CHANGES IN THE GENERAL CONDITION AND BLOOD INDICATORS OF MICE IN THE LONG PERIOD AFTER IRRADIATION OF CHEST

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Abstract. A study was made of the general condition, changes in the relative mass of internal organs and blood parameters of C57Bl/6 mice 3 months after local irradiation of the chest. Irradiation was carried out in five equal fractions with total doses of 5, 10 and 20 Gy. Single cases of death of irradiated animals were noted in each group 2 months after irradiation. 90 days after irradiation, an increase in the relative mass of the lung was noted in all groups of irradiated animals, as well as a decrease in the relative mass of the spleen and liver. A decrease in the number of platelets in all groups after irradiation was established, as well as a change in erythrocyte indices, which was most pronounced in groups irradiated at doses of 10 and 20 Gy. An increase in the activity of transaminase enzymes in the blood serum of animals depending on the dose of irradiation, an increase in the activity of LDH and phosphatases, as well as a decrease in the level of total protein were noted, which indicates damage to the organs of the thoracic region and liver and persistent metabolic disorders in animals 90 days after local irradiation.

Keywords: hematological parameters of blood, blood enzymes, ionizing radiation, laboratory animals, mice.

List of Abbreviations

IR – ionizing radiation
DNA– deoxyribonucleic acid
MCV – mean corpuscular volume
MCH – mean corpuscular hemoglobin
MCHC – mean corpuscular hemoglobin concentration
AST – aspartate aminotransferase
ALT – alanine aminotransferase
LDH – lactate dehydrogenase
CPK – creatine phosphokinase
ALP – alkaline phosphatase
TP – total protein

Introduction

The action of ionizing radiation (IR) manifests itself at all levels of biological organization at the level of macromolecules, cells, tissues, organs, and the whole organism (Burlakova *et al*., 1996).

As a result of the impact of ionizing radiation on the human body, complex physical, chemical and biological processes can occur in the tissues. Changes in the chemical composition of the tissue resulting from the destruction of a significant number of molecules can lead to the death of these cells (Kharlap *et al*., 2015; Johnson, 2013). Moreover, many radiations penetrate very deeply and can cause ionization, and, consequently, damage to cells in deeply located parts of the body. Changes in the cell nucleus under the influence lead to inhibition of DNA synthesis. Single-strand and double-strand breaks occur, leading to chromosomal aberrations. Gene mutations appear. As a result of exposure to ionizing radiation, the normal course of biological processes and metabolism in the body are disturbed (Burlakova *et al*., 1996; Vlasova *et al*., 2022).

Depending on the irradiation dose and duration of exposure, as well as on the individual characteristics of the organism, these changes can be reversible, in which the affected tissue restores its functional activity, or irreversible, which will lead to damage to individual organs or the whole organism (Ivanov *et al*., 2014). The duration of irradiation has a great influence on the effect of irradiation, while not even the dose, but the dose rate of irradiation is of decisive importance. Therefore, fractional exposure to lower doses is less detrimental than receiving the same exposure dose during a single exposure to a total exposure dose (Igisheva & Litvinenko, 2014; Kidun *et al*., 2014).

Much of the research in this area is carried out in experimental models of radiation exposure using laboratory animals, and strain mice are most commonly used. Among the used lines, C57Bl/6 is used in almost 85% of cases, since according to a number of indicators of the development of post-radiation pathology, it most closely matches the changes observed in people after irradiation of the thoracic organs (Kostryukova & Karpin, 2005). Mouse tissues have similar organizational structures to human tissues and therefore develop similar pathologies in terms of early and late radiation toxicity. Normal tissue damage involves a complex pathogenic cascade that affects tissue homeostasis and is dependent on immune status, vascular integrity, cytokine signaling, and levels of oxidative stress (Robbins & Zhao, 2004).

The composition and properties of blood characterize the state of homeostasis of the body and all the parameters involved in ensuring the vital activity of cells and tissues. Quantitative indicators of blood reflect the changes taking place in the body depending on the physiological status and the level of development of the pathology. A biochemical blood test, in particular, allows you to determine the degree of damage in the work of various organs.

There are general patterns in changes in the qualitative and quantitative composition of peripheral blood under the influence of ionizing radiation. Due to the high sensitivity of bone marrow cells associated with their intensive division and differentiation, the decrease in the number of formed elements in peripheral blood occurs earlier and more intensely, the higher the radiation dose (Dabjan, 2016; Shin, 2020).

A decrease in the number of blood cells in laboratory animals under the action of ionizing radiation in doses of 5–10 Gy is accompanied by the activation of compensatory mechanisms, which are expressed in accelerating the maturation of cells in the bone marrow and reducing their viability (Ponomarenko *et al*., 2014; Fomenko *et al*., 2013).

Thus, the conducted studies were based on the principle of a comprehensive analysis of biochemical and hematological parameters of blood serum, determination of enzyme activity, organ mass in laboratory animals under IR at different doses in comparison with clinically healthy animals. This made it possible to establish the nature of the pathological process, the severity and direction of changes (Kostryukova & Karpin, 2005).

Materials and Methods

The experiments were performed on the basis of the State Scientific Institution "Institute of Radiobiology of the National Academy of Sciences of Belarus". The studies were carried out on laboratory mice of the C57Bl/6 line of both sexes at the age of 2.5-3 months. The animals were kept in a stationary vivarium on a full standard diet and free access to water, 12/12-hour light and dark, according to established standards. The experiments were carried out in accordance with the international recommendations of Directive 2010/63/EU of the European Parliament and of the Council of the European Union on the protection of animals used for scientific purposes of September 22, 2010 (Directive of the European Parliament, 2010).

The following experimental groups of animals were identified: 1 – control (all manipulations were performed except for irradiation); 2 – irradiation of the thoracic region at a dose of 1 Gy once a day for 5 days (the total irradiation dose was 5 Gy); 3 – irradiation of the thoracic region at a dose of 2 Gy once a day for 5 days (the total dose of irradiation was 10 Gy); 4 – irradiation of the thoracic region at a dose of 4 G once a day for 5 days (total irradiation dose was 20 Gy) (Fig. 1). Each group consisted of 10 animals (5 females and 5 males).

Mice were irradiated using an X-Rad 320 Precision X-ray Inc (USA) biological X-ray machine; the average dose rate was 98.8 c Gy/min, the distance to the object was 50 cm. Local irradiation of the thoracic region of the animal was achieved by shielding with protective plates.

The clinical condition of the animals was monitored throughout the experimental period. Animals were taken out of the experiment on day 90 after irradiation by decapitation under deep ether anesthesia. Blood sampling, autopsy, examination, isolation and weighing of

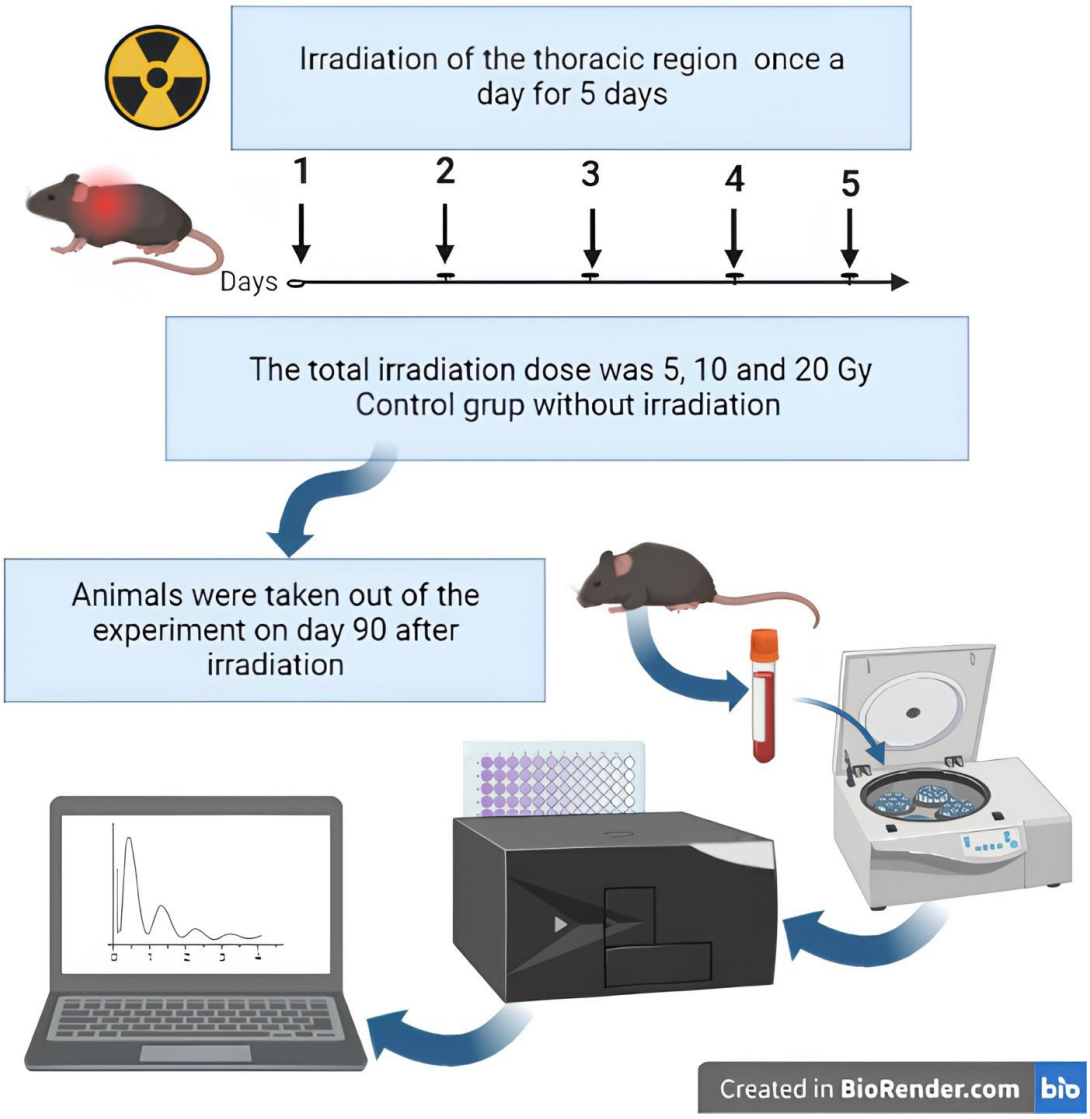

Fig. 1. Scheme of the experiment to study the effect of local irradiation of the thoracic region of mice on blood parameters

internal organs were carried out, after which the organs mass indices (gram organ weight per gram body weight multiplied by 100) was calculated: heart, lungs, liver, spleen.

Complete blood count was performed using a Celltac MEK-63-18J/K hematological analyzer (Japan). Analysis of blood biochemical parameters was determined on a Tecan Infinite M200 microplate reader (Tecan Ltd., Switzerland) using 96-well microplates (SARSTEDT) and specialized Tecan Magellan software (v 7.2).

In the blood of laboratory mice, the following hematological parameters were determined: the number of leukocytes, erythrocytes, hemoglobin, hematocrit, MCV, MCH, MCHC, platelets. In the blood serum of laboratory mice, the activity of the ALT, AST, LDH, CPK, and ALP enzymes was determined using the Diasens commercial kits (Belarus), and the TP concentration using the Fenox commercial kit (LLC Arvitmedicl, Belarus).

Statistical processing of the obtained material was carried out using the STATISTICA 10.0 application package. Since the data did not obey the law of normal distribution according to the Kolmogorov-Smirnov criterion, they were presented in the format Me (25%÷75%),

where Me is the median, 25% is the lower percentile, 75% is the upper percentile, and when comparing 2-x independent groups used a non-parametric method – Mann-Whitney U-test. Differences were considered statistically significant at $p < 0.05$ (Platonov, 2000).

Results

During the observation period (3 months after irradiation), the death of animals was noted in one individual, in groups irradiated at doses of 5 and 10 Gy and 2 individuals in the group – 20 Gy.

Animals of all groups exposed to irradiation had a reduced increase in body weight compared to the control group. At the same time, in groups of animals irradiated at doses of 10 and 5 Gy for 3 months after irradiation, the increase in body weight was positive and did not differ significantly from the control level. When irradiated at a dose of 20 Gy, the increase in body weight was significantly reduced compared to the control group.

Analyzing the indices of organ mass, it was found that in animals irradiated at a dose of 5 Gy, 3 months after irradiation, compared with the control, the relative mass of the heart significantly decreased from 0.50 (0.48÷0.53)% to 0.44 (0.38÷0.47)% ($p < 0.01$) and the relative mass of the spleen from 0.34 (0.28÷0.37)% to 0.25 (0.24÷0.29)% ($p < 0.01$) (Table 1).

In the group of animals irradiated at a total dose of 10 Gy, only a significant increase in the lung mass index ($p = 0.02$) in comparison with animals of the control group.

When mice were irradiated at a dose of 20 Gy, the animals showed a significant increase in the relative mass of the lung to 0.71 (0.68÷0.73)% ($p < 0.01$), as well as a significant decrease in the relative mass of the liver from 4.35 (4.04÷4.60)% to 4.19 (3.97÷4.20)% ($p < 0.05$) and relative weight of the spleen from 0.34 (0.28÷0.37)% to 0.26 (0.24÷0.28)% ($p < 0.01$).

At the same time, in laboratory animals irradiated at a dose of 5 Gy, a significant decrease in the lung mass index was observed from 0.69 (0.64÷0.73)% to 0.62 (0.59÷0.63)% ($p < 0\ 0.01$) and spleen mass from 0.31 (0.30÷0.36)% to 0.25 (0.24÷0.29)% ($p < 0.01$) compared with animals of the group irradiated in total dose of 10 Gy. Also, in mice irradiated at a dose of 5 Gy, a decrease in lung mass index was observed from 0.71 (0.68 0.73)% to 0.62 (0.59÷0.63)% ($p < 0.01$) by compared with mice of the group irradiated at a dose of 20 Gy.

In the group of animals exposed to irradiation at a dose of 20 Gy, there was a decrease in the mass index of the spleen from 0.31 (0.30÷0.36)% to 0.26 (0.24÷0.28)% ($p < 0.01$)

Table 1

Organ mass indices (%) of mice of the C57Bl/6 line 3 months after local fractionated irradiation of the thoracic region

Examined internal organs	Experimental groups			
	Control group	Irradiated mice at a dose of 5 Gy	Irradiated mice at a dose of 10 Gy	Irradiated mice at a dose of 20 Gy
Heart	0.50 (0.48÷0.53)	0.44 (0.38÷0.47)*	0.47 (0.46÷0.52)*	0.48 (0.41÷0.50)*
Lung	0.59 (0.48÷0.67)	0.62 (0.59÷0.63)*,**	0.69 (0.64÷0.73)*	0.71 (0.68÷0.73)*,#
Liver	4.35 (4.04÷4.60)	4.27 (3.30÷4.61)*	4.27 (4.15÷4.65)*	4.19 (3.97÷4.20)*
Spleen	0.34 (0.28÷0.37)	0.25 (0.24÷0.29)*,**	0.31 (0.30÷0.36)*,##	0.26 (0.24÷0.28)*

Note: * – significant differences between control group and a mentioned group by Mann-Whitney U-test,

** – significant differences between groups of mice irradiated at doses of 5 Gy and 10 Gy by Mann-Whitney U-test,

– significant differences between groups of mice irradiated at doses of 5 Gy and 20 Gy by Mann-Whitney U-test,

– significant differences between groups of mice irradiated at doses of 10 Gy and 20 Gy by Mann-Whitney U-test.

Table 2

Hematological blood parameters of C57Bl/6 mice 3 months after local fractionated irradiation of the thoracic region

Indicator	Control group	Irradiated mice at a dose of 5 Gy	Irradiated mice at a dose of 10 Gy	Irradiated mice at a dose of 20 Gy
Number of white blood cells (10^9/l)	5.56 (3.90÷8.80)	4.90 (3.7÷6.10)	4.40 (2.70÷9.31)	4.00 (3.30÷8.41)
Number of red blood cells (10^{12}/l)	8.15 (7.89÷8.41)	7.48 (7.25÷7.91) *	8.12 (7.00÷8.68) *	8.00 (7.71÷8.23) *
Amount of hemoglobin (g/l)	118.50 (116.00÷120.00)	113.00 (104.00÷123.00)	113.50 (106.00÷123.00)	118.00 (116.00÷119.00)
Hematocrit (%)	39.90 (39.20÷40.80)	38.00 (35.90÷42.60)	40.60 (34.90÷43.20)	40.80 (40.40÷41.09)
MCV (g/l)	49.00 (48.20÷49.50)	51.00 (49.20÷51.60) *	50.30 (49.40÷51.60) *	50.70 (49.60÷52.00) *
MCH (g/l)	14.40 (14.10÷14.90)	14.80 (14.30÷15.20)	14.50 (14.10÷15.10)	14.80 (14.30÷15.30)
MCHC (g/l)	294.50 (291.00÷300.00)	290.50 (290.00÷295.00) *,#	286.00 (281.00÷298.00) *	286.00 (282.00÷287.00) *
Platelet count (10^9/l)	439.50 (370.00÷538.00)	138.50 (105.00÷317.00) *	293.00 (156.00÷355.00) *	278.00 (136.00÷427.50) *

Note: * – significant differences between control group and a mentioned group by Mann-Whitney U-test,
– significant differences between groups of mice irradiated at doses of 5 Gy and 20 Gy by Mann-Whitney U-test.

Table 3

Biochemical blood parameters of C57Bl/6 mice 3 months after local fractionated irradiation of the thoracic region

Indicator	Control group	Irradiated mice at a dose of 5 Gy	Irradiated mice at a dose of 10 Gy	Irradiated mice at a dose of 20 Gy
ALT (u/l)	62.06 (48.92÷78.10)*	83.53 (38.74÷118.08)**	145.08 (76.88÷207.36)	132.99 (80.50÷168.72)#
AST (u/l)	137.62 (103.07÷163.98)*	174.82 (120.92÷191.62)	191.49 (123.15÷228.27)	132.99 (80.50÷168.77)
LDH (u/l)	2376.68 (2019,1÷2147,7)*	2963.25 (2146.4÷4019.0)	2958.92 (2189.62÷3286.53)	3614.75 (2451.95÷3703.68)
CPK (u/l)	149.93 (67.56÷191.67)	169.70 (91.72÷197.45)	169.80 (126.90÷180.38)	185.93 (149.27÷231.96)
ALP (u/l)	194.583 (161.68÷228.16)*	285.99 (203.87÷379.40)	308.36 (166.31÷362.86)##	528.24 (354.45÷681.23)#
TP (g/l)	67.40 (60.83÷71.17)*	66.16 (61.89÷69.72)	61.04 (53.26÷70.08)	44.98 (31.10÷65.55)#

Note: * – significant differences between control group and a mentioned group by Mann-Whitney U-test,
** – significant differences between groups of mice irradiated at doses of 5 Gy and 10 Gy by Mann-Whitney U-test,
# – significant differences between groups of mice irradiated at doses of 5 Gy and 20 Gy by Mann-Whitney U-test,
– significant differences between groups of mice irradiated at doses of 10 Gy and 20 Gy by Mann-Whitney U-test.

compared to mice irradiated at a total dose of 10 Gy (Table 1).

Changes in hematological blood parameters in animals irradiated with ionizing radiation at a total dose of 5 Gy compared with the control were expressed in a significant decrease in erythrocytes ($p = 0.04$) and platelets ($p < 0.01$) (Table 2).

In the study of blood parameters in animals irradiated at a dose of 10 Gy, significant changes in the following hematological parameters were established compared with the control: the MCV value increased significantly ($p < 0.03$), the number of platelets decreased ($p = 0.02$), and there was also a downward trend in MCHC ($p = 0.06$).

In the group of animals irradiated with IR at a total dose of 20 Gy, similar changes in blood parameters were revealed, as in animals irradiated at a dose of 10 Gy. In mice of this group, compared with the control, a significant increase in MCV was observed ($p < 0.05$), a significant decrease in MCHC ($p < 0.01$) and a significant decrease in platelets ($p < 0.05$).

When comparing the obtained results of a general blood test in animals in the studied groups, only a significant decrease in the level of MCHC by 2.0% ($p < 0.01$) was revealed in individuals irradiated at a dose of 20 Gy compared with individuals irradiated at a dose of 5 Gy (Table 2).

As a result of a biochemical analysis of the blood of mice, it was found that in irradiated animals at a total dose of 5 Gy, 3 months after irradiation, a significant increase in LDH activity was observed ($p < 0.05$) and ALP activity ($p < 0.05$) compared to control group (Table 3).

Mice of the experimental group irradiated at a dose of 10 Gy showed a significant increase in ALT activity ($p = 0.02$), AST ($p < 0.05$), LDH ($p = 0.02$), as well as the tendency to increase ALP ($p = 0.07$) compared with laboratory animals of the control group.

Changes in blood biochemical parameters in the group of mice irradiated at a dose of 20 Gy compared with animals in the control group were manifested in a significant increase in AST activity ($p < 0.01$), LDH ($p = 0.02$), ALP ($p < 0.01$) and in a significant decrease in concentration TP ($p = 0.02$).

As a result of comparing the biochemical parameters of the blood of mice in groups of 10 and 5 Gy, there is only a tendency to increase the activity of the ALT enzyme by 42.4% ($p = = 0.08$) in animals irradiated at a dose of 10 Gy compared with irradiated animals at a dose of 5 Gy .

In mice irradiated at a dose of 20 Gy, compared with animals irradiated at a dose of 5 Gy, a significant increase in ALP activity by 45.8% ($p = 0.02$), a significant decrease in the amount of TP by 32.0% ($p = 0.02$), and there was also a trend towards an increase in ALT activity by 37.2% ($p = 0.09$).

The biochemical parameters of the blood of animals irradiated at doses of 10 and 20 Gy had similar indicators, only in the irradiation group of 20 Gy a significant increase in the activity of the ALP enzyme by 41.6% ($p < < 0.05$) was noted compared with mice irradiated at a dose of 10 Gy.

Discussion

A study was made of the general condition and peripheral blood parameters of C57Bl/6 mice that were subjected to local irradiation of the thoracic region with five equal fractions with total radiation doses of 5, 10, and 20 Gy. The applied irradiation regimen did not cause significant death of the animals. A decrease in body weight gain was noted only in the group of animals irradiated at a dose of 20 Gy.

Changes in organ mass indices were expressed in a significant increase in lung weight in animals of the groups exposed to irradiation with 10 and 20 Gy ($p < 0.05$), which, apparently, was due to an inflammatory process in the lungs in response to high doses of radiation.

A decrease in the liver mass of animals irradiated at a dose of 20 Gy ($p < 0.05$) may be the result of exposure to the radiation factor, leading to an increase in the formation of free radicals, which can lead to an “attack” of liver cells and their contents by free radicals with the development of inflammation and impaired liver functions.

In this experiment, C57Bl/6 mice were subjected to local irradiation of the thoracic region, but as a result, more than half of the animals'

bone marrow, which functions as a hematopoietic organ, was irradiated. The sternum and forelimbs fell into the irradiation zone, which caused significant changes in hematological parameters that persisted up to 3 months after irradiation. A significant decrease in the relative mass of the spleen in animals irradiated at doses of 5 and 20 Gy ($p < 0.05$) is possibly associated with compensatory-adaptive reactions in response to irradiation of a significant part of the bone marrow and a decrease in bone marrow hematopoiesis.

Also, as a result of the study, it was found that in experimental animals of all groups exposed to irradiation, compared with the control, there was a significant decrease in the number of platelets ($p < 0.05$), which may indicate a violation of hematopoiesis associated with exposure to the radiation factor. Changes in the number of erythrocytes were expressed in a significant decrease in the content of these formed elements in mice irradiated at a dose of 5 Gy ($p = 0.04$), and in mice irradiated at doses of 10 and 20 Gy, a significant increase in MCV was observed ($p < 0.05$) and a significant increase in MCHC ($p < 0.05$). Such changes in animals may be associated with the inclusion of compensatory mechanisms for a decrease in the number of erythrocytes by increasing the total size of erythrocytes (reflects the MCV index), and an increase in the concentration of hemo-globin in erythrocytes (reflects the MCHC index) ($p < 0.05$).

Comparative characteristics of blood biochemical parameters in animals of the studied groups revealed a significant increase in the activity of aminotransferases (ALT and AST), LDH, ALP ($p < 0.05$) in mice of all experimental groups and a decrease in the amount of TP ($p = 0.02$) in animals, irradiated at a dose of 20 Gy compared with the control group.

An increase in the activity of AST and ALT in the blood of mice of the experimental groups indicates damage to the liver tissue, due to both direct and indirect effects of ionizing radiation. This statement is supported by the simultaneous decrease in TP in animals that received the maximum irradiation dose (20 Gy).

An increase in the activity of AST, LDH and ALP in the blood of animals after irradiation can be caused to a greater extent by the developing long-term effects of irradiation of the organs of the thoracic region (heart and lungs) and the liver.

Thus, local fractionated irradiation of the thoracic region of C57Bl/6 mice at total doses of 5, 10, and 20 Gy causes effects not only in the tissues and organs of the irradiation zone, but also affects the state of the animal organism as a whole.

90 days after local irradiation, changes in hematological and biochemical parameters of the peripheral blood of animals are noted, indicating persistent and/or developing pathological processes in the organs of the chest and liver.

References

BURLAKOVA E.B., GOLOSHCHAPOV N.V. & GORBUNOVA N.V. (1996): Features of the biological effect of small doses of irradiation. *Radiation. Biology. Radioecology* **36**(4), 610–631.

DABJAN M.B. (2016): A survey of changing trends in modeling radiation lung injury in mice: bringing out the good, the bad and the uncertain. *Laboratory Investigation* **9**, 936–949.

DIRECTIVE of the European Parliament and of the Council on the Protection of animals used for Scientific purposes of the European Union, September 22, 2010, No. 63: Official Journal of the European Union, **63**, 276/33.

FOMENKO S.E., KUSHNEROVA N.F., SPRYGIN V.G. & MOMOT T.V. (2013): Violation of metabolic processes in the liver of rats under stress. *Pacific Medical Journal* **2**, 67–70.

IGISHEVA A.L. & LITVINENKO V.V. (2014): The effect of the effective irradiation dose during X-ray examinations on the human body: Non-destructive testing. *Proceedings of the V All-Russian Scientific and Practical Conference of Students, postgraduates and young scientists "Non-destructive testing: electronic instrumentation, technology, safety"* **2**, 132–134.

IVANOV S.I., KOTOV N.N. & AKOPOVA N. A. (2014): Biological effects of low doses of irradiation. *Ministry of Health of the Russian Federation: GBOU DPO "Russian Medical Academy of Postgraduate Education"* **72**.

JOHNSON T.V. (2013): Systematic review of evidence of the relationship between chronic psychosocial stress and C-reactive protein. *Mol. Diagnosis. Ibid.* **25**, 137–148.

KIDUN K.A., LITVINENKO A.N., UGOLNIK T.S., GOLUBYKH N.M. & SOLODOVA E.K. (2014): Changes in biochemical parameters of blood serum in Wistar rats undergoing chronic stress. *Health and environmental problems* 62–67.

KOSTRYUKOVA N.K. & KARPIN V.A. (2005): Biological effects of low doses of ionizing radiation. *Siberian Medical Journal* **50**(1), 17–22.

KHARLAP S.Y., DERKHO M.A. & SEREDA T.I. (2015): Changes in the activity of aminotransferases and alkaline phosphatase in the blood and kidneys of chickens during the development of a stress reaction. *Proceedings of Orenburg State Agrarian University* **5**(55), 102–105.

PLATONOV A.E. (2000): *Statistical analysis in medicine and biology: tasks, terminology, logic, computer methods.* Moscow: RAMS, 52 pp.

PONOMARENKO O.V., CHERNOBAI E.N., GUZENKO V.I., KONOPLEV V.I. & MARINICH A.P. (2014): The influence of the stress factor on the physiological and biochemical parameters of pregnant sheep and the productive qualities of offspring. *Bulletin of Agroindustrial Complex of Stavropol* **4**, 140–145.

ROBBINS M.E. & ZHAO W. (2004): Chronic oxidative stress and radiation-induced late normal tissue injury: a review. *Int. J. Radiat. Biol.* **4**(80), 251–259.

SHIN E., LEE S., KANG H., KIMJ., KIM K., YUN H., JINIV., SEO S. & YUN B. (2020): Organ-specific effects of exposure to low doses of radiation: a comprehensive review. *Frontiers in Genetics* **11**. doi: 10.3389/fgene.2020.566244.

VLASOVA N.G., DROBYSHEVSKAYA V.V., DROZD E.A., BUZDALKINA A.M. & YEVTUSHKOVA G.N. (2022): Irradiation doses to the population of the Gomel region from medical X-ray diagnostics before and at the beginning of the COVID-19 pandemic. *Biomedical problems of vital activity* **2**(28), 35–40.