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Original Article

Use of lactate as the main metabolic marker to control the functional state of the body during the preparation of weightlifters

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Abstract:
This article presents data that show both individual and general changes in the level of lactate concentration in the blood of weightlifting athletes depending on the nature and intensity of physical activity, which confirms the possibility of using the abovementioned metabolic indicator during sports training to monitor recovery processes in the body and the effectiveness of planned activities during training cycles. The purpose of this study is to consider the state of glycolytic processes in weightlifters by determining the concentration of blood lactate in the blood using modern, more advanced, and accurate diagnostic methods; based on the obtained results, the objective is to re-evaluate the possibilities of using the indicated biochemical marker in various zones of physical activity intensity. The study involved 25 athletes (14–20 years old) with qualifications ranging from the 2nd adult category to candidates for master of sports. A modern SuperGLeasy lactometer was used. More than 300 samples were analyzed. The results of the study showed that in the samples of athletes of the 1st group [in which the average level of lactate before training was close to the physiological norm (1.22 ± 0.44 mmol/L)], when carrying out planned training loads in the intensity zone from 70% to 80%, the concentration of lactate in the blood showed a decreasing tendency (to 1.17 ± 0.38 mmol/L), which was not a statistically significant difference ($p \geq 0.05$). An increase in the blood lactate level reached a statistically significant value (2.12 ± 0.62 mmol/L, $p < 0.05$) only when planned training loads were performed in the limiting intensity zone (90–100%). Even higher lactate concentrations in the blood were determined in the samples of athletes in the 2nd and especially 3rd groups; in these groups, this indicator was at least 2 times higher than the physiological norm even before the start of training loads.
Key Words: Biochemical control; Training load; Highly qualified weightlifters; Muscle performance; Metabolic changes

Introduction

It is known that the natural–scientific basis of physical education and sports is the general biological knowledge about the laws and adaptation of the body to intense muscle work. Specifically, the review of numerous publications indicates that the markers of critical states in the body are primarily the levels of urea, creatine, creatine phosphokinase (CKD), and aldolase. When characterizing the value of CKD, many researchers believe that the level of this enzyme has a considerable informative value because it reflects the mechanism of rapid energy supply at the beginning of physical work; adenosine triphosphate (ATP) resynthesis is carried out without oxygen (under anaerobic conditions) owing to the transformation of an energy-intensive phosphorus-containing compound creatine phosphate (CF) [2,5]. Of note, the content of CF in the muscles exceeds the level of ATP by 3 times, and this way of energy production can provide muscle contraction in the zone of sufficiently high power. According to some authors, the next most important marker, which reflects the state of metabolic processes in the body of athletes, is the level of lactic acid (lactate) in the blood. It is known that during the biochemical transformation of KF, lactic acid is not formed; this period of ATP resynthesis is called "alactate". However, it is recognized that this way of energy supply is short-term and occurs within only the first 2–5 s.

The anaerobic "lactate" pathway of ATP resynthesis, in which glucose molecules are converted into lactic acid through the formation of an intermediate metabolite pyruvate, appears to be more productive. It can occur under anaerobic conditions by the breakdown of carbohydrates, including glycogen, which is the "spare" form of glucose. Owing to this mechanism, the muscles can produce mechanical work for the next 30–60 s. In some muscles (white, rapidly contracting), this way of energy formation is dominant. These muscles are well developed in athletes from speed–power sports. In these muscles, there are fewer mitochondria; thus, glucose is oxidized to form lactate mainly by an anaerobic mechanism. It is also known that these muscles are not adapted

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to the oxidation of glucose under aerobic conditions, and they "charge" it to stimulate tissues with high aerobic abilities (e.g., heart muscle, brain, kidneys, and liver), where the oxidation processes are performed aerobically. However, owing to the lack of oxygen, these tissues cannot oxidize lactate during intense physical activity when additional oxygen is required, which is associated, for example, with the preservation of high respiratory rate and heartbeat after performing weightlifting exercises. Therefore, the body is forced to postpone the oxidation of lactate during the recovery period, and its concentration in the blood in this regard begins to significantly increase.

Thus, lactate is not only a marker of glycolytic processes in the body but also is an indicator of oxygen debt, which indicates how much additional oxygen is required for its delayed oxidation under the abovementioned anaerobic conditions; therefore, a decrease in its concentration indicates the course of recovery processes because it is known that lactate at high concentrations is toxic to the body, reduces the pH of the blood, and leads to the state called lactatacidosis, i.e., "acidification". In addition, there is a clear relationship between high levels of lactate in the blood and the development of fatigue [1,2,5,15, 21,23].

Currently, with the advent of new techniques and more advanced scientific equipment, there is an interest to study this problem further. Of particular interest are the features of metabolic processes in the body engaged in weightlifting and, accordingly, changes in the level of lactate in the blood when performing training loads in different zones of intensity, which characterize the contribution of glycolysis of carbohydrates, which is an additional mechanism of energy supply of mechanical work in the abovementioned sport. This information is very useful for the further use in coaching practice and is the basis for this comparative study, which was organized and conducted at the "School of Olympic reserve number 2" (SOR2) Moskomsport.

The aim of the study is to consider the state of glycolytic processes in weightlifting by determining the concentration of lactate level in the blood using modern, more advanced, and accurate diagnostic techniques; using the obtained results, we assess the possibility of using this biochemical marker in coaching practice primarily as an indicator of the state of adaptation and recovery processes in the body of athletes and as a means of additional control of the effectiveness of currently used training in different zones of intensity of physical activity.

To achieve this goal, the following tasks are set:

1) to determine the level of lactate in the blood of weightlifters before and after the planned training load and distribute the samples of the results into three groups depending on the concentration and intensity zones;

2) to compare and systematize the obtained results to identify the dynamics of changes in the level of lactate in the blood in the comparison groups when performing physical activities in different intensity zones "before" and "after" training;

3) to substantiate the possibility of using this biochemical indicator as a sufficiently informative indicator of the state of metabolic, adaptation, and recovery processes in the body of weightlifters and to characterize the functional state and the reaction of the body to the performed physical activity.

The hypothesis of the study is as follows. It is assumed that the measurement of the level of blood lactate in athletes allows to identify glycolytic reactions that occur in response to intense exercise as a source of additional energy and at the same time indicates the toxic "acidification" of the body, which can be used in the practice of athletic training as a means of biochemical control and reflects the possibility of further sports development.

Materials and methods

The organization and method of research are as follows. In this study, 25 athletes (14–20 years old) and children from the 2nd adult category to the candidate for master of sports (CMS) participated in a one-year training cycle. The method was based on using a modern lactometer SuperGLeasy. The sampling of a drop of blood from a finger was made under sterile conditions. After centrifugation, the sample was analyzed with an electronic sensor of the device, which was calibrated to the lactate concentration of 10 mmol/L (the manufacturer's declared error does not exceed 15%). For a more accurate result, 2 samples were obtained each time. Blood samples were collected at different times, i.e., in the morning before training (after sleep, "cold") and after training. The obtained results were systematized, and digital values were processed using the method of student's variational statistics. The results were considered statistically reliable if the risk of error (p) did not exceed or was equal to 0.05. In total, more than 300 samples were processed, and the analysis of athletes' diaries was performed.

Results

According to the lactate concentration level in the blood sample of the subjects, the athletes were divided into 3 groups by accounting for the variations in individual indicators (Table 1). Table 1 shows that the first group (39.1% of subjects) included samples in which the average concentration of lactate in the blood in the morning before training was up to 1.5 mmol/L, i.e., close to the physiological norm (1.5 mmol/L) [1,5,6,8,18]. The second group included samples (34.6%) in which the level was from 1.5 to 2.5 mmol/L. The third group consisted of samples (26.3%) in which under the same conditions the concentration of lactate was recorded to be more than 2.5 mmol/L. This figure is determined to be high and indicates an overstrain in the body of the glycolytic lactate system of energy supply, which occurs against the background of prescribed physical activity without controlling the level of lactate. The second possible reason for such high levels of lactate in the blood is presumably the inhibition of the function of lactate utilization in the blood in the form of overcoming the threshold of the body's natural defense against excessive acidification, which is determined by the activity of the enzyme lactate dehydrogenase and the release of buffer systems into the blood [7]. According to the researchers who previously studied this problem [1,3], the high concentration of lactate may also be associated with residual hypoxia of muscle fibers, in which increased lactate production continues in the mode of frequent contractions that are characteristic of weightlifting movements [6]. Such condition, which is referred to as "acidification or acidosis", can lead to undesirable consequences, i.e., lengthening or even disruption of muscle recovery capabilities, lack of growth of sports results, violations of movement techniques associated with pain, and increased risk of sports injuries [5].

Table 1. *Distribution of samples according to the average value of lactate level in the blood in mmol/L before performing training loads at the beginning of a training cycle*

Lactate levels in groups	Number of samples (n)	Percentage ratio
>1.5	54	39.1%
1.5–2.5	46	34.6%
<2.5	35	26.3%

Table 2 shows the samples of athletes of the 1st group, whose average lactate level before training was close to the physiological norm (1.22 ± 0.44 mmol/L); when performing planned training loads in the intensity zone from 70% to 80 % (unsaturated intensity zone), there was a tendency to reduce the concentration of lactate in the blood (to 1.17 ± 0.38 mmol/L), i.e., a statistically significant difference ($p \geq 0.05$). In the same group, when performing planned loads in the 80–90% intensity zone (near-limit intensity zone), no statistically significant increase in this indicator was detected (up to 1.37 ± 0.47 mmol/L, $p \geq 0.05$). Only when performing planned training loads in the maximum intensity zone (90–100%), an increase in the level of lactate in the blood reached a statistically significant value (2.12 ± 0.62 mmol/L, $p < 0.05$).

In addition, in the samples of athletes of the 1st group with such level of lactate in the blood, who did not belong to the high category according to leading experts [1,5], in almost all cases, there was an increased sports performance, which manifested either in setting a personal record or performing superplanned amounts of training loads without excessive effort and without deterioration of health.

Table 2. *Indicators of lactate concentration in the blood samples of athletes from group 1 (n=54) in mmol/L depending on the zone of intensity of training loads during training*

Original value	Intensity zone 70%-80% (n-19)		Intensity zone 80%–90% (n-16)		Intensity zone 90%–100% (n-19)	
	Before training	After a workout	Before training	After a workout	Before training	After a workout
>1.5	1.22 ± 0.44	1.17 ± 0.38	1.16 ± 0.36	1.37 ± 0.47	1.04 ± 4.6	2.12 ± 0.62
Significance of differences compared to the baseline	P ≥ 0.05		P ≥ 0.05		P < 0.05	

Such combination of the moderate level of lactate concentration in the blood with high physical performance indicates the adequacy of the course of recovery processes in the body.

From the theoretical point of view, according to sports biochemists [2,5,7,9, 20], this state is explained by the peculiarity of the mechanism of energy supply owing to the functioning of the anaerobic alactate system without the participation of oxygen and without the formation of lactate, while creatine phosphate quickly gives its phosphate group to adenosine diphosphate (ADP); thus, the production of the necessary number of molecules of adenosine triphosphate (ATP) is performed in the body with sufficient speed; ultimately the chemical energy of ATP decay, which initiates the interaction of contractile proteins actin and myosin in myofibrils, changes into the mechanical energy of muscle contraction in sufficient volume, which corresponds to the term "explosive force". However, Table 2 shows that for the same athletes, when performing routine training loads in the limit zone of intensity (90–100%), there is an increase in the concentration of lactate in the blood compared to the initial value by 103.8%.

This increase occurs because such loads generate energy using only the phosphocreatine path, which becomes insufficient, and the body creates an additional way of resynthesizing ATP by anaerobic lactic glycolysis; these biochemical reactions consume glycogen, and the concentration of lactic acid in the blood starts to increase. The oxidation of this toxic metabolite requires the participation of oxygen; under conditions of oxygen deficiency, the formation of oxygen debt occurs [2]. This increase in intense physical activity can contribute to the lack of activity of the enzyme lactate dehydrogenase and buffer systems in the body [7].

Even higher lactate concentrations in the blood were measured in the samples of athletes from the 2nd and especially 3rd groups, in which this indicator was 2 times or more higher than the physiological norm before the beginning of training loads (see Tables 3 and 4). Though planned training loads were performed, it is unclear at what cost and with what efficiency. Researchers, who studied the effect of lactate on the body, determined that even relatively low concentrations (3.0–5.3 mmol/L) worsen the coordination capabilities of athletes [3,10]. A further increase in the concentration of lactate in the form of acidosis (i.e., an even greater pH shift to the acidic side) can lead to the violation of homeostasis, damage to cell and mitochondrial membranes, output of intracellular substances into the bloodstream, inhibition of many enzyme systems, and inhibition of the activity of enzymes that regulate the ability of muscles to contract by reducing the speed of the abovementioned anaerobic resynthesis of ATP–ATPase of myofibrils, creatine phosphokinase (ckf), and glycolysis enzymes [8,9]. It is determined that after strenuous training, an increased content of urea and other metabolites is detected in the blood of the athletes; for blood counts to return to normal, the athlete may need 24–96 h of recovery [5,7,10]. Therefore, intensive training loads against the background of high lactate levels are not only ineffective but can often lead to overtraining, which will certainly have a negative effect on sports performance [4, 6].

Accordingly, in our studies, the 2nd group of athletes had the initial lactate concentration in the blood of 2.17 ± 0.34 mmol/L, as shown in Table 3; this was an excess of the physiological norm by 44.6%; when performing relatively small training loads in the intensity zone of 70–80% of the limit, only a tendency to increase the abovementioned indicator (to 2.26 ± 0.44 mmol/L) was observed, i.e., without the confirmation of statistical reliability ($p \geq 0.05$).

Table 3. *Indicators of lactate concentration in the blood samples of athletes from group 2 (n=46) in mmol/L depending on the zone of intensity of training loads during training*

Original value	Intensity zone 70–80% (n-21)		Intensity zone 80–90% (n-14)		Intensity zone 90–100% (n-11)	
	Before training	After a workout	Before training	After a workout	Before training	After a workout
1.5–2.5	2.17 ± 0.34	2.26 ± 0.44	1.97 ± 0.37	3.42 ± 0.32	2.42 ± 0.27	4.98 ± 0.3
Significance of differences compared to the baseline	$P \geq 0.05$		$P < 0.05$		$P < 0.05$	

The following planned training of athletes from the 2nd group, at near-limit (80–90%) and limiting (90–100%) intensity showed a considerable, statistically confirmed growth of lactate concentration in the blood by 2 times and higher ($p \geq 0.05$). During the experiment using the abovementioned cycle, examples of the influence of training loads on the level of lactate affecting the well-being of the participants were revealed. Thus, four athletes [who had high levels of lactate (more than 2 mmol/L), and this level remained for several weeks and almost did not decrease to the conditional norm (1.5 mmol/L)] complained of back pain, knee joint paint, and inability to perform a given training plan. By taking into account the deterioration of the health of athletes and high levels of lactate, the coach canceled the planned load, considerably reduced it, and, thus, provided the athletes with a recovery microcycle to normalize their physical condition. Further observation showed that one athlete's back pain disappeared after a week of reduced load, which was accompanied by a decrease in the level of lactate in the blood to 1.0 mmol/L. Two other participants of the experiment did not have time to recover during this period with such noticeable decrease; however, as indicated in the personal diaries of athletes, their health improved, which allowed the coach to adjust the plan and reduce the load to continue training in the zone of maximum intensity.

Table 4. *Indicators of lactate concentration in the blood samples of athletes from group 3 (n=35) in mmol/L depending on the zone of intensity of training loads before and after training*

Original value	Intensity zone 70–80% (n-16)		Intensity zone 80–90% (n-12)		Intensity zone 90–100% (n-7)	
	Before training	After a workout	Before training	After a workout	Before training	After a workout
<2.5	4.67 ± 1.54	4.29 ± 1.01	3.97 ± 0.37	5.66 ± 1.13	3.62 ± 0.97	7.87 ± 2.57
Significance of differences from the baseline	$P \geq 0.05$		$P < 0.05$		$P < 0.05$	

As noted earlier, in four athletes assigned to the 3rd group, an increased lactate concentration in the blood was observed during the experiment both at the beginning and at the end of the observation. At the same time, a straightforward dependence of the increase in concentration depending on the intensity of training loads was observed.

Table 4 shows that in the limit zone of intensity (90–100%), the level of lactate remained high, and an excess of the initial value of more than 2.5 times was recorded. These results indicate the irrational use of physical activity and the risk of reducing the adaptive and reserve capabilities of the body in this group of athletes.

However, among trainers, the position, which originates from traditional experience of planning the preparation of qualified athletes for more rational transition to the pre-competitive period, is known; specifically, it is believed that it is necessary to perform preparatory and transition period loading in unsaturated and near-limit zones of intensity in large volumes. In turn, such training methods are aimed at the development of specific power abilities (power endurance and speed-power endurance) in which aerobic and anaerobic mechanisms of energy supply are combined. According to the researchers [11,12,16,17], this approach provides the psychophysical conditions that are necessary for the growth of sports performance of athletes. Moreover, without organizing such training depending on athletes' bodies, the basis for a higher degree of physical fitness is not formed, especially during the pre-competition period.

To solve this controversial problem, it is necessary to perform additional, more in-depth research by dividing athletes into subgroups by taking into account the periods of preparation in the structure of mesocycle. Thus, it is possible to determine the permissible values of lactate concentrations during various periods and regimes of training with the aim of identifying new approaches for further sporting improvement.

Discussion and Conclusion

Currently, in weightlifting, there is a need for new scientifically based effective technologies for the construction and implementation of the training process of qualified athletes at all stages of training. It is clear that such training should be closely coordinated with the functional capabilities of each athlete. The theoretical analysis of data of special scientific methodological literature over the past decade indicates the sustained attention of researchers to the metabolism and the peculiarities of providing energy in the weightlifter's body. The advent of new computerized diagnostic equipment (SuperGLeasy latest generation lactometer) revived interest in a more in-depth study on changes in lactate concentration in the blood, which is recognized as a more accurate method compared to its determination in saliva or urine.

As a metabolite that reflects the contribution of anaerobic glycolysis with its mechanisms of ATP resynthesis in the overall energy supply system, lactate simultaneously acts as an indicator; thus, it is possible to objectively characterize the adaptation and recovery processes in the body of athletes when performing intense physical activity. During this study, by comparing lactate levels and performed training loads, it was determined that if the level was either within the physiological norm (1.5 mmol/L) or its increase during the training cycle did not exceed 35–40% of the initial value, the functional state of the athletes' body was characterized as high, which indicated the adequacy of the flow of recovery processes. This means that the plans of physical activity may be made correctly; however, to confirm this, it is necessary to conduct repeated studies to determine the relationship between the level of lactate and the performed zone of training load during different periods of training and to compare the data with the dynamics of sports results of the studied athletes.

Conflicts of interest - The authors declare a lack of financial support for this study and no conflicts of interest no.

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