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**Original Article**

# Metabolic response of students' organisms after maximum-power physical activity

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**Abstract**:
The investigation of oxidative metabolism and the potential adaptation of students' bodies to physical activity remains a pressing issue. **Objective:** This study aims to examine the characteristics of free radical processes and the activity of the antioxidant system in students at different academic levels, both at rest and during maximal physical activity. **Materials and methods:** The oxidative metabolism at rest was analyzed in 286 male students from the 1st to 3rd years. From this group, 75 students were chosen to evaluate the response of oxidative metabolism during maximum physical activity. We evaluated the maximum intensity of luminescence and the inverse index related to the total light sum of biochemiluminescence, as well as the concentration of malonic dialdehyde and the activity of superoxide dismutase and catalase, enzymes that inhibit lipid peroxidation reactions. **Results:** The results indicate that, in a resting state, third-year students exhibited signs of relative maladaptation when compared to first-year males, as demonstrated by an increased rate of free radical production measured by the biochemiluminescence method. This is reflected in elevated levels of maximum luminescence intensity (Imax), the reciprocal of the total light sum, and malonic dialdehyde concentration. Additionally, there is a moderate decrease in the activity of antioxidant enzymes, such as superoxide dismutase and catalase. During physical activity, there is a considerable increase in lipid peroxidation and the levels of reactive oxygen species (ROS) observed during 100 m sprints and pull-ups. The Imax values increased by 37.1% and 45.5%, respectively, while the inverse index of the total light sum of chemiluminescence (1/S) values decreased by 49.2% and 45.9%. The dynamics of the secondary product of lipid peroxidation, malondialdehyde (MDA), revealed an increase in its concentration of 17.0% and 19.4%, respectively. Additionally, maximum physical work capacity contributed to a reduction in the activity of superoxide dismutase and catalase, which decreased by 10.8% and 15.0%, and by 11.7% and 13.1%, respectively. **Conclusions:** The results of this study can be used to inform recommendations for enhancing the physical education and sports training programs for university students. They may also serve as a foundation for evaluating the effectiveness of proposed strategies and programs aimed at improving the physical and somatic health of future professionals.
**Key Words**: **physical education, oxidative metabolism, functional state, motor activity, health**

## Introduction

The processes of biological oxidation that lead to the formation of reactive oxygen species (ROS) are continually present in the body during its activities (Arazi et al., 2021). These reactive compounds are highly reactive, and their effects are not entirely understood. On the one hand, they are essential in regulating natural metabolism in cellular structures, promoting skeletal muscle hypertrophy, and supporting proper immune function. On the other hand, they can also inflict damage on cell membranes through cytotoxic attacks on proteins and cellular DNA (Fang et al., 2022; Mischenko et al., 2020). ROS are generated in the body through various mechanisms, including their formation from organic aerosols owing to chemical reactions and macrophage phagocytosis (Shiraiwa et al., 2023). The role of muscle contraction in the generation of ROS and


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nitric oxide, both of which can damage muscle cells, has been established (Powers, & Jackson, 2008; Li et al., 2025). Consequently, the effectiveness of the antioxidant system in neutralizing these ROS becomes crucial because it protects the body from their toxic effects. Therefore, maintaining an appropriate balance between the production and elimination of radicals is an essential physiological process (Kerksick, & Zuhl, 2015). This balance is particularly important during events such as myocardial infarction, where the heart's muscular contractions lead to the production of reactive oxygen, exacerbating the progression of the disease. Further research into oxidative metabolism in the context of physical activity appears to be of great significance.

It is well-established that during physical exertion, oxygen consumption by skeletal muscles increases considerably, resulting in increased production of ROS and an accelerated rate of free radical oxidation (Chaudhary et al., 2023). In response to physical activity, one immediate adaptive mechanism is the activation of the antioxidant system, which plays a crucial role alongside ROS production. The effectiveness of this antioxidant system is vital for the body's ability to adequately respond to the demands of physical work (Jakubczyk et al., 2020; Powers et al., 2020; Rzaev, 2024). When exposed to maximum physical exertion, this can lead to the development of acidosis and an increase in lactic acid concentration (Brooks et al., 2023; Sasso et al., 2025). This influences the onset of oxidative stress during physical exertion, which is related to the body's insufficient functional capacity (Sawada et al., 2023; Posridee et al., 2025; Romanova et al., 2022). As a result, the body's nonspecific resistance is reduced. The production of active free radicals and the activation of lipid peroxidation considerably hinder the possibility of anaerobic energy supply mechanisms for skeletal muscles. Consequently, this limitation prevents the muscles from fully using their contractile potential (Broome et al., 2022; Yu et al., 2025). The education of young people in higher education institutions requires a high level of physical, mental, and somatic health (Kolokoltsev et al., 2023; Romanova et al., 2024; Kudryavtsev et al., 2024).

It is known that physical education and sports are effective non-drug methods for improving the health of the younger generation (Kolpakova, 2018; Osipov et al., 2024). However, many higher education students are inadequately prepared to engage in the required physical activities during their physical education classes. This is attributed to a low level of physical health (Zhao et al., 2024; Landman, & Tagari, 2024) and insufficient functional fitness of the body (Vanhelst et al., 2024). The search for effective informational methods and criteria to improve the study of the body's functional state remains a relevant area of research (Sikora et al., 2024). One such method involves examining oxidative metabolism and evaluating the body's ability to adapt to physical activity in students. However, existing scientific literature on this topic lacks sufficient detail.

Training specialists in higher education institutions should be supported by a thorough and high-quality study of the functional capabilities of their bodies. Such monitoring allows for adjustments to be made to the functioning of physiological systems, promoting a comprehensive approach to maintaining optimal health among students.

**Research aim:** To examine the characteristics of free radical processes and the activity of the body's antioxidant system in students across different years of study, both at rest and under the influence of maximal physical activity.

**Material & methods**

The experiment involved 286 male students, aged 18.7 ± 1.3 years, enrolled in the first, second, and third years at Volga Region Research Medical University in Nizhny Novgorod, Russia. At the beginning of the study, all participants provided informed voluntary consent, in accordance with the 2008 Helsinki Declaration. Researchers from various universities in Russia, Kazakhstan, and Kyrgyzstan also contributed to the study.

Based on the results of the annual medical examination of the experiment participants, no contraindications or restrictions were found regarding physical education or participation in sports competitions. At the beginning of the experiment, a study on the state of oxidative metabolism during relative physiological rest was performed, considering the participants' year of study. Subsequently, 75 subjects were randomly selected from the 286 participants, and their indicators were assessed after exposure to physical activity. The physical exercises "pull-ups from a hang on a high bar" and "100-m sprint" were used as load motor tests. During this phase of the study, measurements were taken twice: initially at rest (baseline) and then immediately after each exercise, with a 5-min rest interval between them.

A medical professional collected 2 ml of blood from the cubital vein of the students in the study group. To assess the rate of lipid peroxidation and the formation of ROS, a BHL-07 biochemiluminometer (Russia) was used. This device operates based on the Fe-induced biochemiluminescence method, which records kinetic curves. For monitoring, the maximum luminescence intensity (Imax, nmol/ml) and the inverse index of the total light sum of chemiluminescence (1/S, arbitrary units (a.u) were selected. The concentration of malondialdehyde (MDA) was determined by reacting with TBA-active products, with an optical density measured at 532 nm. The activity of superoxide dismutase, an antioxidant defense enzyme, was assessed using the method developed by T. Sirota (1999). This spectrophotometric method measures the enzyme's inhibition of adrenaline autooxidation under conditions that generate superoxide anion radicals in alkaline environments, with a wavelength of 347 nm. The activity of catalase, another antioxidant defense enzyme, was determined using the method of Y. Aeble developed in 1952 (Martusevich et al., 2022). Catalase exhibits strict specificity, interacting only with hydrogen peroxide, and is characterized by exceptionally high enzymatic activity. The spectrophotometric method used is based on the interaction between catalase and hydrogen peroxide, followed by the measurement of the kinetics of the enzymatic oxidation reaction at an optical density of 240 nm. A PE-5000VI spectrophotometer (Russia) was used in these experiments.The collected data were analyzed using Statistica 10.1 for Windows and Microsoft Excel 2016. Each sample is presented as the arithmetic mean (M) and the standard error of the mean (m). To assess the normality of data distribution, the Kolmogorov–Smirnov test with Lilliefors correction was applied. Owing to the absence of a normal distribution, the nonparametric Mann–Whitney and Wilcoxon tests were used to evaluate the statistical significance of differences between students of different years of study, as well as before and after physical activity. Differences were considered statistically significant at $p < 0.05$.

**Results**

At the beginning of the experiment, biochemiluminescence indicators were evaluated to estimate the rate of free radical formation in the biological environment, along with the concentration of MDA. The results of the assessment of maximum chemiluminescence intensity and MDA concentration in students of different years of study at rest are shown in Figure 1.

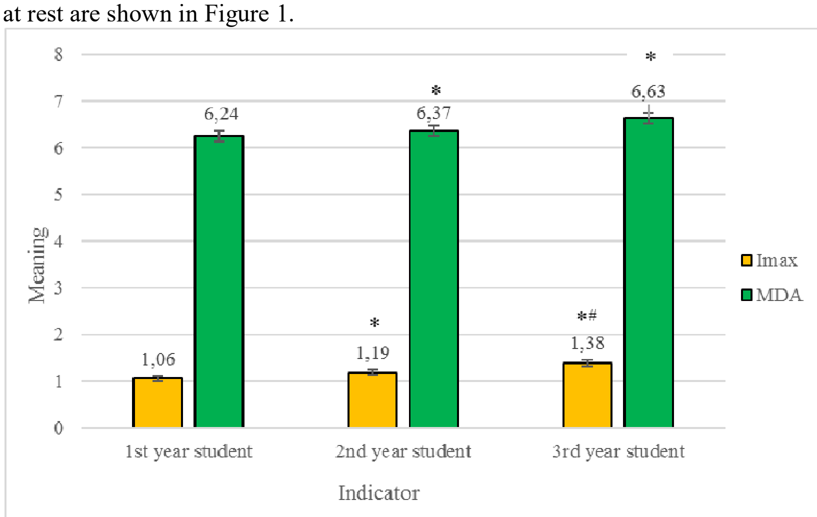


**Fig. 1. Maximum chemiluminescence intensity (mV) and malondialdehyde concentration (nmol/ml) in students of different academic years at rest**

*Note: * indicates statistically significant differences compared to* 1st year students *(p < 0.05); # indicates statistically significant differences compared to* 2nd year students *(p < 0.05).*

It was determined that the Imax among 1st year students was 1.06 ± 0.4 mV, 1.19 ± 0.3 mV among 2nd-year students, and 1.38 ± 0.4 mV among 3rd-year students, with statistically significant differences between all groups ($p < 0.05$). The highest concentration of MDA was observed in 3rd year students (6.63 ± 0.4 nmol/ml), significantly exceeding the levels recorded in 1st and 3rd year students ($p < 0.05$). The 1/S values, which reflect the activity of the antioxidant system among students from the 1st to 3rd years, are shown in Figure 2.

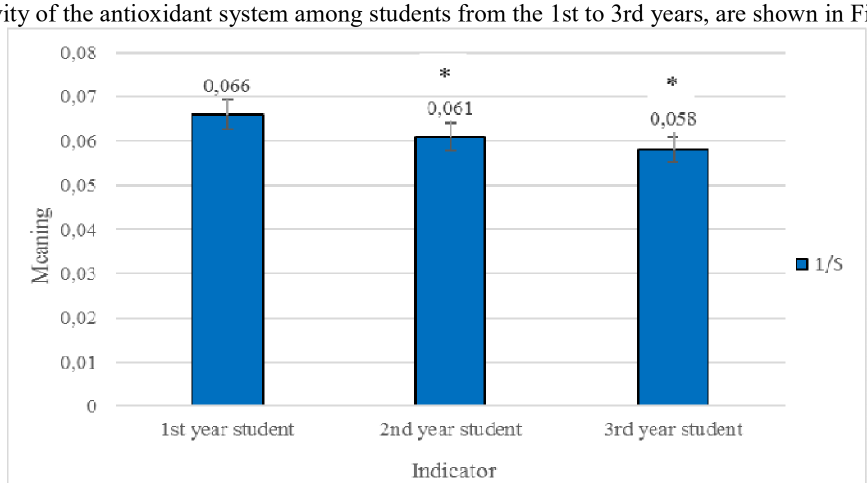


**Fig. 2. 1/S values (relative units) in students of different academic years at rest**

*Note: * indicates statistically significant differences compared to 1st-year students (p < 0.05)*

It was determined that 1st-year students had the highest value of the inverse indicator of the total light sum (0.066 ± 0.003 relative units), which significantly exceeded the corresponding values observed in 2nd- and 3rd-year students ($p < 0.05$). These findings indicate an increased ROS formation and a moderate decline in antioxidant system activity by the 3rd year of university study.

This trend is supported by the results of the MDA content analysis among the participants (Figure 1). In 3rd-year students, its concentration in the blood was 6.6% higher compared to that in 1st-year students ($p < 0.05$). These findings indicate an intensification of free radical processes in 3rd-year students.

At the next stage of the experiment, the functional properties of the body's antioxidant system were examined by determining the activity of the enzymes superoxide dismutase (SOD) and catalase. The results revealed a decrease in SOD activity among 3rd-year students (Figure 3).

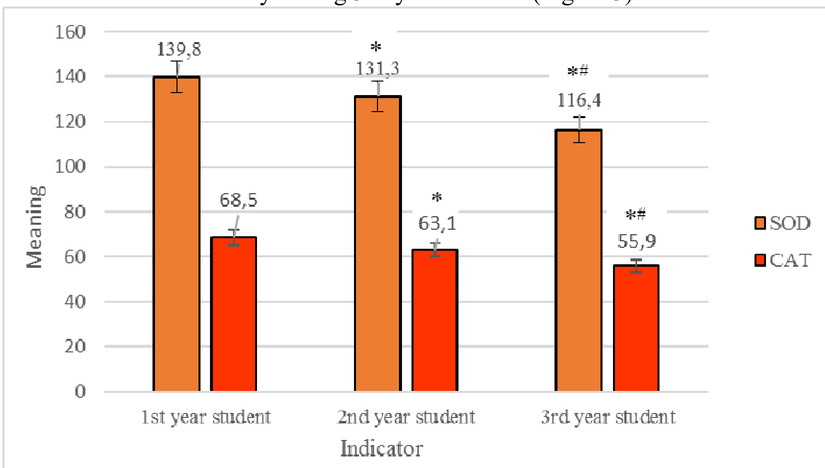


**Fig. 3. Superoxide dismutase and catalase levels (a.u./g Hb) in students of different academic years at rest**
*Note: * indicates statistically significant differences compared to 1st-year students (p < 0.05);*
*# indicates statistically significant differences compared to 2nd-year students (p < 0.05).*

Thus, in 1st-year male students, SOD activity was measured at 139.8 ± 5.3 a.u./g Hb, in 3nd-year students at 131.3 ± 4.2 a.u./g Hb, and in 3rd-year students it was 16.7% lower—116.4 ± 3.6 a.u./g Hb ($p < 0.05$). A similar trend was observed in the assessment of catalase content, which is responsible for breaking down hydrogen peroxide into water and oxygen. In 1st-year students, the catalase level was 7.9% higher than in 2nd-year students and 18.4% higher than in 3rd-year students ($p < 0.05$).

The observed values of superoxide dismutase and catalase suggest a moderate increase in the rate of ROS formation among 3rd-year students, which is partially compensated by the activity of the antioxidant system. The assessment of oxidative metabolism under the influence of physical activity in male students is presented in Table 1.

**Table 1. Biochemiluminescence indicators, malondialdehyde concentration, catalase, and superoxide dismutase levels at rest and during maximum physical activity (n = 75), M ± m**

| Indicator | Physiological state of the body | | |
|---|---|---|---|
| | Rest | 100-m run | Pull-ups |
| Imax, mV | 1.32±0.3 | 1.81±0.4* | 1.92±0.4*# |
| 1/S, relative. units | 0.061±0.003 | 0.031±0.005* | 0.033±0.006* |
| MDA, nmol/ml | 6.35±0.7 | 7.43±0.9* | 7.58±0.4* |
| SOD, a.u./g Hb | 128.6±5.8 | 114.7±4.6* | 109.3±5.7* |
| Catalase, a.u./g Hb | 62.4±4.3 | 55.1±5.7* | 54.2±4.6* |

*Note: * indicates statistically significant differences compared to the resting state (p < 0.05);*
*# indicates statistically significant differences compared to the "100-m run" (p < 0.05).*

In the study of free radical process rates based on biochemiluminescence indicators, it was found that the maximum luminescence intensity significantly increased by 37.1% after a 100-m run and by 45.5% after pull-ups from a high bar, compared to resting conditions. These findings indicate an increase in the formation of ROS with the increasing intensity of physical activity.

A decrease in the activity of the antioxidant system during physical exertion in students is evidenced by the inverse indicator of the area under the biochemiluminescence curve. This parameter decreased by 49.2% after a 100-m run and by 45.9% after pull-ups, compared to the baseline level at rest ($p < 0.05$). These findings suggest a relative intensification of lipid peroxidation and increased activation of ROS in response to physical activity. The dynamics of MDA levels, a secondary product of oxidative stress, demonstrate a moderate increase during physical exercise at maximum effort. After running, this indicator increased by 17.0% from the initial level, and after pull-ups on the horizontal bar, it increased by 19.4%, with $p < 0.05$ for all measurements. These findings indicate an increased level of lipid peroxidation during physical exercise. If adaptation reserves are insufficient, this may lead to decompensation of the antioxidant system owing to the damaging effects of free radicals. The study also examined changes in the activity of key enzymes, catalase and superoxide dismutase, which catalyze the breakdown of superoxide anion radicals and hydrogen peroxide, as well as their role in stopping the hypersynthesis of bioradicals. A moderate decrease in the activity of both enzymes was observed in the proposed sequence of physical exercises. SOD activity decreased by 10.8% after a 100-m run and by 15.0% after pull-ups on the horizontal bar, compared to the resting state. The changes in catalase activity mirrored those of SOD: after running, catalase activity decreased by 11.7%, and after pull-ups, it decreased by 13.1%, with $p < 0.05$ for both SOD and catalase in all exercises.

Thus, the proposed physical activity leads to moderate stress on the antioxidant system, as evidenced by a decrease in the activity of enzymes that neutralize free radicals and an increase in their formation rate. While the formation of ROS and the increased oxygen consumption by skeletal muscles during physical activity do not significantly increase the risk of muscle damage, the risk of cell membrane damage increases as free radical reaction chains branch. This may eventually lead the body to a state of maladaptation.

**Discussion**

The process of vital activity of the human body and its adaptation to changing conditions of the internal and external environment occurs both at the systemic and cellular levels. During the development of the body's adaptation, one of the mechanisms of this process is the creation of new cellular structures. This is accompanied by metabolic processes with the formation of reactive oxygen species (Arazi et al., 2021). The formation of reactive oxygen species regulates the natural metabolism of cellular structures, causes muscle hypertrophy and forms an adequate immune response. At the same time, active oxygen can have a destructive effect on the structural elements of cells (Fang et al., 2022).

To prevent this, the body's antioxidant system is activated. Therefore, its functional state is a trigger for inhibiting the destructive effects of excess free oxygen. As a rule, damage caused by lipid peroxidation during uncontrolled activation of reactive oxygen species can be caused by insufficient antioxidant properties of the body (Martusevich et al., 2022; Kolokoltsev et al., 2021). Therefore, the problem of improving the diagnostics of the state of the body's antioxidant systems is becoming relevant in medical practice and physical education and sports activities (Jakubczyk et al., 2020; Powers et al., 2020; Rzaev, 2024).

Oxidative stress markers can act as indicators of early diagnosis of overtraining and overstrain of the human body engaged in intense physical activity (Powers, & Jackson, 2008; Li et al., 2025). This affects the occurrence of oxidative stress during physical exertion, which is associated with inadequate functional capacity of the body (Sawada et al., 2023; Posridee et al., 2025), which reduces the nonspecific resistance of the body. This is manifested by the development of overfatigue and overtraining, which pose a threat to the normal functioning of the athlete's body. It has been shown that even moderate physical activity in conditions of insufficient physical fitness of a person leads to oxidative stress (Halliwell, 2024; Bocharin et al., 2021). Thus, monitoring the oxidative status of the body during physical activity is necessary for better preparation of the training program in sports activities.

The study demonstrated that in a state of rest, third-year university students show signs of relative maladaptation compared to first- and second-year students. Third-year students have an increased rate of free radical formation, which is reflected in a higher level of maximum luminescence intensity and the inverse indicator to the total light sum. This is confirmed by the concentration of malondialdehyde among this contingent of people. Also, among them, a moderate decrease in antioxidant defense enzymes is noted - superoxide dismutase and catalase, which indicates an intensification of free radical processes with partial compensation by the antioxidant system.

When performing physical exercise in the form of 100 m running and pull-ups on a high bar, an increase in lipid peroxidation and ROS activity is observed in the response to physical tests. Thus, Imax increased by 37.1% and 45.5%, 1/S decreased by 49.2% and 45.9%, respectively. The dynamics of the secondary product of lipid peroxidation (MDA) showed an increase in its concentration by 17.0% and 19.4%, respectively. The maximum power of physical work also contributed to a decrease in the activity of superoxide dismutase and catalase by 10.8% / 15.0% and 11.7% / 13.1%, respectively.

The conducted study is consistent with the opinion of other authors who point out in their works the need to search for informative methods and criteria to improve the way of studying the functional state of the body of athletes and sportsmen (Sikora et al., 2024), including oxidative metabolism. The use of this method has proven its effectiveness in diagnosing the state of the students' body at rest and during physical activity. This method can be used to improve the effectiveness of the educational and training process among students.

**Conclusions**

When assessing the state of oxidative metabolism in students from different years of study during relative physiological rest, it was observed that 3rd-year students exhibited an increased rate of ROS formation and a relative increase in lipid peroxidation processes. Additionally, they show a moderate decrease in antioxidant system activity, as evidenced by the study of enzymes involved in the decomposition of free radicals.

After performing maximum-power physical activity, a significant increase in the generation of ROS and a reduction in antioxidant protection were observed. These findings highlight the need to explore methods for improving the physical fitness of the participants. The data can be used to prepare recommendations for improving the physical education and sports programs at universities. Additionally, the results of this study can serve as a basis for evaluating the effectiveness of proposed strategies and programs aimed at improving the physical and somatic health of future professionals.

**Conflicts of interest**. The authors declare no conflict of interest.

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