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NEUROTROPHIC AND GLIAL MARKERS OF NERVOUS TISSUE RECOVERY IN ACUTE CEREBROVASCULAR DISORDERS: EFFECTS OF CELLULAR THERAPY WITH ANTIOXIDANT

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Acute cerebrovascular disorders remain one of the leading causes of mortality and disability, highlighting the relevance of finding effective approaches for neuroprotection and stimulation of neurogenesis. Therefore, studying changes in neuronal and glial markers during ischemic brain injury is of particular importance. The experiment was conducted on outbred white rats using a model of focal cerebral ischemia induced by endovascular occlusion of the middle cerebral artery. Serum levels of S100b, brain-derived neurotrophic factor, neuron-specific enolase, glial fibrillary acidic protein, and pigment epithelium-derived factor were measured to assess the effects of mesenchymal stem cells and resveratrol. It was found that acute cerebrovascular disorders are accompanied by decreased of neuron-specific enolase and pigment epithelium-derived factor and increased S100b, glial fibrillary acidic protein, and brain-derived neurotrophic factor, reflecting glial activation and adaptive responses of neural tissue. Mesenchymal stem cells monotherapy partially normalized glial activity, while combined treatment with mesenchymal stem cells and resveratrol produced a more pronounced effect: increased of neuron-specific enolase and pigment epithelium-derived factor and decreased S100b and brain-derived neurotrophic factor. This indicates restoration of neuronal metabolic activity, stimulation of angiogenesis, and optimization of glial-neuronal interactions. The novelty of the study lies in demonstrating the synergistic effect of cell-based antioxidant therapy, which enhances neuroregeneration, reduces oxidative stress, and stabilizes neurotrophic status during the early recovery period. These results are significant for the development of modern pathogenetically justified approaches to the treatment of ischemic brain injury.

Key words: acute cerebrovascular disorders, mesenchymal stem cells, resveratrol, neurogenesis, neuroprotection.

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НЕЙРОТРОФІЧНІ ТА ГЛІАЛЬНІ МАРКЕРИ ВІДНОВЛЕННЯ НЕРВОВОЇ ТКАНИНИ ЗА УМОВ ГОСТРИХ РОЗЛАДІВ МОЗКОВОГО КРОВООБІГУ: ЕФЕКТИ КЛІТИННО-АНТИОКСИДАНТНОЇ ТЕРАПІЇ

Гострі розлади мозкового кровообігу залишаються одними з провідних причин смертності та інвалідизації, що зумовлює актуальність пошуку ефективних підходів до нейропротекції та стимуляції нейрогенезу. У зв'язку з цим важливим є дослідження змін нейрональних і гліальних маркерів при ішемічному ушкодженні мозку. Експеримент проведено на білих щурах із використанням моделі фокальної ішемії головного мозку, відтвореної шляхом ендоваскулярної оклюзії середньої мозкової артерії. У сироватці крові визначали рівні білка S100b, мозкового нейротрофічного фактора, нейронспецифічної енолази, гліального фібрилярного кислого білка та фактора росту пігментного епітелію імуноферментним методом для оцінки впливу мезенхімальних стовбурових клітин і ресвератролу. Встановлено, що гостре порушення мозкового кровообігу супроводжується зниженням нейронспецифічної енолази і фактора росту пігментного епітелію та підвищенням білка S100b, гліального фібрилярного кислого білка і мозкового нейротрофічного фактора, що відображає активацію глії та адаптаційні реакції нервової тканини. Монотерапія мезенхімальними стовбуровими клітинами забезпечувала часткову нормалізацію гліальної активності, тоді як їх комбіноване застосування з ресвератролом мало більш виражений ефект: підвищення нейронспецифічної енолази і фактора росту пігментного епітелію та зниження білка S100b і мозкового нейротрофічного фактору. Це свідчить про відновлення нейрональної метаболічної активності, стимуляцію ангіогенезу та оптимізацію гліально-нейрональної взаємодії. Новизна дослідження полягає у встановленні синергічного ефекту клітинно-антиоксидантної терапії, що забезпечує посилення нейрорегенерації, зниження оксидативного стресу та стабілізацію нейротрофічного статусу в ранньому відновному періоді. Отримані результати мають важливе значення для розвитку сучасних патогенетично обґрунтованих підходів до лікування ішемічного ураження мозку.

Ключові слова: гострі розлади мозкового кровообігу, мезенхімальні стовбурові клітини, ресвератрол, нейрогенез, нейропротекція.

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Neurogenesis is a complex, multi-level process of formation, differentiation and integration of new neurons into the neural networks of the brain. Under pathological conditions, including ischaemic damage, the activation or, conversely, suppression of neurogenesis determines the further fate of neuronal structures and the level of restoration of brain functional activity. Total cerebral ischaemia is one of the most severe forms of cerebral circulation disorder, accompanied by profound hypoxia, energy depletion of neurons, the development of oxidative stress, glutamate excitotoxicity and secondary inflammation. These processes result in a cascade of molecular and cellular changes, including both neuronal death and compensatory activation of progenitor cells and growth factors involved in neurogenesis [4, 7, 8].

In recent years, considerable attention has been

paid to the study of neurogenesis markers that can serve as indicators of proliferation, migration, and differentiation of neural stem cells. The study of neurogenesis in acute cerebrovascular disorders in experimental animals, particularly rats, is important for understanding the pathogenetic mechanisms of ischaemic damage, searching for molecular targets for neuroprotection, and developing new therapeutic strategies aimed at stimulating regenerative processes in the central nervous system [2, 6, 8, 10, 12].

The purpose of the study was to establish neutrophilic markers of acute cerebrovascular disorders and the effect of mesenchymal cells in combination with antioxidants.

Materials and methods. The animal experiments were conducted at the State Enterprise "Ukrainian Research Institute of Transport Medicine" (Odesa, Ukraine). The processing of biomaterials and data analysis was also carried out at the State Enterprise "Ukrainian Research Institute of Transport Medicine" (Odesa, Ukraine). The study was conducted over the period from July 2025 to August 2025.

The study was performed on 60 white non-linear white matured Wistar rats of both sexes. The animals used in the experiments were sexually mature. Their approximate age was 8–12 weeks, and their body weight ranged from 200–250 g. All animals were clinically healthy, with no evidence of hormonal or physiological disorders prior to or during the study.

The animals were kept in individual boxes with 12 hrs of light and dark, humidity of 60 %, constant temperature of 22±1 °C, with free access to water and food. Animal preparation, all interventions, anesthetics and withdrawal from the experiment were carried out in full compliance with the requirements of the Guidelines of the State Pharmacological Center of the Ministry of Health of Ukraine (Kyiv, 2001), as well as the GLP rules provided by the European Commission for the supervision of laboratory and other studies, in accordance with Code of Scientist of Ukraine.

We investigated acute cerebrovascular disorder in the ischemic stroke model in rats which was reproduced using a model of endovascular occlusion of the middle cerebral artery (focal ischemia) according to E. Z. Longa. The rats were pre-anesthetised in accordance with the provisions regulated by Annex 8 of the "Rules for the humane treatment of laboratory animals", "Sanitary rules for equipment, equipment and maintenance of experimental biological clinics (vivarium)" No 1045–73, and the surgical field was treated with a 0.05 % chlorhexidine solution (Pharmaceutical Company "Lekhim-Kharkiv", Ukraine). After that, an incision was made in the neck area, and the common carotid artery, external carotid artery, and internal carotid artery were isolated on the right side. The common carotid artery was clamped with a vascular clip, and a No. 3 vicryl ligature was applied to the external carotid artery. The internal carotid artery was cut with scissors at a distance of 3–5 mm from the bifurcation. A 0.25 mm diameter nylon thread coated with silicone and treated with heparin solution was inserted through a segment of the internal carotid artery into the external carotid artery to a depth of 19-21 mm and fixed with a vascular clip. Blood flow was blocked for 60 minutes, after which the thread was removed. After that, the internal carotid artery was closed by coagulation until completely sealed, and the vascular clips were then removed. At the end of the operation, the incision was sutured with Vicryl No. 4 and treated with a 5 % solution of brilliant green (Pharmaceutical Company "Lekhim-Kharkiv", Ukraine). After the operation, continuous thermometry (Medical technology manufacturer "BactoSfera", Ukraine) was performed with the temperature maintained at a physiological level using infrared lamps ("Art Eco Light", Ukraine). During the operation, body temperature was maintained using a heating pad. The average duration of the operation was 7–10 minutes [1].

The levels of S100b protein, brain-derived neurotrophic factor (BDNF), neuron-specific enolase (NSE), glial fibrillary acidic protein (GFAP), and pigment epithelium-derived factor (PEDF) in blood serum were determined using specific reagents from R&D Diagnostics Inc. (USA) by the sandwich-type enzyme-linked immunosorbent assay (ELISA) method according to the manufacturer's instructions. The results were measured using a Multiscan microplate reader (Finland) [14].

The experiment was conditionally divided into two stages. At the first stage, experimental laboratory animals were divided into three groups: 1 – control (intact animals, n=12); 2 – rats with acute cerebrovascular disorder (n=12); 3 – rats with subacute cerebral disorder (n=12). At the second stage, correction of the induced pathology was performed. The animals were divided as follows: 1 group (n=12) consisted of animals that did not receive any treatment during the corresponding period (acute or subacute phase), 2 and 3 groups (n=12 in each group) – animals that received either monotherapy or combined therapy, respectively. All animals were monitored throughout the study period. No significant changes in group composition were observed, and all animals survived until the end of the experiment. No adverse conditions or notable side effects were detected during the study. At the completion of the experiment, animals were euthanized in accordance with standard ethical guidelines using approved humane methods [5].

The correction we proposed included the administration of: MSCs, which have a paracrine effect, exhibit an anti-inflammatory effect and stimulate angiogenesis and neurogenesis; resveratrol ("Sigma-Aldrich", USA, at a dose of 50 mg/kg intraperitoneally) – also increases the viability of MSCs and potentiates their neuroprotective effect.

MSCs were obtained from the EmProCell biotechnology laboratory (Mumbai, India) in accordance with international standards and GMP requirements. After thawing, MSCs were cultured using a standard method. The cells were cultured in a

complete growth medium containing 79 % αMEM (Minimum Essential Medium, Alpha modification), 20 % foetal bovine serum (FBS), 1 % penicillin and streptomycin solution (HyClone, New Zealand) and 0.01 % basic fibroblast growth factor (bFGF, Sigma, Germany). Cultivation was carried out at 37 °C and 5 % CO_2 in a standard incubator. The medium was replaced every 2–3 days. After reaching 70–80 % confluence, the cells were washed with phosphate-buffered saline (PBS) and replated using 0.25 % trypsin-EDTA solution (HyClone, New Zeland). Cells from 3–5 passages were used for further experimental studies. Morphological characteristics were monitored using an inverted microscope (e.g., Olympus CKX41), assessing the typical fibroblast-like shape and homogeneity of the culture [5, 14] .

All manipulations with animals were carried out in accordance with GLP requirements, the recommendations of the State Expert Centre of the Ministry of Health of Ukraine, the General Ethical Principles of Animal Experiments (Ukraine, 2001), the Law of Ukraine of 21 February 2006 No. 3447-IV, as amended "On the Protection of Animals from Cruel Treatment", the resolution of the First National Congress on Bioethics (Kyiv, 2007), and the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes. This study was not reviewed by the Bioethics Expert Committee prior to its approval. This is due to the fact that the study has an observational nature. All procedures involving animals were carried out in accordance with established guidelines, and did not result in additional stress, pain, or harm beyond routine practice. Therefore, in accordance with current ethical requirements, studies of this type do not require mandatory prior review by a bioethics committee

Statistical analysis of the obtained results was performed using the Statistica 10.0 software package. The significance of differences between the indicators of untreated animals and experimental groups was assessed using Student's t-test and Fisher's criterion. A p-value<0.05 was considered statistically significant.

Results of the study and their discussion. The assessment of neurotrophic and neurospecific proteins is of significant importance for understanding the mechanisms underlying acute cerebrovascular disorders. These biomarkers provide valuable information about the extent of neuronal damage and the activation of compensatory and regenerative processes in the brain. Their evaluation may enhance early diagnosis, allow better monitoring of disease progression, and contribute to the development of targeted therapeutic strategies.

It was found that on the first day of simulated pathology, the NSE level decreased by 1.4 times (p<0.05) compared to intact animals, and on the 14th day – by 1.1 times, respectively (Table 1). NSE is a sensitive and quantitative marker of brain parenchyma damage.

Table 1

Study of neurotrophic and neurospecific proteins in rats at different times of experimental acute cerebrovascular disorder (M±m)

Indicator	Intact animals (n=12)	Animals with acute cerebral circulation disorder	
		1st day (n=12)	14th day (n=12)
NSE, ng/ml	1.25±0.05	0.89±0.04	1.11±0.05
S-100, ng/ml	1.46±0.21	3.25±0.26	1.95±0.35
GFAP, ng/ml	0.16±0.05	0.27±0.12	0.25±0.15*
BDNF, ng/ml	32.4±5.8	75.3±5.4	66.3±5.1*/**
PEDF, ng/ml	0.35±0.06	0.28±0.05	0.32±0.04

Notes: 1. n – number of experimental animals in each group; 2. * – p<0.05 compared to intact animals; 3. ** – p<0.05 compared to rats on the first day of the experiment.

The study found that on the first day of the simulated pathology, this indicator increased by 2.2 times (p<0.05) compared to intact animals, and by the end of the experiment – by 1.3 times (p<0.05), respectively. The increase in S-100 protein on the first day after modelling of acute cerebrovascular disorder indicates acute damage to astrocytic glia and disruption of the integrity of the blood-brain barrier. On the 14th day, partial restoration of these structures and a decrease in dystrophic changes in the brain were noted.

In our experiment, already on the first day of observation, the GFAP level increased by 1.5 times (p<0.05) compared to intact animals. On the 14th day, this marker showed a similar trend and exceeded the results of the intact group of animals by 1.5 times (p<0.05).

In animals with simulated pathology, this indicator increased 2.3 times (p<0.05) relative to intact rats on the first day of the experiment, while on the 14th day it increased only 2.0 times (p<0.05). We found a significant decrease in PEDF only on the first day of the experiment by 1.3 times (p<0.05) compared to the intact group.

Taking into account the data obtained on the involvement of neurospecific proteins in the development of acute cerebrovascular disorder, we studied the effect of combination therapy on these indicators. The data obtained during treatment in the acute and subacute periods are presented in Table 2.

In the acute period of simulated acute cerebrovascular disorder with monotherapy of MSC, a significant decrease in S-100 levels by 1.3 times (p<0.05) compared to untreated animals and BDNF by 1.3 times (p<0.05) was established.

Other indicators of neurogenesis in this group of animals did not differ significantly from rats that did not receive correction. In the group of animals that received combined correction (MSK+resveratrol), significant changes were observed in virtually all indicators, in particular, the NSE level increased 1.2 times ($p<0.05$) compared to untreated rats, PEDF increased 1.2 times ($p<0.05$), S-100 concentration decreased 1.6 times ($p<0.05$), and BDNF decreased 1.6 times ($p<0.05$), respectively.

Table 2

Effect of combination therapy on neurogenesis parameters in rats with simulated acute cerebrovascular disorder (M±m)

Indicator	Animals without correction (n=12)	Groups of treated animals	
		Group 1 (n=12)	Group 2 (n=12)
Acute period			
NSE, ng/ml	0.89±0.04	0.96±0.03	1.05±0.12
S-100, ng/ml	3.25±0.26	2.45±0.72	2.05±0.65
GFAP, ng/ml	0.27±0.12	0.21±0.05	0.23±0.06
BDNF, ng/ml	75.3±5.4	57.23±4.1*	47.6±3.8
PEDF, ng/ml	0.28±0.05	0.31±0.03	0.33±0.01
Subacute period			
NSE, ng/ml	1.11±0.05	1.25±0.35	1.31±0.41
S-100, ng/ml	1.95±0.35	2.21±0.82	2.95±0.75
GFAP, ng/ml	0.25±0.15	0.21±0.18	0.28±0.15
BDNF, ng/ml	66.3±5.1	50.3±4.6	42.4±3.8
PEDF, ng/ml	0.32±0.04	0.34±0.02	0.37±0.03

Notes: 1. n – number of experimental animals in each group; 2. * – $p<0.05$ compared to the untreated group of animals.

In the subacute period, when using MSC monotherapy, a significant decrease in BDNF levels was observed by 1.3 times ($p<0.05$) compared to untreated animals. All other results between the groups did not show a significant difference. The use of combination therapy (MSC + resveratrol) led to a significant increase in NSE levels by 1.2 times ($p<0.05$) relative to the group of untreated animals, S-100 by 1.5 times ($p<0.05$), and a decrease in BDNF concentration by 1.6 times ($p<0.05$), respectively.

The results obtained indicate multidirectional changes in markers of neurogenesis and neuronal damage under conditions of experimental acute cerebrovascular disorder and various options for its correction. During the acute period of ischaemia, a significant decrease in the concentration of S-100 and BDNF proteins was observed, which may indicate suppression of acute manifestations of glial activation and a decrease in reactive neurogliosis. The decrease in S-100 levels can be considered a manifestation of the moderate neuroprotective effect of MSCs in the early phase of ischaemia. At the same time, a decrease in the concentration of BDNF, a neurotrophic factor that ensures neuron survival and synaptic plasticity, probably reflects reactive depletion of the trophic reserve of brain tissue against the background of ischaemic stress, which is not fully compensated by MSC monotherapy [5, 14].

With the combined use of MSC and resveratrol in the acute period, a significant increase in NSE and PEDF levels was found, which may indicate the activation of neuronal metabolic activity and processes of angiogenesis and neurogenesis. The simultaneous decrease in S-100 and BDNF concentrations indicates a reduction in glial activation and neurotrophic imbalance, which is consistent with the antioxidant and anti-inflammatory properties of resveratrol. Thus, combined correction has a complex neuroprotective effect aimed at restoring cellular homeostasis and reducing secondary damage to brain tissue.

In the subacute period (on day 14), a decrease in BDNF levels was observed in the MSC monotherapy group 1, which may be associated with the limited ability of MSCs to maintain neurotrophic potential. In turn, combined therapy resulted in a significant increase in NSE and S-100 levels with a simultaneous decrease in BDNF, indicating the activation of reparative processes and metabolic adaptation of neurons in the post-ischaemic period. The increase in NSE can be interpreted as a manifestation of increased neuronal activity and regeneration, while the controlled increase in S-100 against the background of antioxidant therapy may indicate the physiological reactivation of astrocytes necessary for the remodelling of neuronal networks and the formation of glial-neuronal interactions in the recovery phase. This indicates deeper and more balanced neuroprotection compared to MSC monotherapy and demonstrates the potential of a combined approach to improve neuroregenerative processes in the acute and recovery periods of acute cerebrovascular disorder [4, 10, 14].

The results obtained indicate that the development of acute cerebrovascular disorder is accompanied by a significant decrease in NSE levels on the first day of the experiment, indicating acute neuronal damage and impaired metabolic activity of nervous tissue. A partial increase in the indicator on the 14th day may indicate partial activation of recovery processes in the brain parenchyma, but the preservation of lower values compared to intact animals indicates incomplete recovery of neuronal function and a prolonged decrease in neurospecific activity due to ischaemic damage. S-

100 protein is specific to astrocytic glia and is capable of binding calcium. An increase in its concentration in plasma is also considered a marker of brain damage [3, 11, 12, 13].

GFAP belongs to cytoskeletal proteins and is a highly specific brain protein found only in the central nervous system. Due to its high specificity and early release after traumatic brain injury, glial fibrillary acidic protein is a useful marker for the early diagnosis of brain dysfunction. A stable increase in GFAP levels throughout the experiment indicates the activation of astrocytic glia in response to ischaemic damage to brain tissue [5, 9, 14].

BDNF stimulates neuron differentiation and supports their survival. It is expressed in fibroblasts, astrocytes, neurons of various phenotypes and localisations, and Schwann cells (in areas of damage). The functional activity of BDNF is quite significant. During development, it participates in neuron differentiation, maturation, survival, and synapse formation. In the adult body, the main function of BDNF is neuroprotection, protecting brain neurons from ischaemic attacks and motor neurons from death induced by axon removal [4].

PEDF is a neuroprotective and neurotrophic factor that affects various types of neurons. In rats, the pigment factor of epithelial origin serves as a survival factor for cerebellar granule neurons, protecting them from apoptosis and glutamate neurotoxicity [4, 10, 11].

Thus, a comprehensive study of the dynamics of expression of markers of neurogenesis and neuroglial activity in acute cerebrovascular disorder in rats revealed characteristic patterns of formation and progression of ischemic damage to neural tissue. Together, these changes reflect the molecular-cellular cascade of ischaemic damage and partial repair of the brain, where the markers NSE, S-100, GFAP, BDNF, and PEDF play a key role as indicators of different stages of the neuronal-glial response to ischaemic stress.

Limitations. The study is limited by a relatively small sample size and a short observation period, which may affect the generalizability of the findings. Additionally, potential variability in biological responses among animals could not be fully controlled despite standardized experimental conditions.

Conclusions

1. The development of acute cerebrovascular disorder is accompanied by cascading changes in the system of neuronal-glial interactions, which is reflected in the dynamics of neurospecific and neurotrophic protein levels. A decrease in NSE concentration on the first day of the experiment indicates acute neuronal damage and metabolic depletion of nervous tissue, while a partial recovery of the indicator on the 14th day indicates the activation of compensatory-regenerative processes in the brain parenchyma. The increase in the levels of glial markers S-100 and GFAP indicates a reactive astrocytic glial response to ischaemic damage. The increase in S-100 on the first day indicates a violation of the integrity of the blood-brain barrier and acute damage to glial cells, while a consistently elevated level of GFAP throughout the observation period reflects the sustained activation of astrocytes and the formation of glial remodelling of brain tissue.

2. Changes in neurotrophic factor levels demonstrate a compensatory attempt by the nervous tissue system to activate neuroprotection and neuroregeneration processes.

3. Combined therapy with MSC and resveratrol exerts a pronounced neuroprotective and neuroregenerative effect under conditions of experimental acute cerebrovascular disorder. Analysis of specific neurotrophic and glial markers (S-100b, BDNF, NSE, GFAP, and PEDF) revealed that the synergistic action of MSCs and antioxidant treatment contributes to restoring neuronal metabolism, stabilizing glial function, and enhancing neurotrophic support in both the acute and early recovery phases of ischemic injury.

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EXPERIMENTAL STUDY OF THE EMBRYO- AND CARDIOPROTECTIVE ROLE OF ZINC SUCCINATE IN RELATION TO CADMIUM CHLORIDE TOXICITY

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Cardiovascular diseases remain the leading causes of mortality worldwide and in Ukraine. The current direction of modern morphological research is to determine the changes that occur in vivo under the influence of cadmium compounds on the fertilization process, embryogenesis, and formation and development of the heart. The aim of the experiment was to determine changes in heart morphogenesis and the main indicators of embryogenesis under conditions of chronic daily exposure to cadmium chloride with isolated administration and in combination with zinc succinate. The data obtained demonstrated a complex, dose-dependent nature of the interaction of cadmium chloride with the essential trace element zinc succinate. In the heart tissues of adult female rats and its embryos, the level of cadmium accumulation decreased with the combined administration of the studied substances. Also, the simultaneous administration of zinc succinate with cadmium chloride significantly reduced the effects of embryo- and cardiotoxicity of cadmium, which allows us to consider zinc succinate as a potential protector or bioantagonist of the toxic properties of cadmium chloride in the studied doses and method of administration in the experiment on rats.

Key words: rats, heart, embryo, cardiotoxicity, cadmium, zinc, succinates, experiment.

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ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ЕМБРІО- ТА КАРДІОПРОТЕКТОРНОЇ РОЛІ СУКЦИНАТУ ЦИНКУ ВІДНОСНО ТОКСИЧНОСТІ ХЛОРИДУ КАДМІЮ

Серцево-судинні захворювання залишаються лідерами причин смертності в усьому світі та в Україні. Актуальним напрямком сучасних морфологічних досліджень є визначення змін, що виникають in vivo під впливом сполук кадмію на процеси запліднення, ембріогенез та формування і розвиток серця. Метою експерименту було визначення змін морфогенезу серця та основних показників ембріогенезу за умов хронічного щоденного впливу хлориду кадмію при ізольованому введенні та в комбінації з сукцинатом цинку. Отримані дані продемонстрували складний, залежний від тривалості надходження та дози характер взаємодії хлориду кадмію з есенціальним мікроелементом сукцинатом цинку. У тканинах серця дорослих самиць та у ембріонах щурів знижувався рівень накопичення кадмію при комбінованому надходженні досліджуваних речовин. Також одночасне надходження сукцинату цинку з хлоридом кадмію достовірно знижувало ефекти ембріо- та кардіотоксичності кадмію, що дозволяє розглядати сукцинат цинку як потенціальний протектор або біоантагоніст токсичним властивостям хлориду кадмію в досліджуванних дозах та способі введення в експерименті на щурах.

Ключові слова: щури, серце, ембріон, кардіотоксичність, кадмій, цинк, сукцинати, експеримент.

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Cardiovascular diseases (CVD) remain the leading causes of mortality worldwide and in Ukraine. According to the State Statistics Service of Ukraine in 2021 the mortality rate in Ukraine due to CVD was 60 % of the total number of deaths. In addition, CVD significantly affects not only the duration, but also the quality of life; therefore, the treatment and prevention of CVD remain one of the key tasks of the World Health Organization (WHO) and the Ministry of Health of Ukraine. For decades, basic clinical, biological, and statistical studies have identified among the causes of CVD the age component, heredity, gender, bad habits (smoking and excessive alcohol consumption), stress, nutrition, physical inactivity, obesity, diabetes and environmental pollution. Some studies have found