292. Evaluation components of the heart rate kinetics for assessment cardiac adaptation during rehabilitation

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Abstract. The purpose of the study was assessment of the cardiovascular adaptation to the workload and physical training by analysis of the heart rate kinetics and dynamics of power spectrum components in healthy subjects and ischemic heart disease patients during rehabilitation. The contingent of study was 20 healthy subjects and 97 patients post-myocardial infarction (74 without chronic heart failure and 23 with chronic heart failure symptoms). Multistage bicycle ergometry or spiroergometry and computerized analysis of heart rate variability during active orthostatic, symptom-limited workload tests and recovery period after test were performed. The rhythmogram at 50W of the workload, and during bicycle (Kettler) training and recovery period was analyzed and the time constant (τ) of the exponential function (by using Proni method), coefficients of amplification, rapidity as well as heart rate (HR) power spectral components (σVLF, σLF, σHF) were evaluated. Heart rate kinetics response time constant to the low-level (τ_{50W}) workload (30.3 vs. 19.3 s) and during recovery period (40 vs. 45.6 s) was delay in post-myocardial infarction patients, especially in those with CHF and low physical capacity as compared with healthy subjects. Heart rate responses (τ_{50W}) correlated with baseline HR autonomic control components (σLF, r=-0.25, ΔRR_B%, r=-0.24, RR_B, r=0.23,) and with physical capacity (r=-0.30). In CHF patients the delay HR response to the workload and during recovery correlated with expressed ventilatory response (VE/VCO_2, r=0.60) in this group. Positive dynamic of HR kinetics components (τ=37.1 vs. 34.6 s) and power spectrum characteristics after low intensity bicycle training procedure and during recovery (τ=42.4 vs. 39.9 s) period was observed. The faster HR reaction to the physical stressor after 3-weeks bicycle training correlated with positive dynamics of σHF (r=-0.35). The HR power spectrum components during bicycle training changed favorably (σVLF, 15.2 vs. 16.3 ms; σLF, 8.2 vs. 9.4 ms; σHF, 8.8 vs. 9.4 ms) too.
Conclusions. Analysis of the heart rate kinetics components and power spectrum data during exercise provides a new possibility evaluation of the cardiac adaptation to the workload and physical training procedures in ischemic heart disease patients during rehabilitation.

Keywords: heart rate kinetics components, power spectrum analysis, submaximal exercise, physical rehabilitation, post-myocardial infarction patients, healthy subjects.

Introduction

Adaptation of cardiovascular system to the physical stress is proceeding throughout increasing of the heart rate, cardiac output, oxygen uptake and blood pressure. Heart rate (HR), as an integral index, reflect the cardiovascular functional status [1, 2, 3], fast reaction to stressors by autonomic regulation [4, 5, 6] and prognosis [1, 7, 8]. HR and heart rate variability (HRV) are key determinants of the cardiovascular function and its autonomic nervous control. Analysis of the heart rate kinetics and variability during physical workload has some methodical difficulties, because of non-stationary of the process. It is known that during beginning of the workload the HR rapidity (which adequate 30% of oxygen uptake) is proceeding by exponential function, which consists of fast and slow components. It is suspected, that the fast component, with time constant about 10 s, is based on the withdrawal of the reflex control (parasympathetic activity) and belongs from the baseline HR autonomic regulation [9]. The slow component, with time constant about 100 s, reflects sympathetic impact of HR regulation.

It is defined, that time constant of exponential function belongs from age, cardiovascular status, autonomic regulation and training [1, 2, 6, 7]. More delay kinetics of HR and oxygen uptake during workload and recovery in patients with heart failure [6, 7] and after transplantation [10] is characteristic. After workload delay function of HR recovery is related with disturbed parasympathetic control and the poor prognosis [5, 6] in cardiac patients. Modulation of the HR variability at rest is related with the distribution of cardiac output and recurrence of venous blood. During moderate intensity workload characteristics of HR power spectrum is manifesting as function of the metabolic needs and is not related with data of central hemodynamic [9, 10]. During the workload in HR power spectrum decrease of high frequency components with increase of low one, associated with blood pressure, and enlarge of very low frequency values, which related with peripheral regulation, is characteristic [9].

Positive training impacts to the cardiovascular adaptation through modification of HR autonomic regulation, with decrease of catecholamine as well as increase of oxygen uptake and tissue metabolism are appropriate [4, 11]. It is shown usefulness methods of HR analysis and modeling for assessment cardiovascular adaptability to the physical stressors [12, 13]. Evaluation of the cardiovascular reserve in relation to the heart rate variability by using functional tests and methods of non-linear analysis is important during physical rehabilitation in cardiac patients. Applying methods for assessment fast cardiovascular adaptation to the workload and physical training process can be useful in clinical, as well as sport practice.

The aim of the study

The goal of the study was evaluation of the fast cardiac adaptation to the workload and physical training via evaluation and analysis of the heart rate kinetics values and power spectrum components in healthy subjects and ischemic heart disease patients during rehabilitation.

Materials and methods

We investigated 20 healthy subjects and 97 patients post-myocardial infarction (MI), during early rehabilitation period in Cardiovascular Rehabilitation department of institute. According to the NYHA classification, 25 patients were in NYHA class I, 72 - in NYHA class II. There were 23 patients with chronic heart failure (CHF) symptoms, 74 patients – without symptoms of CHF. Patients were divided in three groups according to their physical capacity (PC): with high (>125W), middle (75-100W) and low (25-50W) levels of PC.

All patients underwent a comprehensive assessment of the clinical condition, including measurement of the blood pressure, recording of an electrocardiogram, echocardiography, and testing of the cardiovascular system by the orthostatic test and symptom – limited exercise testing. Spiroergometry or bicycle exercise tests in a sitting position, with increment load 25 W every 3 min until threshold load, was performed using a Siregnost FD 85C apparatus (Siemens) and Elema-380B bicycle ergometer. The values of oxygen uptake at the peak workload (evaluated 70 patients) were analyzed: pulmonary ventilation (VE, l/min), peak O_2 uptake (VO_2 ml/kg/min), peak CO_2 production (VCO_2, ml/min), and oxygen ventilation equivalent (VE/VO_2), carbon dioxide ventilation equivalent (VE/VCO_2) [16]. An anaerobic threshold ($ATVO_2$), calculated as VCO_2/VO_2 at respiratory coefficient $\geq$1.0, was determined with Wasserman's et al. recommendations [20]. Physical capacity (PC) during symptom-limited exercise test was evaluated (high, middle and low).

During functional tests rhythmograms as R-R intervals were recorded continuously. On the basis of the rhythmogram, the following heart rate (HR) variability parameters were determined: the RR interval variance in a supine position (σRR), with identification of very low - (σVLF, less than 0.04 Hz), low- (σLF, 0.04-0.15 Hz), and high frequency (σHF, 0.15-0.40 Hz) components of the spectrum in absolute (ms) and normalized (%) units (NVLF, NLF, and NHF). The maximum HR values in response to an active orthostatic test (RR_B), and the extent of this HR response (ΔRR_B, ΔRR_B% - as index of parasympathetic reflex control) were determined by using computerized system analysis of HR and power spectrum during different functional tests.

During 50W workload of ergometry test and during bicycle exercise training program the rhythmograms (RG) were analyzed in the next order: 1) interpolation of RR intervals as a function of time (every 0.5 s), 2) determination the exponents by using Proni method [15, 16], and the exponent elimination from rhythmogram, 3) estimation autoregression model of remain RR, 4) estimation power spectrum by using autoregression model (the range 10), 5) detection white noise. Calculation the amplitudes of high frequency component (HFC, ms), reflecting parasympathetic regulation, low frequency component (LF, ms), reflecting predominantly sympathetic control, and very low frequency component (VLF, ms), associated with thermal – metabolic regulation, in power spectrum were determined. The time constant (τ, s) of the exponential function and coefficient rapidity (KR, s) (which show how the fast is HR reaction to the workload and during recovery) and coefficient of amplification (KA), which evaluated the quantity of this HR alteration, were calculated (Proni method) [15]. Autospectrum of HR after elimination of exponent is showed in picture 1.

Exercise training program of intensity of 50-60% of HR reserve, duration - 20 min., with "Kettler" ergomerter in 41 patients was performed 3 weeks [17]. The time constants of exponential function of rhythmograms and HR power spectrum components during onset of bicycle cycling and recovery at the starting and finishing training program were evaluated.

Data were analyzed using the statistical package SPSS version 12.1. Student's *t*-test was used for comparing the quantitative parameters for the different groups. The relationship between the time constant (τ, s) of the exponential function values and HR variability, data of AOT, physical capacity, oxygen uptake were determined using Spearman's nonparametric test. The differences between parameters was considered to be significant at $p < 0.05$.

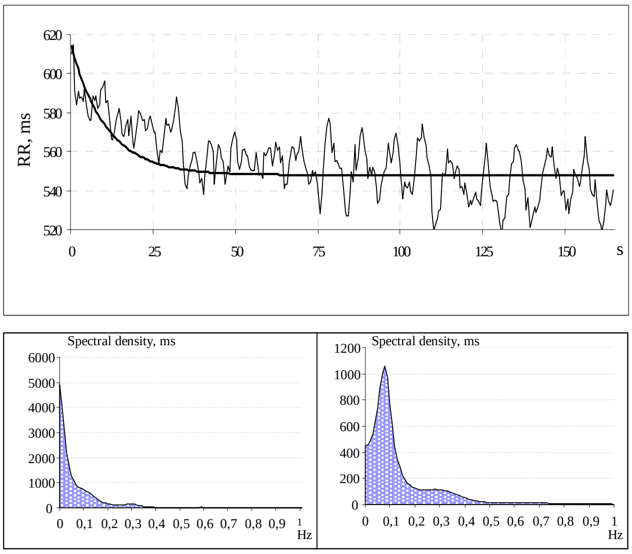

Fig. 1. Elimination exponent from rhythmogram and evaluation of HR power spectrum by using autoregression model

Results and discussion

Time constant of heart rate exponential function to the workload and recovery, and estimation correlation with data of HR autonomic control and physical capacity

Time constant of heart rate exponential function at the beginning of exercise (τ_{50W}) and during recovery was delay in post-myocardial infarction patients, especially with diminished physical capacity. Furthermore, the characteristic of KA_{50W} was bigger and $KR_{recov.}$ - longer ($p<0.05$) in patients group as compared with healthy subjects (table 1). HR autonomic control characteristics, amplitudes of σLF and σHF during workload were higher in healthy subjects than in patients, because of latter diminished HR variability values (σRR) in supine position ($p<0.05$). Reduced data of baroreflectoric control during AOT (according RR_B, ΔRR_B, ΔRR_B%) in patients group was evaluated.

Correlation between τ_{50W} and baseline HR autonomic control data in supine (σLF, r=-0. 25, p=0.011) and with RR_B (r=0.20, p=0.04), ΔRR_B% (r=-0.24, p=0.015) during orthostatic test is showing the relation of baseline HR refectory regulation, as well as baroreflectoric function, with HR kinetic values at the beginning of the workload. Negative relation between τ_{50W} and submaximal physical capacity was determined. (r=-0.30, $p<0.05$). In patients with lower physical capacity more frequent baseline HR, reduced HR variability and diminished parasympathetic regulation reserve (ΔRR_B, ΔRR_B%) as compared with higher PC patients was estimated (table 1).

Table 1. Data of heart rate kinetics and variability during 50W workload, recovery and active orthostatic test in healthy and post-myocardial infarction patients groups

	Characteristics	*Healthy subjects n = 20*	*Patients post MI n = 97*
HR kinetics and power spectrum during 50W workload	τ_{50W} ,s	19.3	30.3*
	KA_{50W}, ms	67.0	83.7
	KR_{50W}	4.2	2.1*
	σVLF_{50W}, ms	9.4	8.8
	σLF_{50W}, ms	15.6	7.8*
	σHF_{50W}, ms	8.9	5.6*
HR kinetics and power spectrum during recovery period	$\tau_{recov.}$, s	40.0	45.6
	$KA_{recov.}$, ms	92.2	182.1*
	$KR_{recov.}$	1.7	3.2*
	$\sigma VLF_{recov.}$, ms	13.0	15.4
	$\sigma LF_{recov.}$, ms	14.6	12.6
	$\sigma HF_{recov.}$, ms	6.9	8.2
HR variability during active orthostatic test	RR, ms	919.7	965.6
	σRR, ms	38.1	31.3
	RR_B, ms	599.1	720.1*
	ΔRR_B, ms	325.3	259.9*
	ΔRR_B%, %	34.4	25.9*
Physical capa-city	MET	7.2	4.5*
	kgm	7000.0	3152.5*

* p <0

.05

In patients with different PC elongated duration of τ_{50W} (25.9, 38.2, 42.9 s) (picture 2), higher coefficient of amplification and reduced data of σLF_{50W} in patients with low PC was determined ($p<0.05$). Data is showing that time constants during workload and recovery belong from physical capacity. In patients with high PC relation between τ_{50W} and performed work (kgm) during ergometric test (r=0.44, p=0.02) was established.

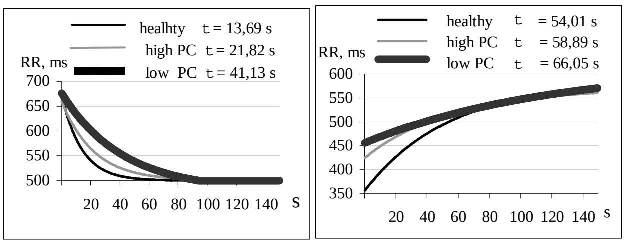

Fig. 2. Time constant of exponential function (τ_{50W}) during workload (left-hand) and recovery (right-hand) in healthy and patients with high and low physical capacity (PC)

Relation between τ_{50W} and oxygen uptake during anaerobic threshold ($ATVO_2$, ml/min, r=0.79, $p<0.05$) had showed link between fast component of cardiovascular adaptation and anaerobic metabolism during workload.

During recovery after ergometric test time constant of heart rate ($\tau_{recov.}$) was longer in patients than in healthy subjects, and became shorter with increasing of PC (picture 2) in patients groups. HR power spectrum components (σVLF, σLF, and σHF) during recovery in healthy and patients were similar and did not belong from different PC (table 2).

Table 2. Data of heart rate kinetics and variability during 50W workload, recovery and active orthostatic test in patients groups due to physical capacity

	Characteristics	*Low PC n = 30*	*Middle PC n = 37*	*High PC n = 30*
HR kinetics and power spectrum during 50W	τ_{50W}, s	42.9	38.2	25.9+ ‡
	KA_{50W}, ms	84.0	95.1	76.0‡
	KR_{50W}	2.1	2.2	1.9
	σVLF_{50W}, ms	8.6	8.4	7.8
	σLF_{50W}, ms	6.0	5.7	7.6‡
	σHF_{50W}, ms	3.7	4.4	5.3^{+}
HR kinetics and power spectrum during recovery	$\tau_{recov.}$, s	36.3	43.4	47.6
	$KA_{recov.}$, ms	112.2	188.6*	201.1+‡
	$KR_{recov.}$	2.8	3.4	3.3
	σVLF_{recov} ms	13.4	15.1	16.4
	$\sigma LF_{recov.}$, ms	11.5	12.6	14.4'
	$\sigma HF_{recov.}$, ms	8.1	9.4	9.8
HR variability during active orthostatic test	RR, ms	914.9	997.1*	956.6
	σRR, ms	25.6	32.6*	34.3+
	RR_B, ms	725.23	741.7	709.5
	ΔRR_B, ms	199.3	276.4*	281.7+
	$\Delta RR_B\%$, %	20.8	26.7*	28.0+ ‡
Physical capa-	MET	3.3	4.4*	5.2+
	kgm	1236.0	2695.9*	5122.7+‡

*p <0.05 between low and middle PC, + p <0.05 –low and high PC, ‡ p <0.05 – middle and high PC patients groups

Positive relation between time constant of HR recovery after workload test and baseline sympathetic components (σLF, r=0.59, p=0.03 and NLF, r=0.60, p=0.030) in healthy subjects and with humoral component (NVLF, r=0.32, p=0.005), as well as parasympathetic impact (NHF, r=-0.26, p=0.02) in patients group was evaluated. Longer τ_{50W} in patients with CHF symptoms (35.7 and 28.2, p=0.07) than without CHF symptoms was established. Irrespective of CHF symptoms baseline characteristics of LF in HR power spectrum none differed (σLF – 11.6 vs. 12.7), but during workload lesser power spectrum LF characteristics (σLF- 5.3 vs. 8.7, p<0.05) were determined in CHF patients group. Positive correlation between τ_{50W} and anaerobic threshold ($ATVO_2$, ml/min, r=0.89, p<0.05) was established in patients without CHF. Relation between τ_{50W} and functional capacity (MET, r=0.43, p<0.03) and submaximal PC (kgm, r=0.42, p<0.05) in patients with CHF was established. In CHF patients group relation between τ_{50W} and VE/VCO_2 (r=0.70, p<0.05) was evaluated, showing link of delay HR reaction to the workload with early anaerobic metabolism, also established by others researches [18-22]. Longer time constant of HR recovery (54.9 and 42.1, p<0.05) in CHF patients compare without CHF was established. The time constant of HR during recovery has satisfactory relation with VE/VCO_2, r=0.60, p=0.05, reflecting link between disturbances of ventilation and perfusion with delay of HR recovery in CHF patients.

Evaluation efficacy of bicycle training program according dynamic of HR kinetic characteristic during rehabilitation

To evaluate efficacy of bicycle training we used computerized analysis of HR variability, evaluation time constant of HR at the beginning of bicycle cycling program, where R-R intervals were recorded continuously during training session – at the starting and after 3 weeks of training. There were established positive dynamic - time constant after training session (37.1 and 34.6 s) and during recovery became shorter (42.4 and 39.9 s). As well increase amplitudes of HR power spectrum components (σVLF- 15.2 and 16.3, σLF- 8.2 and 9.4 ms, σHF 8.8 and 9.4 ms) during cycling were established. The time constant of HR during bicycle training has satisfactory negative relation with parasympathetic components of spectrum (σHF, r=-0.35, p<0.05) and time constant of HR during recovery has relation with sympathetic component of spectrum (σLF, r=-0.35, p<0.05). Shorter time constant after bicycle training related (r=0.34, p<0.05) with increased physical capacity (from 4000 till 4176 kgm) in post - MI patients during rehabilitation.

Assessment characteristics of HR kinetic had showed that time constant of HR during functional tests is related with baseline autonomic HR control, clinical status, and functional capacity and oxygen uptake characteristics and can be used as a tool for estimation quality of cardiac adaptation mechanisms as well as efficacy of treatment in cardiovascular patients during rehabilitation [14,16].

Conclusions

1. Time constant of the heart rate exponential function to the workload and during recovery process is delay in post-myocardial infarction patients, with chronic heart failure symptoms and with low physical capacity as compare to the healthy subjects.
2. Correlation between τ_{50W} and submaximal physical capacity (r=0.42), with oxygen uptake data VE/VCO_2 (r=0.70), anaerobic threshold (r=0.79) had showed linkage between delay HR reaction to the workload and early anaerobic metabolism in cardiac patients.
3. Delay heart rate recovery function is correlated with anaerobic metabolism data (r=0.60) in post-myocardial patients with chronic heart failure.
4. Evaluation time constant of HR exponential function during bicycle training procedure can be used as a tool for estimation quality of cardiac adaptation mechanisms as well as efficacy of treatment in post-myocardial patients during rehabilitation.

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