The Effects of Individualized Physical Rehabilitation Program

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Abstract—

Objective: *to evaluate the effects of long-term aerobic training, designed with individualized method based on lactate threshold definition, on exercise capacity, HF severity and ergoreflex activity.*

Methods: *We evaluated 73 HF patients, mean age 53+/-1.8, 59 men, with NYHA class III, LVEF 40,8+/-0,3%. CPET performed on a treadmill ("Oxycon Pro" (Jaeger, Germany)) at baseline, in every 8 weeks and after 6 months. The cubital venous catheter was inserted before CPET. Blood samples were taken at baseline and at 1-minute intervals during test. Lactate concentration in blood was measured using analyzer i-STAT, cartridge CG4 (Abbot, USA). All patients were randomized into following groups: 50 patients of study group (SG), who underwent physical rehabilitation program (PRP), calculated due to lactate threshold; and 23 HF patients control group (CG), who underwent physical training, calculated based on VO_2 percentage.*

Results: *At baseline CPET results in both groups did not significantly differ. VO_2 at lactate threshold and VO_2peak were 8.7+/-0,5; 13,5+/-0,9 ml/min/kg and 8.9 +/- 0.9; 13,6+/-1,2 ml/min/kg in study group and control group, respectively (p_1=0,08, p_2=0,07, respectively). After 24 weeks of training VO_2LT and VO_2peak were better in the study group than in control group: the increase was 16% and 24% in the main group, and 4% and 7% in the control group, respectively (p_1<0,01, p_2<0,01). The ergoreflex activity at baseline did not significantly differ in two study groups. After long-term aerobic training we recorded a more marked reduction in the ergoreflex activity in study group: for DBP it was 35% and 20%, V_E - 48% and 25%, V_E/V_{CO2} - 39% and 12%, in the study group and control groups, respectively. By the 24th week of training in 34 (85%) patients of the study group the severity of HF was reduced to NYHA class II, and among the patients in the control group such dynamics was observed only in 17(50%) patients.*

Conclusions: *aerobic exercise, designed with individualized method based on lactate threshold definition, increase exercise tolerance, reduces HF severity and ergoreflex activity more than aerobic training, calculated based on VO_2peak percentage.*

Keywords— Physical Rehabilitation, HF patients, threshold, NYHA class III, aerobic exercise.

I. INTRODUCTION

Chronic heart failure (HF) is a pathological condition, which prevalence increasing every year [1, 2]. The main HF symptoms are shortness of breath, weakness and fatigue during physical activity [3]. Traditionally, patients with HF have been instructed not to exercise in order to avoid deterioration. More recently, physical rest advised in acute HF or destabilisation of chronic HF. In stable condition patient should be encouraged to carry out daily physical activities that do not induce symptoms [4], in order to prevent muscle deconditioning.

The one of key problems of HF rehabilitation is to define exercise mode and intensity that are safe and effective [5]. Exercise intensity usually categorized using the percent of maxHR or VO_2 max percentage.

In previous work [6] we have proposed a new method of compensatory-adaptive four exercise stages definition during CPET: lactate threshold (LT), pH-threshold (pH-T), respiratory compensation point (RCP) and aerobic limit. Lactate threshold determined when blood lactate level began to increase. pH-threshold determined when blood pH level began to decrease. Respiratory compensation point (RCP) determined when ventilation dramatically increases relative to carbon dioxide output (V_E/VCO_2). By continuous increase of work rate, oxygen consumption, up to a certain point, increases linearly and become stable - it is aerobic limit. We have already reported significant diagnostic and prognostic value of determination of lactate and pH thresholds in patients with chronic heart failure [7]. We proposed to define a exercise training intensity for HF patients with III NYHA class due to lactate threshold.

II. OBJECTIVE

To evaluate the effects of long-term aerobic training, designed with individualized method based on lactate threshold definition, on exercise capacity, HF severity and ergoreflex activity.

III. METHODS

3.1 Patients' population

We examined 73 HF patients with NYHA class III (59 of them are men) under observation in North-West Medical Research Centre named after V.A. Almazov, Saint- Petersburg, Russia. The inclusion criteria in the study were NYHA class III, clinical stability for two weeks, the ability to perform CPET. Exclusion criteria were myocardial infarction within last three months; acute cerebrovascular accident within last six months; significant mental abnormalities, contraindications to perform CPET.

Patients received standard therapy, including ACE inhibitors or antagonists of type 1 angiotensin I, β- blockers, diuretics, spironolactone.

The study performed in accordance with standards of Good Clinical Practice and principles of the Helsinki's Declaration. All study participants signed informed consent, which was approved by the Ethics Committee of North-West Medical Research Centre named after V.A. Almazov, Saint- Petersburg, Russia.

All patients randomized into following groups: 50 patients of the study group (SG), for this patients the program of physical rehabilitation we calculated using definition of lactate threshold; for 23 patients of the control group (CG) physical exercise have been calculated using percentage of VO_2peak.

The following parameters were initially evaluated: clinical status, echocardiography data, gas exchange parameters during CPET. 5 days prior to the main study patients became familiar with CPET, they performed preliminary cardiopulmonary testing, and then - diagnostic CPET. All patients trained for 24 weeks.

Clinical and instrumental patient characteristics are given in table 1 and 2.

TABLE 1
CLINICAL CHARACTERISTICS

	Study group	Control group
Demographic profile		
Total number of HF patients, n(%)	40 (57)	35 (43)
Men, n (%)	34 (85)	30 (86)
Cause of CHF		
ICM, n (%)	30 (75)	30 (86)
DCM, n (%)	10 (25)	5 (14)

ICM – ischemic cardiomyopathy, DCM – dilated cardiomyopathy

TABLE 2
CLINICAL AND INSTRUMENTAL CHARACTERISTICS

Characteristic	Median		Q1		Q3		IQR	
NYHA class	SG	CG	SG	CG	SG	CG	SG	CG
Age, years old	53	54	48	48	60	59	12	11
BMI, kg/m^2	27	26	25	24	30	30	5	6
LVEF, %	37	36	31	31	43	44	12	13

Q1- Lower Quartile, Q3 - Upper Quartile, IQR - inter-quartile range. BMI – body mass index, LVEF – left ventricular ejection fraction, SG - study group, CG -control group

3.2 Cardiopulminary testing

CPET performed using equipment «Oxycon Pro» (Jeger, Germany). Exercise ramp protocols for initial CPET personified so that each participant reached submaximal effort within 8-10 minutes. CPET stopped due to breathlessness or fatigue or legs' pain (at the level of 8 out of 10 points on a Borg scale), development of severe weakness, faintness.

During the test 12-lead ECG recorded, blood pressure measured every 2 minutes. In evaluation respiratory cycle mode «breath by breath» with automatic averaging data within 10 sec the following parameters were continuously recorded and comprehensively evaluated: the amount of minute ventilation (V_E), breathing reserve (BR), dead space to tidal volume ratio (V_d/V_t), carbon dioxide equivalents (V_E/VCO_2), $PETCO_2$, volume of oxygen uptake (VO_2).

The cubital venous catheter was inserted in all subjects before exercise test. Blood samples were taken at baseline and at 1-minute intervals during test. Lactate concentration was estimated using analyzer i-STAT, cartridge CG4 (Abbot, USA). Lactate threshold was determined when blood lactate level began to increase.

3.3 Ergoreflex activity

Ergoreflex activity measured at baseline and after 24 weeks of training. To evaluate the ergoreflex in arm we used the postexercise regional circulatory occlusion (PE-RCO) method. On a separate day, each subject underwent the forearm ergoreceptor test.

After 5-minute resting period, 2 exercises were performed in a random order: (1) 5-minute session of rhythmic handgrip achieved by squeezing the balloon of a sphygmomanometer (30 squeezes/min) at 50% of the predetermined maximal capacity; and (2) the same protocol followed by 3 minutes of arterial ischemia - posthandgrip regional circulatory occlusion - on the exercising arm by inflation of an upper-arm biceps tourniquet to 30 mm Hg above systolic pressure at the beginning of recovery. This protocol has been shown to fix the metabolic state of the muscle and to maintain activation of the ergoreceptors. Sixty minutes separated each bout of arm exercise (Fig. 1).

FIGURE 1. STUDY OF ERGOREFLEX ACTIVITY.

During test we recorded 12-lead ECG, diastolic blood pressure (DBP), the amount of ventilated air and gas exchange. We calculated the difference between DBP, V_E/V_{CO2}, V_E after 3 minutes of occlusion (+PR -RCO) and on the background of the recovery period without occlusion (PR-RCO), then calculated the percentage of these values.

3.4 Calculation of training walk

For each patient of the study group we calculated individualized mode of training walk with intensity that observed at lactate threshold. After every 8 weeks CPET repeated and the mode of training walk was recalculated. Study group patients trained 60min every day. Patients of CG performed 40 minutes training walk at the level of 45% VO_2peak registered during initial CPET three times a week. After every 8 weeks CPET repeated and the mode of training walk was recalculated.

3.5 The statistical data analysis

The statistical analyses performed with Statistika PC (version 7.0, Windows). Sample size calculation: Step 1. Finding standardized difference/ Standardized difference = target difference : standard deviation = 3,32:3,83= 0,866. Step 2. The definition of the sample size by the Altman nomogram (Fig. 2).

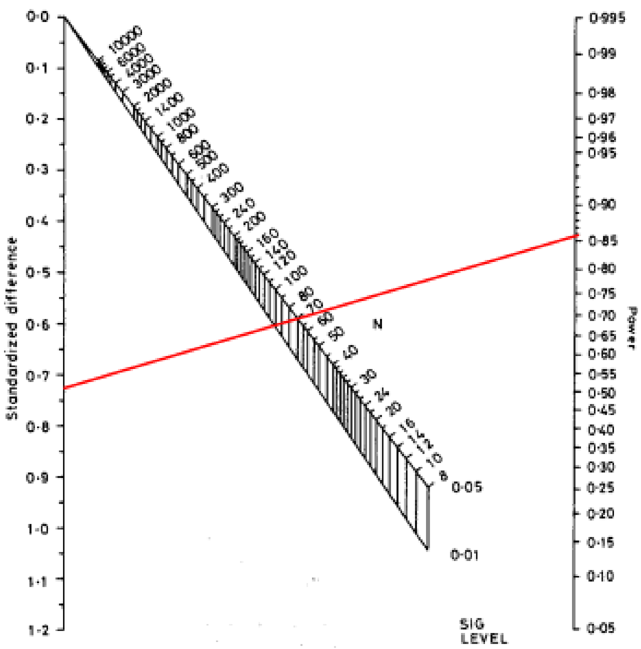

FIGURE 2. SAMPLE SIZE CALCULATION USING ALTMAN NOMOGRAM.

The total sample size for this study that is capable of detecting a 0.838 standardized difference with 85% power using a cutoff for statistical significance of 0.05 is approximately 70. Continuous variables we expressed in Median, Lower Quartile (Q1), Upper Quartile (Q3) and inter-quartile range (IQR). Comparison between groups were analysed by 2-sided t-test or Mann-Whitney U test, depending on normality of distribution. P-value below 0.05 considered significant.

IV. RESULTS

A total of 66 patients completed the study. Seven patients dropped out of the study: 2 patients - from the study group and 5 patients - from the control group. Causes for exclusion of patients from the study: unwillingness to continue training (4 patients), hospitalization for reasons not related to HF (2 patients), hospitalization associated with decompensation of chronic heart failure (1 patient).

All remaining subjects completed the protocol without adverse events. All patients during CPET reached lactate threshold.

The dynamics of CPET results are in table 3 and Fig. 3. At baseline CPET results in both groups were comparable: VO_2 at lactate threshold and VO_2peak were: 8.7+/-0,5; 13,5+/-0,9 ml/min/kg and 8.9 +/- 0.9; 13,6+/-1,2 ml/min/kg in study group and control group, respectively (p_1=0,08, p_2=0,07, respectively). After 24 weeks of training VO_2LT and VO_2peak were better in the study group than in control group: the increase was 16% and 24% in the main group, and 4% and 7% in the control group, respectively (p_1<0,01, p_2<0,01).

TABLE 3
CPET RESULTS BEFORE AND AFTER 24 WEEKS TRAINING

Characteristic NYHA Class	Before training								After 24 weeks training							
	Median		Q1		Q3		IQR		Median		Q1		Q3		IQR	
	SG	CG	SG	CG	SG	CG	SG	CG	SG	CG	SG	CG	SG	CG	SG	CG
VO_2peak, ml/min/kg	13.5	13.6	9.6	9.7	15.1	15.3	5.5	5.6	16.7	14.6	12.5	11.7	17.6	16.1	5.1	4.4
VO_2pH-T, ml/min/kg	11.0	11.5	9.1	9.3	13.9	14.0	4.8	4.7	14.5	12.1	11.5	10.7	15.5	13.6	4.0	2.9
VO_2LT, ml/min/kg	8.7	8.9	6.3	6.3	10.2	9.9	3.9	3.6	11.1	9.3	10.7	8.4	12.2	10.2	1.5	1.8

Q1- Lower Quartile, Q3 - Upper Quartile, IQR - inter-quartile range. II - HF patients with NYHA class II, III - HF patients with NYHA class III, IV - HF patients with NYHA class IV. VO_2peak - VO_2 at the peak exercise, VO_2pH-T - VO_2 at the level of pH-T, VO_2LT - VO_2 at the level of LT, SG - study group, CG -control group

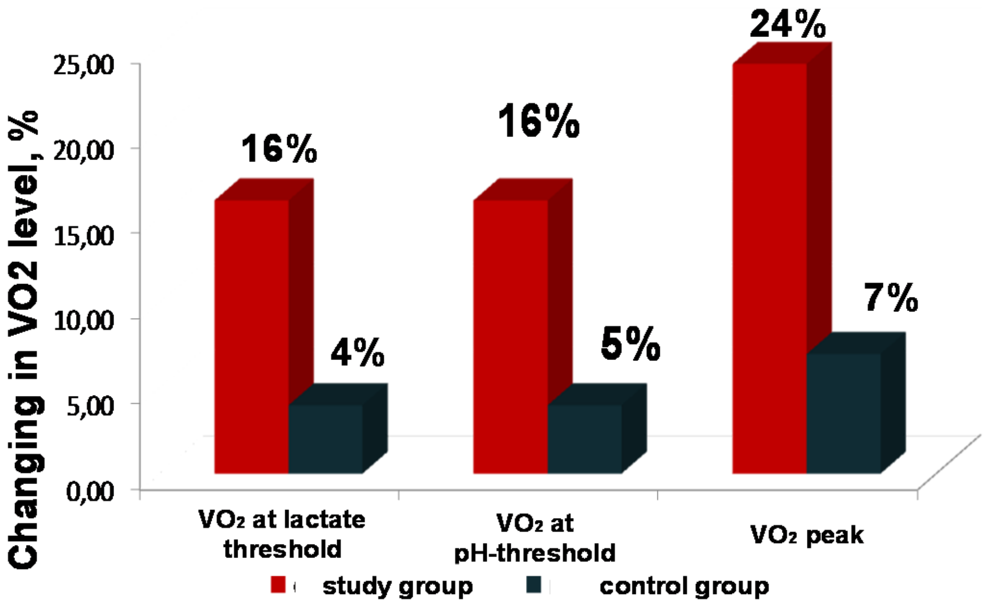

FIGURE 3. CPET RESULTS IN STUDY GROUP AND CONTROL GROUP BEFORE AND AFTER TRAINING

The ergoreflex activity at baseline did not significantly differ in two study groups. After long-term aerobic training in study group we recorded a more marked reduction in the ergoreflex activity: for DBP it was 35% and 20%, V_E - 48% and 25%, V_E/V_{CO2} - 39% and 12%, in the study group and control groups, respectively (tab. 4) and Fig. 4.

TABLE 4
ERGOREFLEX ACTIVITY BEFORE AND AFTER 24 WEEKS TRAINING

Characteristic NYHA Class	Before training								After 24 weeks training							
	Median		Q1		Q3		IQR		Median		Q1		Q3		IQR	
	SG	CG	SG	CG	SG	CG	SG	CG	SG	CG	SG	CG	SG	CG	SG	CG
Changes in DBP, %	77	80	63	61	86	88	23	27	56,2	72,1	39	51	60	74	19	23
Changes in VE, %	83,5	82	65	62	93	91	28	29	48,5	69,5	27	42	69	83	42	41
Changes in VE/VCO2, %	33,9	32,2	25	25	45	42	20	17	20,7	28,2	14	20	40	40	26	20

Q1- Lower Quartile, Q3 - Upper Quartile, IQR - inter-quartile range. II - HF patients with NYHA class II, III - HF patients with NYHA class III, IV - HF patients with NYHA class IV, DBP - diastolic blood pressure, V_E - minute ventilation, V_E/VCO_2 - ventilatory equivalent of carbon dioxide, SG - study group, CG -control group

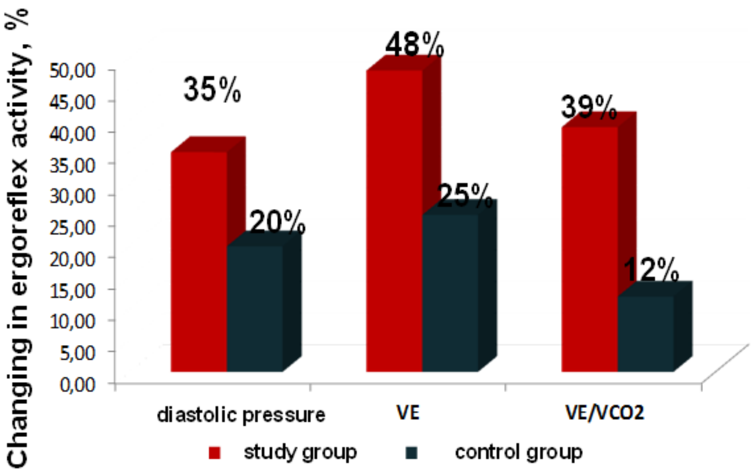

FIGURE 4. ERGOREFLEX ACTIVITY IN STUDY GROUP AND CONTROL GROUP BEFORE AND AFTER TRAINING

By the 24th week of training in 34 (85%) patients of the study group the severity of HF was reduced to NYHA class II, and among the patients in the control group such dynamics was observed only in 17(50%) patients (Fig. 5). LVEF changed insignificant, with 35+/-4,8-37.3+/-5,3 - in the study group, and 34+/-5,5 to 36.6+/-6,0 in the control group.

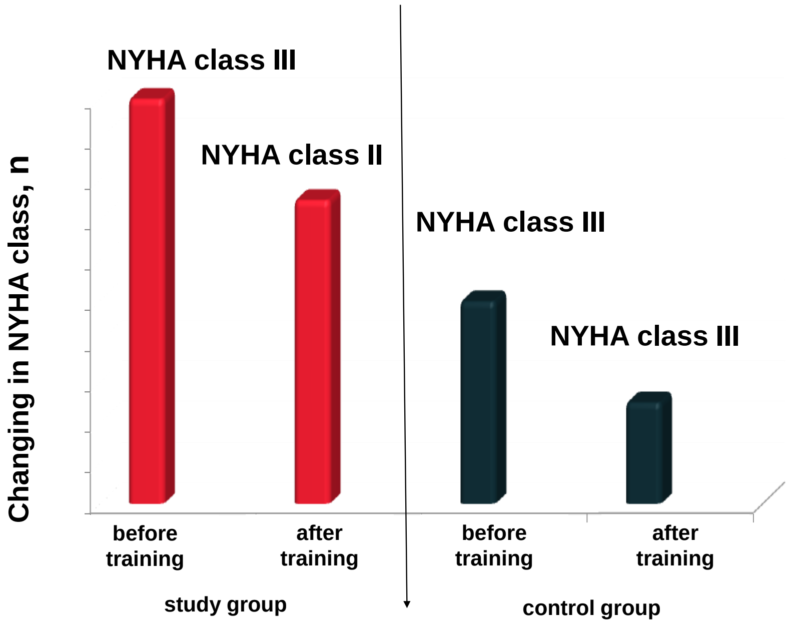

FIGURE 5. NYHA CLASS IN HF PATIENTS IN STUDY GROUP AND CONTROL GROUP BEFORE AND AFTER TRAINING.

V. DISCUSSION

The main findings in current study were improvement in exercise capacity, HF symptoms and ergoreflex activity after long-term aerobic training, designed based on lactate threshold definition.

Despite some recent evidence, pharmacological treatment does not impressively improve the high morbidity and mortality rates associated with HF [8-10]. There is still a lot to gain from non-pharmacological treatment. Reducing ergoreflex activity could probably fill an existing gap in HF therapeutic tactics.

The most physiologic method of reducing the ergoreflex activity is physical training. Finding ways of competent individualized impact on skeletal muscle in CHF patients is very important. Intensity of exercise should be designed individually.

With regular performance of individually designed aerobic exercise increases the number of slow muscle fibers (type I), as a consequence, the metabolism in the muscle tissue will shifted to aerobic oxidation, thus reducing the production of lactic acid, that is the primary and most powerful stimulator of ergoreflex [11-13].

In 12 patients from study group after 32 weeks of aerobic exercise VO_2-level reached over 85% of maximum predicted values, which is normal. Such dynamics of oxygen consumption indicates, probably, the increase the number of mitochondria in muscle fibers of lower extremities.

VI. STUDY LIMITATIONS

The relatively small sample size of the present study is a limitation. The absences of the subjects were NYHA class II and IV limited application of our findings for these patients groups. Future research should investigate the effectiveness of long-term aerobic training designed with individualized method based on the definition of the phases of physical activity in HF patients.

VII. CONCLUSION

Aerobic exercise, designed with individualized method based on lactate threshold definition, increase exercise tolerance, reduces HF severity and ergoreflex activity more than aerobic training, calculated based on VO2peak percentage.

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