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The effects of cardiac rehabilitation on haemodynamic parameters measured by impedance cardiography in patients with heart failure

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Abstract

Background: Cardiac rehabilitation (CR) is an important element of heart failure (HF) treatment although the mechanisms of its beneficial effects remain debatable.

Aim: To evaluate the haemodynamic effects of CR measured by impedance cardiography in patients with HF.

Methods: Study group included 50 HF patients (aged 56.2 ± 8.8 years, NYHA class II and III, left ventricular ejection fraction ≤ 40%) who underwent 8-week CR. Clinical and haemodynamic assessment was performed before and after CR.

Results: As a result of CR, exercise tolerance improved significantly as measured by peak VO_2 (18.7 ± 4.4 *vs* 20.8 ± 4.7 mL/ /kg/min; p = 0.025), six-minute walking test distance (6-MWT; 417.8 ± 103.6 *vs* 467.7 ± 98.4 m, p = 0.016) and NYHA class (change to the lower NYHA class in 30% of subjects). A significant reduction of the left atrial diameter was observed in echocardiography (4.55 ± 0.63 *vs* 4.43 ± 0.59 cm, p = 0.017). Impedance cardiography revealed a significant change in diastolic to systolic wave ratio (O/C ratio; 54.8 ± 24.0 *vs* 47.9 ± 20.8%, p = 0.021). A significant change in the haemodynamic profile of the left ventricular blood ejection was also observed. Before CR, transthoracic fluid content (TFC) correlated with stroke index (SI; R = 0.37, p < 0.01), compared to no correlation after CR (R = 0.00, NS). Reduction in TFC correlated with prolongation of the 6-MWT (R = –0.32, p = 0.06), and increase in systolic time ratio (STR) correlated with increase in peakVO_2 (R = 0.40, p = 0.006). Subjects who benefited from CR tended to have lower heart rate (61.4 ± 9.0 *vs* 67.7 ± 10.7 1/min, p = 0.07), longer pre-ejection period (PEP; 12.2 ± 11.6 ms *vs* –2.6 ± 23.1 ms, p = 0.018) and non-significantly higher STR (0.423 ± 0.123 *vs* 0.377 ± 0.102, p = 0.37).

Conclusions: Impedance cardiography revealed beneficial effects of CR, manifested by reduced fluid retention and a reduced effect of preload on left ventricular relaxation and ejection.

Key words: heart failure, cardiac rehabilitation, impedance cardiography

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INTRODUCTION

Heart failure (HF) is a chronic progressive condition resulting from complex pathogenetic factors. Optimal treatment of HF is one of major challenges of cardiology in the 21st century, with growing interest in non-pharmacological methods such as cardiac rehabilitation (CR). Monitored exercise training (ET) as an element of secondary prevention of HF leads to reduction in overall mortality, morbidity, and the rate of adverse cardiovascular (CV) events, and improves quality of life but the mechanisms of these beneficial effects of CR remain debatable [1, 2].

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Undoubtedly, a major cause of HF is a significant impairment of complex mechanisms of haemodynamic adaptation, and thus beneficial effects of CR may be expected to be associated with an improvement in the haemodynamic function of the CV system. Some data suggest that impedance cardiography (ICG), a non-invasive method of haemodynamic monitoring, may be a useful tool in the clinical assessment of HF patients. The ICG allows measurements of many functional parameters of the CV system including cardiac index (CI), systolic time ratio (STR), systemic vascular resistance index (SVRI), thoracic fluid content (TFC), and the diastolic to systolic wave ratio (O/C ratio). High TFC is an indicator of chest fluid retention and increased preload. The O/C ratio correlates with invasive measurements of pulmonary capillary wedge pressure (PCWP) and may depend on the degree of left ventricular (LV) diastolic dysfunction [3].

The purpose of our study was to evaluate the haemodynamic effects of CR measured by ICG in patients with HF.

METHODS

Study population

We studied 50 patients (44 men; mean age 56.2 ± 8.8 years) with HF. Inclusion criteria included: (1) systolic HF regardless of its aetiology, defined according to the European Society of Cardiology (ESC) guidelines [4] and diagnosed at least 3 months before study enrollment; (2) LV ejection fraction (LVEF) ≤ 40% as assessed by echocardiography; (3) New York Heart Association (NYHA) class II–III; and (4) stable clinical condition and optimal treatment that was not modified during the last 4 weeks before study enrollment. Exclusion criteria included: (1) NYHA class I or IV; (2) unstable angina; (3) an acute coronary syndrome within last 4 weeks, coronary artery bypass grafting within last 8 weeks, or initiation of cardiac resynchronisation therapy (CRT) within last year; (4) symptomatic or exercise-induced arrhythmia or conduction disturbances; (5) valvular heart disease or other acquired cardiac condition requiring surgical intervention; (6) hypertrophic cardiomyopathy; (7) severe pulmonary hypertension or other severe lung disease; (8) uncontrolled hypertension; (9) anemia (haemoglobin level < 10.0 g/dL); (10) acute and/or decompensated non-cardiac disease; (11) impaired motor function due to severe musculoskeletal or neurological disease; (12) severe or chronic inflammatory disorders; (13) neoplasm; (14) severe mental disorder; and (15) lack of patient consent to participate in the study.

Drug therapy used prior to initiation of CR was not modified during the training. Demographic and clinical characteristics of the study group are shown in Table 1.

Table 1. Baseline characteristics

Study group	n = 50
Men	44 (88.0%)
Age [years]	56.2 ± 8.8
LVEF [%]	30.0 ± 7.5
NYHA class II	30 (60.0%)
NYHA class III	20 (40.0%)
BMI [kg/m^2]	28.7 ± 3.8
HF aetiology:	
Ischaemic	42 (84.0%)
Non-ischaemic	8 (16.0%)
Past medical history:	
Myocardial infarction	38 (76.0%)
Previous coronary angioplasty	14 (28.0%)
Previous CABG	29 (58.0%)
Diabetes	14 (28.0%)
Dyslipidaemia	39 (78.0%)
Hypertension	26 (52.0%)
Medications:	
Beta-blocker	50 (100.0%)
ACE inhibitor	46 (92.0%)
Angiotensin receptor blocker	6 (12.0%)
Loop diuretic	40 (80.0%)
Spironolactone	47 (94.0%)
Aspirin	43 (86.0%)
Statin	46 (92.0%)

ACE — angiotensin-converting enzyme; BMI — body mass index; CABG — coronary artery bypass grafting; HF — heart failure; LVEF — left ventricular ejection fraction; NYHA — New York Heart Association

Study protocol

During this prospective study, all patients underwent clinical assessment before and after 8 weeks of CR that included clinical examination with evaluation of symptoms using the NYHA classification, echocardiography, six-minute walk test (6-MWT), cardiopulmonary exercise treadmill test (CPET), and ICG. The study was approved by the local ethics committee at the National Institute of Cardiology, and all patients gaven written informed consent for the participation in the study.

Echocardiography

Two-dimensional echocardiography included standard parasternal, apical and substernal views (VIVID 4 GE Medical System, 2.5 MHz probe). Measurements included LVEF (the Simpson method) [cm], left atrial (LA) diameter [cm], and LV end-diastolic diameter (LVEDD) [cm]. The study did not include precise evaluation of diastolic LV function.

Cardiopulmonary exercise treadmill test

The CPET was performed at the same time of the day, approximately 2 hours after morning medications and a light breakfast. The study was performed using the ramp protocol on a Schiller treadmill (Carrollton, USA) connected to a ZAN 600 spiroergometric system (ZAN Messgarate GmbH, Germany) [5], aiming for respiratory exchange ratio (RER) ≥ 1 or maximal tolerated fatigue (16 to 17 on the Borg scale).

According to the current standards [6], the test was continued until the occurrence of symptoms indicating the need for its termination: (1) increasing chest pain; (2) increasing central nervous system symptoms including dizziness, ataxia, and presyncope; (3) occurrence or worsening of peripheral cyanosis; (4) fall in blood pressure by > 10 mm Hg during increasing load or compared to the baseline values while standing with associated symptoms or evidence of ischaemia in electrocardiography (ECG); (5) increase of systolic blood pressure (SBP) to > 250 mm Hg or diastolic blood pressure (DBP) to > 115 mm Hg; (6) non-sustained ventricular tachycardia; (7) ST segment elevation ≥ 1 mm in leads without pathological Q wave (except for V1 and avR); (8) horizontal or downsloping ST segment depression > 2 mm; (9) fatigue, dyspnea, or lower limb pain resulting in inability to continue exercise; (10) technical problems with ECG monitoring or blood pressure measurements; (11) patient request to terminate the test. During the test, ECG was monitored continuously and blood pressure was measured every 2 min. These parameters were assessed before, during and after the exercise until heart rate (HR) and oxygen consumption (VO_2) returned to baseline values. Peak exercise intensity was assessed using the Borg scale [7]. The peak VO_2 was defined as the mean of measurements during the last 30 s of exercise. Values were expressed in mL/kg/min and as percentages of normal values (peakVO_2% N) predicted for given sex, age, body mass and height using criteria developed by Wasserman et al. [8].

Six-minute walk test

The 6-MWT was performed according to the current guidelines [9] between 11 AM and 1 PM after morning medications and a light breakfast. Patients were asked to walk for 6 min through a flat 25-m corridor, turning back at its end to continue walking. The HR and blood pressure were measured manually at baseline, immediately after the test, and at 1 and 2 min of recovery. Exercise intensity was assessed using the Borg scale. When interpreting the results, the distance made by the patient was taken into account.

Impedance cardiography

All ICG measurements were performed using a Niccomo device (Medis, Germany) in a supine position and after 10 min of rest. Date were recorded during a 10-min study and exported to a dedicated software (Niccomo Software). We analysed parameters of LV systolic function including CI, stroke index (SI), Heather index (HI), acceleration index (ACI), velocity index (VI), pre-ejection period (PEP), LV ejection time (LVET) and STR. We also analysed indirect parameters of preload (TFC and O/C ratio) and afterload (SVRI). In addition, ECG and HR were recorded continuously, and blood pressure was measured every 2 min using a sfigmomanometer.

Exercise training

Cardiac rehabilitation programme was planned individually for each patient based on the current HF guidelines [10–12]. Exercise load was determined by individual patient tolerance including self-assessment using the Borg scale and the ET HR range (HRR) defined for each patient. In accordance with the current standards, we assumed that moderate effort intensity should not be exceeded during the ET (e.g. 11 points on the Borg scale) [7]. Training HR range was calculated using estimation of HR reserve. In this method, a percentage difference between peak and resting HR is set and then added to the resting HR. The target HR during ET was set at 40–70% of the peak HR.

Training session included (1) a 5–10-min warm-up (general rehabilitation exercise, coordination exercise, breathing exercise, mild resistance training), (2) basic 10–30-min endurance training (walking or cycloergometer interval training), and (3) recovery period (5 min). In accordance to standards, initial training sessions lasted 10 min and the target training HR during these sessions was at the lower end of the defined training HR range (40% HRR), and then, during an 8-week CR program, training session duration was gradually increased to 30 min, and the workload was increased to the upper lower end of the defined training HR range (70% HRR) if tolerated, with moderate effort intensity as defined using the Borg scale maintained throughout the training.

Statistical analysis

Statistical analysis was performed using the Statistica 7.0 software (StatSoft Inc.). Data distributions were tested for normalcy using visual assessment and the Shapiro-Wilk test. Results are expressed as mean values ± SD for continuous variables and numbers and percentages for categorical variables. Effects of CR were evaluated using the Student *t*-test for normally distributed variables and nonparametric tests for non-normally distributed variables. Linear correlations were assessed using the Pearson correlation coefficient. Absolute changes in the measured parameters were calculated as post-CR result minut pre-CR result. A p value < 0.05 was considered significant.

RESULTS

Exercise tests

Results of exercise capacity assessment before and after CR are shown in Table 2. The CR resulted in an improved exercise capacity as shown by increased peakVO_2, duration of CPET, and 6-MWT distance. In addition, an improvement in the NYHA class was noted in more than 30% of patients (Table 2, Fig. 1).

Echocardiography

In echocardiographic studies, CR resulted in a decreased LA diameter, with no change of LVEDD and LVEF (Table 2).

Table 2. Comparison of analysed parameters before and after CR

	Before CR	After CR	P
Echocardiography:			
LVEF [%]	30.0 ± 7.5	30.9 ± 7.7	NS
LA [cm]	4.55 ± 0.63	4.43 ± 0.59	0.017
LVEDD [cm]	6.37 ± 0.89	6.44 ± 0.86	NS
NYHA class	2.38 ± 0.49	2.06 ± 0.51	0.00018
Six-minute walking test: distance [m]	417.8 ± 103.6	467.6 ± 98.4	0.016
Cardiopulmonary exercise treadmill test:			
Duration of exercise [s]	428.8 ± 139.6	501.0 ± 156.2	0.017
PeakVO_2 [mL/kg/min]	18.7 ± 4.4	20.8 ± 4.7	0.025
PeakVO_2% N	63.0 ± 13.4	71.1 ± 16.3	0.011
Haemodynamic parameters:			
O/C [%]	54.8 ± 24.0	47.9 ± 20.8	0.021
TFC [1/kOhm]	27.3 ± 5.2	25.6 ± 3.8	NS (p = 0.072)
CI [L/min/m^2]	2.62 ± 0.57	2.55 ± 0.53	NS
SI [mL/m^2]	39.3 ± 10.5	38.5 ± 9.5	NS
HI [Ohm/s^2]	10.9 ± 3.6	11.1 ± 4.7	NS
ACI [1/100/s^2]	64.1 ± 23.1	61.3 ± 19.9	NS
VI [1/1000/s]	38.7 ± 12.2	36.7 ± 11.7	NS
SVRI [dyn·s·m^2/cm^5]	2318.7 ± 500.5	2376.0 ± 454.3	NS
HR [1/min]	68.5 ± 12.8	66.3 ± 10.6	NS
PEP [ms]	113.5 ± 24.3	114.1 ± 25.4	NS
LVET [ms]	290.5 ± 40.5	293.5 ± 45.3	NS
STR (PEP/LVET)	0.395 ± 0.107	0.387 ± 0.108	NS
SBP [mm Hg]	107.6 ± 15.3	105.0 ± 12.2	NS
DBP [mm Hg]	69.2 ± 7.5	69.9 ± 7.5	NS
MAP [mm Hg]	80.1 ± 9.9	79.7 ± 8.8	NS

ACI — acceleration index; CI — cardiac index; CR — cardiac rehabilitation; DBP — diastolic blood pressure; HI — Heather index; HR — heart rate; LA — left atrial size; LVEDD — left ventricular end-diastolic diameter; LVEF — left ventricular ejection fraction; MAP — mean arterial pressure; NS — non significant; LVET — left ventricular ejection time; NYHA — New York Heart Association; O/C — O/C ratio; peakVO_2 — peak oxygen consumption; peakVO_2% N — peak oxygen consumption as percentage of the normal value; PEP — pre-ejection period; SBP — systolic blood pressure; SI — stroke index; STR — systolic time ratio; SVRI — systemic vascular resistance index; TFC — transthoracic fluid content; VI — velocity index

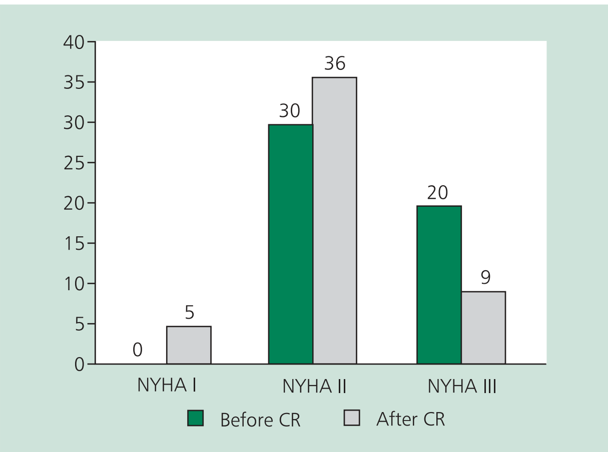

Figure 1. The effects of cardiac rehabilitation (CR) as assessed using the NYHA classification (numbers above bars indicate the number of patients in a given subgroup)

Impedance cardiography

Post-CR ICG showed a significant reduction of the O/C ratio. Overall, TFC was also markedly decreased but this effect was not significant. After CR, we noted no changes of CI, SI, HI, ACI, VI, SVRI, LVET, PEP, STR, SBP, DBP and HR (Table 2).

Assessment of correlations between selected haemodynamic parameters before and after CR (HI, CI, SI, ACI, VI *vs* TFC) showed significant changes in these associations. Before CR, TFC correlated significantly with VI, ACI and SI. After CR, no correlations were noted between TFC and these parameters (Table 3). When the absolute changes in exercise capacity parameters and selected haemodynamic parameters were analysed, significant correlations (weak to moderate) were noted only for TFC reduction *vs* increase in 6-MWT distance and STR increase *vs* increase in peakVO_2 (Table 4).

Table 3. Correlations between selected haemodynamic parameters (before and after CR)

Before CR				After CR			
Haemodynamic parameters	**R**	**R^2**	**P**	**Haemodynamic parameters**	**R**	**R^2**	**P**
TFC *vs* HI	–0.06	0.00	NS	TFC *vs* HI	–0.24	0.06	NS
TFC *vs* CI	0.15	0.02	NS	TFC *vs* CI	–0.14	0.02	NS
TFC *vs* SI	0.37	0.13	< 0.01	TFC *vs* SI	0.00	0.00	NS
TFC *vs* ACI	0.48	0.23	< 0.001	TFC *vs* ACI	0.10	0.01	NS
TFC *vs* VI	0.53	0.33	< 0.0001	TFC *vs* VI	0.09	0.01	NS

ACI — acceleration index, CI – cardiac index, CR — cardiac rehabilitation; HI — Heather index; SI — stroke index; TFC — transthoracic fluid content; VI — velocity index

Table 4. Correlations between changes in selected haemodynamic parameters (before and after CR)

	Change in (Δ)*							
Δ*	**TFC**	**O/C**	**ACI**	**VI**	**SVRI**	**HR**	**CI**	**STR**
6-MWT distance								
R	–0.32	0.25	0.15	0.05	–0.09	0.00	–0.10	–0.11
R^2	0.10	0.06	0.02	0.00	0.01	0.00	0.01	0.01
P	0.06	NS	NS	NS	NS	NS	NS	NS
PeakVO_2								
R	0.23	–0.01	–0.18	–0.16	0.01	–0.23	–0.07	0.40
R^2	0.05	0.00	0.03	0.03	0.00	0.05	0.00	0.16
P	NS	NS	NS	NS	NS	NS	NS	0.006

*Change (Δ) = [measurement after CR] – [measurement before CR]; 6-MWT — six-minute walking test; ACI — acceleration index; CI — cardiac index; CR — cardiac rehabilitation; HR — heart rate; O/C — O/C ratio; peakVO_2 — peak oxygen consumption; STR — systolic time ratio; SVRI — systemic vascular resistance; TFC — transthoracic fluid content; VI — velocity index

Subjects in whom an improvement in NYHA class was seen (n = 16) differed significantly from the subjects with no subjective exercise capacity improvement in regard to resting post-CR HR (61.8 ± 8.9 *vs* 68.4 ± 10.9 1/min, p = 0.015) and HR reduction (–6.6 ± 7.4 *vs* –2.0 ± 14.5 1/min, p = 0.012).

Improvement in CPET was seen in a group (n = 38) with a higher post-CR STR (0.404 ± 0.109 *vs* 0.316 ± 0.071, p = 0.031) and a larger TFC reduction (–2.11 ± 3.87 *vs* –0.22 ± ± 4.35 1/kOhm, p = 0.18). Increased 6-MWT distance was observed in subjects (n = 39) with a significantly lower post--CR O/C ratio (44.8 ± 20.8 *vs* 59.3 ± 17.0%, p = 0.031) and a significantly increased PEP (4.1 ± 22.4 *vs* –12.4 ± 13.7 ms, p = 0.022). Patients who improved in both CPET and 6-MWT (n = 32) were characterised by a higher post-CR STR (0.411 ± 0.107 *vs* 0.338 ± 0.094, p = 0.03), increase in PEP (118.8 ± 25.4 *vs* 105.3 ± 23.6 ms, p = 0.06) and different direction of change of this parameter (7.5 ± 20.1 *vs* –12.1 ± ± 19.7 ms, p = 0.004).

Patients who showed improvement in the NYHA class and also improved in both CPET and 6-MWT (n = 11) were characterised by significantly lower post-CR HR (61.4 ± 9.0 *vs* 67.7 ± 10.7 1/min, p = 0.07), larger HR reduction (–8.2 ± 7.4 *vs* –2.1 ± 13.7 1/min, p = 0.007), increase in PEP by 12.2 ± 11.6 ms (*vs* decrease by 2.6 ± 23.1 ms in a group without improvement, p = 0.018), and a trend towards higher STR (0.423 ± 0.123 *vs* 0.377 ± 0.102, p = 0.37).

DISCUSSION

Effect of cardiac rehabilitation on exercise tolerance

In our study, a positive effect of CR on the CV system was confirmed by improved exercise tolerance as assessed by CPET, increased 6-MWT distance, and a large proportion of patients with subjective improvement manifested with NYHA class reduction. These benefits may result from: (1) improved blood flow in exercising muscle, leading to decreased anaerobic metabolism and increased aerobic metabolism; (2) more effective tissue oxygen and energy use; and (3) reduced sympathetic activation. It is also known that exercise affects myocardial function by reducing LV end-diastolic pressure and improved coronary flow as well as oxygen supply [1, 10, 13, 14]. The observed improvement in exercise capacity, particularly with continued regular exercise, should contribute to a reduction in mortality, morbidity, and CV events [1, 2].

Echocardiography

We did not observe any effect of CR on LVEF. These results confirm earlier observations of no correlation between VO_2 and LVEF and highlight a limited value of resting LVEF as a predictor of CV system function during exercise [10, 15]. Although LVEDD did not change with CR, a significant reduction in LA diameter was noted which might be a clinically important effect. Other authors [16, 17] showed that increased LA size is an independent predictor of CV events. In a study by Thomas et al. [18], LA enlargement was associated with impaired LV diastolic function and LV hypertrophy. Ceresa et al. [19] noted a significant relationship between LA size and exercise capacity in patients with HF, and Abhayaratna et al. [20] suggested that a decrease in LA size may be related to improved exercise tolerance in clinical tests.

Haemodynamic evaluation

Evaluation of haemodynamic mechanisms responsible for clinical improvement of HF patient undergoing CR remains a subject of clinical studies. Previously, ICG was successfully used in HF monitoring and treatment [21–25]. In this study, we used this simple noninvasive method for the first time to assess the effects of CR. Comparison of measurements performed before and after CR revealed changes that suggest a possible haemodynamic effect of ET.

Although the comparison of mean values showed a significant difference only for the O/C ratio, the change in TFC also seems clinically important. A decreased ratio of mitral inflow (O) to LV ejection (C) may be related to reduced fluid retention in the chest. This is supported by the observed correlations between exercise capacity parameters and cardioimpendance indicators of preload (relation of lower O/C ratio with longer 6-MWT distance and of TFC reduction with better CPET result). In patients with HF, exercise may be expected to reduce preload and thus is beneficial in terms of a reduced risk of HF exacerbation [23].

Subgroup analysis based of the effects of CR showed that HR reduction and PEP increase are associated with improved exercise capacity. Although it is assumed that STR should be as low as possible, HR reduction and prolonged isovolumetric contraction seen in our study group suggest improved autonomic control and LV diastolic function. A beneficial effect of CR on neurohormonal control in patients after coronary artery bypass grafting was also seen by Bilińska et al. [26] who evaluated the effects of ET on haemodynamic response during the handgrip test.

Other haemodynamic parameters did not change after CR, suggesting that the functional improvement resulting from CR is independent from their baseline resting values. However, the effects of CR on these parameters cannot be excluded and our findings should be interpreted cautiously due to short duration of follow-up and limited number of study subjects.

Impedance cardiography and echocardiography results

The change in O/C ratio seems to be associated with decreased LA size in echocardiography. Decreased ratio of mitral inflow to systolic aortic outflow may contribute to more effective blood flow through cardiac chambers, and a decrease in LV overload, functional mitral regurgitation and LA size, leading to beneficial effects noted above.

Correlations between haemodynamic parameters

The CR resulted in a significant reduction of the association between TFC and selected haemodynamic parameters describing LV pump function. This observation may be clinically important. In healthy subjects, LV systolic function depends mainly on the inotropic properties of cardiomiocytes, and in much lesser degree on the Frank-Starling mechanism related to the contractile cardiomiocyte response to stretch [27–29]. In contrast, the Frank-Starling mechanism is the predominant determinant of the LV contraction mechanics in patients with advanced HF [15, 27, 30, 31]. It seems that in patients with severe HF, this mechanism is at the verge of decompensation, operating within the flat descending part of the Frank-Starling curve. In these circumstances, every increase in LV load, such as during exercise, results in increased LVEDD and reduced CI. With impaired LV relaxation and increased mitral regurgitant flow, this results in LA stretch, manifesting clinically as dyspnea and low exercise capacity [10, 27, 28, 32, 33]. Our findings suggest that before CR, LV systolic function in the study group might have been more dependent on the Frank-Starling mechanism, and ET reduced this dependency. The hypothetical effects of CR on the haemodynamic of LV blood ejection are shown in Figure 2. An increase in preload-dependent contractile reserve and a leftward shift of the Frank-Starling curve (towards its ascending part) seem to be clinically beneficial effects. Reduced LVEF dependency on the Frank-Starling mechanism may explain the significant improvement of the exercise capacity seen in clinical tests, although this effect cannot be monitored with ICG during exercise for methodological reasons. Our findings also seem consistent with animal data regarding the beneficial effects of ET on the myocardium [34].

Limitations of the study

The number of studied patients was relatively low. Immediate effects of CR may not translate to long-term effects. The ICG was performed at rest, and the haemodynamic parameters obtained were derived from a single impedance curve. Although our findings show that relationships between these parameters vary and may be subject to such analyses, further studies are required to assess the clinical value of rather weak correlations found in our study.

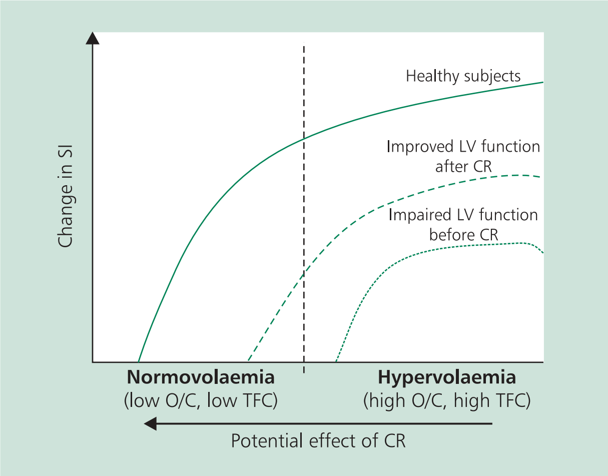

Figure 2. A potential effect of cardiac rehabilitation (CR) on contractile reserve (change in stroke index [SI]) during exercise in patients with heart failure. Regular exercise results in reduced preload and a leftward shift of left ventricular (LV) systolic function on the Frank-Starling curve (towards its ascending part), leading to an increased contractile reserve (during exercise, the increase in stroke volume, i.e. change in SI, may be larger as the flat part of the curve is reached later); TFC — thoracic fluid content

CONCLUSIONS

Our findings confirm a short-term therapeutic value of CR in patients with HF. The ICG is a useful tool for noninvasive assessment of patients with HF, providing additional information regarding the beneficial effects of ET on the haemodynamic function of the CV system. The ET in patients with HF seems to improve the adaptive capability of the CV system by decreasing the effect of preload on cardiac pump function. Our findings may encourage further studies to evaluate usefulness of ICG as tool to measure effects of CR in patients with HF.

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Conflict of interest: *none declared*

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Wpływ rehabilitacji kardiologicznej na określone metodą kardiografii impedancyjnej parametry hemodynamiczne u osób z niewydolnością serca

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Streszczenie

Wstęp: Zainteresowanie niefarmakologicznymi metodami leczenia niewydolności serca (HF), takimi jak rehabilitacja kardiologiczna (CR), stale wzrasta. Główną przyczyną HF jest istotne upośledzenie złożonych mechanizmów adaptacji hemodynamicznej, które mogą być przedmiotem nieinwazyjnego monitorowania metodą kardiografii impedancyjnej (ICG). Umożliwia ona wieloparametryczną ocenę funkcji układu sercowo-naczyniowego poprzez pomiar m.in. rzutu serca (CI), objętości wyrzutowej (SI), okresu przedwyrzutowego lewej komory (PEP), czasu wyrzutu lewej komory (LVET) oraz wskaźnika okresu skurczu (STR), jak również: systemowego oporu naczyniowego (SVRI), zawartości płynu w klatce piersiowej (TFC) i wskaźnika stosunku kardiograficznej fali rozkurczowej O do fali skurczowej C (O/C).

Cel: Celem pracy była ocena efektu hemodynamicznego CR u pacjentów z HF z wykorzystaniem nieinwazyjnego monitorowania metodą ICG.

Metody: Badaniem objęto 50 pacjentów (44 mężczyzn, średni wiek: 56,2 ± 8,8 roku) z HF. Kryteria włączenia do badania obejmowały pacjentów ze skurczową HF w II i III klasie wg NYHA i frakcją wyrzutową lewej komory (LVEF) ≤ 40%. Wszyscy pacjenci zostali poddani ocenie klinicznej przed próbą i po 8 tygodniach programu treningowego z uwzględnieniem: badania klinicznego z oceną objawów podmiotowych wg NYHA, badania echokardiograficznego, 6-minutowego testu marszowego (6-MWT), badania spiroergometrycznego (CPET) oraz ICG.

Wyniki: Efektem CR był wzrost wydolności fizycznej badanych w zakresie szczytowego pochłaniania tlenu w CPET (peakVO_2: 18,7 ± 4,4 *v.* 20,8 ± 4,7 ml/kg/min; p = 0,025), czasu trwania CPET (428,8 ± 139,6 *v.* 501,0 ± 156,2 s; p = 0,017) oraz dystansu 6-MWT (417,8 ± 103,6 *v.* 467,7 ± 98,4 m; p = 0,016). Ponadto u ponad 30% pacjentów zaobserwowano poprawę w zakresie klasy NYHA. Efektem CR w ocenie echokardiograficznej było istotne zmniejszenie wymiaru lewego przedsionka (LA; 4,55 ± 0,63 *v.* 4,43 ± 0,59 cm, p = 0,017), choć wielkość lewej komory (LV) oraz LVEF nie uległy zmianie. W ocenie metodą ICG po cyklu CR zaobserwowano istotne zmniejszenie wartości wskaźnika O/C (54,8 ± 24,1 *v.* 47,8 ± 20,8%; p = 0,021). Zmiana wartości TFC (27,3 ± 5,2 *v.* 25,6 ± 3,8 1/kOhm), choć wyraźna, nie osiągnęła znamienności statystycznej (p = 0,072). W analizie korelacji wybranych parametrów hemodynamicznych przed i po CR (m.in. SI *v.* TFC) zaobserwowano istotną zmianę analizowanych zależności. Przez rozpoczęciem CR korelacja TFC z SI była istotna (R = 0,37; p < 0,01), a po zakończeniu CR nie stwierdzono żadnego związku liniowego między tymi parametrami. W ocenie związków zmian bezwzględnych parametrów wydolnościowych z wybranymi parametrami hemodynamicznymi korelacje istotne statystycznie zaobserwowano jedynie dla redukcji TFC *v.* wydłużenie dystansu 6-MWT (R = –0,32; p = 0,06) oraz dla wzrostu STR *v.* wzrost peakVO_2 (R = 0,40; p = 0,006). W analizie porównawczej podgrup zanotowano, że chorzy, którzy spełnili kryteria poprawy zarówno w ocenie wg NYHA, jak i w CPET oraz 6MWT (n = 11), wyróżniali się niższą wartością rytmu serca po CR (61,4 ± 9,0 *v.* 67,7 ± 10,7 1/min; p = 0,07), jej większą redukcją (–8,2 ± 7,4 *v.* –2,1 ± 13,7 1/min; p = 0,007), wydłużeniem PEP (12,2 ± 11,6 ms *v.* –2,6 ± 23,1 ms; p = 0,018) oraz nieznamiennie wyższym wskaźnikiem STR (0,423 ± 0,123 *v.* 0,377 ± 0,102; p = 0,37).

Wnioski: Kardiografia impedancyjna może być użytecznym narzędziem monitorowania korzystnego wpływu treningu fizycznego na funkcję hemodynamiczną układu sercowo-naczyniowego.

Słowa kluczowe: niewydolność serca, rehabilitacja kardiologiczna, kardiografia impedancyjna

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