function f(y) for $y < y_{min}$, $y > y_{max}$ are equal to zero.

Distribution functions $f(y)$ shall meet the meet the normalization requirements [4]:

$$\int_{-\infty}^{\infty} f(y)dy=1. \qquad (1)$$

Empirical distribution function $f(y)$ on substituting into (1) can give just a close to 1 integration result, thus for future use, they shall be normalized according to requirements (1).

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

[4] *E.S. Ventcel* Teoriya veroyatnostej — 10-e izd. ster. — M.: Akademiya, 2005. — 576 s.

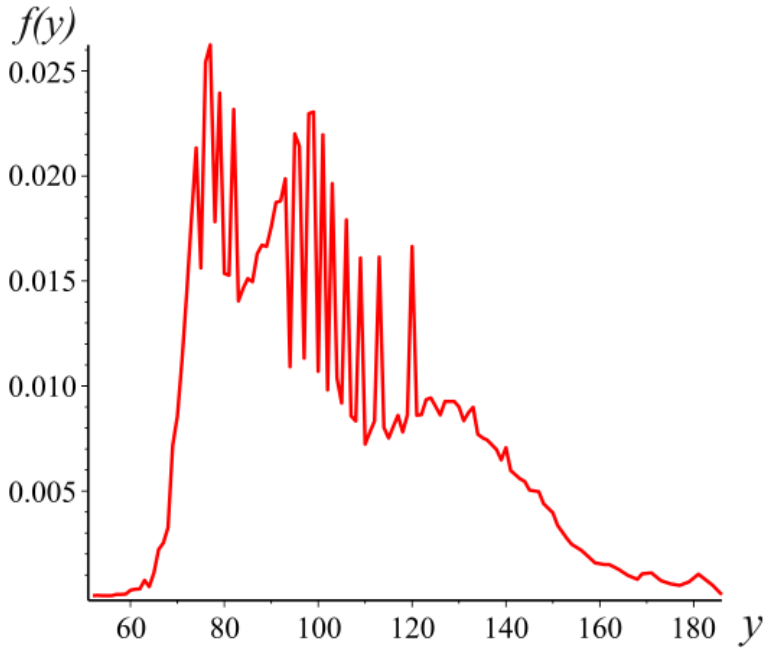

Fig. 1

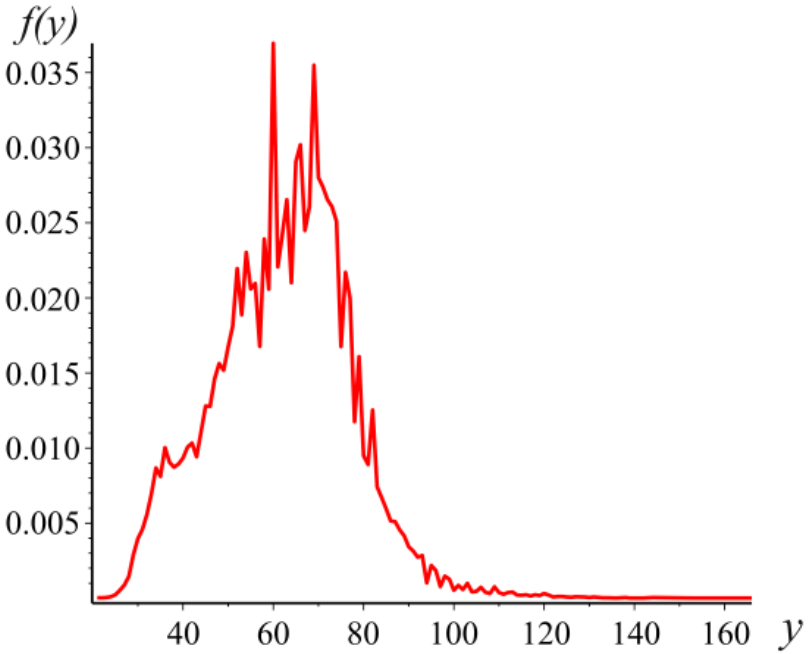

Fig. 2

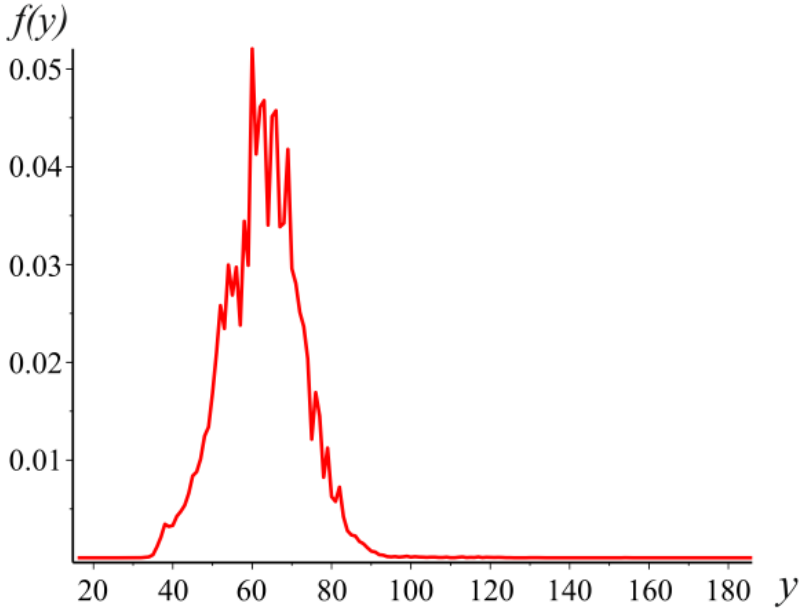

Fig. 3

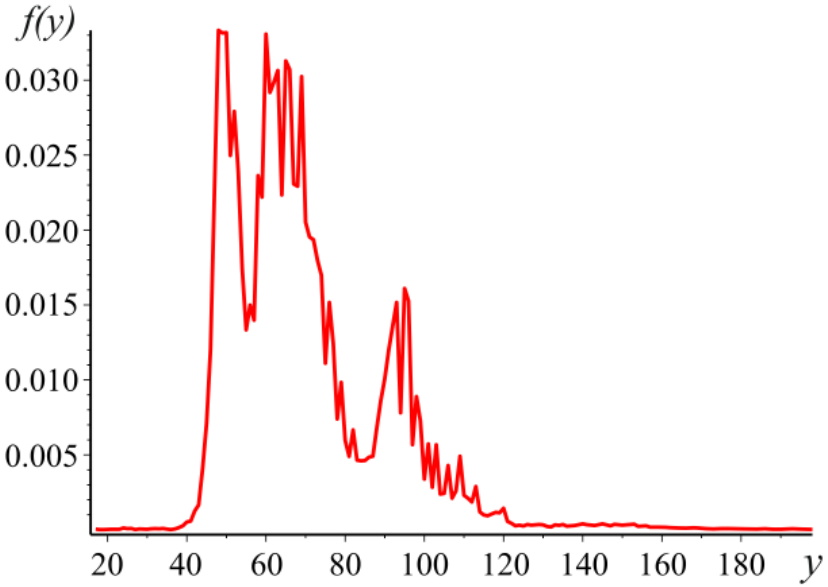

Fig. 4

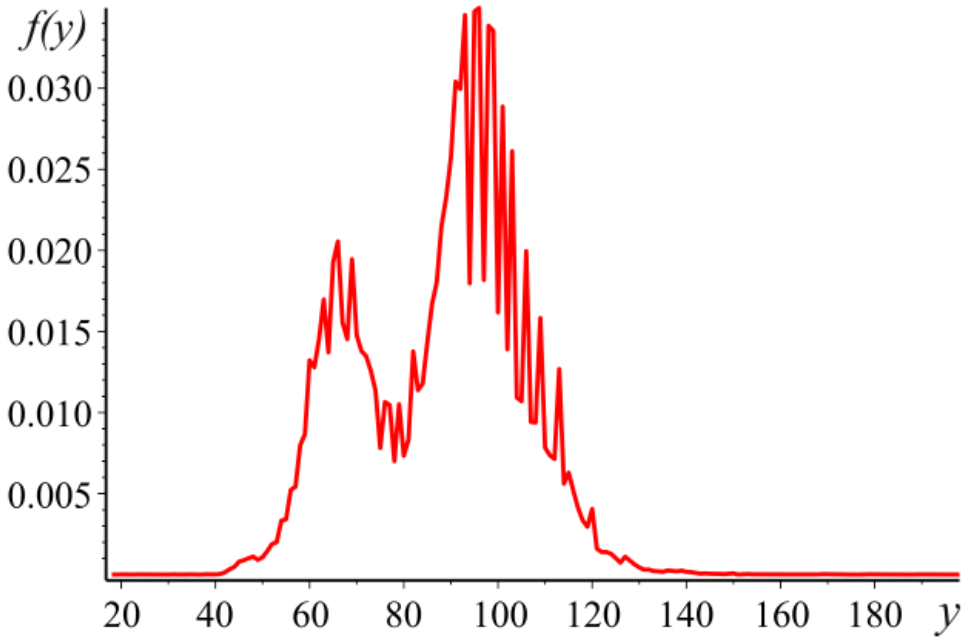

Fig. 5

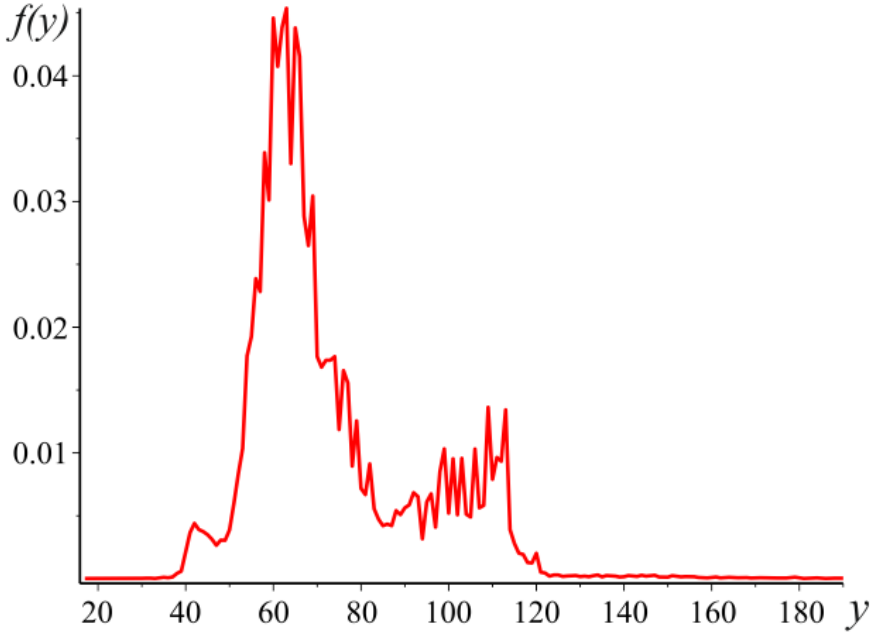

Fig. 6

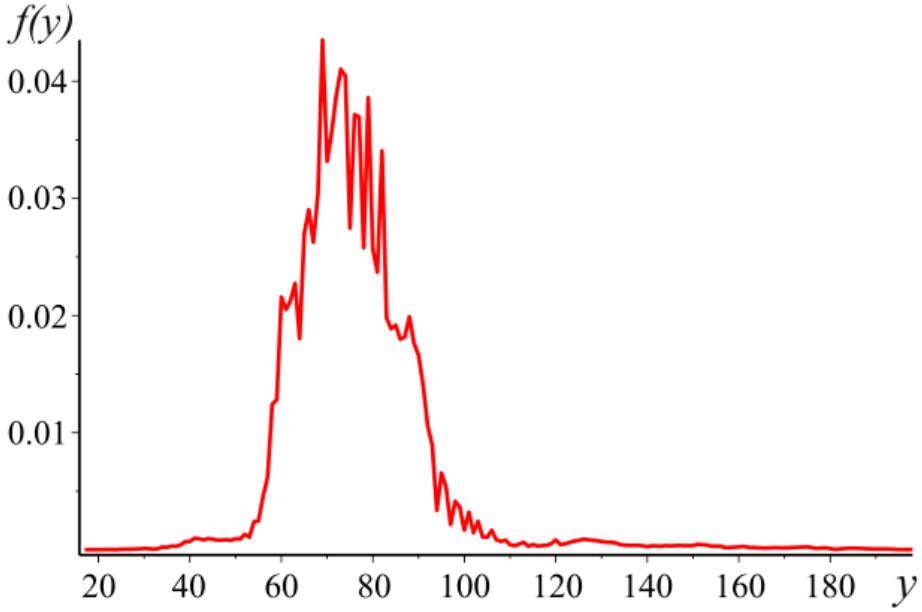

Fig. 7

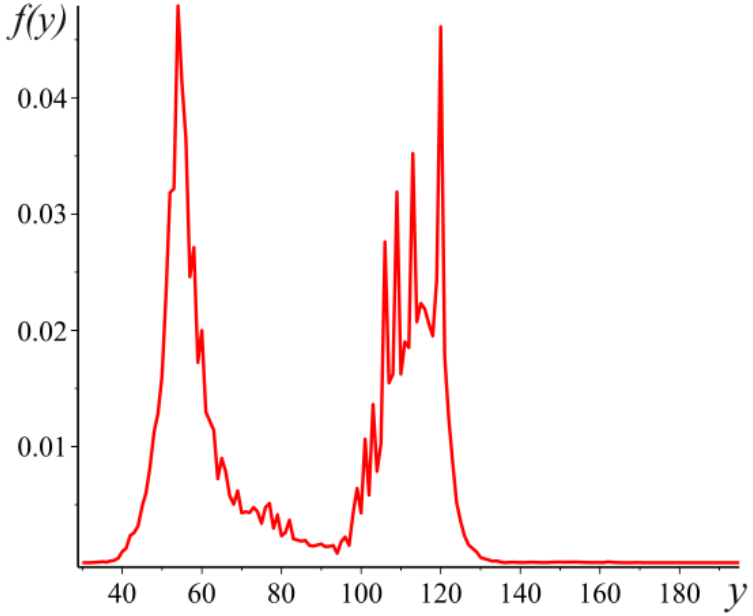

Fig. 8

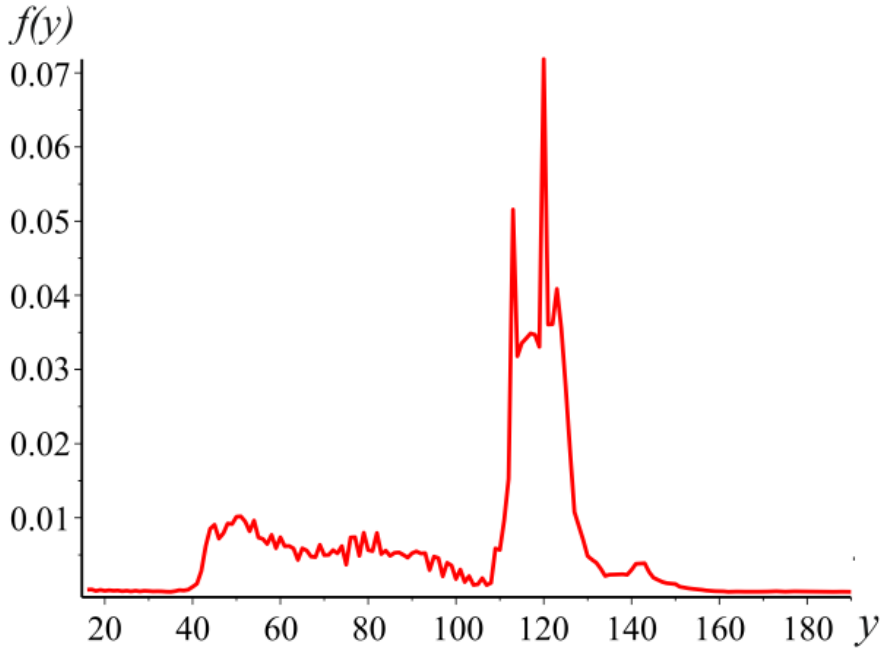

Fig. 9

The $f(y)$ function analysis shows that the IHR spectrum consists of continuous component $g(y)$ and IHR resonances $h_i / \left(1 + \frac{2(y-y_i)}{\Gamma_i}\right)^2$, $i=1,\ldots R$. Where h_i - resonance height, Γ_i- resonance width, y_i -resonance frequency. If $h_i > 0$, we will call the IHR spectrum near y_i a rate resonance, and if $h_i < 0$ – a rate antiresonance.

We will characterize continuous IHR spectrum $g(y)$ by its half-width Γ_g, where Γ_g – range of values y on which $g(y) \geq \frac{1}{2} y_{max}$. The Γ_g, h_i, Γ_i, y_i calculation results for patients whose IHR spectra are given in Table 1.

Table 1.

Patient Num-ber	Γ_g	Γ_i	h_i	y_i	Diagnosis
1.	67	2	0.0043	74	Norm
		3	0.0090	77	
		2	0.0070	79	
		2	0.0081	82	
		3	0.0103	95	
		3	0.0114	99	
		2	0.0111	101	
		2	0.0090	103	
		2	0.0086	106	
		2	0.0079	109	
		2	0.0075	113	
		2	0.0076	120	
2.	33	2	0.0156	60	Normal bradysystolic form of atrial fibrillation
		3	0.0074	66	
		2	0.0084	69	
		3	0.0074	76	
		2	0.0054	79	
3.	22	2	0.0164	60	Ventricular arrhythmia
		3	0.0117	66	
		4	0.0098	69	
4.	31	4	0.0332	48	Norm
		2	0.0073	60	
		3	0.0085	65	
		2	0.0084	69	
		3	0.0093	95	
5.	45	3	0.0059	66	Norm
		2	0.0047	69	
		2	0.0105	93	
		3	0.0168	96	
		3	0.0166	98	
		2	0.0138	101	
		2	0.0136	103	
		2	0.0098	106	
		2	0.0072	109	
		2	0.0062	113	

Patient Num-ber	Γ_g	Γ_i	h_i	y_i	Diagnosis
6.	15	3	0.0128	65	Ventricular arrhythmia (Grade 5, Ryan)
7.	31	2	0.0116	69	Ventricular arrhythmia (Grade 4a, Ryan)
		3	0.0104	76	
		2	0.0128	79	
		2	0.0122	82	
8.	25	2	0.0111	54	Ventricular arrhythmia (Grade 4a, Ryan)
		2	0.0146	106	
		2	0.0156	109	
		2	0.0155	113	
		2	0.0249	120	
9.	14	2	0.0274	113	Ventricular arrhythmia (Grade 2, Ryan)
		2	0.0365	120	

As is clear from Figures 1-9 and Table 1, ICR rate spectra $f(y)$ obtained from HM contain abundance of data on cardiovascular system state.At that, the IHR rate spectra are in exact accordance with the requirements of diagnostics in the region of cardiology.

We turn our attention to a unique phenomenon known as IHR resonance. Mathematically, it means that function $y(t)$ near point y_i of width Γ_i will take place several thousand times in a span of 24 hours of HM. To our opinion, physiologically, IHR resonances are based on the structure and functional characteristics of cardiac pacer. At that, the cardiac pacer mathematical models being created shall also explain occurrence and structure of IHR resonances.

In the context of the chaos theory, IHR resonances are reflections of a definite degree of determinism in IHR dynamics.