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Chronotropic response during exercise and recovery in men with mild systolic chronic heart failure

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Abstract

Background and aim: Pattern of heart rate (HR) changes during exercise and recovery is deranged in patients with cardiovascular disease, being considered as an independent predictor of poor outcome. This issue has been poorly examined in patients with chronic heart failure (CHF), particularly in the early stages of this syndrome.

Methods: Cardiopulmonary exercise testing (CPX) was performed in 54 men with sinus rhythm with mild stable systolic CHF in NYHA class I–II (age 57 ± 12 years, LVEF 31 ± 8%) and in 27 male volunteers without CHF (age 54 ± 8 years, LVEF 67 ± 7%). Apart from peak oxygen consumption (peakVO_2), chronotropic response was evaluated using the following parameters: peak heart rate (HR) expressed in absolute values (maxHR) and age-predicted maximal values (%maxHR), HR increase during exercise (ΔHR), chronotropic index (CI = ΔHR/predicted ΔHR) and a regression coefficient of a linear function between HR and time during exercise (HR-time slope). Chronotropic response was also evaluated during recovery based on a regression coefficient of a linear function between HR and time during the first three-min of recovery (HR-time slope) and HR decrease after 90 s (HRR90), 120 s (HRR120) and 180 s (HRR180) from peak exercise.

Results: Men with CHF in NYHA II and I class demonstrated impaired chronotropic response to exercise as compared to control peers: NYHA II *vs* NYHA I *vs* control: maxHR 122 ± 24 *vs* 154 ± 25 *vs* 166 ± 13 bpm, all $p < 0.05$; %maxHR 76 ± 14 *vs* 91 ± 11 *vs* 101 ± 7%, all $p < 0.001$; ΔHR 48 ± 20 *vs* 75 ± 20 *vs* 91 ± 14 bpm, all $p < 0.01$; HR-time slope during exercise 5.6 ± 2.2 *vs* 6.5 ± 2.6 *vs* 8.3 ± 1.2, all $p < 0.01$ (NYHA I *vs* NYHA II, $p > 0.2$); CI 0.56 ± 0.36 *vs* 0.85 ± 0.21 *vs* 1.02 ± 0.13, all $p < 0.01$; HR-time slope during three-min of recovery –14.0 ± 7.0 *vs* –19.2 ± 5.1 *vs* –23.5 ± 3.8, $p < 0.05$ (NYHA I *vs* control $p > 0.2$); HRR90 30 ± 17 *vs* 44 ± 14 *vs* 49 ± 9 bpm, $p < 0.05$ (NYHA I *vs* control $p > 0.2$); HRR120 35 ± 8 *vs* 51 ± 13 *vs* 59 ± 9 bpm, all $p < 0.05$; HRR180 41 ± 17 *vs* 57 ± 15 *vs* 68 ± 10 bpm, all $p < 0.01$. In CHF men, impaired peakVO_2 was related to HR response to exercise ($r = 0.60$, $p < 0.001$) and recovery ($r = 0.50$, $p < 0.001$). Abnormal HR response to recovery correlated also to high NT-proBNP ($r = 0.33$, $p < 0.05$). In 13 men with CHF in whom CPX was performed twice between 17 ± 11 days, variability coefficients for analysed parameters of chronotropic response ranged 8–15%.

Conclusions: Parameters reflecting the chronotropic response to exercise and recovery are characterised by a good reproducibility, hence may be useful in the clinical assessment of patients with CHF. There is a marked reduction of chronotropic response in patients in the early stages of CHF, which may be another mechanism limiting exercise capacity.

Key words: chronic heart failure, chronotropic response, exercise capacity, cardiopulmonary exercise testing, heart rate

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INTRODUCTION

Pattern of heart rate (HR) changes in humans both during exercise and after exercise cessation was analysed as early as in the thirties of the 20th century [1, 2]. Experimental studies in dogs [3, 4] and subsequently in humans [5] proved that HR is regulated by the autonomic nervous system. In the course of chronic heart failure (CHF) in humans, deranged autonomic balance [6, 7], beta-receptor density changes in the heart [8, 9] and cardiomyocyte desensitisation to adrenergic stimulation [9, 10] are observed. It is assumed that deranged chronotropic response and related impairment of the exercise capacity in patients with CHF [11, 12] are due to these mechanisms.

Impaired autonomic balance is observed as early as in the initial stages of CHF [11, 12], what implies that in this group of patients chronotropic response can differ from that observed in subjects without myocardial injury.

The aim of the study was to assess the pattern of chronotropic response during exercise and immediately post-exercise in male patients with mild systolic CHF and to evaluate the reproducibility of the measured parameters.

METHODS

Study groups

Inclusion criteria for the group with systolic CHF were as follows: male patients with sinus rhythm aged 18–75 years; diagnosed with CHF NYHA class I or II at least six months prior to inclusion; absence of angina; stable disease course — without decompensation and therapy changes within four weeks prior to inclusion; ejection fraction (EF) as confirmed by echocardiography ≤ 45%; cardiopulmonary testing (CPX) in which RER of 1.05 was achieved and fatigue or dyspnea was at least seven on the ten-point Borg scale.

Inclusion criteria for the control group were as follows: men with sinus rhythm aged 18–75 years; absence of CHF symptoms and absence of angina; absence of chronic conditions and chronic treatment; normal systolic function as confirmed by echocardiography (EF > 50%) and no diastolic dysfunction; CPX in which RER of 1.05 was achieved and fatigue or dyspnea was at least seven on the ten-point Borg scale.

Exclusion criteria for both groups were as follows: history of an acute coronary syndrome, percutaneous coronary intervention or coronary artery bypass grafting within three months prior to inclusion; chronic inflammatory, neoplastic conditions as well as chronic skeletal, nervous or muscular system diseases influencing exercise capacity; lack of patient's informed written consent to the participation in the study.

The study was approved by Bioethical Committee of the Medical University of Wroclaw and all patients gave their written consent.

Study protocol

All the included persons underwent medical examination and basic laboratory workup; resting transthoracic echocardiographic study and CPX preceded by spirometry were also performed.

In all, N-terminal pro-peptide of the brain natriuretic factor (NT-proBNP) by immunoenzymatic method (ELISA, Elecsys 1010/2010 System, Roche Diagnostics GmbH, Mannheim, Germany) and C-reactive protein by high sensitivity immunonephelometric assay (Dade Behring Marburg GmbH, Germany) were measured. The remaining laboratory tests were performed with standardised laboratory methods. Glomerular filtration rate was estimated based on the modification of diet in renal disease formula [13].

CPX protocol

The CPX was carried out with use of GE/Marquette Series 2000 treadmill, according to ramp protocol (in which workload is a linear function of time) with workload increment of 1.33 MET/min. Throughout the study, continuous expired gas analysis was performed on Ultima Medgraphics system, along with continuous ECG recording. At intervals no longer than 5 s the following parameters were recorded in an integrated manner: oxygen consumption (VO_2) [mL/min], carbon dioxide production (VCO_2) [mL/min], minute ventilation (VE) [L/min] and heart rate (HR) [bpm].

The following CPX parameters were analysed:

— related to ventilatory and metabolic response to exercise: peak oxygen uptake (peakVO_2) [mL/kg/min]; exercise ventilation index (VE-VCO_2 slope, linear regression coefficient describing minute ventilation as a function of CO_2) — during the entire exercise period; peak exercise capacity expressed in standard metabolic equivalents (max MET);

— related to chronotropic response to exercise (Fig. 1): peak heart rate (maxHR) expressed in beats per minute [bpm]; %maxHR — expressed as proportion of the maximal predicted HR [%]; HR increase (ΔHR) [bpm] — during the entire exercise period; chronotropic index (CI = ΔHR/ /ΔHR predicted); HR-time slope (linear regression coefficient of HR function over time) — during the entire exercise period;

— related to chronotropic response immediately post-exercise (Fig. 1): HR-time slope (linear regression coefficient of HR function over time) — during the first 180 s after exercise cessation; HR recovery at 90, 120 and 180 s post-exercise (HRR90, HRR120, HRR180) [bpm].

In order to assess the reproducibility of the measurements, CPX was repeated in 13 patients with stable CHF within 7–40 days.

Statistical analysis

The results are presented as means and standard deviations or medians (with upper and lower quartiles) for variables showing a skewed distribution. Between-group differences were analysed with Student t, χ^2 or Mann-Whitney tests, respective of data type. Correlations are presented as Pearson coeffi-

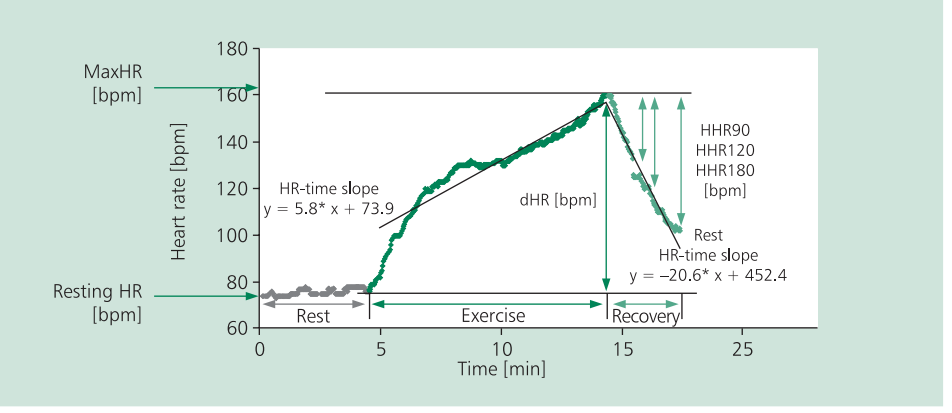

Figure 1. Relationship between heart rate (HR) and time during cardiopulmonary testing

cients (for variables showing normal distribution) or as Spearman rang correlations for the remaining variables showing a skewed distribution. Statistical significance level of < 0.05 was assumed.

The reproducibility of measurements was evaluated with Bland-Altman method by calculating variability coefficients (VC) [14]. The VC was defined as standard deviation of the differences of the measurements divided by the arithmetic mean of the measurements , and expressed as a percentage.

RESULTS

Fifty-four men with stable systolic CHF were included in the study, 17 (31%) in NYHA class I and 37 (69%) in NYHA class II, along with 27 men without CHF. Clinical characteristics of the group are presented in Table 1. In Table 2, information on beta-blocker use is summarised.

Patients with CHF had lower exercise capacity, lower peakVO_2 and higher exercise ventilatory coefficient VE-VCO_2 slope (Table 3). Exercise workload and peakVO_2 (but not the VE-VCO_2 coefficient) were lower in the group of men with NYHA II CHF than in NYHA I group (Table 3).

All the studied groups had comparable resting HR values (Table 3). Chronotropic response during exercise as well as during recovery was impaired in men with NYHA I and NYHA II CHF as compared to controls (Table 3). Strong correlations were found between chronotropic response parameters in patients with CHF (Table 4).

In CHF patients no correlation between any of the laboratory parameters and chronotropic response parameters was found, except for a negative correlation between plasma NT-proBNP measurements and chronotropic response post-exercise (min. $r = 0.34$; max. $r = 0.39$; all $p < 0.01$; Fig. 2). No correlation between body mass index, treatment (including beta-blocker dose), coexistent arterial hypertension and history of myocardial infarction and chronotropic response parameters was found. Men with CHF and diabetes had worse chronotropic response than non-diabetics: maxHR 138 ± 33 *vs* 114 ± 21 bpm, %maxHR 84 ± 18 *vs* 70 ± 13%; ΔHR 62 ± 27 *vs* 39 ± 20 bpm; CI 0.73 ± 0.34 *vs* 0.45 ± 0.24; HR-time slope during rest –17.1 ± 6.1 *vs* –10.1 ± ± 7.5; HRR90 39 ± 19 *vs* 23 ± 13 bpm; HRR120 46 ± 20 *vs* 25 ± 15 bpm; HRR180 51 ± 20 *vs* 31 ± 14 bpm (all $p <$ < 0.05).

Also, a relation was noted between worse chronotropic response parameters during exercise and recovery and lower oxygen consumption and lower workload (Table 5).

In order to assess reproducibility of the studied parameters, CPX was repeated within 17 ± 11 days of the first test. The VC were within the range of 8–15% (Table 6).

DISCUSSION

In our study we have demonstrated that chronotropic response during exercise and during recovery is impaired also at the early stages of CHF (NYHA class I and II). It should be underlined, that baseline HR did not differ between the study groups so probably the changes in HR dynamics in the course of the disease occur earlier during exertion whereas resting values of heart rate are affected rather at advanced stages of heart failure. Beta-blocker dosage did not influence HR-derived indices, which is in line with earlier observations [15, 16].

Exercise and post-exercise HR changes are controlled by autonomic nervous system. Autonomic balance impairment, which is a background phenomenon of heart failure pathophysiology [17, 18], results in blunted chronotropic response. Therefore our results imply that clinical consequences of the deranged autonomic tone occur in the early, including asymptomatic, stages of CHF.

Markedly reduced chronotropic response parameters in patients with concomitant diabetes (within the CHF group in both NYHA subgroups) are most probably due to diabetic neuropathy [19], which further increases autonomic imbalance in these patients.

In our study, we found a relationship between chronotropic response to exercise and peakVO_2. This explains the

Table 1. Clinical characteristics of the studied groups of men with systolic chronic heart failure (CHF) and the control group

Variable [unit]	Control group (C; n = 27)	Men with CHF NYHA I (I; n = 17)	Men with CHF NYHA II (II; n = 37)	P C *vs* I	P C *vs* II	P I *vs* II
Age [years]	54 ± 8	52 ± 13	59 ± 11			
Body mass index [kg/m^2]	27.0 ± 4.1	25.8 ± 3.4	28.5 ± 3.6			**
Ischaemic etiology of CHF	–	8 (47%)	28 (76%)			***
Arterial hypertension	0 (0%)	5 (29%)	19 (54%)	–	–	
Diabetes	0 (0%)	0 (0%)	9 (24%)	–	–	***
LVEF [%]	67 ± 7	33 ± 7	30 ± 8	*	*	
LVEDD [mm]	50 ± 5	68 ± 9	67 ± 9	*	*	
Haemoglobin [g/dL]	14.9 ± 0.9	14.4 ± 1.0	14.7 ± 1.1			
eGFR-MDRD	92 ± 14	92 ± 20	86 ± 25			
Sodium concentration [mmol/L]	142 ± 1	142 ± 2	141 ± 3		***	
NT-proBNP concentration [pg/mL]	21 (10–33)	607 (319–1235)	688 (266–1659)	*	*	
hsCRP concentration [mg/L]	0.7 (0.5–1.1)	1.2 (0.4–2.0)	2.4 (0.6–6.3)		**	
ACEI and/or ARB	0 (0%)	14 (82%)	31 (84%)	–	–	
Beta-blocker	0 (0%)	16 (94%)	37 (100%)	–	–	
Aldosterone antagonist	0 (0%)	4 (23%)	10 (27%)	–	–	
Digoxin	0 (0%)	3 (18%)	8 (22%)	–	–	
Loop diuretic	0 (0%)	6 (35%)	16 (43%)	–	–	
Thiazide diuretic	0 (0%)	5 (29%)	22 (59%)	–	–	***
Statin	0 (0%)	11 (65%)	35 (95%)	–	–	***
Acetylsalicylic acid	0 (0%)	13 (76%)	32 (86%)	–	–	***

Variables are presented as means ± standard deviation, medians (with upper and lower quartiles) or numbers with fractions %; ACEI — angiotensin converting enzyme inhibitor; ARB — angiotensin receptor blocker; LVEF — left ventricular ejection fraction; LVEDD — left ventricular end-diastolic diameter; eGFR-MDRD — estimated glomerular filtration rate-modification of diet in renal disease; NT-proBNP — N-terminal pro-B-type natriuretic peptide, hsCRP — high-sensitivity C-reactive protein; *$p < 0.001$; **$p < 0.01$; ***$p < 0.05$ (whenever no p value is reported — no statistical significance was found; $p > 0.2$)

Table 2. Proportion of patients taking beta-blockers and doses of beta-blockers in the studied groups

Drug and dose	CHF NYHA I group	CHF NYHA II group	P
Bisoprolol [mg]	2 (12%); 7.5 ± 3.5	5 (14%); 8.5±2.2	NS
Carvedilol [mg]	14 (82%); 26 ± 17	32 (86%); 38 ± 13	NS

CHF — chronic heart failure

correlation between HR and cardiac output, which, in the course of CHF, is related chiefly to the chronotropic response profile. The reduction of HR response to exercise contributes greatly to exercise intolerance [20].

The relationship between decreased chronotropic response immediately after exercise cessation and peakVO_2 and workload merits attention. However the dynamics of HR decrease during recovery can simply result from the magnitude of peakHR, peakVO_2 and workload. It should be kept in mind that the rate of HR decrease after exercise cessation is related to parasympathetic reactivation [21] and autonomic balance in general, and this influences exercise tolerance and peakVO_2 as well as maximal workload. Moreover, NT-proBNP remains interrelated with chronotropic response during recovery, but not with exercise parameters, what points out to coincidence of reduced parasympathetic reactivation and increased neurohormonal activation.

In our study, only men were included due to obvious, sex-related differences of exercise physiology [22–25]. Hence, a similar study in women would be a valuable contribution.

Our patients with heart failure were on optimal medical therapy concordant with the current guidelines, most of

Table 3. Parameters of the CPX in the studied groups of men with CHF and in the control group

Variable [unit]	Control group (C; n = 27)	Men with CHF NYHA I (I; n = 17)	Men with CHF NYHA II (II; n = 37)	P C *vs* I	P C *vs* II	P I *vs* II
Resting HR [bpm]	74 ± 9	79 ± 15	74 ± 12			
Peak workload [MET]	15 ± 2	12 ± 3	9 ± 3	*	*	**
peakVO_2 [mL/kg/min]	32 ± 5	24 ± 6	18 ± 5	*	*	*
Exercise ventilation coefficient VE-VCO_2	27 ± 3	32 ± 9	35 ± 11	***	*	
Chronotropic response parameters during exercise						
maxHR [bpm]	169 ± 11	154 ± 25	122 ± 24	**	*	*
%maxHR [%]	102 ± 6	91 ± 11	76 ± 14	*	*	*
ΔHR [bpm]	95 ± 12	75 ± 20	48 ± 20	*	*	*
HR-time slope	8.4 ± 1.0	6.5 ± 2.6	5.6 ± 2.2	*	*	
CI	1.03 ± 0.11	0.85 ± 0.21	0.56 ± 0.36	*	*	*
Chronotropic response parameters during recovery						
HR-time slope	–20.9 ± 5.8	–19.2 ± 5.1	–14.0 ± 7.0		*	***
HRR90 [bpm]	50 ± 11	44 ± 14	30 ± 17		*	**
HRR120 [bpm]	60 ± 12	51 ± 13	35 ± 18	***	*	**
HRR180 [bpm]	69 ± 11	57 ± 15	41 ± 17	**	*	**

Data expressed as means ± standard deviation; bpm — beats per minute; CPX — cardiopulmonary exercise testing; CHF — chronic heart failure; HR — heart rate; MET — metabolic equivalent; peakVO_2 — peak oxygen consumption; VE-VCO_2 — ventilation index of carbon dioxide; maxHR — maximal HR; %maxHR — achieved fraction of maximal predicted HR; ΔHR — increase of HR during exercise; HR-time slope — linear regression coefficient of HR as a function of time; CI — chronotropic index; HRR90 — recovery of HR at 90 s post-exercise; HRR120 — recovery of HR at 120 s post-exercise; HR180 — recovery of HR at 180 s post-exercise; *$p < 0.001$; **$p < 0.01$; ***$p < 0.05$ (if no p value reported — lack of statistical significance; $p > 0.2$)

Table 4. Interrelations between chronotropic response parameters during exercise and during recovery in men with CHF

	maxHR	%maxHR	ΔHR	HR-time slope	CI	HR-time slope	HRR90	HRR120	HRR180
HRR180	0.71	0.80	0.73	0.53	0.72	0.73	0.79	0.95	
HRR120	0.61	0.74	0.65	0.45	0.62	0.65	0.81		
HRR90	0.66	0.76	0.72	0.52	0.65	0.72			
HR-time slope	–0.56	–0.52	–0.64	–0.54	–0.58				
CI	0.93	0.99	0.92	0.66					
HR-time slope	0.63	0.64	0.67						
ΔHR	0.88	0.90							
%maxHR	0.94								

Data expressed as r. All $p < 0.001$; abbreviations as in Table 3

them received beta-blockers and angiotensin I converting enzyme inhibitors or angiotensin II receptor antagonists. Receiving standard therapy for four weeks prior to participation was one of the inclusion criteria. The majority of earlier studies, concerning the relationship between chronotropic response and exercise capacity, were carried out when such therapy was not a part of standard management [26–28]. While pathophysiologic rationale exists, pointing out to relations between beta-blockers [29, 30] or renin-angiotensin-aldosterone system blockade [31, 32] and chronotropic response, this issue remains equivocal. There are studies showing that there is no difference in the rates of impaired chronotropic response between CHF patients receiving and not receiving beta-blocking agents [15].

An important part of our work is the reproducibility assessment, which has not been studied to date. In clinical studies, peakVO_2 variability or ventilation index variability do not exceed 10% [33, 34]. However, in functional studies of

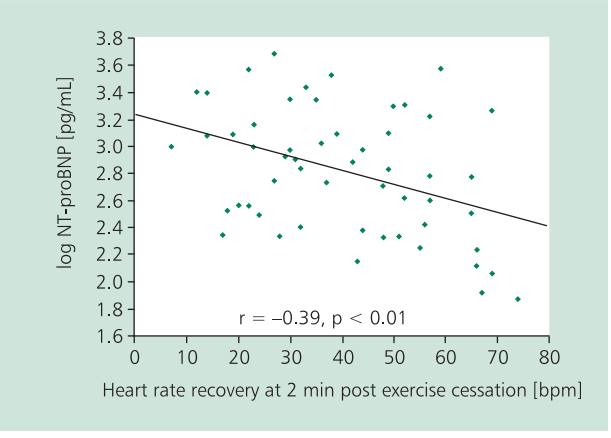

Figure 2. Relationship between NT-proBNP and HRR120; abbreviations as in Tables 1 and 3

the autonomic nervous system it can be as high as 30% [35]. Therefore, the variability coefficient of chronotropic response parameters in our work, which did not exceed 15%, is satisfactory and allows for their use in the clinical assessment of CHF patients.

CONCLUSIONS

Chronotropic response impairment occurs at the early stages of CHF, despite preserved exercise capacity. Pathomechanisms underlying this important, yet so far neglected issue, are probably related to impairment of the autonomic balance. However, this issue needs further study.

The chronotropic response parameters measured during exercise as well as during recovery, are characterised by good reproducibility, what allows for their use in the clinical assessment of patients with CHF.

Table 5. Correlations of chronotropic response parameters with peak VO_2 and maximal workload expressed in METs in men with chronic heart failure

Variable	peakVO_2 [mL/kg/min]	Peak exercise capacity [MET]
Chronotropic response parameters during exercise		
maxHR [bpm]	0.66*	0.62*
%maxHR [%]	0.61*	0.58*
ΔHR [bpm]	0.60*	0.60*
HR-time slope	0.17	0.30***
CI	0.61*	0.60*
Chronotropic response parameters during recovery		
HR-time slope	–0.48*	–0.51*
HRR90 [bpm]	0.50*	0.46*
HRR120 [bpm]	0.53*	0.44**
HRR180 [bpm]	0.54*	0.48*

Data expressed as r; abbreviations as in Table 3; *p < 0.001; **p < 0.01; ***p < 0.05 (if no p value reported — lack of statistical significance; p > 0.2)

Table 6. Repeatability of CPX parameters in the group of 13 men with chronic heart failure

Variable	First test	Second test	Δ	VC [%]
Chronotropic response parameters during exercise				
maxHR [bpm]	148	148	0,17	9
%maxHR [%]	87	87	–0.16	9
ΔHR [bpm]	65	65	–0.3	12
HR-time slope	6.9	6.8	0.1	11
Chronotropic response parameters during recovery				
HR-time slope	19	19	–0.42	13
HRR90 [bpm]	39	40	–0.9	14
HRR120 [bpm]	48	49	–1.1	15
HRR180 [bpm]	55	56	–0.6	10
Standard CPX parameters				
Exercise time [min]	9.1	9.2	–0.2	8
VE-VCO_2 slope	32.2	32.0	0.2	10
peakVO_2 [mL/kg/min]	22.2	22.5	–0.3	8

VC — variability coefficients, rest abbreviations as in Table 3

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Odpowiedź chronotropowa podczas wysiłku i bezpośrednio po nim u mężczyzn z łagodną skurczową przewlekłą niewydolnością serca

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Streszczenie

Wstęp i cel: Dynamika zmian częstotliwości rytmu serca (HR) w trakcie wysiłku i bezpośrednio po nim jest nieprawidłowa u osób z chorobami sercowo-naczyniowymi, stanowiąc niezależny czynnik ryzyka zgonu. Problem ten jest znacznie słabiej poznany u pacjentów z przewlekłą niewydolnością serca (CHF), zwłaszcza w początkowych stadiach tego zespołu.

Metody: Badanie spiroergometryczne (CPX) przeprowadzono u 54 mężczyzn ze stabilną skurczową CHF z rytmem zatokowym w klasie czynnościowej NYHA I i II (wiek 57 ± 12 lat, LVEF 31 ± 8%) oraz u 27 mężczyzn bez CHF (wiek 54 ± 8 lat, LVEF 67 ± 7%). Oprócz szczytowego zużycia tlenu (peakVO_2) oceniano odpowiedź chronotropową, wykorzystując następujące parametry: szczytową HR wyrażoną w wartościach bezwzględnych (maxHR) i jako procent należnej wartości maksymalnej (%maxHR), przyrost HR w trakcie całego wysiłku (ΔHR), wskaźnik chronotropowy (CI = ΔHR/ΔHR należne) oraz współczynnik nachylenia prostej będącej liniową zależnością między HR a czasem (HR-*time slope*) w trakcie całego wysiłku. Odpowiedź chronotropową oceniano także po zaprzestaniu wysiłku poprzez: współczynnik nachylenia prostej będącej liniową zależnością między HR a czasem w trakcie pierwszych 3 min odpoczynku (HR-*time slope*) i spadek HR po 90 s (HRR90), 120 s (HRR120) i 180 s (HRR180) od zaprzestania wysiłku.

Wyniki: Odpowiedź chronotropowa na wysiłek była gorsza u mężczyzn z CHF niż w grupie kontrolnej: NYHA II *v.* NYHA I *v.* grupa kontrolna: maxHR 122 ± 24 *v.* 154 ± 25 *v.* 166 ± 13/min, wszystkie $p < 0,05$; %maxHR 76 ± 14 *v.* 91 ± 11 *v.* 101 ± 7%, wszystkie $p < 0,001$; ΔHR 48 ± 20 *v.* 75 ± 20 *v.* 91 ± 14/min, wszystkie $p < 0,01$; HR-*time slope* w trakcie wysiłku 5,6 ± 2,2 *v.* 6,5 ± 2,6 *v.* 8,3 ± 1,2; wszystkie $p < 0,01$ (NYHA I *v.* II $p > 0,2$); CI 0,56 ± 0,36 *v.* 0,85 ± 0,21 *v.* 1,02 ± 0,13; wszystkie $p < 0,01$; HR-*time slope* bezpośrednio po przerwaniu wysiłku –14,0 ± 7,0 *v.* –19,2 ± 5,1 *v.* –23,5 ± ± 3,8; wszystkie $p < 0,05$ (NYHA I *v.* kontrola $p > 0.2$); HRR90 30 ± 17 *v.* 44 ± 14 *v.* 49 ± 9/min, wszystkie $p < 0,05$ (NYHA I *v.* kontrola $p > 0.2$); HRR120 35 ± 18 *v.* 51 ± 13 *v.* 59 ± 9/min; wszystkie $p < 0,05$; HRR180 41 ± 17 *v.* 57 ± 15 *v.* 68 ± 10/min; wszystkie $p < 0,01$. U mężczyzn z CHF obniżone peakVO_2 towarzyszyło upośledzonej odpowiedzi chronotropowej w trakcie wysiłku ($r = 0,60$; $p < 0,001$) oraz po jego zaprzestaniu ($r = 0,50$; $p < 0,001$), natomiast spośród oznaczonych badań laboratoryjnych jedynie stężenie NT-proBNP korelowało z parametrami odpowiedzi chronotropowej po zaprzestaniu wysiłku ($r = 0,33$; $p < 0,05$). Współczynniki zmienności analizowanych parametrów odpowiedzi chronotropowej u 13 mężczyzn z CHF zbadanych po 17 ± 11 dniach wynosiły 8–15%.

Wnioski: Parametry odpowiedzi chronotropowej cechuje dobra powtarzalność i mogą być stosowane do klinicznej oceny chorych z CHF. Już we wczesnych stadiach CHF stwierdza się nieprawidłową odpowiedź chronotropową, co może stanowić jeden z mechanizmów ograniczających wydolność fizyczną w tej grupie pacjentów.

Słowa kluczowe: przewlekła niewydolność serca, odpowiedź chronotropowa, wydolność fizyczna, próba spiroergometryczna, częstotliwość rytmu serca

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