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REVIEW ARTICLE

ReHabilitation of the Ability to Work in Patients with Ischaemic Heart Disease (Review)

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Introduction

Patients with ishemic heart disease (IHD) need rehabilitation and increase of physical performance, including professional activity. Especially it is actual for IHD patients who have undergone myocardial infarction. In such patients the specified problem becomes even more difficult because IHD, being one of the most frequent causes of disability and mortality among able-bodied population, can be aggravated at irrational employment.

This problem is not only medical, but also social, due to its great social significance, to a certain extent, associated with the problem of restoration of working capacity in a large part of the population.

The questions of evaluation and optimal restoration of labour capacity of IHD patients are rather complicated and not completely solved for today. It is especially difficult to manage such IHD patients with severe functional classes (FC), which is associated with the loss of working capacity due to extremely low tolerance not only physical but also emotional loads, which is due to the limitation of coronary reserve.

Some aspects of peculiarities of haemodynamic and oxygen supply during dynamic, static and emotional loads are not fully studied. Such loads form the basis of any type of labour activity, and IHD patients need to determine the adequacy of labour loads to their functional state.

For the purpose of correct construction of everyday and labour regime of IHD patients of different FC it is necessary to carry out determination of daily variability of tolerance to physical loads with parallel development of measures reducing myocardial ischemia manifestations, increasing tolerance to loads (as this process is closely conneced with working capacity). When assessing the ability to work should be taken into account and the fact that, in contrast to the standardised load, studied in laboratory conditions on a bicycle ergometer or treadmill, professional work refers to non-standardised loads that are carried out with the lvement of small muscle groups.

The solution of the above questions can contribute to the development of an individualised approach to the creation of a mode of work activity of IHD patients depending on the FC of the latter, calculation of the optimal level and time of domestic and work employment, determination of the effective duration of physical training (PT) for IHD patients of different FC.

As a result of the our work it was shown that angina threshold at physical loads (especially dynamic) on different muscle groups is in direct dependence on the change of heart contractility irrespective of IHD patients FC. For comparative assessment of myocardial oxygen consumption during work of different muscle groups we proposed the index of myocardial oxygen consumption (IMOC), which takes into account not only the value of sistolic arterial pressure (SAP) and heart rate (HR) at the peak of load, but also the multiplicity of changes in the value of cardiac stroke volume.

The analysis of oxygen cost per unit of work has shown that at dynamic loads on arm muscles the values of this index are large in comparison with the work of leg muscles. This study shows that the value of oxygen tension in the skin at rest is in direct dependence on the functional abilities of IHD patients. When performing physical work the dynamics of this index is identical in all groups of patients.

When analysing the haemodynamic response to static load on different muscle groups, it is shown that with deterioration of IHD patients' functional capacity there is a drop in cardiac stroke volume at the height of the load and an increase in total peripheral resistance (TPR). The most pronounced shifts of these parameters were observed in the group of patients with III-IV FC, especially in patients with concomitant postinfarction cardiac aneurysm.

In the course of work it was found that at static loads in patients with IHD low (III-IV FC) in the recovery period there is an increase in the consumption of oxygen, compared to the peak of the load test.

The results of the work allowed to note with certainty that IHD patients with behavioural type A personality (especially III-IV FC) are in energetically unfavourable conditions when performing physical and psychoemotional loads.

Daily fluctuations of skin oxygen regime indices in IHD patients of different FC and tolerance to physical loads adequately reflecting the state of coronary reserve were studied. It was found out that the character of daily curve of skin oxygenation changes and tolerance to dynamic load is different in IHD patients of high (I-II) and low (III-IV) FC. In patients with IHD I and II FC maximum values of work capacity indices are shifted to the morning period, the minimum values are observed by 22 hours (evening period). Such dynamics is also noted in the value of oxygen tension in the skin.

In patients with low FC along with the increase of oxygen tension in the skin by evening and stable low indices of the threshold load value in all three studies there was found a decrease by evening of the volume of work performed and the value of the double product reflecting myocardial oxygen consumption.

In work special methods of "local" and "combined" physical training were developed and tested, allowing to increase the efficiency of small muscle groups, to improve the tolerance of static loads, that in patients with III-IV FC is of paramount importance, as they contribute to the economisation of heart work within the requirements imposed by everyday household and labour activity.

Rehabilitation of IHD patients, first of all, is aimed at providing the maximum opportunity to return to active labour activity, which is associated with the improvement of tolerance of physical loads. For this purpose in the work we determined the duration of PT, necessary for maximum increase of general endurance of IHD patients of different FC, including those with postinfarction cardiac aneurysm.

It is well known that rational labour placement of IHD patients promotes mobilization of compensatory-adaptive mechanisms, has a beneficial psychological effect. The testing devices and methodology of labour capacity assessment proposed in the work allow to determine the adequacy of the type of labour activity, permissible amount of physical work load, tolerance of neuro-psychic tension for IHD patients. First of all, it concerns IHD patients of severe (III-IV) FC, including those with postinfarction heart aneurysm.

In case of patient's wish to keep the labour activity close to his profession, the methods of physical training (PT), increasing both the general endurance and positively acting on the "local" tolerance of small muscle groups, are offered. The duration of PT necessary to achieve the maximum level of training effect has been determined [1], [2].

Discussion

Hemodynamic Changes During Physical Exercise

In recent years, great interest is aroused by the study of the reaction of the cardiorespiratory system to physical load in patients with IHD. The conducted studies have shown that the study of the functional state of these systems allows to get a more complete picture of the participation of cardiac and extracardiac factors in the mechanisms of adaptation of the organism of patients suffering from heart disease, and the assessment of changes in gas exchange in response to physical load allows to establish signs of disorder of coordination between the circulatory and respiratory systems.

Physiological response to the load depends on the type of load: isometric (static) or isotonic (dynamic) [3-6].

Response to Dynamic Loading

Circulatory regulation during exercise includes the following 4 adaptation factors [7]:

Local

Resistive vessels of the working muscle dilate under the influence of muscle metabolism products. At a sudden increase in the content of metabolites, arteries and arterioles in the active muscle immediately dilate. This causes blocking the action of sympathetic nerves on muscle vessels, preventing their contraction. These factors, in turn, lead to a decrease in systemic vascular resistance in proportion to the muscle mass involved in the work.

Adaptation of the nervous system

The flow of impulses of the sympathetic nervous system to the heart and systemic vessels increases to maintain blood pressure, at the same time the flow of vagus stimulation of the heart decreases. This causes tachycardia, increased cardiac contractility and constriction of resistive vessels of the kidneys and abdominal organs. In addition, the resistive vessels in non-working muscles also narrow. Arterial and cardiopulmonary baroreceptors prevent significant fluctuations of systemic arterial pressure from normal values. As the load continues, body temperature increases, in this connection hypothalamic cells sensitive to temperature are activated. They inhibit sympathetic impulse to skin vessels and stimulate cholinergic fibers of sweat glands. This is manifested by dilation of skin vessels and increased sweating.

Humoral adaptation

At sufficiently intense exercise, the cholinergic fibers of the adrenal glands are activated, resulting in the release of epinephrine. This further increases HR, myocardial contractility, venous and renal arterial vasoconstriction.

Mechanical adaptation

During exercise, active leg muscles return blood from the lower limbs to the central channel, using venous valves (which allow blood to flow in only one direction) and the pumping effect of contracting muscles. As cardiac output increases, there is an increase in systemic arterial pressure. Increase in blood flow to the lungs causes a slight increase in the average pressure of the pulmonary artery.

The relationship between pressure, flow and resistance in rigid tubes is defined in Poiseuille's law. The law assumes that the resistance is proportional to the pressure divided by the flow. Peripheral resistance increases in tissues that do not take part in the load and decreases in active (active) tissues. The result is a decrease in systemic vascular resistance. During loading, with a slight increase in pressure, flow can increase several times compared to the outcome. Since flow increases to a much greater extent than pressure, the result is a decrease in systemic resistance.

Another type of mechanical adaptation is observed when increased venous return dilates LV and cardiac function increases through the Frank-Starling mechanism.

There is a highly significant relationship between total oxygen consumption and between haemodynamic and respiratory response to load. Both parameters increase linearly with increasing oxygen consumption until maximum oxygen consumption is reached. In order to ensure this relationship, the main hypotheses put forward were summarized. The arterial baroreflex hypothesis is based on the idea that vasodilatation of arteries in working muscles causes a fall in blood pressure, which reflexively stimulates tachycardia through arterial baroreceptors. However, the fall in blood pressure cannot be the beginning of the load response. A vulnerability of this hypothesis is that the feedback mechanism of the central nervous system in controlling the regulation between oxygen consumption and working muscle is unknown. The role of the central command in the load response is not easily quantified. Mechanoreceptors of skeletal muscles are probably not included in the load reflexes, because in response to muscle vibration, serving as a potential stimulator of mechanoreceptors, there is no response from the cardiovascular or respiratory systems. In addition, blockade of efferent impulsation of large mechanoreceptors does not block the load response.

Chemoreflexes in the arterial or central venous system can regulate changes in respiration. Muscle chemoreceptors may play an important role in the response to exertion. This idea was originally proposed 100 years ago, when the authors of the idea tried to experimentally prove the correctness of the hypothesis that sensitivity in the working muscle causes a rise in blood pressure observing the blood supply of working skeletal muscle, they demonstrated a marked increase in mean arterial pressure. This reaction persisted after the cessation of the load. The authors suggested that the metabolites remaining in the muscle are stimulators of the pressor response. Neurophysiological studies have demonstrated that unmyelinated afferent fibers increase the speed of impulse conduction when exposed to a preparation isolated from contracting muscle [8-12].

Cardiac Function During Exercise

The indicator of cardiac function in any study is HR. Increase of this index is the main factor of increase of cardiac output under load. Increased tension, which accompanies the increased HR, is a consequence of increased contractility. Although the mechanism of this phenomenon is unknown, presumably it may be related to the access of calcium to contractile elements. What factors alter HR during exercise? Initial factors include central autonomic impulse release, which leads to tachycardia and dilatation of skeletal muscle arterioles. Dilatation of regional skeletal muscle arterioles, subsequently regulated by local factors within the working muscle, leads to further increases in HR and cardiac output.

It has been shown that denervated dog hearts were able to maintain the normal relationship between cardiac output and oxygen consumption during significant exercise. The dogs were trained by running on a treadmill at different levels. Cardiac output was estimated by dilution of the indicator, and oxygen consumption was determined directly. Left and right cardiac catheters were inserted into the animals. Two groups of animals were studied: normal dogs and animals with selective cardiac denervation. Peripheral vascular resistance was sharply increased due to reflex vasoconstriction caused by bilateral occlusion of carotid arteries. In both groups there were no changes in the relationship between oxygen consumption and cardiac output.

At the same time, the nature of changes in HR and stroke volume (SV) differed significantly. In denervated dogs there was an increase in HR starting from the 1st minute of exercise. In this group of dogs at the beginning of exercise, the SV increased 2 times compared to the resting level, while the HR increased more slowly.

In normal animals, no increase in SV was observed throughout the entire loading period. The effects of the vasoconstriction reflex (after loading) were similar in both groups of animals, cardiac output was maintained due to a significant increase in systemic arterial pressure. It seems that the main mechanism of maintaining normal cardiac output in dogs with denervated heart is the Frank-Starling mechanism. Increased SV preserved the normal ratio between cardiac output and oxygen consumption.

The degree to which changes in SV contribute to cardiac output depends to a certain extent on the end-diastolic volume at baseline, if end diastolic volume (EDV) is close to maximal, then in this case SV can only increase due to more complete emptying and the Frank-Starling mechanism only slightly contributes to the increase in cardiac output. In this situation, cardiac function depends on the chronotropic mechanism to increase cardiac output. The relationship of SV and HR to cardiac output was studied by measuring cardiac output in patients with rhythm imposed from the right atrium. When the heart rate was increased by stimulation up to 150% (of the outcome), no increase in cardiac output was found. An inversely proportional relationship between HR and SV was established. When bicycle ergometry (BE) was performed in patients, both an increase in HR and SV was noted. When the HR during BE was high enough (120 beats/min), there was an increase in cardiac output due to a gradual increase in SV. Thus, cardiac output is regulated by different mechanisms than HR. Homeostatic mechanisms modify cardiac output according to metabolic needs; determination of HR alone may give an incorrect estimate of cardiac output in patients [13-15].

The Importance of Venous Return

Venous blood volume is an important determinant of cardiac output. During exercise, sympathetic stimulation and increased pliability of venous blood makes the chronotropic effect more favorable. At an ejection of a certain force, dynamic loading of the arms causes a greater aerobic demand than loading of the legs. HR, mean arterial pressure at a certain value of ejection is significantly higher at dynamic loads on the arms in comparison with loads on the leg muscles. It is suggested that variations in venous return may explain the different HR response. Thus, the pumping action of leg muscles may facilitate venous return. However, the increase in cardiac output due to the Frank-Starling mechanism occurs to a greater extent with leg exercise than arm exercise.

Differences in reaction to dynamic load of different muscle groups were also studied. Healthy untrained individuals were tested with different types of dynamic loads (twisting with one arm, bending with one arm, pedaling with one and two legs). The load levels were 25, 50, 75 and 100% of the predetermined VO_2 for each muscle group under study, cardiac output was determined by the acetylene inhalation method (correlation with the dye dilution method is quite high ($r = 0.94$). It was found that when both legs were exercised at a load of 50% of VO_2 max for the legs, cardiac output and HR were higher than at the same comparative level of load performed with the arms. The blood pressure (BP) response was reversibly proportional to muscle mass. Greater muscle mass causes greater local vasodilatation and thus a relatively greater decrease in TPR, the SV increased more with leg exercise than with arm exercise. It could be connected with the fact that the pumping action of muscles facilitates venous inflow. It seems that cardiac output is closely related to the total work performed and depends on the muscle masses involved in the work. HR at the maximum load was lower during BE than during treadmill test and even lower than during swimming. This once again confirms the relationship of HR increase with the volume of working muscle mass [16-18].

Hemodynamic Response to Static Load

As noted above, during dynamic exercise, the increase in oxygen demand of the organism is provided by the increase in minute volume due to the increase in heart rate and stroke volume. At the same time, there is an increase in systolic BP, while diastolic BP decreases or remains unchanged.

In contrast to dynamic, static exercise increases both systolic and diastolic blood pressure without a significant increase in HR and minute volume. BP increase during isometric exercise is a characteristic reaction of the organism to the cessation of blood flow in the contracted muscles. Accumulation of metabolites and their reflex effect on baroreceptors is considered to be the trigger mechanism providing BP increase. It was assumed that such metabolites may be potassium ions, as infusion of small doses of potassium into the isolated hind limb causes the same pressor response as static load. Indeed, an increase in potassium concentration was observed in parallel with an increase in arterial pressure in venous blood flowing from the isometrically contracted limb.

Estimation of the stress effect of isometric loads depends on the intensity of effort, and, according to some researchers, does not depend on the mass of muscles involved in contraction. At the same time, it was noted that the increase in BP depends on and increases with the participation of large muscle groups in contraction. Interesting is the fact that there is no summation of haemodynamic effects during contraction of different muscle groups. So, for example, if the load of 40 kg is held by one hand, the changes in BP and HR will be more pronounced than if the load of 20 kg is held by both hands. Another important factor determining the severity of haemodynamic shifts is the timing of the static force. At isometric tension of 10-15% of maximum compression force (MCF), the load can be held by the patient for quite a long time, as blood flow remains preserved. However, the greater the static force, the shorter its duration, because as blood flow decreases, significant metabolic disturbances develop, accompanied by a decrease in the level of energy-forming metabolic products.

However, echocardiography data showed a statistically significant decrease in the rate of circular shortening of myocardial fibers. Thus, with dynamic load, an increase in venous return is noted – an increase in “preload”, and with static effort, due to an increase in ejection resistance, “afterload” increases. An increase in minute volume is noted with dynamic and static loads, but the work performed and metabolic demand during a test with a dynamic load are significantly greater, in connection with which the minute volume with this type of physical activity increases to a greater extent mainly due to the heart rate, ensuring an increase in the oxygen transport need of the body [19], [20].

Changes in Oxygen Consumption and It's Tension in Tissues in Patients with Coronary Heart Disease Under the Influence of Physical Activity

Vital activity is associated with certain energy costs. The main energy accumulator in a living organism is macroergic compounds, in particular adenosine triphosphate (ATP). The leading way to replenish expended energy reserves is aerobic, for the maintenance of which there is an oxygen transport system. The oxygen transport system in the full sense of the word is a functional system that is formed dynamically depending on a specific situation and leads to a positive result of adequate oxygen supply to tissues. The ways of compensating for oxygen delivery disorders are varied and include changes in respiratory volume, vital capacity of blood. An objective assessment of the qualitative disorders of the oxygen transport system and the functional reserves of the body is possible only on the basis of studying the performance of the system of its function to mobilize certain mechanisms aimed at achieving the result [21], [22].

Effect of Physical Activity on Oxygen Consumption in Patients with Coronary Heart Disease

Physical activity leads to rapid mobilization of the body's reserves. This applies both to the state of the muscular system, in which metabolism at the cellular level is sharply intensified, and to the activity of the circulatory, respiratory, nervous, endocrine, excretory and other systems. Mobilization of the body's reserves is realized through increased resynthesis of ATP – the main source of energy for muscle contraction, which requires an increasing increase in oxygen supply. The ability to perform muscle work depends mainly on the body's ability to ensure the transport of a sufficient amount of oxygen to the mitochondria. The higher the maximum oxygen consumption (maximum aerobic capacity), the greater the amount of energy that can be produced and, consequently, the higher the physical performance. An important role in physical activity belongs to regulatory processes that ensure the coordination of the activities of various systems involved in providing physical work, mobilization of vegetative functions, and redistribution of blood. During physical activity, the blood flow of the working muscles increases, since the accumulation of metabolic products in them leads to local vasodilation. At the same time, skeletal muscles during exercise extract oxygen from the flowing blood several times more than at rest and, accordingly, the arteriovenous difference increases. There is an increase in the productivity of the external respiratory system: the minute volume of respiration, maximum pulmonary ventilation, vital capacity of the lungs, and oxygen absorption increase. The cardiovascular system plays a primary role in providing the load. The increasing need for oxygen is satisfied due to the greater minute volume of the heart, as well as due to the constant increase in the arteriovenous difference in oxygen. The same author's studies showed that the increase in cardiac output relative to the increase in oxygen consumption is practically linear. Cardiac output for a given oxygen consumption is the same for trained and untrained subjects during different types of exercise: running, cycling, swimming. Thus, the oxygen consumption can be used to indirectly judge the magnitude of cardiac output. At maximum physical exertion, there is a linear relationship between oxygen consumption and maximum cardiac output. A relationship between maximum oxygen consumption and stroke volume was also found. Thus, the increase in maximum oxygen consumption occurred almost equally due to both an increase in LV stroke volume and the arteriovenous oxygen difference.

In parallel with the increase in work power, the volume of oxygen consumption increases, and the minute volume of blood circulation increases. The increase in minute volume occurs until the capacity of blood circulation is exhausted. The limit of increase in minute volume is expressed in the cessation of the increase in oxygen absorption. The level of the load achieved in this case is called maximum aerobic work and is a criterion for maximum aerobic capacity or productivity. And although after reaching the maximum level of oxygen absorption, the load continues to increase, it will be performed under conditions of oxygen debt. In practice, the achievement of maximum aerobic work is judged by the pulse rate, which under physical exertion is a linear function of oxygen absorption and is within 160-190 beats per minute. When studying physical performance or the activity of the circulatory system during physical exertion, the most important thing is to take into account the indicators characterizing the external work of the heart (minute volume, HR, total oxygen absorption). At the same time, the assessment of blood circulation would be incomplete without taking into account the "internal work" of the heart. The work expended by the cardiac muscle to develop tension, the internal work of the heart is strictly and linearly determined by the oxygen consumption of the myocardium, since it is completely aerobic. Under hypoxic conditions, the myocardium cannot contract.

During physical activity, the myocardium is supplied with oxygen only by increasing coronary blood flow. It should be noted that while skeletal muscles are capable of increasing oxygen extraction up to 5 times during exercise, the myocardium is deprived of this ability, since it almost completely extracts it from the blood already at rest. The fact that in patients the level of physical performance is even more limited by the capabilities of the heart due to reduced coronary circulation makes it especially important to take into account its internal work. It has been shown that the metabolism in the heart muscle is affected by the pulse rate, BP, and the positive sympathetic isotropic effect on the myocardium. The internal work of the heart and the absorption of oxygen by the myocardium during physical activity increase to a greater extent in cases where the increase in minute volume occurs mainly due to an increase in pulse rate and BP – the higher the share of stroke volume in the increase in minute volume, the more economical and effective the internal and general work of the heart. High heart rate and inappropriately high blood pressure are potentially disadvantageous for coronary circulation. At the same time, the expulsion of minute blood volume is metabolically more expensive, the higher these indicators. Excessive increase in the internal work of the heart can lead to a discrepancy between coronary blood flow and tissue metabolism with the development of myocardial ischemia, and, as a result, the occurrence of angina pectoris, myocardial infarction, sudden death.

As noted above, physical activity increases the myocardial oxygen demand, which inevitably causes an increase in its delivery. In healthy individuals and patients with a small degree of coronary vascular damage, an increase in oxygen delivery is ensured by an increase in coronary blood flow due to the regulation of the tone of the coronary vessels and due to a more complete extraction of oxygen from the blood. In patients with pronounced narrowing of the lumen of the coronary vessels, another way remains – to reduce the myocardial oxygen demand. Another factor in the adaptation of hemodynamics to physical activity, increasing oxygen transport, is the optimal redistribution of the circulatory minute volume. It has been established that the energy cost of the same external work in healthy and sick people is different; moreover, it can differ significantly in patients with coronary heart disease with different severity of the disease. The efficiency of work in patients with coronary heart disease is significantly lower than in healthy people. This is manifested by an increase in the energy cost of work, i.e. an increase in oxygen consumption per unit of work. It has been shown that after the load is stopped, an «oxygen debt» is formed in the body, associated with the accumulation of lactic acid in it. It is formed at the beginning of any work, since the adaptation of the respiratory and circulatory systems to work requires a certain amount of time.

The main condition for the effectiveness of rehabilitation of patients who have suffered a myocardial infarction is "knowledge of aerobic needs, compliance with individual capabilities and strict control." The energy cost of individual exercise therapy exercises performed by patients with coronary artery disease were given. It turned out that performing exercises with a moderate load was accompanied by higher energy expenditure in them than in healthy people. Energy expenditure was also studied during various exercise therapy exercises, walking at different speeds, and bicycle ergometric loads in healthy people and patients with coronary artery disease of FC I-III. It was found that the total energy expenditure with the same loads was highest in patients with FC III and lowest in healthy people. When studying various types of loading on oxygen consumption, it was found that swimming was the most stressful for patients with coronary artery disease. The authors associate these phenomena with the predominant load on the arms during swimming. The results obtained in patients differ from those in healthy people, in whom oxygen consumption during swimming is 15% lower than during running [22-28].

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