



The Effect of Electromagnetic Waves of the Terahertz Range on the Frequency of Molecular Oxygen (129.0 Ghz) On the Processes of Lipid Peroxidation in Experimental Animals Under Chronic Stress

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Abstract

The aim of this scientific research is to study the effect of electromagnetic waves of the terahertz range on the frequency of molecular oxygen (129.0 GHz) on the processes of lipid peroxidation in experimental animals under chronic stress.



Overtraining is a psychological and/or physiological condition that manifests itself as impairment in athletic performance. This condition may be based on prolonged competitive stress and stressful psychological factors that can lead to the activation of lipid peroxidation processes (LPO). Moreover, the activation of the processes of lipoperoxidation is the main pathogenetic link of many socially significant diseases, especially cardiovascular disease. These circumstances require the development of modern and relevant methods of prevention and treatment of post-stress disorders. In the last ten years, a new method has been used to assess the effect of stress on the pro-oxidant activity of blood plasma and the concentration of antioxidants by exposure to electromagnetic radiation. In this paper electromagnetic waves of terahertz range, at frequencies of active cellular metabolites, were used to correct the processes of lipoperoxidation (LPO) changes at chronic stress. The innovative device "Orbit" was used to emit Terahertz (THz) radiation at frequencies of molecular oxygen 129,0 GHz in fractional mode. From the marked activation of lipid peroxidation processes and inhibition of antioxidant activity of blood, it is possible to observe a partial normalization, in the conditions of long-term immobilization or through cold water swimming of animals (rats), by using THz waves 5 days for 15 minutes; moreover, if the same procedure was applied for 30 minutes, a complete normalization of lipid peroxidation and antioxidant levels in the blood of stressed animals occurred. The study shows the high efficiency and expediency of using the device for terahertz therapy "Orbit" in the correction of altered processes of lipid peroxidation and it encourages future application for humans.

Key words: elite sport, overtraining, chronic stress, lipoperoxidation, antioxidants, THz waves, T-rays, terahertz therapy,

Introduction

Overtraining is the accumulation of training and/or non-training stress, leading to a long-term decrease in performance in the presence or absence of corresponding physiological and psychological signs and symptoms of poor adaptation, due to which recovery of performance can take several weeks or months [1–3]. A highly qualified athlete constantly balances between the optimal level of training and overtraining. Overtraining can be experienced in the course of the athlete's sports career; up to 20% of highly qualified athletes in the general selection, made without taking into account specialization, and up to 70% of elite athletes in sports associated with the predominant development of endurance [4–6].



It should be especially noted that overtraining is a pathological condition manifested by maladjustment that includes a violation of the level of functional readiness achieved during training, a change in the regulation of the body's systems as well as the optimal relationship between the cerebral cortex and the underlying parts of the nervous system, the motor apparatus and the internal organs. The main risk factors and causes for the onset of overtraining syndrome in athletes are physiological stress factors including multiple change of time zones, underdosed use of additional adaptation factors (mid-altitude, high-altitude, hypoxic training in laboratory conditions), training in conditions of high or low temperatures, polluted air, domestic and professional intoxication; as well as stressful psychological factors (increased expectations from a coach or family members, lasting competitive stress, personality structure characteristics, an unfavorable social environment, poor relations with family and friends, personal or emotional problems, and additional requirements related to school or work) [1–7]. These stress factors trigger excessive lipid peroxidation and oxidative stress in the athlete's body [7–9].

The signal of stress-reaction is a stereotypical and biologically important change in the internal environment of the cell within the body [8–10]. This signal is oxidative stress and displacement of prooxidant-antioxidant balance in the direction of activation of lipid peroxidation in biological membranes and liquids. Under the influence of extreme stimuli, the processes of biological oxidation and lipoperoxidation are naturally enhanced, and there is a significant inhibition of the functional activity of the enzyme and non-enzyme chains of the antioxidant system [10]. Particularly, oxidative stress and an increase in the concentration of lipid peroxidation products above the stationary level are considered as a universal mechanism of cell damage in various pathological conditions, including the pathology of the cardiovascular system [11–12]. Consequently, the correction of the level of intermediate products of lipoperoxidation and normalization of the activity of antioxidant systems of the blood are pathogenetically justified.

THz waves (T-rays) are the electromagnetic waves with a frequency diapason of 10^2 – 10^4 GHz (or with the lengths from 3 mm to 30 micro millimeters) [13–15]. Biophysical and biomedical effects of THz waves is a new field of research. The main features of THz rays are:

1. Maximum energy quantum $h\nu$ is quite twice higher than in classical Extremely High Frequency (EHF), where the EHF range includes electromagnetic radiation with an



intensity of less than 10 mW/mm^2 and a frequency from 30 to 300 GHz (wavelengths from 1 to 10 mm);

2. Nonthermal effects, as integral heating of radiating objects in the experiment does not exceed $0,1 \text{ }^\circ\text{C}$ [16];
3. As radiofrequency waves, THz waves penetrate through many nontransparent solid materials, and as light, can be focused.
4. Can be used at the specific frequencies corresponding to the absorption of the most important cellular metabolites (NO, O₂, CO₂, CO, OH⁻).

Consequently, metabolic processes in biological environment can be successfully regulated by using the electromagnetic THz waves [13-15]. In particular, the greatest interest in experimental science is caused by electromagnetic waves of molecular spectrum of radiation and absorption of molecular oxygen and nitric oxide (NO), which perform the function of one of the universal regulators of physiological, pathophysiological and biochemical processes in the cell and in the body as a whole [17-19].

From a collaboration between the Institute of Radio technique and electronics (RAS) (named after V.A. Kotelnikov (Moscow, RF)) and the Central Scientific Institute of Measuring Equipment (CIME, Saratov, RF), an innovative device for terahertz therapy, named "Orbit", was created. This device (Domestic patent RU 50835 [20]) emits THz waves at frequencies of active cellular metabolites (NO, molecular oxygen, etc.) [21-22]. Earlier studies have shown a positive effect of terahertz waves on the frequencies of nitric oxide on the lipoperoxidation in animals under short-term (acute) stress. In this work the effect of these waves in conditions of chronic immobilization stress was studied on rats, because it could be considered the more adequate model of long-term exposure to damaging factors in human [13]. In particular, the aim of this scientific research is to study the effect of electromagnetic waves of the terahertz range on the frequency of molecular oxygen (129.0 GHz) on the processes of lipid peroxidation in experimental animals under chronic stress.

Materials and Methods

Subjects and Immobilization protocol

The blood samples of 75 white «Wistar» male rats weighing 180-220 g were studied, obtained from the vivarium of the Russian Academy of Science. The animals were kept in



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standard conditions of the University vivarium, light 12/12. The animals had ad libidum access to water and drinks.

As a model, imitating the intensification of processes of lipid peroxidation and inhibition of the activity of the antioxidant system was done through the use of chronic immobilization stress - fixation of white male rats in the back position for 3 hours, every day, for 7 days [21]. The study was conducted in 4 groups of 15 animals as follows: group 1 (control) was "intact" animals; group 2 was animals in a state of chronic immobilization stress; groups 3 and 4 were animals that were exposed to the fractional mode for 15 and 30 minutes, respectively, after the immobilization protocol.

Another experimental factor was the stress of cold swimming. To simulate cold water immersion, rats were immersed in a bath with cold ($t = +4\text{ }^{\circ}\text{C}$) water daily. The water level was deep enough to allow the animals to float. The animals were forced to swim for 10 min, after which they were taken out, water was removed from their hair, and they were placed back in their cages. The animals were immersed in cold water once a day for 7 days [22]. Overall, there were 3 groups of animals: group 5 – cold swimming stress, and groups 6 and 7 animals that were exposed to fractional mode for 15 and 30 minutes, respectively, after cold water swimming.

In group 1 (Control) the blood was taken directly during the formation of the group, without radiation; in group 2 (animals in a state of chronic immobilization stress – chronic stress develops within 7 days), the blood sampling was performed on day 7, without radiation. In groups 3 and 4 (animals that were exposed to fractional mode for 15 and 30 minutes, respectively, after immobilization protocol), the blood sampling was performed on the last day, after the last radiation exposure. In group 5 (cold swimming stress), blood was collected on day 7 without radiation. In groups 6 and 7 (animals that were exposed to fractional mode for 15 and 30 minutes, respectively, after cold water swimming protocol), the blood sampling was performed on the last day, after the last radiation exposure. The same was done with animals of groups 6 and 7 after cold swimming

THz waves irradiation by fractional irradiation mode

In fractional mode, irradiation of animals was carried out with electromagnetic waves at the frequencies of the molecular spectrum of radiation and absorption of molecular oxygen at 129.0 GHz using the "Orbit" apparatus, on the skin area of 3 square cm above the area of the



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xiphoid process of the sternum. The irradiator was located at a distance of 1.5 cm above the surface of the animal's body. The radiation power of the device was 0.7 mW, and the power density falling on the skin area of 3 square cm was 100 microwatt/square cm [21].

The most physiological and effective is the fractional mode of action of terahertz waves on biological objects of different levels of organization. This mode of exposure was first used in this study. Fractional exposure mode "3/5" is an alternation of irradiation of a biological object –3 minutes and 5 minutes – with a break (no irradiation). The effective irradiation period was 15 and 30 minutes, the total exposure periods were 40 and 80 minutes, respectively [13, 21].

Blood analysis to assess lipid oxidation and antioxidant activity

Blood sampling for the study was carried out in plastic tubes by heart puncture. As a blood stabilizer, we used 3.8% sodium citrate solution in a ratio of 9:1. Status of lipid peroxidation was judged by the blood of the intermediate products of lipid peroxidation – hydroperoxides of lipids, malonic dialdehyde. To assess the degree of autointoxication and the development of cytotoxicity syndrome, an indicator of the content of medium-mass molecules in the blood was used [21].

The following parameters were evaluated and reported in Table 1:

- 1) Determination of Malondialdehyde in blood plasma (erythrocytes) (MDA):** malondialdehyde is a secondary product of fatty acid peroxidation, determined photometrically by the color of the MDA - thiobarbituric acid complex. The method is based on the ability of malonic dialdehyde to form a coloured complex in the reaction with a 2-thiobarbituric acid [21].
- 2) Determination of Hydroperoxides in lipids (LOOHs):** lipid hydroperoxides are formed during oxidation of fatty acids and are considered as the primary product of peroxidation of biopolymers. A method of determining the concentration of lipid hydroperoxides based on intensive absorption of conjugated diene structures of lipid hydroperoxides in the region of UV absorption (from 232 to 234 nm) with spectrophotometry [21, 24-25]
- 3) Determination of medium-mass molecules in blood serum (MM):** medium-mass molecules are endogenous components with different chemical structures whose molecular weight is 300–5000 daltons. A 10% solution of trichloroacetic acid added to the test samples and caused the precipitation of coarse proteins of the test liquid, was



centrifuged for 20 minutes at 3000 rpm, followed by detection of the eluted fraction in the supernatant on a spectrophotometer at a wavelength of 254 nm against the idle sample. The measurement results were expressed marked in units of optical density [21].

In Table 2 are reported the integrative indicators of the state of *activity of the antioxidant system* of the blood during immobilization stress; specifically, they determined the activity of cellular fractions of high-molecular compounds of the enzymatic link – catalase and superoxide dismutase (SOD), as well as low-molecular compounds of the non-enzyme link – common sulfhydryl groups (**SH-group**) and vitamin E [21].

- 1) **Catalase activity (CAT)** by Spectrophotometric method. Catalase is a heme-containing enzyme localized mainly in peroxisomes at a concentration of 10^{-6} M, catalyzing the two-electron reduction of hydrogen peroxide to water during superoxide anion dismutation. The method is based on the ability of hydrogen peroxide to form a stable coloured complex with molybdenum salts [21].
- 2) **Spectrophotometric method for determining superoxide dismutase activity (SOD)** by Spectrophotometric method. Superoxide dismutase is an antioxidant enzyme that catalyzes the disproportionation of superoxide radicals and prevents oxygen electronic excitation. Superoxide dismutase activity was determined by the suppression of testing nitroformazan – the product recovery of blue nitrotetrazolium with superoxide formed by the interaction of NADH and phenazinemethosulphate [21].
- 3) **Total sulfhydryl groups (SH)** by Photocolourimetric micromethod in blood serum. The method is based on the equivalent interaction of molecular iodine with free sulfhydryl groups of proteins and low molecular weight compounds in the presence of potassium iodide and phosphate buffer [21].
- 4) **Vitamin E (VitE)** by Spectrophotometric method. α -tocopherol is an antioxidant concentrated in the hydrophobic layer of mitochondrial membranes, erythrocytes and plasma membranes. The concentration of α -tocopherol was determined by serum spectrophotometry at a wavelength of 295 nm and fluorescence of 320 nm [21].

Animal experiments were made in accordance with the Geneva Convention "International Guiding principles for Biomedical Research Involving Animals" (Geneva, 1990), Helsinki Declaration of the world Medical Association (October 2000 edition), and also approved by the local ethics Committee of Sechenov University.



Statistical Analysis

For an objective assessment, all study results were statistically processed with the Statistica 10.0 software package. The indicators MDA, LOOHs, MM, SH, CAT, SOD and VitE were compared among groups. We tested hypotheses about the form of distributions (Shapiro-Wilkes criterion). Since, most of the data obtained did not correspond to the law of normal distribution, the Mann-Whitney U-test was used to compare the values. The differences were considered statistically significant at $p < 0,05$. p_1 comparing with the Control group (group 1) of intact animals; p_2 comparing with the group of animals subjected to chronic immobilization stress without THz exposition (group 2); and p_3 comparing with the group of animals subjected to chronic immobilization stress with THz exposition of 15-minute for 7 days (group 3).

Results

The lipid peroxidation processes (LPO) were sharply activated in rats under chronic immobilization stress and the stress of cold water swimming, which was accompanied by a statistically significant increase in the toxic intermediate products of lipoperoxidation – malondialdehyde (MDA) and lipid hydroperoxides (LOOHs) compared to the control group. Excessive accumulation of LPO products under chronic immobilization stress and the stress of cold water swimming was accompanied by the development of cytolysis syndrome, as evidenced by excessive accumulation of medium-mass molecules (MM) in the blood (Table 1).

In rats in a state of chronic immobilization stress and the stress of cold water swimming, there was also a sharp inhibition of both enzymatic and non-enzymatic links of the antioxidant system. This was manifested in a statistically significant decrease in the activity of superoxide dismutase (SOD) and catalase (Cat) in red blood cells, and a decrease in the number of total sulfhydryl groups (SH) and vitamin E (VitE) in serum (Table 2).

Thus, during immobilization stress as well as with the stress of cold water swimming there was a lack of all links of antioxidant protection of cells-enzyme and non-enzyme and activated lipid peroxidation. Under the influence of electromagnetic waves of the terahertz range on the animals under the background of chronic immobilization stress and the stress of cold water swimming on the frequencies of molecular oxygen for 15 minutes in fractional mode, there was a partial normalization of the processes of lipoperoxidation and antioxidant



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activity, which manifested in a decrease in the concentration of toxic intermediate products of lipid peroxidation and partial restoration of antioxidant properties of their blood.

Being exposed to terahertz radiation at these frequencies for 30 minutes in fractional mode caused a complete normalization of the processes of lipoperoxidation, which was expressed in reducing the concentration of toxic intermediate products of lipid peroxidation to the level of intact animals. Functional activity of enzyme and non-enzyme units of antioxidant cell protection was also restored and did not differ significantly from the level of intact animals (Tables 1, 2). Consequently, there was a complete normalization of the course of the processes of lipoperoxidation and restoration of the activity of the antioxidant system of its enzyme and non-enzyme link.

Discussion

Intense physical and psychoemotional loads that professional athletes undergo in the process of systematic training could lead to the development of overtraining syndrome due to a decrease in the body's adaptive capabilities, activation of lipid peroxidation processes and inhibition of the antioxidant activity of the blood. The overtraining syndrome in athletes is a pathological condition and it is accompanied by a pronounced impairment of working capacity, lack of recovery after the training process and, that is manifested during training, the optimal level of neurohumoral regulation [1–6].

The problems of stress, adaptation and prevention of stress injuries is the most urgent issue in modern biology and medicine [7–9]. One of the main pathogenetic mechanisms of acute and chronic stress reactions is the disturbance of the structure and functions of biological membranes of cells and tissues and the disorganization of well-consolidated visceral systems of the body [26]. In order to correct these symptoms, drugs are often used but can be also accompanied by the development of allergic reactions, individual intolerance, polypragmasia, and finally, the high cost of drugs should be taken into account. Currently, a complementary or non-drug approach to the treatment and prevention of socially significant diseases is extremely relevant. Lipid peroxidation parameters and parameters of the antioxidant activity of the blood should be studied as markers of overtraining [27].

The results of our study have shown that the efferent link of stress-dependent cell disorganization is the activation of free radical oxidation and inhibition of antioxidant system activity (Tables 1,2). This fact is fully consistent with previous research showing that activation



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of LPO is a common metabolic link of the stress reaction [9]. It is developed directly in response to extraordinary effects and, in turn, can initiate the accumulation of intermediate products of lipoperoxidation and decrease the functional activity of antioxidant systems [28]. The revealed excessive accumulation of intermediate products of lipoperoxidation in the blood under immobilization stress is a consequence of insufficient functional activity of enzyme and non-enzyme links of antioxidant protection of cells, as the activity of catalase and superoxide dismutase of blood, the content of vitamin E in the blood, and the level of total sulfhydryl groups of blood serum, decreased compared with the control group. It should be noted that the detected deficiency of vitamin E (Tables 1, 2) in experimental stress indicates destabilization of mitochondrial, lysosomal, and cytoplasmic membranes. Fat-soluble antioxidants, in particular, vitamin E, are localized mainly in biological membranes, protecting them from free radical destruction. Simultaneously, a significant suppression of the activity of blood superoxide dismutase leads to excessive accumulation of superoxide anion radical. The latter, although it has less reactogenicity with respect to lipids, protein components of biomolecules, as well as nucleic acids, but causes a rather pronounced disorganization of these structures with a violation of their function. This is confirmed by the results of our study, according to which malonic dialdehyde and lipid hydroperoxides accumulated in the blood during immobilization stress in excess (Table 1). The latter are known to be toxic intermediate products of lipoperoxidation induced in the process of interaction of reactive oxygen species with polyunsaturated fatty acids of biomembranes, in particular, linoleic and arachidonic.

The effect of terahertz radiation on the frequencies of the molecular spectrum of radiation and absorption of molecular oxygen 129.0 GHz for 30 minutes caused a complete normalization of the antioxidant system activity – its enzyme and non-enzyme link and lipid peroxidation processes. The mechanism hypotheses is that active forms of oxygen mediate the action of terahertz electromagnetic radiation in cells and biological fluids. Then in turn, calcium ions stimulate soluble guanylate cyclase, which leads to the accumulation of cGMP in vascular endothelial cells and increases the activity of NO-synthase, which in turn, increases the production of nitric oxide. Nitric oxide acts as a stress-limiting factor, limiting the release of pituitary stress hormones including the release of catecholamines in synaptic structures and from the adrenal glands. Nitric oxide also prevents the increase of intracellular concentration of calcium ions, increases the activity of antioxidant enzymes and the expression of genes encoding them, activates the synthesis of Hsp70 protector proteins, stabilizes and modifies the



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phospholipid bilayer of biological membranes, energy and plastic support of cells, the activity of transport and membrane receptor systems, cell excitability, many intracellular metabolic processes and intercellular interactions [13; 26, 29-30].

We have shown that the fractional mode of irradiation of terahertz waves at the frequencies of nitric oxide carried out in parallel with the action of the chronic stress agent prevents the development of chronic stress-dependent changes in the antioxidant system of the body and reduces the activity of LPO.

Conclusions

Among the internal causes of overtraining syndrome, the stress is of paramount importance, since its adverse effect on the constancy of the internal environment is well known. Stress is a typical phenomenon in athletes during training and competitive loads; under its influence, the body's energy reserves are mobilized. In the training process, not only the release of hormones occurs, but a certain sensitivity of receptors and tissues to them is also formed. A stable imbalance of hormones during prolonged stress is a source of pathological processes leading to the activation of lipid peroxidation processes and inhibition of the activity of the antioxidant system. The present experiment demonstrated that in conditions of chronic stress, there are marked changes in prooxidant-antioxidant balance in experimental animals. The presented data indicate the possibility of correction of disturbed processes of lipid peroxidation and insufficient functional activity of antioxidants by terahertz radiation at frequencies of molecular oxygen 129.0 GHz in the fractional mode. In this regard, terahertz waves can be considered as a complementary (or additional) therapy of post-stress and cardiovascular diseases, accompanied by the activation of lipid peroxidation. Thus, on the basis of the presented data, it can be concluded that terahertz radiation has a positive effect on the antioxidant properties of blood and the processes of lipoperoxidation in animals under two types of stress studied, chronic immobilization stress and cold water swimming stress. The most effective in restoring lipid peroxidation and antioxidant activity is a 30-minute irradiation.



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Table 1. Features of the influence of terahertz radiation on the frequencies of molecular oxygen 129,0 GHz (fractional irradiation mode) on post-stress changes **in the processes of lipoperoxidation** in male rats under chronic stress

Group	1	2	3	4	5	6	7
Indicators	Intact animal s (n = 15)	Chronic immobilization stress (n = 15)	Irradiation THz waves (T-rays) within		Swimming test (n=15)	Irradiation THz waves (T-rays) within	
			15 minutes (n = 15)	30 minutes (n = 15)		15 minutes (n = 15)	30 minutes (n = 15)
MAD (μmol/ml)	3,51 (2,80; 4,16)	11,9 (7,24; 14,01) P ₁ < 0,01	8,78 (6,32; 11,2) P ₁ < 0,05; P ₂ > 0,05	5,1 (3,01; 6,91) P ₁ > 0,05; P ₂ < 0,01 P ₃ < 0,05	11,3 (7,02; 14,01) P ₁ < 0,01	7,79 (5,53; 10,8) P ₁ < 0,05; P ₅ > 0,01	4,01 (2,91; 5,99) P ₁ > 0,01 P ₅ < 0,01 P ₆ < 0,05
LOOHs (1/mm)	4,0 (2,22; 5,88)	13,1 (6,88; 15,97) P ₁ < 0,01	9,01 (5,01; 13,99) P ₁ < 0,05; P ₂ < 0,05	5,4 (3,33; 6,68) P ₁ > 0,05; P ₂ < 0,01 P ₃ < 0,05	11,3 (5,95; 13,71) P ₁ < 0,05	8,77 (4,15; 12,91) P ₁ < 0,05; P ₅ < 0,05	5,5 (3,55; 7,81) P ₁ > 0,05; P ₅ < 0,05 P ₆ < 0,05
MM	0,44 (0,23; 0,81)	1,98 (0,60; 2,29) P ₁ < 0,05	1,08 (0,55; 1,29) P ₁ < 0,05;	0,69 (0,20; 1,19) P ₁ > 0,05;	2,09 (0,65; 2,44) P ₁ < 0,01	1,05 (0,44; 1,36) P ₁ < 0,05;	0,58 (0,25; 0,98) P ₁ > 0,05;



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$P_2 < 0,05$	$P_2 < 0,01$	$P_5 < 0,01$	$P_5 < 0,01$
	$P_3 < 0,05$		$P_6 < 0,01$

Note to table: In each case, the median and lower and upper quartiles (in bracket: 25%, 75%) of the corresponding number of measurements are reported.

p_1 comparing with the Control group (group 1) of intact animals; p_2 comparing with the group of animals subjected to chronic immobilization stress without THz exposition (group 2); p_3 comparing with the group of animals subjected to chronic immobilization stress with THz exposition of 15-minute for 7 days (group 3).

p_1 comparing with the Control group (group 1) of intact animals; p_2 comparing with the group of animals subjected to cold water swimming stress without THz exposition (group 5); p_3 comparing with the group of animals subjected to chronic immobilization stress with THz exposition of 15-minute for 7 days (group 6).

Table 2. Influence of terahertz waves on the frequencies of molecular oxygen 129.0 GHz on **antioxidant activity** of blood in male rats under chronic stress

Group	1	2	3	4	5	6	7
Indicators	Intact animal (n = 15)	Chronic immobilization stress (n = 15)	Irradiation THz waves (T-rays) within 15 minute (n = 15)	Irradiation THz waves (T-rays) within 30 minute (n = 15)	Swimming test (n=15)	Irradiation THz waves (T-rays) within 15 minute (n = 15)	Irradiation THz waves (T-rays) within 30 minutes (n = 15)
Vit E	19,11 (14,2; 24,66)	7,02 (5,25; 12,66) $P_1 < 0,01$	12,1 (7,04; 14,58) $P_1 < 0,05$	16,1 (14,3; 20,22) $P_1 > 0,05$	9,23 (6,33; 14,65) $P_1 < 0,01$	12,3 (7,41; 15,81) $P_1 < 0,05$	19,21 (9,51; 21,67) $P_1 > 0,05$
			$P_2 < 0,05$	$P_2 < 0,01$		$P_5 < 0,05$	$P_5 < 0,01$



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				$P_3 < 0,05$			$P_6 < 0,01$
SOD	366,66	180,1	240,99	293,9	195,9	269,4	340,1
conventiona	(300,1;	(170,2; 240,2)	(200,1;	(280,5;	(150,1;	(221,5;	(270,7;
l unit/ml	401,22	$P_1 < 0,01$	290,19	350,6)	280,9)	390,7)	440,5)
erythrocyte)))	$P_1 > 0,05;$	$P_1 < 0,01$	$P_1 < 0,05;$	$P_1 > 0,05$
s				$P_2 < 0,05;$		$P_5 < 0,01$	$P_5 < 0,01$
				$P_2 < 0,05$			
				$P_3 < 0,05$			
SH	3,44	0,37	0,88	2,79	0,42	1,08	3,27
(mmol/l)	(2,0;	(0,24; 1,55)	(0,84;	(2,02;	(0,22;	(0,89;	(2,24;
	5,25)	$P_1 < 0,01$	1,24)	4,77)	1,24)	1,41)	3,55)
			$P_1 < 0,05;$	$P_1 > 0,05;$	$P_1 < 0,01$	$P_1 < 0,01;$	$P_1 > 0,05$
			$P_2 > 0,05$	$P_2 < 0,05$		$P_5 < 0,05$	$P_5 < 0,01$
			5	0,05		5	0,01
				$P_3 < 0,05$			
CAT (mu/l)	6,01	3,03	3,99	8,87	3,35	3,88	7,03
	(3,33;	(2,02; 4,25)	(2,88;	(4,45;	(2,21;	(2,23;	(3,25;
	8,01)	$P_1 < 0,05$	5,01)	11,13)	4,54)	5,11)	9,50)
			$P_1 < 0,05;$	$P_1 < 0,05;$	$P_1 < 0,05$	$P_1 < 0,05;$	$P_1 > 0,05$
			$P_2 > 0,05$	$P_2 < 0,01$		$P_5 > 0,05$	$P_5 < 0,01$
				$P_3 < 0,05$			

Note to table: In each case, the median and lower and upper quartiles (25%, 75%) of the corresponding number of measurements are reported.

p_1 comparing with the Control group (group 1) of intact animals; p_2 comparing with the group of animals subjected to chronic immobilization stress without THz exposition (group 2); p_3 comparing with the group of animals subjected to chronic immobilization stress with THz exposition of 15-minute for 7 days (group 3).



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p₁ comparing with the Control group (group 1) of intact animals; p₂ comparing with the group of animals subjected to cold water swimming stress without THz exposition (group 5); p₃ comparing with the group of animals subjected to chronic immobilization stress with THz exposition of 15-minute for 7 days (group 6).

Abbreviations

LPO, lipid peroxidation processes

THz, terahertz

EHF, Extremely High Frequency

NO, Nitric oxide. It is one of the principal oxides of nitrogen. Nitric oxide is a free radical

MDA, Malonic dialdehyde or malonaldehyde Analysis

LOOHs, lipid hydroperoxides

MM, medium-mass molecules

SH, sulfhydryl groups

CAT, Catalase activity

SOD, superoxide dismutase

VitE, vitamine E