ORIGINAL ARTICLE

EXPERIMENTAL BACKGROUND FOR HORMONE-VITAMIN COMPLEX USING IN COURSE OF REHABILITATION AFTER IONIZING RADIATION

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ABSTRACT

The aim: To determine the efficacy of the original hormone-vitamin complex in terms of biochemical activity enhancement and muscle system functional activity restoration in the irradiated rat's descendents.

Materials and methods: The activity of NADP-dependent malatedehydrogenase and the content of ATP, ADP and AMP were determined in the blood, myocardium and thigh muscles of rats exposed to ionizing gamma-radiation. The rats were also checked in the forced swimming test. The efficacy of the hormone-vitamin complex was determined in all mentioned indexes.

Results: Our results testify the expressed changes in muscle tissue functioning in an irradiated person, which was expressed by the dysfunction of biochemical reactions aimed at synthetic energy processes, and by the macroergic compounds level depletion together with physical performance minimization. Our data showed the hormone-vitamin complex injection to irradiated animals and their descendants improved the muscle energy resources due to glycolytic substrate phosphorylation enhancement and due to tricarboxylic acids cycle oxidative potential strengthening.

Conclusions: Original scheme of post-radiation lesions complex pharmacological correction prevented the development of tissues providing with macroergic compounds, anaerobic processes strengthening, metabolic acidosis, weakening of both substrate phosphorylation and tricarboxylic acids cycle. The original scheme of ionizing radiation-induced energetic disorders pharmacological corrections in the irradiated animals' descendents we consider as an experimental basis for the reasonability of these compound radioprotective effects testing during the physiotherapeutic treatment of persons exposed to ionizing radiation.

KEY WORDS: ionizing radiation, muscle dysfunction, energetic exhaustion, physical performance, hormone-vitamin complex, treatment efficacy, rehabilitation

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INTRODUCTION

The concept of medical support of rehabilitation in response to ionizing radiation provoked damage of the human body acquires not only medical and industrial but also economic, social and state importance [1, 2]. A significant period of time which separates us from the terrible nuclear disaster in Chernobyl significantly reduced the severity of the problem, but already the accident at the Fukushima nuclear power plant reminded us of the extremely dangerous impact of ionizing radiation on the biological organism [3]. The military aggression currently taking place against our country urgently raises the question of improving existing and developing new methods of rehabilitation after ionizing radiation, since the enemy is resolutely trying to destroy the Zaporizhzhya nuclear power plant, and depleted uranium ammunition is increasingly being used on the battlefield [2, 4].

The medical side of this problem allows us to recall the development of degenerative-destructive changes at all structural and functional levels of organization and systemic regulation of the activity of a biological organism after exposure to ionizing radiation [5, 6]. Rehabilitation schemes that were used had the resulting effect on the ionizing factor harmful effects elimination and the body's energy reserve direct stimulation (or activation) [7]. We have been conducting experimental trials aimed at elucidating the details of the radioprotective effect of the original hormone-vitamin complex [8, 9]. We chose as the main concept the activation of the body's protective adaptive resources with an emphasis on pharmacologically-induced muscle system activity increase during the rehabilitative effect implementation. Our attention is focused on the descendents of irradiated animals which allows us to follow the depth of damage and pathophysiological mechanisms of

Table I. Changes of NAD-dependent malatedehydrogenases activity in the tissues of 1-month-old rats born from animals irradiated with different doses and exposed to radiation at a dose of 1.0 Gy as s result of hormone-vitamin complex influence

N	Enzymes	Myocardium		Skeletal muscle		Blood
		Cytoplasm	Mitochondria	Cytoplasm	Mitochondria	
Intact rat pups, n=10						
1	NAD-MDH (direct reaction)	0.58±0.05	0.29±0.02	0.21±0.01	47.37±3.24	1.93±0.16
2	NAD-MDH (reverse reaction)	2.46±0.02	0.22±0.03	1.07±0.03	54.18±3.61	4.37±0.36
1-month-old rats born from animals once irradiated by 0.5 Gy and exposed to irradiation at a dose of 1.0 Gy, n=10						
Before correction						
1	NAD-MDH (direct reaction)	0.66±0.18	0.24±0.01	0.28±0.01	40.36±2.80	2.24±0.19
2	NAD-MDH (reverse reaction)	2.46±0.15	0.27±0.05	1.45±0.07[a]	68.24±2.92	4.62±0.31
After correction						
1	NAD-MDH (direct reaction)	0.63±0.18	0.23±0.01	0.26±0.01	43.28±3.20	1.79±0.18
2	NAD-MDH (reverse reaction)	2.08±0.14	0.25±0.06	1.28±0.06	66.48±2.86	4.28±0.31
1-month-old rats born from animals once irradiated by 1.0 Gy and exposed to irradiation at a dose of 1.0 Gy, n=10						
Before correction						
1	NAD-MDH (direct reaction)	0.98±0.36	0.18±0.01[a]	0.31±0.01[a]	26.56±1.41[a]	1.25±0.13[a]
2	NAD-MDH (reverse reaction)	3.81±0.24[a]	0.29±0.09	1.84±0.10[a]	78.52±3.64[a]	5.72±0.39[a]
After correction						
1	NAD-MDH (direct reaction)	0.69±0.20[b]	0.25±0.02	0.28±0.01	41.94±3.21[b]	1.92±0.19[b]
2	NAD-MDH (reverse reaction)	1.99±0.13[b]	0.28±0.07	1.29±0.07	68.42±2.92	4.55±0.34

Notes: [a] – $p<0.05$ – studied indexes significant differences compared with the same in intact rat pups; [b] – $p<0.05$ – studied indexes significant differences compared with the same before pharmacological correction.

radio-induced changes in the organism of the second generation of animals and to determine the necessary level of sanogenetic restorative effects implementation.

THE AIM

The aim of the present work was to determine the efficacy of the original hormone-vitamin complex in terms of biochemical activity enhancement and muscle system functional activity restoration in the irradiated rat's descendents.

MATERIALS AND METHODS

This study was conducted in accordance with the "General Ethical Principles of Animal Experiments" adopted by the Fifth National Congress on Bioethics (Kyiv, 2013). We used the recommendations of the European Convention on the Protection of Vertebrate Animals for Experimental and Other Scientific Purposes (Strasbourg, 1985) and the rules of humane treatment of experimental animals and conditions approved by the Bioethics Commission of the Odessa National Medical University (protocol No. 32D dated 03/17/2016).

Experimental trials were carried out on 66 Wistar rats, weighing 200-250 g. Rats were kept at a constant temperature of 24-26°C, 55-60% humidity, 12/12 hr light/dark cycle and on a standard vivarium diet. The cages were changed weekly, and rats' fluids were changed every two day.

The mature rats were exposed to a single total gamma irradiation of ^{60}Co in the morning on an empty stomach on the "Agat" telegammatherapy unit (the distance to the device was 75 cm, the dose rate was 0.54 Gy/min, the absorbed dose was 0.5 Gy and 1.0 Gy).

The rats were randomly divided into 7 groups: the 1st group (n=10) – 1-month-old rats born from intact animals; the 2nd and the 3rd groups (n=2x10) – 1-month-old rat pups born from animals once totally irradiated by 0.5 Gy and 1.0 Gy; the 4th and the 5th groups (n=2x10) – 1-month-old rat pups born from animals once totally irradiated by 0.5 Gy and by 1.0 Gy and exposed to a dose of 1.0 Gy; the 6th and the 7th groups (n=2x8) – 1-month-old rat pups born from animals once totally irradiated by 0.5 Gy and by 1.0 Gy and exposed to a dose of 1.0 Gy, which were administered with a hormone-vitamin complex (HVC).

The HVC included tocopherol acetate (i.m., 50 mg/kg, 30 min after irradiation), retabolil (i.m., 2.5 mg/kg, 3 hrs after irradiation), cocarboxylase (s.c., 5 mg /kg) and nicotinamide (s.c., 10 mg/kg), which were administered 1 day after irradiation dissolved in 0.5 ml of saline. The HVC was administered during 12 days [10].

After euthanasia (i.v., propofol, 60 mg/kg) the animals' blood was collected, the heart (2/3 of the heart`s apex) and the frontal group of thigh muscles (mainly quadriceps femoris and sartorius muscle) were

Table II. Changes of ATP, ADP and AMP content in the tissues of 1-month-old rats born from animals irradiated with different doses and exposed to radiation at a dose of 1.0 Gy as s result of hormone-vitamin complex influence

N	Investigated compounds	Skeletal muscle	Myocardium
Intact rat pups, n=10			
1	ATP	2.86±0.24	4.93±0.37
2	ADP	0.39±0.04	0.24±0.02
3	AMP	0.22±0.02	0.10±0.01
1-month-old rats born from animals once irradiated by 0.5 Gy and exposed to irradiation at a dose of 1.0 Gy, n=10			
Before correction			
1	ATP	2.29±0.19	4.53±0.35
2	ADP	0.77±0.07[a]	0.44±0.04[a]
3	AMP	0.29±0.02[a]	0.16±0.02[a]
After correction			
1	ATP	2.83±0.23	4.93±0.37
2	ADP	0.40±0.04[b]	0.24±0.02[b]
3	AMP	0.23±0.02	0.11±0.01[b]
1-month-old rats born from animals once irradiated by 1.0 Gy and exposed to irradiation at a dose of 1.0 Gy, n=10			
Before correction			
1	ATP	1.17±0.14[a]	2.45±0.44[a]
2	ADP	0.52±0.05[a]	0.57±0.05[a]
3	AMP	0.40±0.04[a]	0.18±0.02[a]
After correction			
1	ATP	2.79±0.22[b]	4.81±0.35[b]
2	ADP	0.40±0.04	0.25±0.02[b]
3	AMP	0.23±0.02[b]	0.11±0.01[b]

Notes: [a] – $p<0.05$ – studied indexes significant differences compared with the same in intact rat pups; [b] – $p<0.05$ – studied indexes significant differences compared with the same before pharmacological correction.

removed. We determined the activity NADP-dependent malatedehydrogenase in both direct and reverse reactions and the content of ATP, ADP and AMP in one sample using combined reactions [11]. All indexes of energy metabolism were expressed in μmol per 1 g of the studied tissue.

The physical working capacity of the animals was determined in the forced swimming test with a load and was evaluated by the swimming duration with a load of 10% of body weight attached with a rubber ligature to the root of the animal's tail [12]. Swimming was carried out in the time interval from 10.00 to 12.00 in glass vessels with an inner diameter of 30 cm and a height of 50 cm. The moment of the trial finish was considered the animal's fatigue in the form of an inability to rise to the surface of the water for 8 s or the animal's refusal to swim (immersion to the bottom for more than 10 s).

The data obtained were presented as mean (x) and the standard error of the mean (SE). $\chi 2$ criterion was used to detect the significant differences between the investigated groups $p<0.05$ was considered as statistically significant difference.

RESULTS

The activity of NAD-dependent MDH in the cytoplasm of cardiac and skeletal muscles of descendents born from irradiated animals in different doses and exposed to radiation 1.0 Gy after the HVC introduction is comparable to the same index in the control animals ($p>0.05$; Table I). The activity of the direct NAD-dependent MDH reaction in the mitochondria of cardiac and skeletal muscles of descendents born from irradiated animals in different doses and exposed to radiation 1.0 Gy after the HVC injection is reduced, and the lowest values are observed in rats born from irradiated animals by 1.0 Gy and exposed to irradiation at a dose of 1.0 Gy ($p<0.05$). The pharmacological correction, however, results in these indexes being identical to corresponding ones in intact rats ($p>0.05$).

Direct NAD-dependent MDH reaction activity in the blood of descendents born from irradiated animals in different doses and exposed to radiation 1.0 Gy after the HVC administration is reduced. The lowest index is observed in rats born from animals irradiated by 0.5 Gy and exposed to radiation at a dose of 1.0 Gy after pharmacological correction.

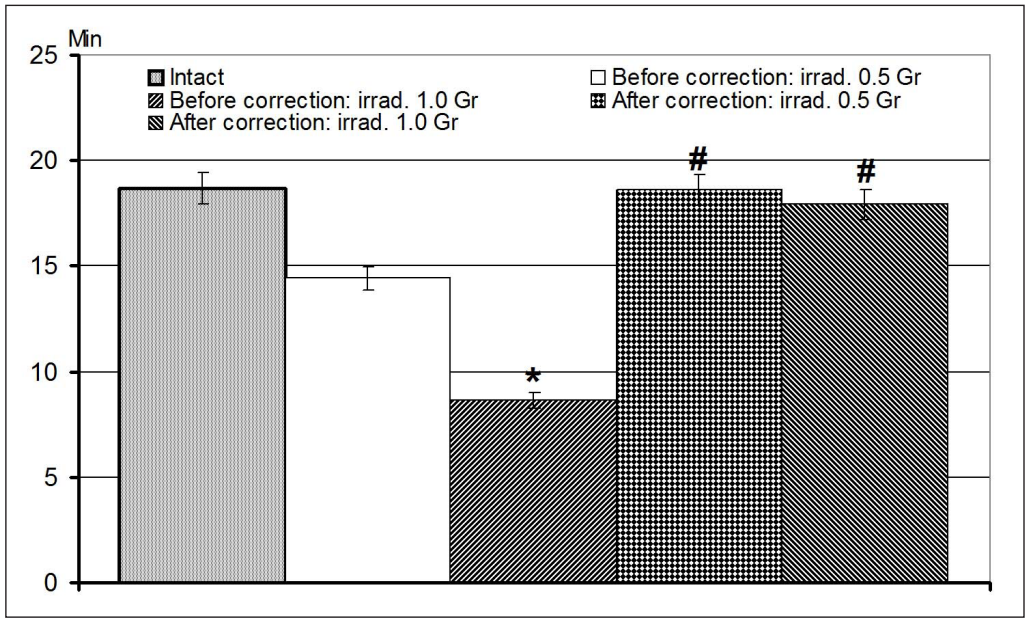

Fig. 1. Changes of forced swimming time of 1-month-old rats born from animals irradiated with different doses and exposed to radiation at a dose of 1.0 Gy as s result of hormone-vitamin complex influence.
Notes: * – $p<0.05$ – studied indexes significant differences compared with the same in intact rat pups; # – $p<0.05$ – studied indexes significant differences compared with the same before pharmacological correction.

The activity of NAD-dependent MDH in the cytoplasm of myocardium of descendents born from irradiated animals in different doses and exposed to radiation by 1.0 Gy after the HVC injection is lower vs the same control index. The lowest index of its activity is observed in the cytoplasm of the myocardium in rats born from animals irradiated at a dose of 1.0 Gy and exposed to irradiation by of 1.0 Gy after the HVC administration ($p>0.05$).

The activity of NAD-dependent MDH (reverse reaction) in the mitochondria of cardiac and skeletal muscles, as well as in the blood of descendents born from irradiated animals in different doses and exposed to radiation by 1.0 Gy after the HVC introduction is comparable to such control indexes. The indexes obtained depend on the dose exposed to parents.

The ratio direct/reverse NAD-dependent MDH reaction in descendents born from irradiated animals in different doses and exposed to radiation by 1.0 Gy after the HVC injection increases drastically. This becomes significant in rats born from animals once irradiated by 1.0 Gy and exposed to radiation at a dose of 1.0 Gy, compared with such indexes in descendents born from irradiated animals in different doses and exposed to radiation by 1.0 Gy without the pharmacological correction ($p<0.05$).

Adenylnucleotides content change was recorded in rat pups born from irradiated animals at a different doses and exposed to irradiation by 1.0 Gy ($p<0.05$; Table II).

We registered both ADP and AMP content significant increase due to which a stable ATP concentration is maintained in the muscles of 1-month-old rats born from animals irradiated at a dose of 0.5 Gy and exposed to irradiation by 1.0 Gy, and an acute ATP content decrease (by 2.0-2.4 times; $p<0.05$) within the skeletal and cardiac muscle, respectively, and an acute ADP and AMP levels increase ($p<0.05$) in muscle tissue of 1-month-old rats born from parents once irradiated at dose 1.0 Gy and then exposed to radiation at the same dose. Pharmacological correction of these metabolic disorders resulted in ATP concentrations increase in both rat pups born from animals once irradiated at a doses of 0.5 Gy and 1.0 Gy and exposed to radiation by 1.0 Gy (in both groups $p<0.05$).

The values of ADP and AMP content in the studied groups of animals exceeded the same indexes in 1-month-old rats and were comparable to them, which indicated the pronounced changes development as the result of HVC use ($p<0.05$).

Physical activity of the descendents born from irradiated animals and exposed to a maximal dose of radiation significantly differed from the same in the intact rats and, moreover, it was changed after the HVC administration (Fig. 1). Swimming time of 1-month-old rats born from animals once irradiated at a dose of 0.5 Gy and exposed to irradiation by 1.0 Gy was 23% less compared with the same index in intact rats and 30% less compared with the same index in non-irradiated rat pups born from animals once irradiated by 0.5 Gy ($p<0.05$).

We registered the muscle tissue functioning significant changes in rats born from once irradiated at a dose of 1.0 Gy and exposed to irradiation at the same dose after the HVC pharmacological correction. These rats demonstrated swimming time significantly less by more than 2 times compared with the same control index ($p<0.05$) and by 32% compared with the same index in non-irradiated rat pups born parents once irradiated at a dose of 1.0 Gy.

DISCUSSION

Thus, the obtained results testify the expressed changes in muscle tissue functioning in an irradiated person, which was expressed by the dysfunction of biochemical reactions aimed at synthetic energy processes, and by the macroergic compounds level depletion together with physical performance minimization, which, in a systemic analysis, illuminates pathogenetic mechanisms intended to destructive, degenerative and necrotic directions, the result of which should be a regulatory "breakdown", systemic-anti-systemic dysfunction and/or energetic exhaustion, the comorbid pathology burden and the death of the organism [6].

It has been proven that HVC introduction for the muscle tissue metabolic disorders correction in irradiated animals and their descendants improved the muscle energy resources due to glycolytic substrate phosphorylation enhancement and due to tricarboxylic acids cycle oxidative potential strengthening on at the stage of MDG action and on the stage catalyzed by succinatedehydrogenase. Our results are confirmed by a significant array of actual data concerning the physical performance increase in the studied rats.

We specially organized such a method of post-radiation lesions complex pharmacological correction to prevent the development of providing tissues with macroergic compounds, anaerobic processes strengthening, metabolic acidosis, weakening of both substrate phosphorylation and tricarboxylic acids cycle as well as cellular genetic apparatus damage cells and strengthening the normalization of regeneration processes [5]. We had already optimistic results of HVC using in animals and their descendants, which proved the energy supply processes restoration in irradiated rats [8].

We consider important to provide the experimental study of muscle tissue dysfunction not only and not so much in irradiated animals, but in their descendants, which has the adequate clinical validity (the second generation is living after the accident at Chernobyl nuclear power plant) and provides an opportunity to investigate thoroughly the pathophysiological mechanisms of radiation-induced morphological, functional, biochemical and regulatory violations, and also allows to comprehensively study the possibilities of rehabilitation effects and establish its efficacy.

We achieved positive results in the case of a full-fledged pharmacological correction of the formed energetic disorders, which should be the background of a complete rehabilitation scheme for the specified contingent of victims, taking into account the multimodal concept of health restoration of military personnel adopted by the medical service of the Military Forces of Ukraine [13]. It is important to understand and be able to change dynamically the composition of the complex pharmacological therapy of radiation-induced functional disorders depending on the clinical condition of the patients. This is possible in case of a clear understanding the original scheme of pharmacocorrection mechanisms of action. It's important to understand that under the specified pathological conditions, the activation of the reverse NAD-dependent MDH occurs in the cytoplasm and in the mitochondria of muscle tissue, as well as the predominance of the reverse NADP-dependent MDH reaction. Reduced forms of $NADH^+$ accumulate in the tissues, which induces the acidosis and creates conditions for competition between aerobic and anaerobic processes, where anaerobic reactions have an advantage. The formation of pronounced epigenetic changes induced by ionizing radiation has also been shown, as a result of which the ATP content decreases due to (a) the delay in the processes of adenyl system phosphorylation from its dephosphorylation, (b) an increase in the methylated ATP derivatives content and (c) this metabolite increased degradation, which will definitely lead to a change in physical performance of an organism [14].

The original treatment scheme includes drugs with antioxidant properties - multivitamin complexes, which additionally strengthen the whole organism resistance to the negative impact of adverse environmental factors [15]. The HVC ensures the coherence of metabolic processes in the body, resistance to the influence of extreme environmental factors, and the ability to adapt the regulatory systems of the body [16]. We believe that this is important in the processes of utilization and resynthesis of metabolites of a carbohydrate nature, which are under complex and multi-stage hormonal and vitamin control, in which the hormones of the pancreas and adrenal glands play a leading role, supporting the metabolism and the functional activity of the bodies vital systems [6, 17].

We consider our idea, consisting in the above-mentioned pharmacological compounds combined use to test their efficacy in the irradiated animals' descendents as an experimental basis for the reasonability of the original scheme radioprotective effects testing during the physiotherapeutic treatment of persons exposed to ionizing radiation.

CONCLUSIONS

1. The data obtained testify the expressed changes in muscle tissue functioning in an irradiated person, who was expressed by the dysfunction of biochemical reactions aimed at synthetic energy processes,

and by the macroergic compounds level depletion together with physical performance minimization.
2. The hormone-vitamin complex introduction in irradiated animals and their descendants improved the muscle energy resources due to glycolytic substrate phosphorylation enhancement and due to tricarboxylic acids cycle oxidative potential strengthening on at the stage of MDG action and on the stage catalyzed by succinatedehydrogenase. We registered also the physical performance increase in the studied rats.
3. Original scheme of post-radiation lesions complex pharmacological correction prevented the development of tissues providing with macroergic compounds, anaerobic processes strengthening, metabolic acidosis, weakening of both substrate phosphorylation and tricarboxylic acids cycle as well as cellular genetic apparatus damage cells and strengthening the normalization of regeneration processes.
4. The original scheme of ionizing radiation-induced energetic disorders pharmacological corrections in the irradiated animals descendents we consider as an experimental basis for the reasonability of these compound radioprotective effects testing during the physiotherapeutic treatment of persons exposed to ionizing radiation.

REFERENCES

1. Pechyborshch VP, Volyanskyi PB, Yakimets VM et al. Medychnyy zakhyst naselennya v nadzvychaynykh sytuatsiyakh v yedyniy derzhavniy systemi tsyvil'noho zakhystu [Medical protection of the population in emergency situations in the unified state system of civil protection]. Kyiv : Lyudmila Publishing House. 2019, p.693. (Ukrainian)
2. Chekhun VF, Domina EA. Suchasnyy pohlyad na stokhastychni efekty ionizuyuchoho vyprominyuvannya [Modern view on the stochastic effects of ionizing radiation]. Oncology. 2022;24(1):5-10. doi: 10.32471/oncology.2663-7928.t-24-1-2022-g.10339. (Ukrainian)
3. Konoplev A. Fukushima and Chernobyl: Similarities and Differences of Radiocesium Behavior in the Soil–Water Environment Toxics. 2022;10(10):578. doi: 10.3390/toxics10100578.
4. Maidanyuk VP, Volianskyi PB, Pechiborshch VP et al. Viyna y teroryzm: medyko-sanitarni naslidky ta derzhavne rehulyuvannya medychnym zakhystom naselennya [War and terorism: health consequences and state regulation of the population medical protection]. Current Issues of Transport Medicine. 2023;3(73):7-20. doi: 10.5281/zenodo.8254462. (Ukrainian)
5. Burgio E, Piscitelli P, Migliore L. Ionizing Radiation and Human Health: Reviewing Models of Exposure and Mechanisms of Cellular Damage. An Epigenetic Perspective. International Journal of Environmental Research and Public Health. 2018;15(9):1971. doi: 10.3390/ijerph15091971.
6. Moroz VM, Shandra OA, Vastyanov RS, et al. Physiology. Vinnytsia: Nova Knyha. 2016, p.722.
7. Wei Z, Edin J, Karlsson AE, et al. Can gamma irradiation during radiotherapy influence the metal release process for biomedical CoCrMo and 316L alloys? J Biomed Mater Res B Appl Biomater. 2018;106(7):2673-2680.
8. Stepanov GF, Kostina AA, Dimova AA. Porivnialna kharakterystyka terminalnoi lanky hlikolizu v miazakh statevozrilykh tvaryn ta yikhnikh nashchadkiv [Comparative characteristics of the terminal link of glycolysis in the muscles of sexually mature animals and their offspring]. Odesa Medical Journal. 2021;5:9-13. (Ukrainian)
9. Stepanov GF, Vastyanov RS The peculiarities of low dose ionizing radiation influence on muscles metabolism in experimental animals. World of Medicine and Biology. 2023;2(84):233-238.
10. Mardashko OO, Popyk GS, Storchilo OV. Sposib korektsii homeostazu orhanizmu, yakyi zaznav vplyvu radiatsiinoho urazhennia [A method of correcting the homeostasis of an organism affected by radiation damage]. Ukraine Patent UA 68126. 2004, p.4. (Ukrainian) https://sis.ukrpatent.org/uk/search/detail/378445/ [data access 11.04.2023]
11. Kodali ST, Kauffman P, Kotha SR et al. Oxidative Lipidomics: Analysis of Oxidized Lipids and Lipid Peroxidation in Biological Systems with Relevance to Health and Disease. In L. J. Berliner (Eds.) et al. Measuring Oxidants and Oxidative Stress in Biological Systems. Springer. 2020:61-92.
12. Armario A. The forced swim test: Historical, conceptual and methodological considerations and its relationship with individual behavioral traits. Neurosci Biobehav Rev. 2021;128:74-86.
13. Babov KD, Khomenko IP, Tertyshnyi SV et al. Orhanizatsiya etapnoyi reabilitatsiyi viys'kovosluzhbovtsiv z vohnepal'nymy defektamy m"yakykh tkanyn na rivnyakh nadannya medychnoyi dopomohy [Organization of staged rehabilitation of servicemen with gunshot defects of soft tissues at the levels of providing medical assistance]. Medical Perspectives. 2021;26(4):188-195. (Ukrainian)
14. Fix DK, Hardee JP, Bateman TA et al. Effect of irradiation on Akt signaling in atrophying skeletal muscle. Journal of applied physiology. 2016;121(4):917-924.
15. Azzam EI, Colangelo NW, Domogauer JD et al. Is Ionizing Radiation Harmful at any Exposure? An Echo That Continues to Vibrate. Health physics. 2016;110(3):249-251.

16. Stotska SV, Moisienko VV, Kotkova TM et al. Zastosuvannia likarskykh roslyn pry radiohennykh zakhvoryuvanniakh [Use of medicinal plants in radiogenic diseases]. Chornobylska katastrofa. Aktualni problemy, napriamky ta shliakhy yikh vyrishennia. Zhytomyr : Poliskyi universytet. 2021, pp.174-177. (Ukrainian)
17. Liu L, Liang Z, Ma S, et al. Radioprotective countermeasures for radiation injury (Review). Molecular medicine reports. 2023;27(3):66. doi.org/10.3892/mmr.2023.12953.

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The Authors declare no conflict of interest.

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