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Influence of Bicycle Ergometric Loads on the Energy Supply System in Patients After Surgery with an Artificial Circulation

Kuular Arzhana Makarovna, Kakuchaya Tea Tamazovna, Dzhitava Tamara Georgievna, Pachuashvili Nona Vazhaevna, Filatova Angelina Gennadevna

Federal State Budgetary Institution "A.N. Bakulev National Research Center for Cardiovascular Surgery" of the Ministry of Health of the Russian Federation (A.N. Bakulev NMRCVS), Moscow, Russia

Email address:

Lebed8507@mail.ru (Kuular Arzhana Makarovna)

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Abstract: The reduction in the risk of repeated hospitalizations was revealed against the background of ongoing cardiac rehabilitation after CABG. A number of studies have revealed a reduction in the risk of repeated hospitalizations on the background of ongoing cardiac rehabilitation after CABG. Physical cardiorehabilitation is an effective means of restoring the adaptive capabilities of the organism. The goal of the cardiorehabilitation training program after cardiac surgery is optimization of energy supply systems. Objective: To study the effectiveness of the optimal cardiac rehabilitation program for the lactate system in cardiac patients. Methods: We examined 36 patients undergoing coronary artery bypass grafting under conditions of artificial circulation, with an IR duration of 56 ± 20.5 minutes, were divided into two groups: a control group (n = 15) - without performing bicycle ergometric, the age of 54.2 ± 1.4 years, the main group (n = 21) - with the exercise of the bicycle ergometric load at the age of 53.9 ± 1.3 years (p> 0.05). Of these, 17 men (62.5%), 14 women (37.5%). Gender was not considered. Anaerobic exercise carried out on exercise bikes SCHILLER 10 days after CABG. The load power was from 25 to 70-90 W. Before cardiorehabilitation estimated lactate, glucose, pH, PCO_2, pO_2, BE blood before and after the load ergometric data of external respiration, heart rate and blood pressure. After the rehabilitation course, the above parameters were evaluated. Results: When assessing the indices in the basis of the group at the end of the course of cardiac rehabilitation, a significant decrease in systolic blood pressure after exercise is 155 ± 5.7 mm Hg. (P <0.05), an increase in the value of VO_2peak to 19.0 ± 0.9 ml / kg / min (p <0.05), lactate in the blood decreased to 1.7 ± 0.2 mmol / l (p <0.05). There were no significant changes in pH, blood glucose, or heart rate. Conclusions: Analysis of the results showed that a properly fitted load ergometric parameters can optimize the anaerobic glycolysis in patients undergoing surgery with cardiopulmonary bypass, as well as increase the functionality of patients.

Keywords: Cardiorehabilitation, Anaerobic and Aerobic Energy Supply, Artificial Circulation

1. Introduction

Diseases of the cardiovascular system are a paramount public health problem and occupy the leading place in the mortality structure of the population - more than 56% of all deaths of which about half falls on mortality from coronary heart disease [6].

One of the main surgical methods of myocardial revascularization has been the generally accepted and effective coronary artery bypass grafting (CABG) with artificial circulation for half a century since 1967 [4]. According to a report in the May 2003 Chest issue, approximately one in every five patients who undergo heart surgery has hyperlactataemia [15]. A study by French scientists at the Nordic Cardiology Center of Saint-Denis, analyzing 325 patients who underwent cardiac surgery with artificial circulation, identified predictors of hyperlactatemia - non-elective surgery, duration of artificial circulation, postoperative hyperglycemia, and adrenaline prescription [14, 15]. In many publications, authors use blood lactate dynamics as an effectiveness criterion of therapy and a predictor of the fatal case [14]. 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 costs of the government and deterioration of living standards not only for patients but also for their families [8]. In the U.S., the use of cardiac rehabilitation saved from $2,193 to $28,193 per year of a patient's life [3]. It was shown in a large-scale meta-analysis of the Cochran database, that exercising by patients with coronary artery disease reduces overall mortality by 27% and cardiovascular mortality by 31% [9]. The effectiveness of rehabilitation programs that optimize energy supply systems is now indisputable [16], however, it is possible to compose an optimal training program only with good knowledge of the mechanisms of energy supply. In the anaerobic energy supply system, adenosine triphosphate resynthesis happens due to the breakdown of glucose and glycogen in the absence of oxygen. [11], the aerobic one – with oxygen. 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 [13]. High values of lactate are indicative of the aerobic system failure of patients after surgery [10], so physical training should be based on aerobic exercises [1]. The prevalence of the lactate (anaerobic) energy supply system among patients is a consequence of decreased peak oxygen consumption level, anemia, the presence of heart failure, and the development of acidosis after cardiac surgery with artificial circulation [5]. Aerobic exercise tolerance can be determined by the cardiopulmonary test, which measures the maximum oxygen consumption (VO_2peak), anaerobic threshold, a ratio of minute respiratory volume (VE) to carbon dioxide excretion (VCO_2), metabolic cells. [7]. It is known that in order to determine the intensity of aerobic exercise it is necessary to achieve 40-70% of maximum oxygen consumption, up to 80% with good tolerance, which is close to the anaerobic threshold of a healthy person [8]. There are few publications on the improvement of the aerobic and anaerobic energy supply system of patients after surgery, therefore, new studies are required in order to assess the possible impact of cardiac rehabilitation on the energy supply system.

2. The Goal of Research

To evaluate the effect of ergometric loads on the energy supply system in cardiac surgical patients.

3. Study Materials and Methods

In our study, we examined 36 patients who underwent aortocoronary bypass grafting under artificial circulation, with a 56±20.5 minute artificial circulation duration. Patients were divided into two groups: the control group (n=15), who did not undergo cardiac rehabilitation on ergocycles, aged 54.2±1.4 years, and the main group (n=21) - with a course of cardiac rehabilitation on ergocycles, at the age of 53.9±1.3 years ($p>0.05$). There were 22 men (61.1%) and 14 women (38.9%). Gender was not taken into consideration. Among subjects in the control group, 46.1% had CHF class I according to NYHA and 53.8% had CHF class II according to NYHA; in the main group, 28.5% had CHF class I according to NYHA and 71.4% had CHF class II according to NYHA.

Exclusion criteria were patients with diabetes mellitus, hypo- and hyperthyroidism, hyperthermia, COPD, musculoskeletal diseases, hepatic disorders, CHF III-IV by NYHA, prolonged cardia 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.

Based on the equation $MET = (90 + 3,44 \times W)/kg$ (from the instructions to the SICARD 460 S stress system, manufactured by Siemens) [2], we can calculate the load capacity for ergometric loads - $W=(Mets\times weight)-90/3,5$. Cardiac rehabilitation exercises were performed on SCHILLER ERG-911S/BP (SWITZERLAND) bicycles from the 9-10th day after surgery, against the background of basic therapy, one hour before lunch, according to the Bruce protocol, every day for 10-14 days. Gradually increase in physical activity by 1-10 W/min until the target intensity is reached. During exercise, HR (heart rate), ECG, and BP are constantly monitored. The duration of physical activity increased by 4-5 minutes every day. The following parameters were evaluated before and after bicycle ergometric exercise: lactate, glucose, pH (blood acid-base balance parameter), pCO_2 (partial pressure of carbon dioxide in blood), pO_2 (partial pressure of oxygen in blood), BE (deviation index of buffer bases concentration from normal level), external respiration data (VE/VCO_2, FEV1/EFEL, VC), HR and BP. The FEV1 is the volume of air coming out of the lung under forced conditions and determines the amount of air that is expelled in 1 second. The normal value is between 70 and 85% of the VC (vital capacity of the lungs). The FVC (forced volume vital capacity) is a parameter that determines the amount of accelerated lung capacity. It is the amount of air that is exhaled when a person takes a significant effort after taking a deep breath. The concentration of lactate, glucose, pH, CO_2, O_2, BE in the 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.

4. Results and Discussion

As a result of the study, according to the cardiopulmonary test in patients after CABG surgery under artificial circulation (AC) conditions, the peak oxygen consumption ranged from 16-19 ml/kg/min, which corresponds to the K. Weber classification of moderate severity of CHF, with a normal VO_2peak >20 ml/kg/min. The presence of cardiac insufficiency is accompanied by impaired systolic and diastolic heart function, inadequate blood flow distribution in the peripheral circulation, and in the postoperative state under AC also by detrained muscles, decreased pulmonary vascular response to load effect and pathological changes in ventilation parameters when exposed to load [17]. A training heart rate requires 70% of maximum oxygen consumption, which corresponded to a VO_2peak of ~11.2-13.3 (HR=87-103 bpm) in our study. The metabolic equivalent of patients who underwent surgery with AC was Mets=4.4-5.4. To determine the threshold power of load for bicycle ergometric exercise, metabolic units were converted to W, which amounted to 70-90 W. 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, FEV1/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 Figure 1.

Table 1. *Indices of cardiopulmonary test (M±m).*

CPET parameters	Main group	Control group	p
VO_2peak, ml/kg/min	17,15±0,6	17,0±0,9	>0,05
VCO_2, ml/min	2767±8,5	2760±7,2	>0,05
VE, ml	980±2,1	982±1,9	>0,05
VE/CO_2	35,4±0,4	35,5±0,5	>0,05
Mets	4,9±0,6	4,9±0,6	>0,05
FEV1/ FVC, %	67±12	60±15	>0,05
VC, ml	2780±173	2850±155	>0,05
t- CPET, min	7±2,6	6,5±2,7	>0,05

Based on the data shown in Figure 1, we can note that the moderate decrease of parameters (VO_2, FEV1/ FVC, VC) is associated with the surgery under the artificial circulation, with temporary respiratory muscle disorder, moderate pain in the sternotomy area, postoperative anemia, tissue hypoxia, and presence of CHF I-II FC according to NYHA. 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 the conditions of activation of anaerobic energy supply there is an increase in VCO_2 production, ml/min (in the main group-2767±8.5; in the control group-(2760±7.2), which is a respiratory stimulant, thereby leading to a pathological increase in VE, ml (in the main group-980±2.1; in the control-982±1.9), respectively, to a rapid achievement of the anaerobic threshold.

Blood pressure was measured during ergometric exercise at 3-minute intervals. On average, before exercise, systolic BP was 128±7.1 mmHg, and diastolic BP was 76±8.0 mmHg. On the first day after exercise, systolic BP increased to an average of 178±10 mmHg, and diastolic BP 80±9.2 mmHg. The comparison of BP data after a course of ergometric exercise revealed a significant decrease in systolic BP after exercise of 155±5.7 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.

Before performing ergometric exercise, both groups underwent blood sampling to determine the following parameters: lactate, glucose, pH, pCO_2, pO_2, 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 4.3±0.5 mmol/L. Reference values of pO_2 in blood were 37-42 mmHg, pCO_2-42-55 mmHg, pH=7.32-7.42. Initially, there was a moderate decrease in pO_2 (37±4.3 mm Hg) in both groups, the other parameters were within normal limits- pCO_2=47±5.5 mm Hg, pH=7.38±0.5. The data of laboratory studies also confirm the predominant function of the lactate energy supply in patients after CABG. After a course of ergometric loads on the 7th 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 (3.6±0.7 mmol/l) (Figure 1).

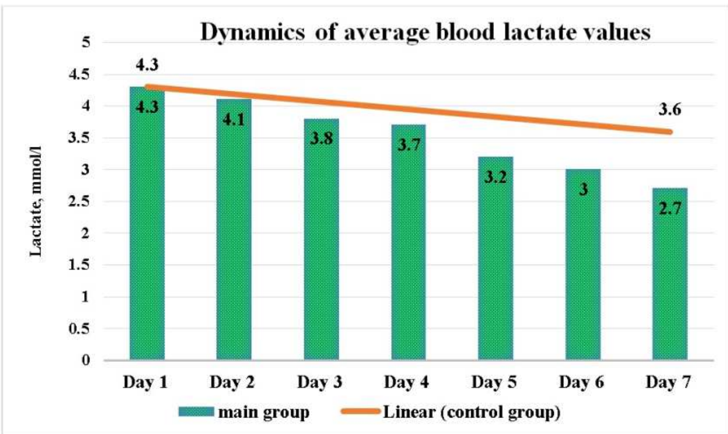

Figure 1. *Dynamics of average blood lactate values on the 7th day.*

After a course of ergometric exercises, reliable changes in blood lactate concentration of 1.7±0.2 mmol/l ($p<0.05$) were observed in the main group. Regarding the average values of glucose and pH there were no reliable changes (Figure 2).

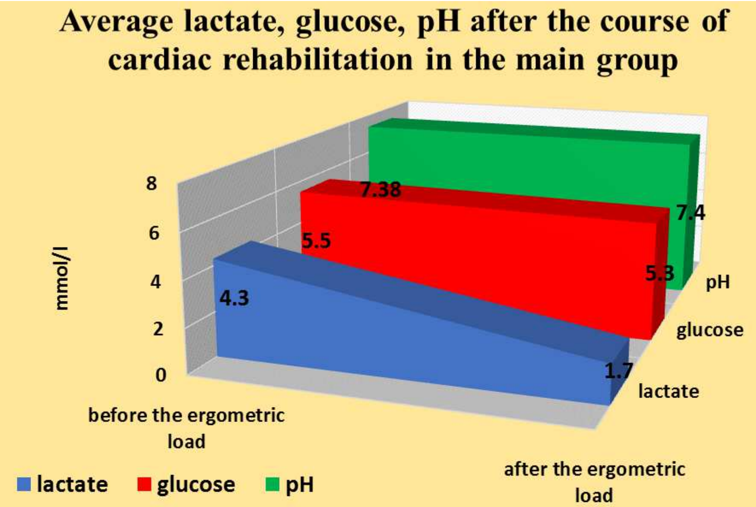

Figure 2. *Dynamics of lactate, glucose, pH after the course of ergometric exercises.*

The findings regarding blood lactate concentration show the optimization of aerobic energy supply as a result of exercising on a bicycle ergometer and the correctness of individual selection of power and intensity of aerobic loads. After the course of ergometric exercise, the patients were repeatedly tested to assess the dynamics of cardiorespiratory test, aerobic and anaerobic energy supply system; the results are shown in Figure 2.

Table 2. *Dynamics of CPRT parameters after a course of ergometric loads in the main group.*

CPET parameters	Before the rehabilitation course	After the rehabilitation course	p
VO_2peak, ml/kg/min	17,15±0,6	19,0±0,9	<0,05
VCO_2, ml/min	2767±8,5	2800±8,0	>0,05
VE, ml	980±2,1	770±1,4	>0,05
VE/CO_2	35,4±0,4	32,1±0,4	>0,05
Mets	4,9±0,6	7,3±0,4	<0,05
FEV1/ FVC	67±12	75±10	>0,05
VC	2780±173	3350±133	<0,05
t- CPET, min	7±2,6	12,5±2,7	<0,05

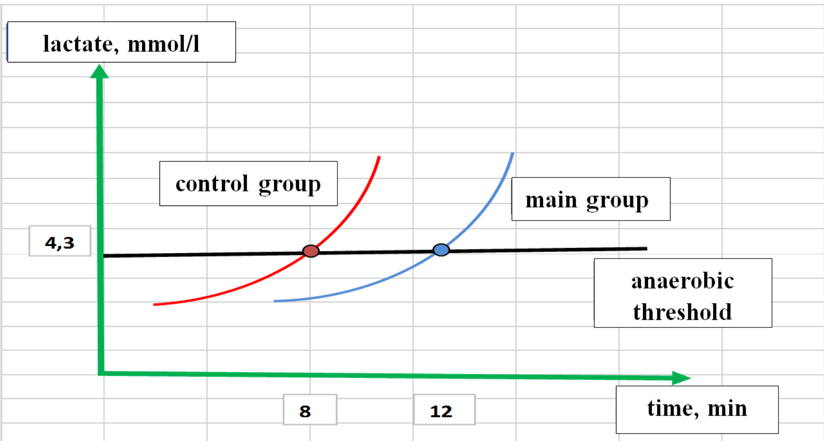

Figure 3. *Comparison of anaerobic threshold time in the main and control groups.*

The chosen aerobic cardiorespiratory load in the patients who underwent AC surgery according to the data leads to the increase of VO_2peak value up to 19,0±0,9 ml/kg/min ($p<0,05$), that shows the increase of oxygen transportation and utilization, thereby improving the aerobic mechanism of the energy supply. 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 ($p<0,05$) in comparison with the basic data-2780±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.

Reliable changes were observed in relation to the time of reaching the anaerobic threshold in the main group, which underwent a course of ergometric loads, equal to 12.5±2.7 min. ($p<0,05$). If we take into consideration that the concentration of anaerobic threshold is 4.3 mmol/l, then there is an increase in time in the main group, in comparison with the control group, and this fact indicates the predominance of the aerobic energy supply system, the endurance of the body to loads (Figure 3). During regular aerobic exercise, the blood flow acceleration increases the number of mitochondria in the muscles, accelerates lipolysis, thereby increasing the body's oxygen demand.

The course of ergometric exercise increased cardiovascular performance in postoperative IR patients: metabolic equivalent reliably grew to 7.3±0.4 ($p<0.05$).

In some works, the threshold value of VE/VCO_2 is 34, the increase of which exceeds the risk of failure occurrence [12]. In patients after CABG in our study, VE/VCO_2 was 35.4±0.4, after aerobic exercise (cycling) there was a tendency to decrease to 32.1±0.4 ($p>0.05$) (Figure 3). In the control group, which did not undertake cardiac rehabilitation and ergometric exercise, the VE/VCO_2 index was 33.4±0.3 ($p>0.05$).

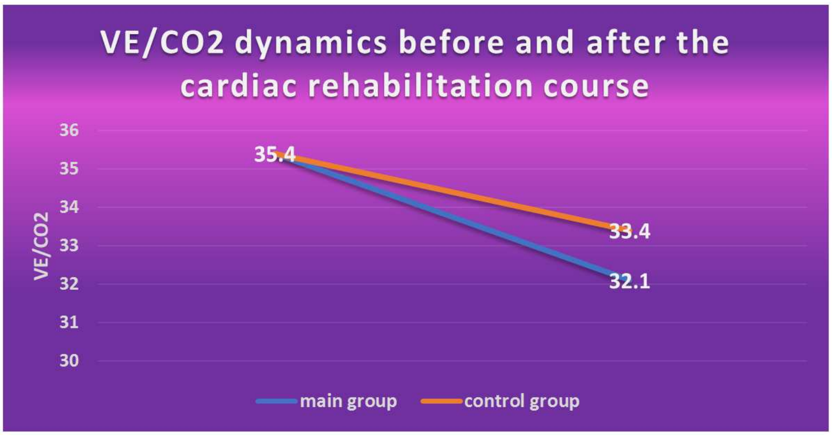

Figure 4. *VE/VCO_2 dynamics of both groups before and after the cardiac rehabilitation course.*

5. Conclusions

Aerobic exercise on a cycle ergometer activates the cardiorespiratory system activity in patients who have undergone cardiac surgery under cardiopulmonary bypass, contributes to the blood flow acceleration, increasing the metabolism [12]. The aerobic energy system is unique because it can be optimized at any age, which makes it possible to use ergometric loads for patients after cardiac surgery. This requires the use of chosen training program parameters. The training load conducted in the aerobic mode of the energy supply adapts to the cardiovascular, respiratory systems of the body. The analysis of the results showed that carefully chosen parameters of ergometric loads can optimize aerobic glycolysis in patients who underwent surgery under conditions of artificial circulation, as well as improve their clinical condition.

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Biography

Kuular Arzhana Makarovna - Federal State Budgetary Institution “A.N. Bakulev National Research Center for Cardiovascular Surgery” of the Ministry of Health of the Russian Federation (A.N. Bakulev NMRCVS), the research assistant, the Candidate of Medicine;

Kakuchaya Tea Tamazovna - A.N. Bakulev NMRCVS, head of the Department of Cardiac Surgery and Rehabilitation of Adult Patients with Cardiac Pathology, Doctor of Medicine;

Dzhitava Tamara Georgievna - A.N. Bakulev NMRCVS, the assistant manager of the Department of Cardiac Surgery and Rehabilitation of Adult Patients with Cardiac Pathology, the Candidate of Medicine;

Filatova Angelina Gennadevna- A.N. Bakulev NMRCVS, cardiologist;

Pachuashvili Nona Vazhaevna - A.N. Bakulev NMRCVS, the graduate student.