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Features of Application of the Optimized Physical Rehabilitation Program in Patients with Coronary Heart Disease

Abstract. Multisymptomatic coronary heart disease (CHD) remains a leading problem in cardiology. A person's ability to perform physical work determines their quality of life, especially in patients with existing symptoms of damage to the cardiovascular system. The most advanced approach in the physical rehabilitation of patients with CHD is the use of ergometric testing indicators.

The aim. To study the influence of the developed method of cycling training on the indicators of cardiopulmonary exercise (CPX) in patients with CHD.

Materials and methods. We examined 65 men with CHD, I-II functional class stable angina pectoris, mean age 44.6 ± 1.39 years (from 32 to 60 years). The diagnosis was made on the basis of clinical findings, electrocardiography and laboratory examination according to the generally accepted criteria of the European Society of Cardiology.

Results. The treatment results were evaluated two weeks after the completion of the physical rehabilitation program. Qualitative assessment was performed by using the CPX test with the recording of cardiac bioelectric potentials from 12 leads. The criteria for discontinuation of the test were generally accepted provisions based on WHO recommendations.

While developing a physical rehabilitation program and predicting the timing of a functional recovery, several factors have to be taken into account that significantly affect the patient's motor activity and determine the pace and outcome of the rehabilitation process as a whole. Long-term, regular physical activity in patients with CHD with limited coronary reserve have an impact on the mechanisms of cardiac function regulation, synchronization and optimization of the activity of the muscular, cardiovascular and respiratory systems. Systematic training sessions reduce the volume of drug therapy and can improve the patients' quality of life.

Conclusions. The use of the proposed individualized uniform interval cycling training combined with the intake of citrulline malate leads to a significant improvement in the achieved load capacity, heart rate, duration of work, total volume of completed work, inotropic reserve index, optimization of coronary blood circulation and improvement of bioenergy metabolism in the myocardium.

Keywords: *physical rehabilitation, endothelial dysfunction, ergometry, cardiopulmonary exercise, citrulline malate, exercise tolerance, physical performance.*

Attributed to the bright of the memory
of professor JAKOV BENDET

Introduction. Progressive and multisymptomatic coronary heart disease (CHD) is still one of the leading problems in cardiology, as its share in the 2022 mortality structure in Ukraine remains rather large. According to the official statistics, the prevalence of all forms of CHD in the adult population of Ukraine is 24% including people of working age (about 10%). The incidence is 2% per year. Angina pectoris is found in 35.5% of patients with CHD who seek medical care [1]. However, in a large part of patients the disease remains in a latent form without any pronounced clinical manifestations and is detected by chance. As a basis in the system of physical rehabilitation of patients with cardiovascular pathology rests the ability of patients to satisfactorily cope with the physical activity encountered in everyday life [2]. The ability to perform physical work not only expands motor capabilities of the person, but also determines the patient's quality of life [3]. It is proved that regular physical training, which is dosed purely individually, is important in the prevention of CHD [4, 5]. It is physiologically substantiated, because it provides significant positive physiological changes in the body as a whole, with the influence on the main risk factors for developing CHD with weight loss, normalization of lipid metabolism and blood pressure.

At present, the most advanced approach in the physical rehabilitation of patients with CHD is the use of indicators of the exercise tolerance [6, 7]. There are many methodological approaches for selecting the optimal exercise regimen for both healthy individuals and athletes. However, there is no optimal way for the treatment of patients with CHD. The variety of individual training programs reveals a number of disadvantages when applied to patients with CHD. Despite the versatility of exercise programs and the use of different types of exercise in them, very often it is impossible to achieve the expected effect in some patients [6], even with the personalized selection [5] of one or several parameters: exercise power, duration or frequency of pedaling. Against the background of the wide variety of rehabilitation programs, there is no adequate methodology for outpatient polyclinic stage for patients with CHD using a specific form and method of controlling the impact of physical activity on the body. That is because the duration of the parts of the training that changes the method and capacity of the exercise and convenience of controlling it is not taken into account.

The aim. To study the influence of the developed method of cycling training on the indicators of cardiopulmonary exercise (CPX) in patients with CHD.

Materials and methods. We examined 65 men with CHD, I-II functional class stable angina pectoris, mean age 44.6 ± 1.39 years (from 32 to 60 years). The diagnosis was made on the basis of clinical findings, electrocardiography (ECG) and laboratory examination according to the generally accepted criteria of the European Society of Cardiology (2019) [8].

The patients were divided into 3 groups depending on the purpose of the rehabilitation program. All the patients received citrulline malate at a dose of 2 g 3 times a day. The group I consisted of patients who received only citrulline malate, group II included patients who additionally held a standard complex of therapeutic gymnastics [5], group III included patients who, against the background of drug administration, had bicycle training according to our developed method, the essence of which is a combination of different methods of activity in different parts of the training with a different rate of pedaling and duration of training, which makes it easy to control the activity by the heart rate and to reach the training level [9, 10].

For carrying out CPX test we used load device, DX 1 PRO ergometer (Kettler, Germany) with parallel ECG using Cardiotest 995.01.04 ECG complex (DX-SYSTEMS, Kharkiv, Ukraine), with registration of bioelectric potentials of the heart from 12 leads. The sampling was performed according to the standard method [11]. The criteria for discontinuation of the test were generally accepted provisions based on WHO recommendations [12].

Statistical processing of the research results was performed on a personal computer using Statistica 6.0 for Windows software by StatSoft (USA) and Excel 2000 with Office 2000 Professional by Microsoft (USA) with determination of average values, standard deviation, Student's t-test.

Results and discussion. In the course of treatment in the groups of examined patients, the estimated load power and heart rate remained unchanged, which confirms the homogeneity of the groups (table 1). The power achieved after treatment in group I decreased insignificantly, from 148.70 ± 74.31 W to 133.35 ± 10.39 W. A probable increase was found in groups II and III, where the index after treatment was 140.45 ± 11.74 W ($p < 0.001$) and 141.84 ± 15.54 W ($p < 0.001$), respectively, indicating the effectiveness of aerobic physical training. The rate of achieved heart rate in the course of treatment probably increased, reaching 149.10 ± 3.54 bpm (+5%) ($p < 0.05$) in group I, 146.20 ± 5.44 bpm (+9%) ($p < 0.01$) in group II and 144.36 ± 6.11 bpm (+11%) ($p < 0.01$) in group III. We have shown that physical rehabilitation, in addition to medication therapy with citrulline malate, leads to a more significant improvement in the mechanisms of adaptation at the top of physical activity while increasing the amount of the performed work.

The magnitude of baseline systolic and diastolic blood pressure tended to decrease in groups I and III, amounting to 134.50 ± 3.94 mm Hg and 87.75 ± 3.08 mm Hg, and 131.20 ± 4.63 mm Hg and 89.40 ± 4.01 mm Hg, respectively. Possible changes were found in group II, where there was a decrease in systolic (from 139.00 ± 5.81 mm Hg

Table 1

Indicators of bicycle ergometry (CPX) in the course of treatment

	Group I (n=20)		Group II (n=20)		Group III (n=25)	
Index	**Before treatment**	**After treatment**	**Before treatment**	**After treatment**	**Before treatment**	**After treatment**
Calculated Watt (Wt)	160.65 ± 8.09	160.65 ± 8.09	164.15 ± 14.74	164.15 ± 14.74	161.84 ± 14.26	161.92 ± 14.32
Achieved Watt (Wt)	148.70 ± 74.31	133.35 ± 10.39	114.80 ± 10.50	140.45 ± 11.74***	113.20 ± 11.87	141.84 ± 15.54***
Calculated HR (bpm)	152.30 ± 1.67	152.30 ± 1.67	151.65 ± 2.02	151.65 ± 2.02	150.40 ± 1.66	150.84 ± 1.38
Achieved HR (bpm)	142.35 ± 6.19	149.10 ± 3.54*	133.55 ± 8.71	146.20 ± 5.44**	130.32 ± 8.29	144.36 ± 6.11**
Initial systolic BP (mm Hg)	138.50 ± 6.17	134.50 ± 3.94	139.00 ± 5.81	132.00 ± 5.00*	134.40 ± 5.38	131.20 ± 4.63
Initial diastolic BP (mm Hg)	89.25 ± 3.33	87.75 ± 3.08	93.25 ± 3.42	87.75 ± 3.17**	91.60 ± 3.14	89.40 ± 4.01
Achieved systolic BP (mm Hg)	188.75 ± 8.55	192.00 ± 6.85	186.25 ± 8.52	187.00 ± 8.09	186.00 ± 10.86	191.60 ± 7.72
Achieved diastolic BP (mm Hg)	103.50 ± 4.81	102.75 ± 4.59	109.50 ± 3.63	105.75 ± 6.63	104.40 ± 4.47	99.80 ± 3.93
Duration of work (s)	295.95 ± 52.59	397.90 ± 50.70**	320.20 ± 67.87	457.10 ± 51.84***	332.52 ± 58.10	464.56 ± 48.31***
Total amount of work performed (Wt×S)	27 634.90 ± 7352.75	40 779.70 ± 8166.46*	31 193.45 ± 7373.31	47 470.60 ± 7425.71**	32 109.44 ± 6595.99	51 858.12 ± 7655.80***
Exercise tolerance (%)	49.40 ± 10.25	69.60 ± 5.51***	56.30 ± 11.78	76.25 ± 7.35**	57.56 ± 7.95	80.08 ± 6.88***
ICR	1.65 ± 0.14	1.80 ± 0.13	1.74 ± 0.80	1.78 ± 0.12	1.79 ± 0.17	1.71 ± 0.08
IIR	1.37 ± 0.07	1.42 ± 0.05	1.34 ± 0.07	1.43 ± 0.07*	1.33 ± 0.10	1.45 ± 0.06*

BP, blood pressure; HR, heart rate; ICR, index of chronotropic reserve; IIR, index of inotropic reserve.
Note. The coefficient of probability in the groups studied in the dynamics of treatment: * p <0.05, ** p <0.01, *** p <0.001.

to 132.00 ± 5.00 mm Hg) ($p < 0.05$) and diastolic (from 93.25 ± 3.42 mm Hg to 87.75 ± 3.17 mm Hg) pressure ($p < 0.01$).

The decrease in blood pressure under the influence of physical activity is a complex multicomponent mechanism, which is realized on different "stages" of pressure regulation. The decrease in blood pressure is due to a decrease in the activity of the sympatho-adrenal system, the restoration of altered sensitivity of baroreceptors, changes in the distribution of fluid volumes, normalization of the function of the renin-angiotensin and depressor systems [8, 13]. As a result of these processes, the hemodynamics are normalized by reducing cardiac output and overall peripheral vascular resistance. Physical training has the most pronounced antihypertensive effect at the stage I hypertension. The mechanism of pressure decrease involves reduction of the minute blood volume, decrease in the peripheral resistance of blood vessels, decrease in the body weight, correction of saline regime, decrease in the level of catecholamines and insulin [5, 14].

In the course of treatment at the top of the load index the achieved systolic blood pressure had a slight tendency to increase up to 192.00 ± 6.85 mm Hg (group I), 187.00 ± 8.09 mm Hg (group II), and 191.60 ± 7.72 mm Hg (group III). The magnitude of the achieved diastolic blood pressure tended to decrease, reaching 102.75 ± 4.59 mm Hg in group I, 105.75 ± 6.63 mm Hg in group II, and 99.80 ± 3.93 mm Hg in group III.

The duration of work after treatment probably increased, amounting to 397.90 ± 50.70 s ($p < 0.01$) in group I, 457.10 ± 51.84 s ($p < 0.001$) in group II, and 464.56 ± 48.31 s ($p < 0.001$) in group III. The total amount of work performed during the test increased significantly, reaching 40 779.70 ± 8166.46 W×s ($p < 0.05$) in group I, 47 470.60 ± 7425.71 W×s ($p < 0.01$) in group II, and 51 858.12 ± 7655.80 W×s ($p < 0.001$) in group III. Exercise tolerance also increased significantly and reached 69.60 ± 5.51% ($p < 0.001$) in group I, 76.25 ± 7.35% ($p < 0.01$) in group II and 80.08 ± 6.88% ($p < 0.001$) in group III.

Under the influence of the load, vital activity of the organ increases with subsequent onset of fatigue. It is a well-known fact that fatigue decreases performance but at the same time stimulates recovery processes in the working organ or the body as a whole. The effectiveness of the physical training performed depends on how comprehensively the individual characteristics of the patient will be taken into account [13]. According to the literature, peripheral disorders of hemodynamics play a significant role in decreasing tolerance to physical activity and the progression of the disease symptoms. These include changes in pulmonary ventilation, microcirculation and damage of skeletal muscles [15].

Normally, increase of the frequency and depth of breathing, sympathetic stimulation and heart rate, which are required to perform dynamic loading, are provided by two types of nerve mechanisms, namely the central and reflex [5]. At the beginning of the work, the central mechanism directly activates locomotor, autonomic and respiratory centers of the brain, and while continuing to ensure the proportionality between the need for and delivery of oxygen, the muscle ergoreflex plays a significant role. Ergoreceptors are divided into mechanoreceptors that react to the muscle contraction or stretching, and baroreceptors that are sensitive to metabolic changes (usually acidosis). Namely the baroreceptors are most sensitive to metabolic changes and play a more important role in the regulation of respiration and circulation [8]. Excessive activation of muscle mechanoreceptors causes hyperstimulation of circulatory and respiratory responses to loading, which in turn leads to excessive ventilation, vasoconstriction and fatigue [16].

In patients with CHD, cardiac output usually does not meet the metabolic needs of the body or is supported only by the increased left ventricular filling pressure, which will be manifested primarily in loads [3]. It is the insufficient contractile reserve that is the main reason of the decrease of physical performance [7], which leads to an increase in sympathetic tone, pulmonary ventilation and vasoconstriction [17]. In the long-term ergoreflex hyperactivation, it becomes a negative source of persistent hypersympaticotonia, vasoconstriction, leads to a decrease in parasympathetic activity and baroreflex activity, which forms a vicious circle of compensatory mechanisms. Modern perceptions of the value of peripheral and regulatory disorders correct the choice of therapeutic methods that affect precisely the links of the pathogenesis of destabilization of CHD. Namely the usage of dosed physical training in complex therapy can partially enhance normalization of metabolism and autonomic regulation [12, 17]. These effects are accompanied by regression of clinical manifestations such as increased fatigue, shortness of breath, muscle weakness, sleep disturbance by increasing physical performance, exercise tolerance and quality of life of patients [4]. So, an individual approach to physical activity in patients with CHD by using exercise training according to the developed method [7] with the use of initial indicators of exercise tolerance makes it possible to develop adequate training schemes which provide a 61.5% increase in the total amount of work performed and a 22.5% increase in exercise tolerance.

The ICR in the course of treatment changed significantly, being 1.80 ± 0.13 (group I), 1.78 ± 0.12 (group II) and 1.71 ± 0.08 (group III). The IIR in group I tended to increase, reaching 1.42 ± 0.05. Possible changes were found in groups II and III, where the index was 1.43 ± 0.07 ($p < 0.05$) and 1.45 ± 0.06 ($p < 0.05$), indicating the formation of early adaptation of the cardiovascular system to physical activity, as well as optimization of regulation mechanisms of cardiac function, development of collateral blood supply to the myocardium, synchronization and optimization of the muscular activity, cardiovascular and respiratory systems, which in turn will contribute to the decrease in the drug therapy volume, and may also be an alternative to standard treatment [3]. In patients with CHD, insufficient contractual reserve is the main reason for the decrease in physical performance. In patients with clinical manifestations of the disease, glycolytic metabolism prevails over oxidative, which leads to a decrease in the number and surface area of mitochondria, violation of the ratio of muscle fibers, decrease in muscle mass [17]. As a result of these changes, lactate acidosis and depletion of macroergic phosphates rapidly develop during loading, which in turn provokes the activation of compensatory mechanisms, namely activation of central and peripheral chemoreflexes and baroreceptors of skeletal muscles [14, 15]. The use of dosed physical training in complex therapy can improve metabolism and normalize the autonomic balance [13, 16]. These effects are accompanied by regression of indices of ICR and IIR, as well as clinical manifestations of the disease by increasing physical performance and exercise tolerance, which is clearly revealed by us in the group that was engaged in uniform-interval cycling by the developed method.

Physiological norm of the motor activity of the patient is the value which provides therapeutic and preventive action on the body, responds to the clinical form and stage of the disease, the functional capabilities of the body, contributes to the improvement of the physical condition of the person and increase in their physical performance. We developed a uniform-interval method of exercise (Patent No. 18353 "Method for physical rehabilitation of patients with ischemic heart disease") [10]. Taking into account the given level of tolerance to physical activity, it can be used at the outpatient clinic stage of patients with CHD as it uses a combination of methods, capacity and duration of physical activity in different parts of the training, and also allows to control the volume and efficiency of the work performed.

So, while developing a physical rehabilitation program and predicting the timing of a functional recovery, several factors must be considered that significantly affect the patient's motor activity and determine the pace and outcome of the rehabilitation process as a whole. Basically, these are functional changes in hemodynamics and myocardial activity, which were formed during the course of the disease [8]. Long-term, regular physical activity in patients with CHD with limited coronary reserve has an impact on the regulation mechanisms of heart, synchronization and optimization of the activity of the muscular, cardiovascular and respiratory systems [6]. Systematic trainings help to decrease the volume of drug therapy and may also be an alternative to drug treatment.

Conclusion. The use of the proposed individualized uniform interval training combined with the uptake of citrulline malate leads to a significant improvement in the achieved load capacity, heart rate, duration of work, total volume of work performed, IIR and exercise tolerance, which indicates the optimization of coronary circulation and improvement of bioenergy metabolism.

Prospects for further research. Results of the research have shown the need for further study of the possibility of applying a uniform-interval method of cycling training and the formation of a stable adaptation of the cardiovascular system to exercise in patients with cardiac diseases.

Conflict of interest. The authors declare that there is no conflict of interest.

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Особливості використання програми оптимізованого фізичного навантаження в реабілітації хворих з ішемічною хворобою серця

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Резюме. Мультисимптомність ішемічної хвороби серця (ІХС) залишається провідною проблемою в кардіології. Здатність людини виконувати фізичну роботу визначає якість її життя, особливо у пацієнтів із наявними симптомами ураження серцево-судиної системи. Найдосконалішим підходом у фізичній реабілітації хворих з ІХС є використання показників ергометричного тестування.

Мета – вивчити вплив розробленої методики велотренувань на показники велоергометрії у хворих на ІХС.

Матеріали та методи. Обстежено 65 чоловіків з ІХС, стабільною стенокардією I–II функціонального класу, віком від 32 до 60 років, у середньому 44,6 ± 1,39 роки. Діагноз встановлено на підставі даних клініки, електрокардіограми та лабораторного дослідження відповідно до загальноприйнятих критеріїв Європейського товариства кардіологів.

Результати. Оцінювання результатів лікування проводили через 2 тижні після завершення програми фізичної реабілітації. Якісне оцінювання здійснювали за допомогою ергометричного тесту з реєстрацією біоелектричних потенціалів серця у 12 відведеннях. Критеріями скасування тесту були загальноприйняті положення, засновані на рекомендаціях ВООЗ.

Під час розробки програми фізичної реабілітації та прогнозування термінів функціонального відновлення необхідно враховувати кілька факторів, які суттєво впливають на рухову активність пацієнта та визначають темп і результат реабілітаційного процесу загалом. Тривалі регулярні фізичні навантаження у пацієнтів з ІХС з обмеженим коронарним резервом впливають на механізми регуляції серцевої функції, синхронізації та оптимізації діяльності м'язової, серцево-судинної та дихальної систем. Систематичні тренування скорочують обсяг медикаментозної терапії та можуть покращити якість життя пацієнтів.

Висновки. Використання запропонованого індивідуалізованого рівномірно-інтервального тренування на велоергометрі, у поєднанні з прийманням малату цитруліну, призводить до достовірного досягнення підвищення толерантності до фізичного навантаження, нормалізації частоти серцевих скорочень, збільшення тривалості роботи, загального обсягу виконаної роботи, індексу інотропного резерву, оптимізації коронарного кровообігу та покращення біоенергетичного обміну в міокарді.

Ключові слова*: *фізична реабілітація, ендотеліальна дисфункція, ергометрія, малат цитруліну, толерантність до фізичного навантаження, фізична працездатність.

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