

**REPUBLIC OF AZERBAIJAN**

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**PHYSIOLOGICAL-BIOCHEMICAL INDICATORS OF  
BLOOD IN ORGANISM AFFECTED BY MICROWAVES  
DURING PRENATAL DEVELOPMENT IN THE  
EXPERIMENTAL MODEL**

Specialty: 2411.01 – Human and Animal Physiology

Field of Science: Biology

Applicant: Aynur Teymur Guliyeva

**ABSTRACT**

of the dissertation for the degree of Doctor of Philosophy

**Baku – 2025**

The dissertation was carried out in Radiation Physiology Laboratory at the Institute of Physiology named after Academician Abdulla Garayev of the Ministry of Science and Education of the Republic of Azerbaijan.

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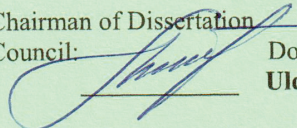
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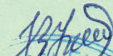
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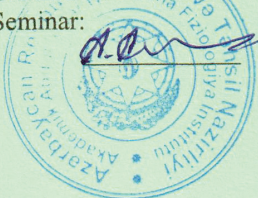
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## GENERAL CHARACTERISTICS OF THE STUDY

**Actuality and problem of the study.** In modern times, the intensive use of electrical and electromagnetic energy has led to a multiple increase of the electromagnetic background in the environment. As a result, exposure to electromagnetic radiation (EMR) causes changes in the organism at physiological, biochemical, and morphological levels. According to literature data, the nervous, endocrine, immune, and reproductive systems of the organism are more sensitive to EMR. EMR poses a particular risk to children and pregnant women, since the organism of an underdeveloped child is extremely sensitive to the influence of such fields<sup>1</sup>. At the same time, exposure during the prenatal period may result in intrauterine growth retardation, fetal death, the formation of congenital developmental defects, and alterations of the developmental program of the organism during ontogenesis<sup>2</sup>. Some studies have also shown that low-frequency EMR negatively affects the reproductive system of female rats, for example, reducing the number of mature blastomeres and increasing the size of epithelial cells in the fallopian tubes. Radiation can cause changes in the uterus and ovaries of rats, affect follicle development and ovarian maturation, and may lead to congenital anomalies, miscarriages, and premature births<sup>3</sup>. It has also been established that exposure to EMR during the first 20 days of pregnancy reduces the number of embryos.

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<sup>1</sup> Григорьев, Ю.Г. Мобильная связь и здоровье детей: проблема третьего тысячелетия / Ю.Г. Григорьев, А.С. Самойлов, А.Ю. Бушманов, Н.И. Хорсева // Медицинская радиология и радиационная безопасность. - 2017. - Т. 62, № 2. - с. 39-46

<sup>2</sup> Лепехина А.С. Роль электромагнитных излучений в формировании синдрома задержки внутриутробного развития плода / А.С.Лепехина.// Биомедицинская инженерия и электроника, - 2012. № 2 (2), -с. 7-11.

<sup>3</sup> Cao Y, Zhang Y, Liu Y. Effects of exposure to extremely low frequency electromagnetic fields on reproduction of female mice and development of offsprings. Zhonghua lao dong wei sheng zhi ye bing za zhi = Zhonghua laodong weisheng zhiyebing zazhi // Chin J Ind Hyg Occup Dis. – 2006. -24(8), -p.468–470.

Another study showed that exposure to electromagnetic fields during embryonic development causes morphological changes in oocytes, leading to a reduction in the ovarian reserve and resulting in infertility or decreased fertility<sup>4</sup>. It has also been shown that EMR, including radiation emitted by mobile phones, can cause various types of damage to chromosomes and the entire human genome<sup>5</sup>. At the same time, it has been noted that electromagnetic radiation has the potential to damage cell organelles, particularly mitochondria, by inducing oxidative stress<sup>6</sup>.

It is known that a developing organism has a high level of oxidation and energy metabolism, which is accompanied by the generation of additional reactive oxygen and nitrogen species. In this case, the main function of the antioxidant system is to maintain the concentration of reactive oxygen species - molecules that participate in vital processes such as cell proliferation and differentiation - at a stable level. When antioxidants are deficient in the organism, oxidative stress processes develop, leading to shifts in the oxidant-antioxidant system<sup>7</sup>. From this perspective, the study of total oxidant and antioxidant activity during different stages of prenatal development is of great importance. The study of sensitivity to EMR during various stages of prenatal development, as well as clarification of the patterns of the effects of low-intensity EMR on the organism under both normal and pathological conditions, is of significant scientific and practical interest and stands out in terms of relevance.

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<sup>4</sup> de Vocht F, Hannam K, Baker P, Agius R. Maternal residential proximity to sources of extremely low frequency electromagnetic fields and adverse birth outcomes in a UK cohort // *Bioelectromagnetics*, - 2014, -35(3), -p.201–209.

<sup>5</sup> Jagetia, G. C. Genotoxic effects of electromagnetic field radiations from mobile phones // *Environmental Research*, - 2022.- 212(D), -p. 113321.

<sup>6</sup> Santini, S.J., Cordone, V., Falone, S. et al. Role of mitochondria in the oxidative stress induced by electromagnetic fields: Focus on reproductive systems // *Oxidative Medicine and Cellular Longevity*, - 2018, - 5076271.

<sup>7</sup> Gadzhiev A.M., E.Yu. Yusifov, M.T. Abbasova et al., “The study of microwave irradiation oxidative effect on living organism,” *Modern Problems of Comparative Physiology and Biochemistry*, Baku: - 2005, -p.278-290.

**The object and subject of research.** In the dissertation, a comparative study was carried out on a number of physiological and biochemical indicators in offspring obtained from mother rats exposed to electromagnetic radiation during different stages of prenatal development, compared with the norm.

**Purpose and objectives of the study.** The purpose of the study was to investigate the effects of exposure to decimeter-range electromagnetic radiation during prenatal development on the “lipid peroxidation–antioxidant defense” system and leukocyte morphology in the blood of rat offspring.

To achieve this purpose, the following research objectives were set:

1. To study the intensity of lipid peroxidation (LPO) processes in the blood on the 20th and 30th days of postnatal development in offspring obtained from mothers exposed to EMR during different stages of prenatal development;

2. To study the levels of hemoglobin and total protein in the blood on the 20th and 30th days of postnatal development in offspring obtained from mothers exposed to EMR during different stages of prenatal development;

3. To study the total oxidant activity and total antioxidant activity in plasma and erythrocytes of 20- and 30-day-old offspring obtained from mothers exposed to EMR during different stages of prenatal development;

4. To study the concentration of reduced glutathione in erythrocytes on the 20th and 30th days of postnatal development in offspring obtained from mothers exposed to EMR during different stages of prenatal development;

5. To study the activity of antioxidant enzymes (catalase, superoxide dismutase) in plasma and erythrocytes on the 20th and 30th days of postnatal development in offspring obtained from mothers exposed to EMR during different stages of prenatal development;

6. To study the morphology of leukocytes in the blood on the 20th and 30th days of postnatal development in offspring obtained from mothers exposed to EMR during different stages of prenatal

development.

**Main provisions submitted for defense:**

1. The oxidative effects of non-ionizing decimeter-range electromagnetic radiation on the pregnant organism are reflected in fertility and hematological parameters.

2. Changes in the “lipid peroxidation–antioxidant defense” system of the blood and their dependence on the period of radiation exposure are observed in the early ontogenesis of rat offspring exposed to decimeter-range electromagnetic radiation during prenatal development.

3. On the 20th and 30th days of postnatal development, offspring obtained from mothers exposed to electromagnetic radiation during pregnancy show the emergence of stress characterized by changes (imbalance) in free radical oxidation (lipid peroxidation), oxidant and antioxidant activity (total oxidant and antioxidant activity, glutathione, catalase, SOD), as well as age-related dynamics.

4. The shift of exposure to EMR during prenatal development from the embryonic stage to the pre-fetal stage leads to a delay in the formation of a new oxidant/antioxidant balance in plasma during postnatal ontogenesis; that is, the balance characteristic of 20-day rats for irradiation during the embryonic period is observed in 30-day puppies for irradiation during the pre-fetal period.

5. In the early ontogenesis of rat offspring exposed to EMR during prenatal development, changes are observed in the morphological composition of leukocytes, mainly characterized by an increase in the relative number of lymphocytes and a decrease in monocytes, and these changes correlate with the redox status of the blood.

**Scientific novelty of the research.** For the first time, the status of the “lipid peroxidation - antioxidant defense” system and the morphological composition of blood were studied in offspring born to mothers exposed to low-intensity non-ionizing electromagnetic radiation (460 MHz frequency).

As a result of exposure to electromagnetic radiation during 3 stages of prenatal development – embryonic, pre-fetal, and fetal

stages, the shifts in the oxidant-antioxidant balance in plasma and erythrocytes were detected in the early ontogenesis of offspring, compared with age-matched intact control rat pups.

Based on measurements of the concentration of lipid peroxidation products in blood, total oxidant and antioxidant activity, and enzymatic antioxidant activity in pups on postnatal days 20 and 30 obtained from mothers exposed to decimeter-range electromagnetic radiation at different prenatal stages, it was shown that delays occur in the formation of the redox state depending on the prenatal developmental stage during which exposure occurred. For instance, the balance characteristic of 20-day-old pups exposed during the embryonic period appears in 30-day-old pups when exposure occurs during the pre-fetal period.

For the first time, the effects of low-intensity (non-thermal) non-ionizing electromagnetic radiation, commonly used in physiotherapy, on different stages of intrauterine development were analyzed in terms of changes in the leukocyte formula and discussed in the context of free radical processes occurring in the organism.

**Theoretical and practical significance of the study.** The results of this dissertation expand the knowledge base regarding the role of free radical processes in mediating the effects of non-ionizing electromagnetic fields and radiation on living organisms. They provide new scientific evidence for understanding the pro- and antioxidant effects of electromagnetic exposure on organisms, as reflected in the physiological and biochemical parameters of blood. The experimental substantiation of these effects contributes fundamentally and practically to research in electromagnetic biology and medical applications of electromagnetic fields.

From a practical perspective, the findings of this study can serve as a theoretical basis for developing scientifically grounded preventive measures and recommendations for diagnosing and mitigating the impact of certain technogenic factors, including electromagnetic fields, on pregnancy. The results may also be applied in postgraduate and doctoral programs across fields such as normal physiology, pathological physiology, biochemistry,

biophysics, embryology, gynecology, and other related scientific disciplines.

**Approbation of the work.** The materials of the dissertation have been presented and discussed at the following conferences, symposia, and congresses:

- XII International Interdisciplinary Congress “Neuroscience for Medicine and Psychology,” Sudak, Crimea, Russia (2017);
- V Congress of the Society of Azerbaijani Physiologists dedicated to the 50th anniversary of the Academic Abdulla Qarayev Institute of Physiology (2017);
- International Symposium of Ecology 2018, Kastamonu, Turkey, Symposium Abstract Book, 19–23 June 2018;
- VI Congress of Russian Biophysicists, Collection of Scientific Works, Sochi, 16–21 September 2019;
- International Congress of the Georgian Ivane Beritashvili Society of Physiologists, Proceedings, Tbilisi, 23–25 September 2019;
- Conference dedicated to the 110th anniversary of Academic Abdulla Qarayev (2020);
- XVII International Interdisciplinary Congress “Neuroscience for Medicine and Psychology,” Sudak, Crimea, Russia (2020);
- XVI International Scientific Conference “Current Issues in Biological Physics and Chemistry,” Sevastopol (2021);
- 4th International Congress on “Medical Sciences and Innovations” (Uluslararası Sağlık Bilimleri ve İnovasyon Kongresi), 5–6 July 2021, online;
- “Multifaceted Neuroscience: Celebrating 140 Years of Ivane Beritashvili,” Tbilisi, 12–14 June 2025.

**Organization where the work was performed:** The dissertation was carried out at the Laboratory of Radiation Physiology of the Academician Abdulla Qarayev Institute of Physiology, Ministry of Science and Education of Azerbaijan.

**Publications.** 9 articles and 8 abstracts related to the topic of the dissertation have been published.

**The volume and structure of the dissertation.** The total volume of the dissertation is 203130. Of these, “table of contents” -

4651 characters, “Introduction” - 16548 characters, literature review - 64151, materials and methods of research - 14361 characters, results of personal research - 73071, conclusion - 25965 characters, conclusions - 3176 characters and recommendations - 1207 characters. The reference list includes 237 sources: 5 in Azerbaijani, 113 in Russian, and 119 in English. The scientific work is illustrated with 12 tables and 15 figures.

## **LITERATURE REVIEW**

In this chapter, a review is given on the results of research conducted in the world on the effect of non-ionizing EMR on the developing organism, and the implementation of the goals and objectives of the study of biochemical and physiological indicators of blood in the dissertation work is substantiated. Changes in oxidant-antioxidant relations, leukocytic formula were considered as methodological aspects in the study of the effects of radiation exposure.

## **MATERIALS AND METHODS**

The study was conducted on 20- and 30-day-old offspring born to mother rats exposed to non-ionizing EMR at various stages of prenatal development. A total of 70 female rats were used: 15 served as controls, and 55 were selected for exposure. Of the exposed animals, 20 were assigned to the embryonic stage, 20 to the fetal stage, and 15 to the perinatal stage (Table 1).

For mating, the animals were kept under standard vivarium conditions for 3–4 days. Subsequently, the mothers were exposed to EMR as follows: during the embryonic period for 7 days (gestation days 1–6), during the fetal period for 10 days (gestation days 7–16), and during the perinatal period for 3–4 days (gestation days 17–21). Radiation exposure was performed using the “Volna-2” apparatus (Russia) at a frequency of 460 MHz, with an energy flux density of  $30 \mu\text{W}/\text{cm}^2$ , for 20 minutes daily.

All animal experiments were conducted in accordance with the ethical standards set out in the “International Guiding Principles for Biomedical Research Involving Animals” (Geneva, 1990). The

experimental study protocol was approved by the local ethics committee (Protocol No.4, April 3, 2017).

The total number of offspring used in the study was 160.

Table 1.

Animal groups used in the study

Stages	Total Number	Giving Birth	Not Giving Birth	Maternal Deaths	Number of Offspring	Offspring Death
Control Group	15		-	-	68	-
Embryon stage	20	8	12		40	
Pre-fetal stage	20	6	11	3	28	2
Fetal stage	15	6	8	1	22	
Total	70	35	31	4	160	2

In the experiments, whole blood was collected during decapitation. Hematological, oxidative, and morphological parameters of the blood were analyzed using standard biochemical and microscopic methods.

Statistical analysis was performed using the MS Excel software package (2010). The significance of differences between groups ( $p < 0.05$ ) was evaluated using Student's t-test.

## RESULTS AND DISCUSSION OF THE STUDY

### Assessment of Weight and Development of Offspring from Mothers Exposed to Non-Ionizing Electromagnetic Radiation at Different Prenatal Stages

It was found that among the 20 female rats exposed during the embryonic stage, 12 (60%) did not give birth. For the fetal stage, 11 out of 20 (55%) did not give birth, and during the perinatal stage, 8 out of 15 (53.3%) failed to deliver offspring. Maternal deaths were

also observed during exposure: in contrast to the embryonic stage, 15% (3 rats) of mothers exposed during the fetal stage and 6.7% (1rat) during the perinatal stage died during the experiment (Table 1).

The number of offspring born decreased in all 3 exposure periods. Specifically, 68 pups were born in the control group, 40 in the embryonic stage group, 28 in the pre-fetal stage group, and 22 in the fetal stage group.

Literature data indicate that electromagnetic waves can cause constriction of peripheral blood vessels, primarily reducing blood circulation to all abdominal organs, particularly the uterus. This leads to impaired metabolic processes in the fetus during gestation.

According to studies by S.A. Denichenko<sup>8</sup> and G.I. Vakulik<sup>9</sup>, exposure to electromagnetic radiation during intrauterine development accelerates apoptosis in the epiphyseal cells of rat pups. Reduced epiphyseal function disrupts metabolism, modifies the immune and reproductive systems, and contributes to age-related pathologies and decreased lifespan<sup>10</sup>.

In the present study, the body weight of pups born to mothers exposed at all three stages was analyzed (Figure 1). It was found that pups from mothers exposed during the embryonic period showed an 11.6% decrease in body weight at postnatal day 20 compared to the control group ( $p < 0.001$ ), while at day 30, their weight increased by 3.4% ( $p < 0.05$ ).

During fetal stage exposure, weight gain was observed in both age groups. Specifically, at day 20, a 32.9% increase was recorded

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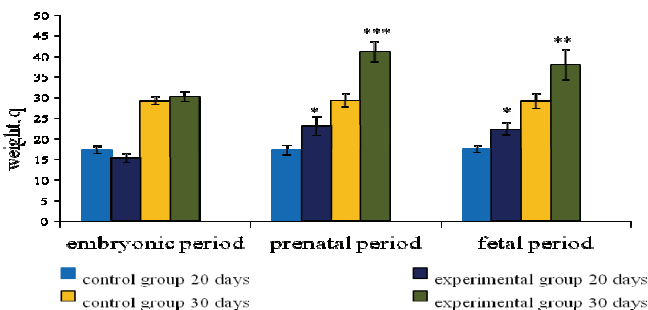
<sup>8</sup> Денисенко, С.А. Изучение ориентировочной активности крыс, внутриутробно испытывавших воздействие низкоинтенсивного электромагнитного излучения сантиметрового диапазона / С.А. Денисенко. // *Світ медицини та біології*, - 2009. № 2, -с. 99-104

<sup>9</sup> Губина-Вакулик, Г.И. Электромагнитное излучение как фактор цивилизации, ускоряющий процесс старения на примере надпочечников потомков / Г.И. Губина-Вакулик, С.А. Денисенко // *Буковинський медичний вісник*. 2009. - Т. 13, №4, - с. 10-104

<sup>10</sup> Reiter R.J. Melatonin and the circadian system: contributions to successful female reproduction/ R.J. Reiter, H. Tamura, D. Xian Tan, Xiao-Ying Xu. // *Fertility and Sterility*. - 2014. -v. 102, Issue 2, -p.321–332

( $p < 0.05$ ), and at day 30, a 39.9% increase was observed ( $p < 0.001$ ).

During perinatal stage exposure, the body weight of 20-day-old pups increased by 28.0% ( $p < 0.01$ ) compared to the control group, and at day 30, the increase was 29.8% ( $p < 0.05$ ) (Figure 1).



**Figure 1.** Body weight of 20- and 30-day-old pups born to mothers exposed to radiation at different stages of prenatal development

A comparative analysis of the body weight of pups across all three exposure periods showed that the lowest weight was observed in the embryonic stage group.

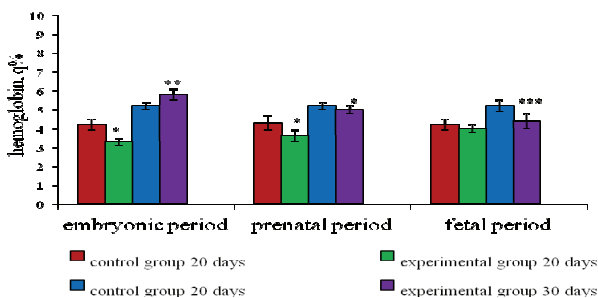
According to the literature, common causes of low birth weight include inadequate maternal nutrition during gestation, various maternal illnesses, multiple pregnancies, and placental developmental changes that reduce nutrient transport to the fetus, leading to both quantitative and qualitative deficiencies. In addition, based on experiments conducted by Semyonova et al., electromagnetic waves emitted by mobile phones affect the formation of the musculoskeletal system in offspring<sup>11</sup>. Exposure to electromagnetic waves slows osteoblast activity, and during the last three days of gestation (days

<sup>11</sup> Семенова Н.В., Денисов А.П., Денисова О.А., и др. Влияние электромагнитного излучения от сотовых телефонов на здоровье детей и подростков (обзор литературы) //Международный журнал прикладных и фундаментальных исследований. - 2016. № 6, - с.701-705.

14–17), stress-induced hormonal changes occur. These changes are particularly evident in corticosterone, progesterone, and testosterone levels. Such hormonal alterations persist for an extended period, and even at 30 days of age, the blood hormone levels and behavior of pups from exposed mothers differ from those of control group animals<sup>12</sup>.

### Assessment of Total Protein and Hemoglobin Levels in Pups from Mothers Exposed to Non-Ionizing Electromagnetic Radiation at Different Prenatal Stages

In pups born to mothers exposed at the three stages of prenatal development, hemoglobin levels on postnatal day 20 were lower compared to controls (Figure 2). Specifically, at day 20, hemoglobin levels decreased by 22.3% ( $p < 0.05$ ) in the embryonic stage group, by 14.3% ( $p < 0.05$ ) in the fetal stage group, and by 4.8% ( $p < 0.05$ ) in the perinatal stage group.



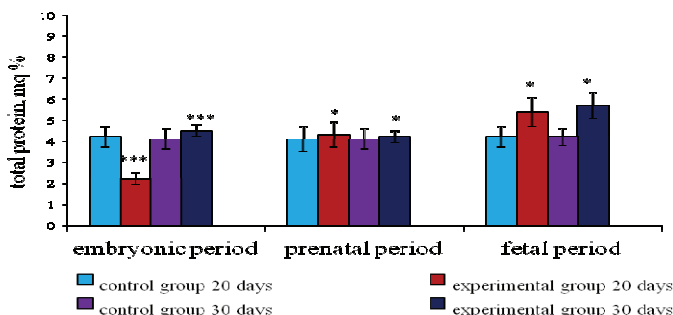
**Figure 2.** Hemoglobin levels in the blood of 20- and 30-day-old pups born to mothers exposed to radiation at different stages of prenatal development

At day 30, hemoglobin levels in the experimental groups varied depending on the prenatal stage of exposure. In the embryonic stage

<sup>12</sup> Seckl J.R. Glucocorticoids, developmental “programming” and the risk of affective dysfunction // Prog Brain Res. – 2008. N 167.-p. 17-37.

group, an 11.5% increase ( $p < 0.01$ ) was observed relative to controls, while in the pre-fetal stage group there was a 3.7% decrease ( $p < 0.05$ ), and in the fetal stage group a 15.4% decrease ( $p < 0.001$ ).

Studies have shown that electric fields and electromagnetic waves primarily affect the secondary and tertiary structures of proteins<sup>13</sup>. In pups born to mothers exposed during each of the three prenatal stages, total protein levels on postnatal day 20 were lower compared to the control group (Figure 3). Specifically, in the embryonic stage exposure group, total protein levels decreased by 47.6% ( $p < 0.001$ ) relative to controls. In the pre-fetal stage group, total protein levels decreased by 4.9% ( $p < 0.05$ ), while in the fetal stage group, total protein levels increased by 28.6% ( $p < 0.05$ ) compared to controls.



**Figure 3.** Total protein concentration in the blood of 20- and 30-day-old pups born to mothers exposed to radiation at different stages of prenatal development

In 30-day-old pups, these parameters showed characteristic differences depending on the prenatal exposure period. Specifically, total protein levels increased by 9.8% ( $p < 0.001$ ) in the embryonic stage group, by 2.4% ( $p < 0.05$ ) in the pre-fetal stage group, and by

<sup>13</sup> Zhong Han, Meng-jie Cai, Jun-Hu Cheng, Da-Wen Sun Effects of electric fields and electromagnetic wave on food protein structure and functionality: A review // Trends in Food Science & Technology, -2018. -v.75, -p. 1-9

35.7% ( $p < 0.05$ ) in the fetal stage group compared to controls.

A comparative analysis of hemoglobin and total protein levels on postnatal days 20 and 30 was also conducted across the three exposure periods for pups born to mothers subjected to radiation.

In pups born to mothers exposed during the embryonic stage of prenatal development, hemoglobin levels on postnatal day 20 were lower compared to those in the pre-fetal and fetal stage groups.

Similarly, hemoglobin levels in the pre-fetal stage group were lower than those in the fetal stage group.

In 30-day-old pups, hemoglobin levels increased in the embryonic stage group compared to the pre-fetal and fetal stage groups. Similarly, hemoglobin levels in the pre-fetal stage group were higher than in the fetal stage group.

In 20-day-old pups exposed during the embryonic stage, hemoglobin levels were lower compared to the pre-fetal and fetal stage groups. A similar decrease was observed in the pre-fetal stage group relative to the fetal stage group.

Regarding total protein levels, in 30-day-old pups, the embryonic stage group showed an increase compared to the pre-fetal stage, but a decrease compared to the fetal stage. In the pre-fetal stage group, total protein levels were lower than in the fetal stage group. These results indicate that, compared to the fetal stage, total protein levels were reduced in pups from mothers exposed during the embryonic and pre-fetal stages.

Thus, changes in hemoglobin and total protein concentrations during early postnatal ontogenesis are multifaceted: at 20 days of age, total protein levels are higher than in control animals, while hemoglobin levels are lower, increasing only after 20 days.

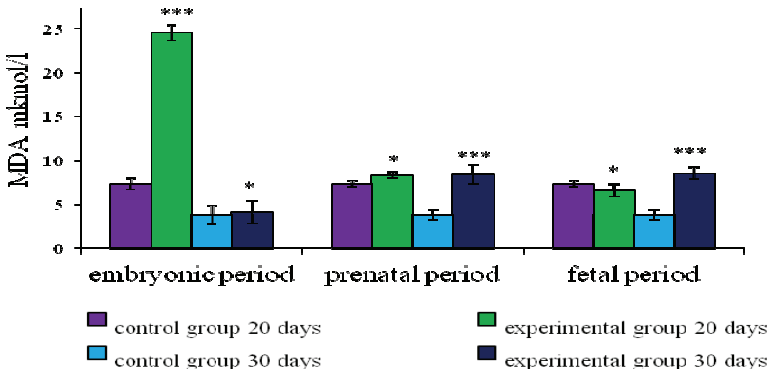
### **Assessment of Lipid Peroxidation Levels in Pups Born to Mothers Exposed to Non-Ionizing Electromagnetic Radiation at Different Prenatal Stages**

In the study, the concentration of malondialdehyde (MDA) in plasma and erythrocytes was measured in pups born to mothers exposed to electromagnetic waves during different stages of prenatal

development on postnatal days 20 and 30.

It was found that, in 20-day-old pups, plasma MDA levels increased 3.4-fold ( $p < 0.001$ ) in the embryonic stage group and by 13.7% ( $p < 0.05$ ) in the pre-fetal stage group compared to controls. In the fetal stage group, MDA levels in plasma decreased by 9.6% ( $p < 0.05$ ) compared to controls (Figure 4).

The same experiments were conducted in 30-day-old pups across all three exposure stages.



**Figure 4.** Plasma MDA levels in 20- and 30-day-old pups born to mothers exposed to radiation at different stages of prenatal development

In 30-day-old pups exposed during prenatal development, plasma MDA levels increased by 7.9% ( $p < 0.05$ ) in the experimental group compared to controls. In the pre-fetal stage group, MDA levels increased 2.2-fold ( $p < 0.001$ ), and in the fetal stage group, MDA levels increased 2.2-fold ( $p < 0.001$ ) (Figure 4).

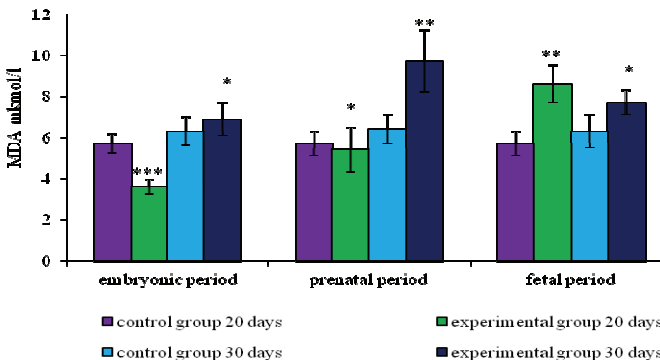
In pups born to mothers exposed to radiation at different stages of prenatal development, MDA levels in erythrocytes were also measured on postnatal days 20 and 30.

It was found that in 20-day-old pups from mothers exposed during the embryonic stage, MDA levels in the experimental group

were 36.8% higher than in the control group ( $p < 0.001$ ). In the pre-fetal stage group, MDA levels decreased by 5.3% ( $p < 0.05$ ), whereas in the fetal stage group, MDA levels increased by 50.9% ( $p < 0.01$ ) compared to controls.

In 30-day-old pups, MDA levels increased by 9.5% ( $p < 0.05$ ) in the experimental group of the embryonic stage, by 51.6% ( $p < 0.05$ ) in the pre-fetal stage group, and by 25.4% ( $p < 0.05$ ) in the fetal stage group (Figure 5).

A comparative analysis of MDA levels in plasma and erythrocytes on days 20 and 30 across all three exposure periods showed that, in plasma, MDA levels in the embryonic stage group were higher compared to the pre-fetal and fetal stage groups. Similarly, a comparison between the pre-fetal and fetal stages revealed higher MDA levels in the pre-fetal stage group. In 30-day-old pups, MDA levels in the embryonic stage group were lower compared to the pre-fetal and fetal stage groups. As a result of a comparative analysis of the fetal and perinatal stages it was found that the amount of MDA in the prenatal period decreases compared to the fetal period.



**Figure 5.** Erythrocyte MDA levels in 20- and 30-day-old pups born to mothers exposed to radiation at different stages of prenatal development

A comparative analysis of MDA levels in erythrocytes on postnatal days 20 and 30 was performed across the exposure periods. It was found that, in 20-day-old pups, MDA levels decreased in the embryonic stage group compared to the pre-fetal and fetal stage groups, and in the pre-fetal stage group compared to the fetal stage group.

In 30-day-old pups, MDA levels in the embryonic stage group were lower compared to the pre-fetal and fetal stage groups. Additionally, in the fetal stage group, MDA levels were lower compared to the pre-fetal stage group. According to the comparative analysis of all three stages in 30-day-old pups, MDA levels were highest in the pre-fetal stage group.

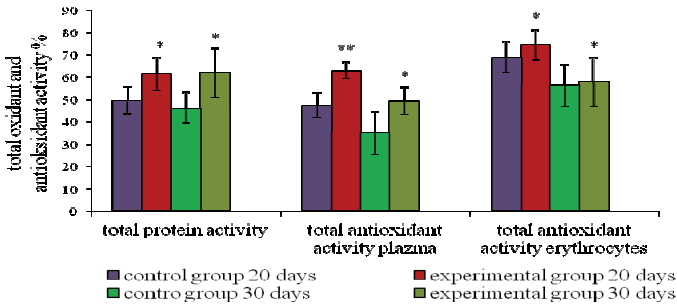
The activation of lipid peroxidation throughout the organism mainly depends on the duration of exposure. Radiation intensity and the specific absorbed power are of lesser importance for the pro-oxidant effect of electromagnetic radiation.

### **Assessment of the Effect of Electromagnetic Fields on Total Antioxidant Activity in Pups Exposed During Prenatal Development**

A deficiency of antioxidants in the organism leads to the development of oxidative stress processes and disrupts the balance of the pro-oxidant–antioxidant system. Therefore, total oxidant and antioxidant activities were studied in pups born to mothers exposed at all 3 prenatal stages.

It was determined that, in 20-day-old pups from mothers exposed during the embryonic stage, total oxidant activity (TOA) in plasma increased by 24.0% ( $p < 0.05$ ), total antioxidant activity (TAA) in plasma increased by 33.1% ( $p < 0.01$ ), and TAA in erythrocytes increased by 8.1% ( $p < 0.05$ ) compared to controls.

In 30-day-old pups, compared to controls, TOA increased by 34.1% ( $p < 0.05$ ), plasma TAA increased by 40.9% ( $p < 0.05$ ), and erythrocyte TAA increased by 2.7% ( $p < 0.05$ ) in the experimental group (Figure 6).

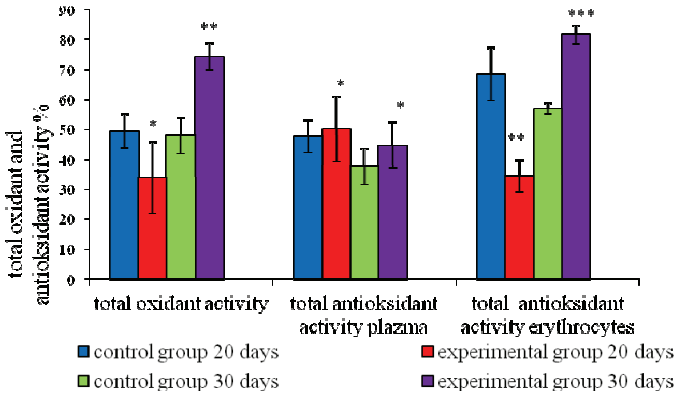


**Figure 6.** Total oxidant and antioxidant activity in 20- and 30-day-old pups born to mothers exposed to radiation during the embryonic stage

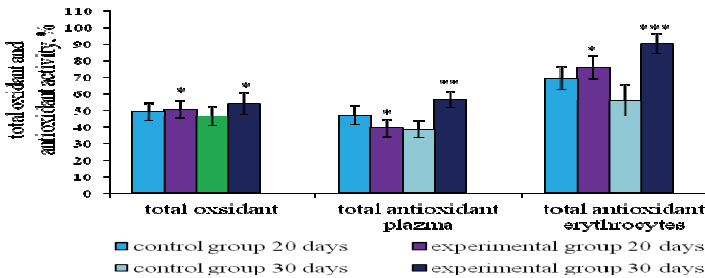
According to the results, in pups born to mothers exposed during the embryonic stage of prenatal development, an increase in oxidant activity in the blood was observed, which was compensated by a corresponding increase in antioxidant system activity, maintaining the oxidant–antioxidant balance.

In pups from mothers exposed during the pre-fetal stage, on postnatal day 20, total oxidant activity (TOA) in plasma decreased by 32.1% ( $p < 0.05$ ), and total antioxidant activity (TAA) in erythrocytes decreased by 49.7% ( $p < 0.01$ ) compared to controls. Plasma TAA increased by 5.0% ( $p < 0.05$ ) in the experimental group relative to controls. In 30-day-old pups, TOA increased by 54.9% ( $p < 0.01$ ), plasma TAA increased by 18.9% ( $p < 0.05$ ), and erythrocyte TAA increased by 43.5% ( $p < 0.001$ ) compared to the control group (Figure 7).

In pups from mothers exposed during the fetal stage, on postnatal day 20, TOA increased by 2.7% ( $p < 0.05$ ) and erythrocyte TOA increased by 9.7% ( $p < 0.05$ ) compared to controls. However, plasma TAA decreased by 16.8% ( $p < 0.05$ ) in the experimental group relative to controls (Figure 8).



**Figure 7.** Total oxidant and antioxidant activity in 20- and 30-day-old pups born to mothers exposed to radiation during the pre-fetal stage



**Figure 8.** Total oxidant and antioxidant activity in 20- and 30-day-old pups born to mothers exposed to radiation during the fetal stage

According to the results of studies conducted on 30-day-old pups, total oxidant activity (TOA) increased by 16.6% ( $p < 0.05$ ) in the experimental group compared to controls, plasma total

antioxidant activity (TAA) increased by 47.0% ( $p<0.01$ ), and erythrocyte TAA increased by 58.7% ( $p<0.001$ ) (Figure 8).

A comparative analysis between exposure periods revealed that, in 20-day-old pups, TOA, plasma TAA, and erythrocyte TAA were higher in the embryonic stage group compared to the pre-fetal and fetal stage groups.

Comparison between the pre-fetal and fetal stage groups in 20-day-old pups showed that TOA and erythrocyte TAA increased in the fetal stage group compared to the pre-fetal stage, while plasma TAA decreased.

In 30-day-old pups, comparative analysis showed that, in the embryonic stage group, TOA and erythrocyte TAA decreased compared to the pre-fetal stage, whereas plasma TAA increased. Comparison between the pre-fetal and fetal stage groups revealed that TOA decreased in the fetal stage, while plasma and erythrocyte TAA increased.

These results indicate that prenatal exposure to electromagnetic radiation disrupts the oxidant–antioxidant balance in pups' blood. Specifically, in early postnatal development (20 days old), total antioxidant activity is low, whereas at a relatively later age (30 days old), total antioxidant activity increases.

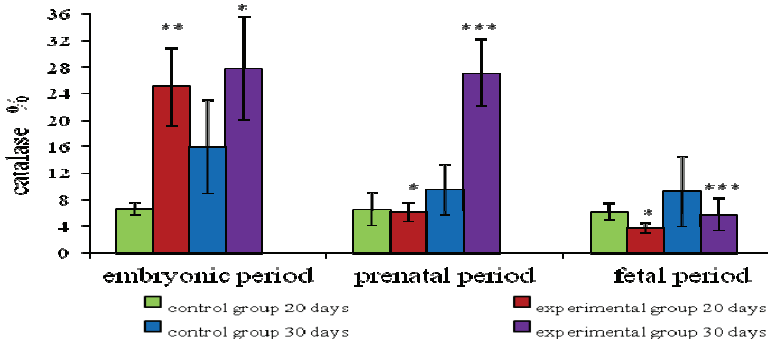
### **Assessment of Catalase, Superoxide Dismutase, and Reduced Glutathione Levels in Pups Born to Mothers Exposed to Non-Ionizing Electromagnetic Radiation at Different Prenatal Stages**

In pups born to mothers exposed to non-ionizing EMR during different prenatal stages, catalase activity was measured on postnatal days 20 and 30. In 20-day-old pups exposed during the embryonic stage, catalase activity decreased by 73.6% ( $p<0.01$ ) compared to controls, i.e., catalase activity in the experimental group increased 3.7-fold. In the pre-fetal stage group, catalase activity increased by 6.2% ( $p<0.05$ ), while in the fetal stage group, it decreased by 41.1% ( $p<0.05$ ) (Figure 9).

In 30-day-old pups, catalase activity in the embryonic stage group decreased by 74.9% ( $p<0.05$ ), in the pre-fetal stage group it

increased by 65.3% (i.e., 2.9-fold higher) ( $p < 0.01$ ), and in the fetal stage group, it decreased by 38.0% ( $p < 0.01$ ) (Figure 9).

Experiments conducted by Othman et al. showed that in pups born to mothers exposed to radiation during prenatal development, by postnatal day 28, there is an increase in reactive oxygen species and lipid peroxidation levels, accompanied by a decrease in antioxidants such as catalase and SOD<sup>14</sup>.



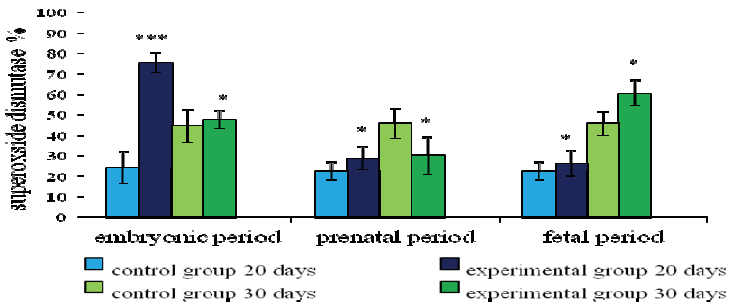
**Figure 9.** Catalase activity in 20- and 30-day-old pups born to mothers exposed to radiation during the embryonic, pre-fetal, and fetal stages

The results of superoxide dismutase (SOD) activity assessment revealed that in 20-day-old pups whose mothers were exposed during the embryonic stage, SOD activity increased 3.1-fold ( $p < 0.001$ ) compared to the control group; in the pre-fetal stage, it increased by 20.1% ( $p < 0.05$ ), and in the fetal stage, it increased by 10.5% ( $p < 0.05$ ) (Figure 10).

<sup>14</sup> Othman, H., Ammari, M., Rtibi, K., et al. Postnatal development and behavior effects of in-utero exposure of rats to radiofrequency waves emitted from conventional WiFi devices. *Environ //Toxicol. Pharmacol.* - 2017, - 52, -p.239-247.

In 30-day-old pups, SOD activity increased by 4.2% ( $p < 0.05$ ) in the embryonic stage group and by 28.6% ( $p < 0.05$ ) in the fetal stage group compared to controls, whereas in the pre-fetal stage group, it decreased by 34.4% ( $p < 0.05$ ) (Figure 10).

It appears that the changes in SOD and catalase activity exhibit a wave-like pattern. In all cases, the increase in catalase activity occurs against a background of a significant decrease in SOD activity compared to controls. Cross-regulation of activity is characteristic for many enzymes, including superoxide dismutase and catalase. For catalase, the superoxide radical anion acts as a negative effector, while  $H_2O_2$  acts as a positive effector; the opposite is true for SOD.



**Figure 10.** Superoxide dismutase (SOD) activity in 20- and 30-day-old pups born to mothers exposed to radiation during the embryonic, pre-fetal, and fetal stages.

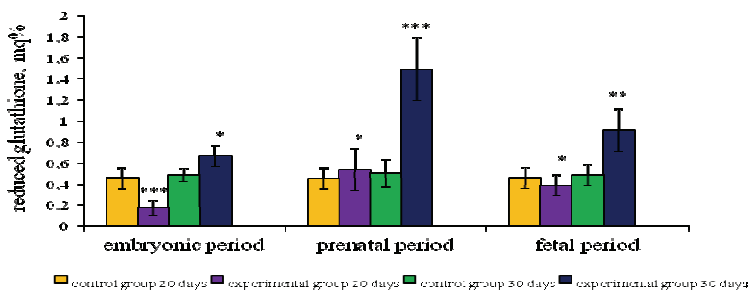
Reduced glutathione is the primary antioxidant in red blood cells, serving as a coenzyme in the reduction of methemoglobin to functional active hemoglobin.

Based on the assessment of reduced glutathione activity during postnatal development (20–30 days), it was found that in 20-day-old pups, levels of reduced glutathione decreased by 62.5% ( $p < 0.001$ ) in the embryonic stage and by 15.5% ( $p < 0.05$ ) in the fetal stage, while in the pre-fetal stage, it increased by 18.6% ( $p < 0.05$ ) (Figure 11).

In 30-day-old pups, reduced glutathione activity was higher than in controls across all three stages. Specifically, it increased by

37.4% ( $p < 0.05$ ) in the embryonic stage, 3.1-fold ( $p < 0.05$ ) in the pre-fetal stage, and 88.4% ( $p < 0.05$ ) in the fetal stage (Figure 11).

The increase in reduced glutathione levels in plasma and erythrocytes under prolonged EMR exposure may represent an adaptive mechanism, reflecting the activation of antioxidant defense in response to the harmful effects of EMF<sup>15</sup>.



**Figure 11.** Levels of reduced glutathione in 20- and 30-day-old pups born to mothers exposed to radiation during the embryonic, pre-fetal, and fetal stages

The results of catalase, SOD, and reduced glutathione activity were analyzed comparatively across prenatal developmental (exposure) periods. It was found that in 20-day-old pups, compared to the embryonic period, catalase activity decreased during the pre-fetal and fetal periods. Furthermore, it was observed that catalase activity in the fetal period decreased compared to the pre-fetal period. In 30-day-old pups, catalase activity decreased during the pre-fetal and fetal periods compared to the embryonic period. Catalase activity in the fetal period also decreased compared to the pre-fetal period.

<sup>15</sup> Терехина Н.А., Селин А.Д., Терехин Г.А. Влияние электромагнитного излучения на показатели антиоксидантной защиты в эритроцитах и плазме крови крыс //Патологическая физиология и экспериментальная терапия, - 2021. - 65(3), - с. 73-79

Comparative analysis of SOD activity showed that in 20-day-old pups, SOD activity decreased during the pre-fetal and fetal periods compared to the embryonic period. Similarly, activity in the fetal period decreased compared to the pre-fetal period. In 30-day-old pups, SOD activity decreased in the pre-fetal period compared to the embryonic period, but increased in the fetal period.

Comparative analysis of reduced glutathione (GSH) activity revealed that in 20-day-old pups, activity decreased during the fetal and postnatal periods compared to the embryonic period. In the fetal period, GSH activity increased compared to the postnatal period. In 30-day-old pups, GSH activity decreased during the fetal and postnatal periods compared to the embryonic period. Additionally, activity in the postnatal period decreased compared to the fetal period.

Age-related decreases in GSH levels may lead to two potential harmful consequences. First, the homeostasis of hydrogen peroxide may be disrupted, causing its intracellular concentration to rise. This can increase the formation of hydroxyl radicals, leading to significant damage to various macromolecular structures. Lipid peroxidation increases, resulting in higher levels of compounds such as malondialdehyde and 4-hydroxynonenal, which interact with DNA and proteins, altering their structure and function<sup>16</sup>. Second, the formation of mixed disulfides with proteins can significantly alter the catalytic capacity of enzymes, potentially affecting their ability to maintain adaptive responses under stress. Both of these changes occur alongside age-related modifications<sup>17,18</sup>. Therefore, maintaining optimal redox status through GSH is crucial to limit the damaging effects of oxidative stress on macromolecules.

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<sup>16</sup> Uchida K., Stadtman E. R. Quantitation of 4-hydroxynonenal protein adducts // *Methods Mol. Biol.*, - 2000.- v. 99. -p. 25–34.

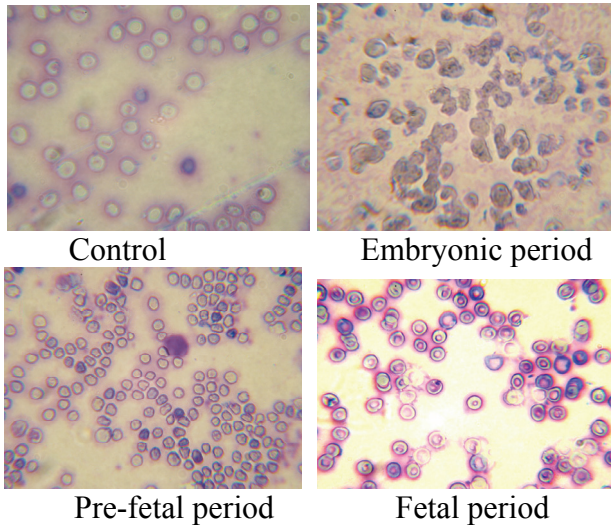
<sup>17</sup> Ghezzi P. Oxidoreduction of protein thiols in redox regulation // *Biochem. Soc. Trans.*, - 2005. -vol. 33, -p. 1378–1381

<sup>18</sup> Humphries K. M., Szweda P. A., Szweda L. I. Aging: a shift from redox regulation to oxidative damage. *Free Radic. Res.* 2006. Vol. 40. P. 1239–1243

## Leukocyte formula of peripheral blood in rats under electromagnetic exposure

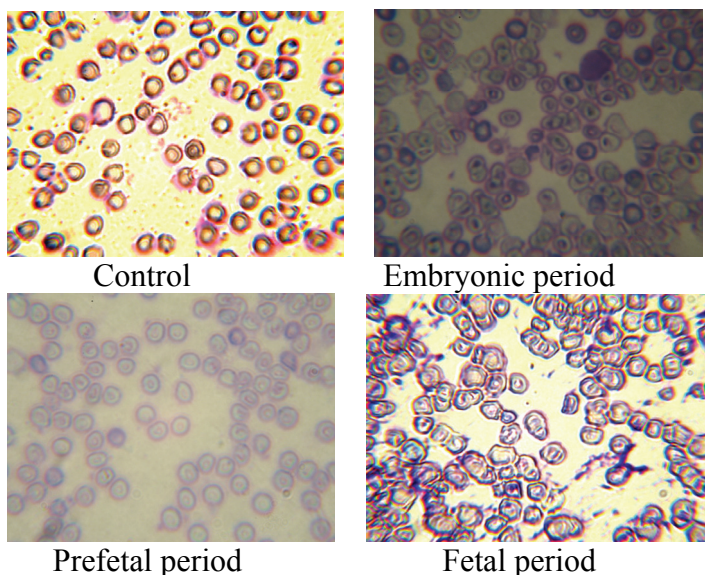
In pups born to mothers exposed to electromagnetic radiation during different prenatal periods, on postnatal day 20, erythrocyte and lymphocyte disruption and anisocytosis were observed. Additionally, leukocyte counts were reduced (Figure 12). In 30-day-old pups, immature erythrocyte forms, anisocytosis, and target-shaped erythrocytes were observed.

In the pre-fetal period, 20-day-old pups exhibited erythrocyte and lymphocyte disruption and immature erythrocyte forms. Leukocyte counts were also reduced. In 30-day-old pups, erythrocyte fragmentation, anisocytosis, poikilocytosis, immature forms, and cup-shaped erythrocytes were observed.



**Figure 12.** Microscopic view of the blood smear of 20-day-old rat pups born to mothers exposed to EMR during different stages of prenatal development.

In the fetal period exposure, in 20-day-old rat pups, erythrocyte fragmentation, anisocytosis, the presence of a very small number of leukocytes, poikilocytosis, and target-shaped erythrocytes are observed. In 30-day-old pups, erythrocyte fragmentation, anisocytosis, poikilocytosis, immature forms, and pouch-shaped erythrocytes are observed (Figures 12–13).



**Figure 13.** Microscopic view of the blood smear of 30-day-old rat pups born to mothers exposed to EMR during different stages of prenatal development.

During the study of the leukocyte formula, it was found that in offspring obtained from mothers exposed to EMR at various stages of prenatal development, on the 20th day of postnatal development, compared with the control group, the number of lymphocytes in the experimental group increased by 15.5% ( $p < 0.001$ ) in the embryonic period, by 15.1% ( $p < 0.001$ ) in the pre-fetal period, and by 13.8% ( $p < 0.001$ ) in the fetal period.

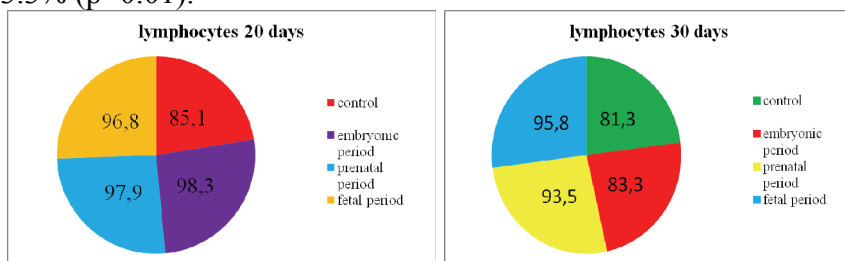
The number of monocytes decreased in all three periods. Thus, compared with the control group, it decreased by 75.5% ( $p < 0.001$ ) in

the embryonic period, by 92.5% ( $p < 0.001$ ) in the pre-fetal period, and by 79.2% ( $p < 0.01$ ) in the fetal period. Eosinophils, compared with the control group, were not observed in the embryonic and pre-fetal periods. In the fetal period, however, their number was 84.2% lower ( $p < 0.01$ ). As for neutrophils, as we know, they exist in two forms: segmented-nucleus and band-nucleus.

It was shown that segmented neutrophils decreased in the experimental group compared with the control group. Thus, in the embryonic period, neutrophils were not detected in either group. In the pre-fetal period, the number of segmented neutrophils in the experimental group decreased by 90.5% ( $p < 0.001$ ) compared with the control group, and in the fetal period by 87.6% ( $p < 0.001$ ).

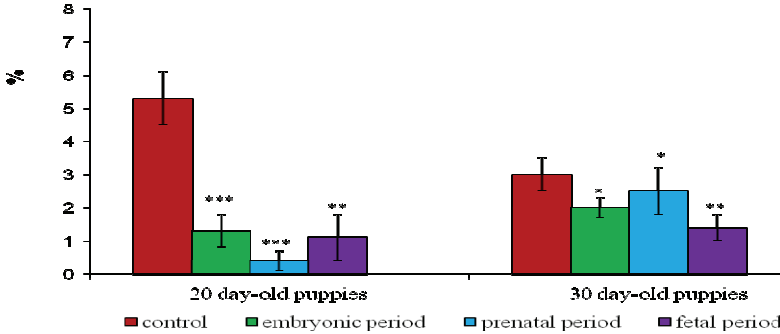
Band neutrophils were also reduced compared with the control group. It was found that in the pre-fetal period their number decreased by 91.4% ( $p < 0.001$ ), and in the fetal period by 86.2% ( $p < 0.001$ ). On the 20th day of postnatal development, metamyelocytes and prolymphocytes were not detected in the offspring (Figure 14).

In 30-day-old offspring exposed during the embryonic period, the number of lymphocytes increased by 2.3% ( $p < 0.01$ ), in the pre-fetal period by 15.0% ( $p < 0.01$ ), and in the fetal period by 17.8% ( $p < 0.001$ ). The number of monocytes decreased in all three periods under irradiation: in the embryonic period – by 33.3% ( $p < 0.05$ ), in the pre-fetal period – by 16.7% ( $p < 0.05$ ), and in the fetal period – by 53.3% ( $p < 0.01$ ).



**Figure 14.** The amount of lymphocytes in 20- and 30-day-old offspring obtained from mothers irradiated at different stages of prenatal development.

In the embryonic period, eosinophils increased by 37.5% ( $p < 0.05$ ) in the experimental group compared with the control group. They were not observed in the pre-fetal period. In the fetal period, however, they were reduced by 50% ( $p < 0.05$ ).



**Figure 15.** The amount of monocytes in 20- and 30-day-old offspring obtained from mothers irradiated at different stages of prenatal development

In the embryonic period, neutrophils were observed in both groups. The number of segmented neutrophils increased by 17.9% ( $p < 0.001$ ) compared with the control group, while in the pre-fetal period the number of segmented neutrophils decreased by 81.1% ( $p < 0.001$ ), and in the fetal period by 78.6% ( $p < 0.001$ ). Band neutrophils, compared with the control group, increased in the embryonic period but decreased in the pre-fetal and fetal periods. Prolymphocytes were detected only in the irradiated group during the fetal period.

An increase in the level of leukocytes in the blood indicates enhanced activity of the leukopoietic system, while a decrease indicates suppression of leukopoiesis. Changes in the level of eosinophils are among the most sensitive indicators of the immune eactivity of the organism. Usually, an increase in their number is

associated with the body's defense against parasitic helminths<sup>19</sup>.

Analysis of lymphocytes, monocytes, neutrophils, and eosinophils on days 20 and 30 of postnatal development in offspring obtained from mothers irradiated at different stages of prenatal development showed that in 20- and 30-day-old offspring irradiated during the embryonic period, the number of lymphocytes was lower compared with the pre-fetal and fetal periods. In addition, compared with the pre-fetal period, a decrease was observed in the fetal period.

In 20-day-old offspring, compared with irradiation in the embryonic period, the number of monocytes decreased in the pre-fetal and fetal periods. In the pre-fetal period, the number of monocytes was lower than in the fetal period. In 30-day-old offspring, the number of monocytes was lower in the embryonic period compared with the pre-fetal period, but higher in the embryonic period compared with the fetal period. In the pre-fetal period, the number of monocytes increased compared with the fetal period.

Comparison of the results for eosinophils in all three periods of irradiation showed that in 20-day-old offspring irradiated during the embryonic and pre-fetal periods, eosinophils were not detected. In the fetal period, eosinophils constituted  $0.3 \pm 0.2\%$ . In 30-day-old offspring, eosinophils were not detected in the pre-fetal period. Comparison with embryonic period irradiation showed that the number of eosinophils decreased in the fetal period.

In 20-day-old offspring irradiated during the embryonic period, neither form of neutrophils was detected. In 30-day-old offspring, compared with the embryonic period, the number of segmented neutrophils was lower in the pre-fetal and fetal periods. The number of band neutrophils was also lower in the pre-fetal and fetal periods compared with the embryonic period.

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<sup>19</sup> Узенбаева Л. Б., Голубева А.Г., Илюха В.А., Тютюнник Н.Н., Коросов С.А. Морфофункциональные особенности лейкоцитов млекопитающих, разводимых в неволе в условиях европейского севера // Экология. Экспериментальная генетика и физиология. Труды Карельского научного центра РАН. Петрозаводск, - 2007. –вып. 11, - с. 109-117.

A decrease in the number of lymphocytes in peripheral blood may indicate a weakening of immunity in offspring obtained from irradiated mothers. Lymphopenia and neutrophilia indicate that irradiation is a strong stress factor that can cause adverse effects in the organism. The wave-like nature of changes in the indicators of the organism's morphofunctional state is observed under the influence of the factors themselves and should naturally be regarded as a manifestation of the organism's adaptive reorganization<sup>20</sup>.

Exposure of the mother to non-ionizing EMF during pregnancy may cause the fetus's temperature to rise above acceptable levels<sup>21</sup>.

Under conditions of prolonged exposure to electromagnetic radiation, deficiency or insufficient activity of one of the protective components of the antioxidant defense system can lead to disruption of the body's compensatory capacity. Despite the changes associated with the strengthening of the antioxidant defense system against the background of weakened free radical processes, long-term exposure to electromagnetic radiation in the decimeter range can be considered an unfavorable factor exerting a clearly destructive effect on erythrocyte membranes.

An analysis of modern data on the biological effects of low-intensity electromagnetic radiation, together with the obtained results, allows us to conclude that this physical agent is a powerful oxidative stress factor for living cells. The oxidative effect of microwave radiation may be mediated by changes in the activity of systems that generate reactive oxygen species (ROS), including mitochondria and NADPH oxidases, by direct effects on water molecules, and by induction of conformational changes in biologically significant macromolecules. In turn, the broad biological

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<sup>20</sup> Девятова Н. В., Куница В. Н., Кривенцов М. А. и др. Изменения состояния лейкоцитов после облучения и введения цереброспинальной жидкости/ Материалы V международной (XII итоговой) научно-практической конференции молодых ученых, посвященной 70-летию ЮУГМУ, - Челябинск, 2 октября, - 2014. – с.53-56.

<sup>21</sup> Sahin Bozok, Erturk Karaagac The effects of long-term prenatal exposure to 900, 1800, and 2100 MHz electromagnetic field radiation on myocardial tissue of rats // Toxicology and Industrial Health, 2023. –v. 39, Issue 1, -p. 1-9

potential of ROS and other free radicals, including their mutagenic effects and signaling regulation potential, suggests that non-ionizing radiation may represent a hazardous factor for human health. Therefore, we recommend minimizing both the intensity and duration of such exposure and adopting a cautious approach to wireless technologies in daily human life.

## CONCLUSIONS

1. In the early ontogenesis of offspring born to rats exposed to 460 MHz radiation which belongs to the decimeter range spectrum of non-ionizing electromagnetic radiation (widely used in mobile communication, radar, physiotherapy, etc.), some physiological and biochemical parameters were studied, and the specific effects of irradiation during the embryonic, pre-fetal, and fetal stages of prenatal development were investigated [8]. It was shown that:

- the number of offspring born to irradiated pregnant rats decreased regardless of the stage of irradiation, with the greatest reduction observed in those irradiated during the embryonic stage; in addition, decreased body weight of offspring was observed in all irradiation stages [8];

- in the early ontogenesis of offspring irradiated during the embryonic and pre-fetal stages, hematological parameters such as hemoglobin were lower compared with the control group and recovered faster than in those irradiated during the fetal stage; conversely, the level of total protein recovered more quickly in the fetal stage and showed higher values than in the control group [10,11].

2. In the early ontogenesis of rat offspring exposed to decimeter-range electromagnetic radiation during prenatal development, changes associated with stress in the “lipid peroxidation – antioxidant defense” system of blood were observed:

- lipid peroxidation in blood plasma was intensified: in the embryonic stage, this intensification appeared earlier and more sharply, while in later stages it occurred later and more mildly; intensification of lipid peroxidation in erythrocytes was observed

during pre-fetal and fetal stage irradiation, with earlier onset in the fetal stage [13,14,15];

- based on the analysis of antioxidant system indicators (catalase, superoxide dismutase, glutathione, total oxidant and antioxidant activity), it was shown that in offspring irradiated during the embryonic stage, the main role in oxidative–antioxidant stress was played by non-enzymatic antioxidants, while in offspring irradiated during the pre-fetal and fetal stages, the stress resulted from uncoordinated changes in catalase and superoxide dismutase activity [1,2,3,4,9].

3. In the early ontogenesis of offspring born to rats exposed to non-ionizing electromagnetic radiation (decimeter range) during pregnancy, compared with intact organisms, a new oxidant/antioxidant balance in the blood was formed depending on the irradiation stage. Shifting irradiation from the embryonic to the pre-fetal stage delayed the formation of this new balance in early postnatal ontogenesis. In other words, the balance observed in 20-day-old rats irradiated during the embryonic stage appeared only at 30 days in those irradiated during the pre-fetal stage [5,6,12].

4. Quantitative and qualitative changes in the leukocyte formula of blood were revealed in the early ontogenesis of offspring born to rats irradiated during pregnancy with non-ionizing electromagnetic radiation (decimeter range), depending on the prenatal irradiation stage. In all three stages, lymphocyte counts increased while monocytes decreased in 20- and 30-day-old offspring. In the embryonic stage, neutrophils were absent in peripheral blood, while in the pre-fetal and fetal stages their levels were reduced [16,17].

5. It is proposed as a working hypothesis for future studies that changes in leukocytosis during postnatal ontogenesis of organisms exposed to irradiation in the prenatal period are modulated by the tension (oxidative stress) in the newly formed oxidant–antioxidant relationships in the blood, as well as by the degree of this stress.

### **Practical recommendations.**

To protect yourself from the harmful effects of electromagnetic fields (EMF), it is important to carefully consider the placement of electrical devices in the home:

- It is not recommended to group electrical devices together or place them near dining tables, work desks, resting areas, or beds.

- In children's rooms, it is advised to avoid continuous presence of radio-controlled or electric toys, tablets, smartphones, or laptops.

- A radiotelephone base creates a constant magnetic field within a 10-meter radius, so it should be removed from bedrooms and workspaces.

- It is not advisable to have a TV or computer in the bedroom; unused devices near your head should be turned off and unplugged.

- Using a hairdryer for extended periods is not recommended; breaks should be taken.

- When using a microwave oven, it is advised not to approach closer than 1 meter; maintain a distance of 2 meters from both the front and back of TV screens.

- Keep mobile phone conversations short and use a landline phone whenever possible.

### **List of published scientific works on the topic of the dissertation:**

1. Аббасова М.Т., Гаджиев А.М., Кулиева А.Т. Влияние пренатального электромагнитного облучения на общую антиоксидантную и оксидантную активность в крови у молодых крыс / XII Международный междисциплинарный конгресс нейронаука для медицины и психологии. Судак, Крым, Россия, 30 май-10 июня 2017 года. s.47-48

2. Quliyeva A.T., Abbasova M.T., Prenatal inkişaf dövründə qeyri-ionlaşdırıcı elektromaqnit dalğaları ilə şüalanmaya məruz qalmış orqanizmdə oksidant-antioksidant statusu / Azərbaycan Fizioloqlarının A.İ.Qarayev adına Fiziologiya İnstitutunun 50-illiyinə həsr edilmiş V qurultayının materialları. Bakı.10-11 oktyabr, 2017. s. 149-151

3. Guliyeva A.T., Abbasova M.T. Erythrocytes Glutathione of Young Rats Exposed to Non-Ionizing Electromagnetic Radiation in the Prenatal Period of Development / International ecology symposium abstract book, Kastamonu/ Turkey republic of turkey Kastamonu University- 19-23 June, 2018 p.826.

4. Quliyeva A.T., Abbasova M.T. Elektromaqnit dalğalarının təsirindən siçovulların qanında ümumi oksidant və antioksidant fəallığının dəyişilməsi // Azərbaycan Zooloqlar cəmiyyətinin əsərləri, 2018, X cild, № 1. s.40-44

5. Кулиева А.Т. Постнатальные эффекты влияния неионизирующего электромагнитного излучения (460 мГц) на окислительную и антиоксидантную активность крови / VI Съезд биофизиков Сборник научных трудов. Сочи. 16-21.09, 2019, Т.2. с.209

6. Quliyeva A.T. Prenatal inkişaf zamanı elektromaqnit şüalanmanın qanın oksidant-antioksidant sisteminə təsiri // BDU, Xəbərlər jurnalı təbiət elmləri seriyası, 2019, N 1, s.64-68.

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## **LIST OF ABBREVIATIONS**

AOS	Antioxidant system
DNT	deoxyribonucleic acid
EM	Electromagnet
EMW	Electromagnetic waves
EMR	electromagnetic radiation
GSH	reduced glutathione
CAT	catalase
LPO	Lipid peroxidation
MDA	Malondialdehyde
AFO	active forms of oxygen
SOD	superoxide dismutase
HRV	heart rate variability
TOA	total oxidant activity
TAA	total antioxidant activity

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