

THE EFFECT of HIGH-INTENSITY INTERVAL PHYSICAL TRAINING ON THE ENERGY SUPPLY SYSTEM IN PATIENTS AFTER HEART SURGERY

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SUMMARY

Introduction. A number of studies have found a reduction in the risk of rehospitalization during cardiorehabilitation after heart surgery. The purpose of the training program for cardiorehabilitation after cardiac surgery is to optimize energy supply systems. Depending on the intensity and duration of the load being performed, energy supply systems 'switch on' in the body.

Purpose of the study: to study the effectiveness of the optimal cardiorehabilitation training program on the aerobic energy supply system in cardiac surgery patients.

Materials and methods. In our study, we examined 47 patients who underwent aortic valve replacement under cardiopulmonary bypass, with an EC duration of 52 ± 20.5 minutes. The patients were divided into two groups: the control group ($n=23$), who underwent a course of cardiorehabilitation on exercise bikes with constant aerobic training of moderate and medium intensity, at the age of 50.2 ± 3.4 years, and the main group ($n=24$) – with a course of cardiorehabilitation on exercise bikes with aerobic high-intensity interval physical training, at the age of 51.2 ± 2.8 years ($p > 0.05$). Gender was not taken into account. Anaerobic training was carried out on SCHILLER exercise bikes from day 14 after aortic valve replacement. The load power ranged from 25 to 70–95 watts. Before cardiac rehabilitation, the level of lactate, glucose, pH, pCO₂, pO₂, BE, lipid profile, BNP in the blood before and after ergometric exercise, data on external respiration, heart rate and blood pressure were assessed. After the course of rehabilitation, the above parameters were evaluated. The duration of the course was 2 weeks.

Results. When evaluating the indicators at the end of the course of cardiorehabilitation was being done, a significant decrease in the controlled parameters after training was observed in both groups, and largely in the group of high-intensity interval physical training than in the group of constant training of medium intensity. **Conclusions.** Analysis of the results showed that properly selected parameters of high-intensity interval training could optimize anaerobic glycolysis in patients undergoing operations under cardiopulmonary bypass, as well as increase the functionality of patients. As more and more repetitions of the load are performed, interval training becomes more and more aerobic.

KEYWORDS: intense physical activity, cardiorehabilitation, anaerobic and aerobic energy supply, artificial circulation

CONFLICT of INTEREST. The authors declare no conflict of interest.

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Introduction

Diseases of the cardiovascular system are the primary health problem and occupy a leading place in the structure of mortality of the population – more than 56 % of all deaths, of which about half are deaths from coronary artery disease [1]. The increase in life expectancy of the population is associated with an increase in the prevalence of cardiovascular diseases (CVD) in the population. The increase in the frequency of acquired heart defects (AHD) among patients allowed J.L. d'Arcy et al. consider degenerative heart valve disease as a new cardiac «epidemic» [2]. According to J.M. Takkenberg et al. [3] there is no complete data on the prevalence of PPS in the world. Thanks to the success of cardiac surgery, complex reconstructive operations have become possible for previously inoperable PPS. According to a report in the May 2003 issue of Chest, approximately one in five patients undergoing heart surgery has hyperlactatemia [4]. According to the results of a

study by French scientists from the Northern Cardiology Center Saint-Denis, after analyzing 325 patients who underwent heart surgery with artificial circulation, predictors of hyperlactatemia were identified – non-elective surgery, duration of EC, postoperative hyperglycemia and the appointment of adrenaline [4,5]. In many publications, the authors use the dynamics of blood lactate as a criterion for the effectiveness of the therapy and a predictor of a lethal outcome [6]. Patients with high lactate after heart surgery are prone to a large number of postoperative complications, as well as a long stay in the intensive care unit, which leads to significant government costs and a deterioration in the quality of life not only for patients, but also for their families [7]. A large-scale meta-analysis of the Cochran database showed that exercise in patients with coronary artery disease reduces overall mortality by 27 %, and mortality from cardiovascular diseases by 31 % [8]. Exercise

improves oxygen delivery to tissues through vasodilation and angiogenesis, protecting against ischemia-reperfusion injury to the heart, according to Borges J.P. et al. [9]. Aerobic training is accompanied by an increase in the energy capacity of mitochondria not only in skeletal muscles, but also in other tissues; the number of mitochondria and the activity of their enzymes increase; increases tolerance to endurance loads. After exercise, myocardial perfusion improves. One of the possible mechanisms for this is the correction of endothelial function [10]. According to Stanford K. I. et al., Vettor R. et al. enhance mitochondrial biogenesis in adipocytes [11], skeletal muscle myocytes, cardiomyocytes [12], increasing aerobic respiration in these tissues. High-intensity interval training (HIIT), an exercise technique for cardiac rehabilitation, is showing increasing evidence for improved prognosis and health outcomes in patients with cardiovascular disease [13]. Portuguese researchers performed interval intensive training in heart transplant recipients, which showed a significant improvement in VO_{2peak} , heart rate and peak blood pressure after 8–12 weeks after training [14]. Several studies have examined the effect of high-intensity exercise on overall mortality and cardiovascular mortality in cardiac patients. P. Williams et al. [15] reported a gradual decrease in the risk of cardiovascular mortality (–15 % per METs-hour /day) in myocardial infarction survivors ($n=2377$) while running or walking with an exercise level up to 7.2 METs-hour/day. There are four main zones of intensity of physical activity, each of which corresponds to a certain level of bioenergetic processes and a range of heart rate:

- 1) physical activity of low intensity with heart rate less than 75 % of its maximum value;
- 2) physical activity of a supporting nature with a heart rate of 75 to 85 % of the maximum heart rate, carried out in the aerobic mode of energy supply;
- 3) physical activity of a developmental nature with a heart rate of 85 to 95 % of the maximum value and a transitional aerobic-anaerobic regime of energy supply;
- 4) physical activity of submaximal and maximum intensity with a heart rate of more than 95 % of the maximum and anaerobic energy supply [16].

The optimal training program is set in two ways: by determining the level of lactate (lactic acid) in the blood or by recording the heart rate (HR) [17]. The predominance of the lactate (anaerobic) energy supply system in patients is a consequence of a decrease in the level of peak oxygen consumption, anemia, the presence of heart failure, and the development of acidosis after heart surgery with EC [18]. To determine the tolerance of aerobic exercise allows the cardiopulmonary test, which measures the maximum oxygen consumption (VO_{2peak}), anaerobic ventilation threshold, the ratio of minute tidal volume (VE) to carbon dioxide release (VCO_2), metabolic units (MU) [19]. Without providing energy, the vital activity of the body is impossible, and the more intense the physical load on it, the higher the energy supply should be. The number of publications on the improvement of the aerobic and anaerobic energy supply system of patients after surgery is limited, therefore, new studies are required to evaluate the

possibility of the impact of cardiorehabilitation on the energy supply system. Obviously, interval training, like any highly effective technology, can be dangerous if used ineptly [20].

The purpose of the study: to research the effectiveness of the optimal cardiorehabilitation training program on the aerobic energy supply system in cardiac surgery patients/

Materials and methods

In our study, we examined 47 patients who underwent aortic valve replacement under cardiopulmonary bypass, with an EC duration of 52 ± 20.5 minutes. The patients were divided into two groups: the control group ($n=23$), who underwent a course of cardiorehabilitation on exercise bikes with constant aerobic training of moderate and medium intensity, at the age of 50.2 ± 3.4 years, and the main group ($n=24$) – with a course of cardiorehabilitation on exercise bikes with aerobic high-intensity interval physical training, at the age of 51.2 ± 2.8 years ($p>0.05$). Gender was not taken into account.

The exclusion criteria were patients with arrhythmias, coronary heart disease, diabetes mellitus, hypo- and hyperthyroidism, hyperthermia, COPD, musculoskeletal diseases, hepatic disorders, CHF III–IV by NYHA, prolonged cardiac bypass time (>80 min).

To evaluate the aerobic/anaerobic system, for individual selection of loading power (W) on a bicycle ergometer, the patients of both groups underwent cardiorespiratory test, it differs from the usual exercise tests by the fact that in addition to ECG and blood pressure (BP) during its exercise the parameters of pulmonary gas exchange are recorded through a face mask connected through an airflow transducer to the gas analyzer.

A cardiopulmonary test was carried out before training and at the end of the cardiac rehabilitation course. Cardiorehabilitation training was carried out on SCHILLER ERG-911S/BP (SWITZERLAND) exercise bikes from the 14-th day after the operation, on the background of basic therapy, an hour before lunch, according to the Bruce protocol, every day for 14 days.

In our study, for the main group, we used a high-intensity training scheme that has been proven in terms of safety and effectiveness with 30-second high-intensity training, followed by intermediate 1-minute rest pauses, training was carried out every other day (*Fig. 1*). For the control group, a gradual increase in physical activity by 5–10 W / min until a moderate intensity is reached (*Fig. 2*). During exercise, heart rate, ECG and blood pressure were continuously monitored. The duration of the load increased every day by 2–4 minutes. The following indicators were assessed before and after the exercise cycle: lactate, glucose, pH, pCO_2 , pO_2 , BE, lipid profile, BNP, external respiration data (VE/VCO_2 , FEV1/FVC, VC), heart rate and blood pressure. The concentration of lactate, glucose, pH, CO_2 , O_2 , BE in venous blood was measured using a blood analyzer (ABL800 FLEX, Radiometer, Denmark).

Data processing was conducted using Statistica 8.0 applied statistics package. There were used such parametric methods as descriptive statistics – mean value, standard deviation; comparison of two independent samples by non-parametric Wilcoxon-Mann-Whitney criterion. The data were considered statistically significant at p value ≤ 0.05 .

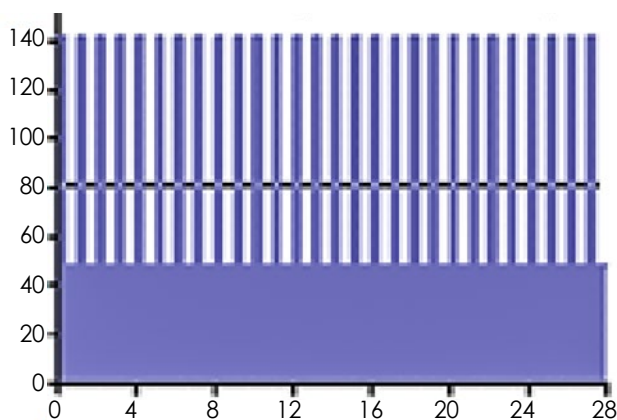


Fig. 1. High intensity interval training.

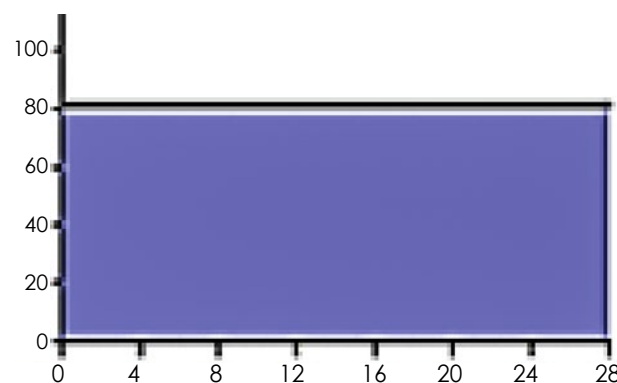


Fig. 2. Constant moderate load intensity.

Results and discussion

Because of the study, according to the cardiopulmonary test in patients after aortic valve replacement under EC conditions, peak oxygen consumption ranged from 17–19 ml / kg / min, which corresponds to the K. Weber classification of moderate CHF, with a VO_{2peak} rate of > 20 ml / kg / min. The presence of heart failure is accompanied by the presence of impaired systolic and diastolic function of the heart, inadequate distribution of blood flow in the peripheral circulation, and in the state after surgery under EC conditions, also muscle detraining [16]. Based on the results of the cardiopulmonary test, patients with a high level of cardiorespiratory training readiness were offered a course of high-intensity interval training every other day, and patients with a low level of exercise readiness and an average risk of developing adverse events were offered only aerobic training at a moderate / medium intensity (consistent training of medium intensity).

To assess patients' cardiorespiratory system we determined several parameters, in particular, peak oxygen consumption (VO_{2peak}), oxygen consumption volume VO_2 , carbon dioxide excretion volume VCO_2 , anaerobic threshold ($VCO_2/VO_2=1$), minute ventilation (MV), ventilation equivalent VE/VCO_2 , FEV_1/FVC , VC, and cardiorespiratory test time before anaerobic threshold occurred. Gas exchange indices and Mets determined during CPET in the main and control groups were similar ($p>0.05$) and are presented in Table 1.

Analysis of the results showed that properly chosen load ergometric parameters can optimize the anaerobic glycolysis in patients undergoing surgery with cardiopulmonary bypass, as well as increase the functionality of patients.

Table 1
Indices of cardiopulmonary test ($M \pm m$)

CPET parameters	Main group	Control group	p
VO_{2peak} , ml/kg/min	$17,2 \pm 0,5$	$17,0 \pm 0,9$	$>0,05$
VCO_2 , ml/min	$2697 \pm 7,5$	$2710 \pm 6,2$	$>0,05$
VE, ml	$981 \pm 2,0$	$982 \pm 1,7$	$>0,05$
VE/VCO_2	$35,4 \pm 0,4$	$35,5 \pm 0,5$	$>0,05$
Mets	$6,0 \pm 0,6$	$4,5 \pm 0,7$	$>0,05$
$FEV_1/FVC, \%$	67 ± 12	62 ± 14	$>0,05$
VC, ml	2780 ± 173	2850 ± 155	$>0,05$
t- CPET, min	$8 \pm 2,6$	$5,5 \pm 2,7$	$>0,05$

Based on the data shown in Table 1, we can note that the moderate decrease of parameters (VO_2 , FEV_1/FVC , VC) is associated with the surgery under the artificial c

irculation, with temporary respiratory muscle disorder, moderate pain in the sternotomy area, postoperative anemia, tissue hypoxia, and presence heart failure. The time of cardiorespiratory test before the onset of anaerobic threshold in postoperative patients with AC occurs faster, compared with the literature data (15–30 min), indicating the ineffective predominance of anaerobic energy supply system in the patients undergoing cardiac surgery. Under conditions of activation of anaerobic energy supply, an increase in the production of VCO_2 , ml/min (in the main group – 2697 ± 7.5 ; in the control group – 2710 ± 6.2), which is a respiratory stimulant, thereby leads to a pathological increase in VE, ml (in the main group – 981 ± 2.0 ; in the control group – 982 ± 1.7), respectively, to the rapid achievement of the anaerobic threshold.

The level of blood pressure (SBP and DBP) was almost the same in the groups before training (SBP – $p=0.533941$; DBP – $p=0.107650$) and had significant differences after exercise with a more pronounced decrease in the group with intensive training. The comparison of BP data after a course of ergometric exercise revealed a significant decrease in systolic BP after exercise of $145 \pm 10,7$ mmHg. ($p<0,05$), which shows the increased number of dilated arterioles in the active muscles, causing a decrease of total peripheral vascular resistance. During physical activity, previously non-functioning skeletal muscle vessels become involved in the blood circulation, and the peripheral blood flow changes in order to supply the increased oxygen demand of the working muscles.

Table 2

Parameters	High-intensity exercise	Regular moderate exercise	p-value
Total cholesterol, mmol/l	$3,61 \pm 0,70$	$4,56 \pm 0,71$	$<0,05$
High density lipoproteins, mmol/l	$1,27 \pm 0,24$	$1,12 \pm 0,25$	$<0,05$
Low density lipoproteins, mmol/l	$1,93 \pm 0,50$	$1,99 \pm 0,55$	$<0,05$
Triglycerides, mmol/l	$1,47 \pm 0,99$	$1,45 \pm 0,90$	$<0,05$

Serum levels of TG, LDL and HDL are considered the main indicators of lipid metabolism. Serum TG and LDL are a risk factor for atherosclerosis, while HDL is a protective factor. Serum LDL and TG did not clearly change between the two groups, while serum HDL increased slightly in the HIIT group (1.27 ± 0.24 mmol/l) (Table 2).

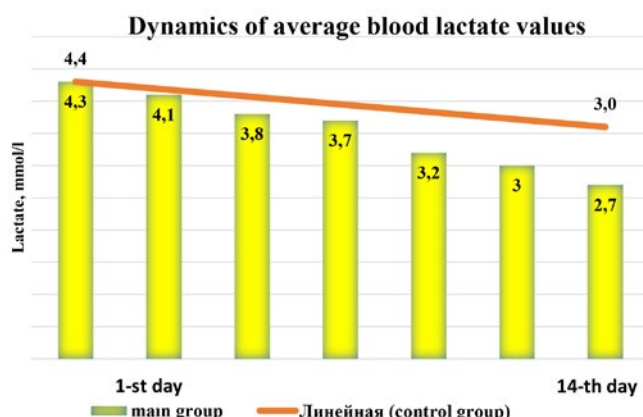


Fig. 3. Dynamics of average blood lactate values on the 14-th day.

Before performing ergometric exercise, both groups underwent blood sampling to determine the following parameters: lactate, glucose, pH, pCO₂, pO₂, and BE. The generally accepted upper limit of serum lactate is up to 2 mmol/L, but in postoperative patients with AC, in both groups, the average value was 4.4 ± 0.5 mmol/L. Reference values of pO₂ in blood were 37–42 mmHg, pCO₂–42–55 mmHg, pH=7.32–7.42. Initially, there was a moderate decrease in pO₂ (37 ± 4.5 mmHg) in both groups, the other parameters were within normal limits- pCO₂= 47 ± 5.5 mmHg, pH= 7.38 ± 0.5 . The data of laboratory studies also confirm the predominant function of the lactate energy supply in patients after aortic valve replacement under cardiopulmonary bypass. After a course of ergometric loads on the 14-th day already there were positive dynamics concerning blood lactate concentration in patients in the main group (2.7 ± 0.1 mmol/l) in comparison with the control group (3.0 ± 0.7 mmol/l) (Fig. 3).

The data obtained regarding the concentration of lactate in the blood indicates the optimization of aerobic energy supply as a result of exercises on a bicycle ergometer and the correctness of individual selection of power and intensity of aerobic loads. After a course of ergometric loads, the patients underwent a repeated cardiorespiratory test to assess the dynamics of the state of the cardiorespiratory test, aerobic and anaerobic energy supply systems. Relative to the average values of glucose and pH, no significant changes were observed.

According to the obtained data, the selected aerobic cardio load in patients undergoing surgery with CI leads to an in-

crease in the VO_{2peak} value in both groups, in the main group with intense exercise, a more pronounced increase to 21.0 ± 0.9 ml/kg/min ($p < 0.05$). An increase in peak oxygen consumption indicates an increase in oxygen transport and utilization, thereby improving the aerobic energy supply mechanism. The improved ventilatory function of the lungs is shown by the vital capacity of the lungs (VC). This value after training in the main group increased up to 3350 ± 133 ($p > 0.05$) compared to the control group 3180 ± 173 . VC is an important parameter of functional abilities of the system of external respiration, and also indirectly specifies the maximum area of a respiratory surface of lungs, which provides gas exchange.

The course of the cardiorehabilitation program in both groups increased the performance of the cardiovascular system in patients after surgery with EC: the metabolic equivalent significantly increased in the control group to 6.0 ± 0.9 , and in the main group to 7.8 ± 0.4 ($p < 0.05$).

Significant changes are observed regarding the time to reach the anaerobic threshold, the VE / VCO₂ coefficient, which proves the acceleration of blood flow with regular aerobic exercise, the improvement of endothelial function and increases the number of mitochondria in the muscles, accelerates lipolysis, thereby increasing the body's need for oxygen.

BNP levels are elevated in patients with left ventricular dysfunction. At the same time, the content of BNP in blood plasma significantly correlates with the functional classes of chronic heart failure. Determining the level of BNP in blood plasma helps to assess the severity of chronic heart failure, predict the further development of the disease, and also evaluate the effect of ongoing therapy. The guidelines of the Association of Pediatric Cardiologists of Russia for the diagnosis and treatment of chronic heart failure in children and adolescents (2010) determined that BNP more than 100 pg/ml is associated with congestive heart failure [02]. In our patients after aortic valve replacement, BNP averaged 95.1 ± 15 pg/mmole. After completing the course of ergometric loads in both groups, there was a downward trend, but mainly in the group with intense loads.

Conclusions

Analysis of the results showed that properly selected parameters of ergometric loads could optimize aerobic glycolysis in patients undergoing operations under cardiopulmonary bypass, as well as improve their clinical condition. During the implementation of a rehabilitation program with aerobic exercise, the patient's self-confidence increases, self-esteem increases, anxiety and depression decrease [23]. Physical exercise on a bicycle ergometer activates the activity of the cardiorespiratory system in patients undergoing heart surgery under EC conditions, accelerates blood flow, leading to an increase in metabolism. Intensive interval training triggers metabolic changes in the body, which is reflected in the mechanism of fat oxidation, a decrease in lipid profile. Leading cardiology societies in North America and Europe recommend that patients switch from moderate physical training to more intense interval training to improve the quality of life [24]. The uniqueness of the energy supply system lies in the fact

Table 3
Dynamics of CPET indicators after a course of ergometric loads in both groups

CPET parameters	Control group	Main group	p
VO _{2peak} , ml/kg/min	19.05 ± 0.6	21.0 ± 0.9	< 0.05
VCO ₂ , ml/min	2807 ± 8.5	2800 ± 8.0	> 0.05
VE, ml	920 ± 2.1	870 ± 1.4	> 0.05
VE/CO ₂	34.4 ± 0.4	32.5 ± 0.4	> 0.05
Mets	6.0 ± 0.9	7.8 ± 0.4	< 0.05
FEV1/ FVC	67 ± 12	75 ± 10	> 0.05
VC	3180 ± 173	3350 ± 133	> 0.05
t- CPET, min	11 ± 2.6	14.5 ± 2.7	< 0.05

that it can be optimized at any age, which makes it possible to use ergometric loads for patients after heart surgery. For this, it is necessary to use the selected parameters of the training program. Constant high-intensity interval loads, with the right selected regular mode, are equated to constant moderate loads, and even have an advantage in some indicators. Meta-analyses have found superiority of high- and moderate-intensity high-intensity training over continuous moderate-intensity training in terms of cardiovascular performance [25] and increased VO₂ peak.

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