Garapko, T. V., Mateshuk-Vatseba, L. R., Holovatskyi, A. S., & Foros, A. I. (2022). Changes in the structural organization of spleen during short-term exposure of monosodium glutamate. *Actual Issues of Modern Science. European Scientific e-Journal*, *23*(8), 73-82. Ostrava: Tuculart Edition, European Institute for Innovation Development.
Гарапко, Т. В., Матешук-Вацеба, Л. Р., Головацький, А. С., Форос, А. І. (2022). Зміни в структурній організації селезінки при короткочасному впливі глутамату натрію. *Actual Issues of Modern Science. European Scientific e-Journal*, *23*(8), 73-82. Ostrava: Tuculart Edition, European Institute for Innovation Development.

DOI: 10.47451/med2022-11-01

The paper will be published in Crossref, ICI Copernicus, BASE, Academic Resource Index ResearchBib, J-Gate, ISI International Scientific Indexing, Zenodo, OpenAIRE, BASE, LORY, EBSCO, ADL, Mendeley, eLibrary, and WebArchive databases.

Tetyana V. Garapko, Doctor of Medical Sciences, Docent, Department of Human Anatomy and Histology, Faculty of Medicine, Uzhhorod National University. Uzhhorod, Ukraine.
ORCID 0000-0003-0596-9622.
Lesia R. Mateshuk-Vatseba, Doctor of Medical Sciences, Professor, Department of Normal Anatomy, Danylo Halytskyi Lviv National Medical University. Lviv, Ukraine.
ORCID 0000-0002-3466-5276.
Andrii S. Holovatskyi, Doctor of Medical Sciences, Professor, Department of Human Anatomy and Histology, Faculty of Medicine, Uzhhorod National University. Uzhhorod, Ukraine.
Anatolii I. Foros, Doctor of Philosophy, Department of Fundamental Medical Disciplines and Orthopedic Dentistry, Faculty of Dentistry, Uzhhorod National University. Uzhhorod, Ukraine.
ORCID 0000-0003-0824-6702.

Changes in the structural organization of spleen during short-term exposure of monosodium glutamate

Abstract: Monosodium glutamate is one of the most common food additives in the world. Its effect on the organs of the immune system is not sufficiently studied. The article presents and analyzes the data of an experimental study conducted on 40 white male and female rats of reproductive age (2.5-3.5 months old) weighing 125-195 g. The purpose of the study was to study the histological, morphometric and ultrastructural changes of the spleen under conditions of exposure to monosodium glutamate for four weeks. An experimental group of animals (10 male rats, 10 female rats), which was on a standard vivarium diet, was given monosodium glutamate at a dose of 0.07 g/kg of rat body weight every day for four weeks. In animals of the intact group, the structure of the spleen corresponded to the species norm. In the experimental group of animals, after four weeks of exposure to monosodium glutamate, an immunoinducing effect was observed with increased proliferation of activated lymphocytes and their further differentiation into plasma cells. There is a significant increase in the relative area of the germinal centers of splenic lymphoid nodules and the outer diameter of the central artery of the spleen. Arteries with a thickened wall, their lumen is full of blood. Degeneratively changed erythrocytes are located around the vessels. The veins have a deformed shape, are dilated, the lumen is also full of blood. The share of active macrophages, apoptically changed cells increases. The red pulp is full-blooded, filled with hemosiderin. Therefore, even a short-term daily exposure to monosodium glutamate, namely four weeks, causes changes in the structural organization of the spleen.

Keywords: experiment, monosodium glutamate, spleen, white pulp, red pulp, lymphocytes.

Тетяна Василівна Гарапко, доктор медичних наук, доцент, кафедра анатомії людини та гістології, медичний факультет, Ужгородський національний університет. Ужгород, Україна. ORCID 0000-0003-0596-9622.
Леся Ростиславівна Матешук-Вацеба, доктор медичних наук, професор, кафедра нормальної анатомії, Львівський національний медичний університет імені Данила Галицького. Львів, Україна. ORCID 0000-0002-3466-5276.
Андрій Степанович Головацький, доктор медичних наук, професор, кафедра анатомії людини та гістології, медичний факультет, Ужгородський національний університет. Ужгород, Україна.
Анатолій Ілліч Форос, доктор філософії, кафедра фундаментальних медичних дисциплін та ортопедичної стоматології, стоматологічний факультет, Ужгородський національний університет. Ужгород, Україна. ORCID 0000-0003-0824-6702.

Зміни в структурній організації селезінки при короткочасному впливі глутамату натрію

Анотація: Глутамат натрію є однією з найбільш поширених харчових добавок у світі. Його вплив на органи імунної системи є не достатньо вивченим. В статті наведено та проаналізовано дані експериментального дослідження, проведеного на 40 білих щурах-самцях і самках репродуктивного віку (2,5-3,5-місячних) масою 125-195 г. Мета дослідження – вивчити гістологічні, морфометричні та ультраструктурні зміни селезінки в умовах впливу глутамату натрію впродовж чотирьох тижнів. Експериментальній групі тварин (10 щурів-самців, 10 щурів-самок), яка перебувала на стандартному харчовому раціоні віварію, впродовж чотирьох тижнів щодня додавали глутамат натрію в дозі 0,07 г/кг маси тіла щура. У тварин інтактної групи будова селезінки відповідала видовій нормі. В експериментальній групі тварин через чотири тижні дії глутамату натрію спостерігається імуноіндукуючий ефект з посиленою проліферацією активованих лімфоцитів та їх подальшим диференціюванням у плазматичні клітини. Відбувається достовірне збільшення відносної площі зародкових центрів селезінкових лімфоїдних вузликів та зовнішнього діаметру центральної артерії селезінки. Артерії з потовщеною стінкою, їх просвіт повнокровний. Навколо судин розташовані дегенеративно змінені еритроцити. Вени мають деформовану форму, розширені, просвіт також повнокровний. Зростає частка активних макрофагів, апоптично змінених клітин. Червона пульпа повнокровна, заповнена гемосидерином. Отже, навіть короткотривалий щоденний вплив на організм глутамату натрію, а саме чотири тижні, викликає зміни структурної організації селезінки.

Ключові слова: експеримент, глутамат натрію, селезінка, біла пульпа, червона пульпа, лімфоцити.

Introduction

Monosodium glutamate is one of the most common food additives in the world. It is the monosodium salt of glutamic acid (*Bautista et al., 2019*). Belongs to taste enhancers, due to which it increases appetite. This leads to increased food intake, causing a high-calorie diet (*Bhandari, 2018*). The result of a high-calorie diet is excess body weight and obesity. Obesity contributes to the occurrence of numerous organ diseases, but the mechanisms of these processes remain unclear (*Camacho & Ruppel, 2017*).

In the professional literature, obesity is considered a state of chronic inflammation, which is often associated with complications such as type two diabetes, cardiovascular disease,

hypertension, stroke, gallbladder disease, osteoarthritis, and psychosocial problems (*Bibik, 2018*; *Escobedo & Oliver, 2017*; *Coppey, 2018*). Numerous studies describe that a high-calorie diet leads to metabolic syndrome, insulin resistance, diabetes, splenomegaly, arterial hypertension, heart attacks, etc. (*Finlayson, 2017*; *Buchan et al., 2018*).

In obesity, the functions of both T cells and B cells are impaired. Obesity-induced reduction of IL-10 synthesis in the spleen leads to inflammatory reactions in the kidneys and metabolic disturbances (*Gotoh et al., 2017*).

Scientists conclude that monosodium glutamate causes metabolic disorders and contributes to the development of obesity. A number of separate studies on glutamate-induced obesity have been described in foreign publications (*Bautista et al., 2019*). The results of the study, which was conducted on eight-week-old rats that were on a high-calorie diet, showed an increase in blood levels of triglycerides, total cholesterol, low-density lipoproteins, and an increase in body weight (*Farias et al., 2019*). These are all signs of the development of obesity, which also negatively affects the organs of the immune system.

The effect of monosodium glutamate on the organs of the immune system is not sufficiently studied. Therefore, this study is relevant, because it is these organs that react to the penetration of foreign antigens into the body (*Escobedo & Oliver, 2017*; *Begay et al., 2022*; *Habashy et al., 2021*).

The purpose of the study was to study the histological, morphometric and electron microscopic changes in the spleen of monosodium glutamate rats for four weeks.

The study was conducted on 40 white male and female rats of reproductive age (2.5-3.5 months old) weighing 125-195 g.

The normal structure of the spleen was studied in 10 intact animals, of which there were 5 male rats and 5 female rats. The experimental group of animals included 10 male rats and 10 female rats. They received a standard vivarium diet, to which monosodium glutamate was added daily for four weeks at a dose of 0.07 g/kg of rat body weight. The animals had free access to water and food. The control group of animals consisted of 5 male rats and 5 female rats, which received a physiological solution (0.9% NaCl solution) with a standard vivarium diet.

All experimental animals were kept in the vivarium of Lviv National Medical University named Danylo Halytsky. The research was conducted in accordance with the provisions of the European Convention on the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (Strasbourg, 1986), Council of Europe Directives 86/609/EEC (1986), Law of Ukraine No. 3447-IV On the Protection of Animals from Cruelty Handling, general ethical principles of experiments on animals, adopted by the First National Congress of Ukraine on Bioethics (2001).

Morphometric studies were performed during the required period of the experiment on histological preparations stained with hematoxylin and eosin. VideoTest-5.0, KAARA Image Base, Stepanizer and Microsoft Excel programs were used. Statistical processing of digital data was performed with the help of the "Excel" software using the parametric method.

Preparation of spleen preparations for microscopic and ultrastructural examination was carried out according to well-known methods. Spleen pieces were fixed with a 1.5% solution of osmium tetroxide in a 0.2 M solution of sodium cacodylate at pH 7.2 for 2-2.5 hours in the cold. Sections were made on an ultramicrotome UMTP-6M with a diamond knife (DIATOM), double contrast was performed according to Reynolds and uranyl acetate. The submicroscopic study

was carried out using a TEM-100 transmission electron microscope. Photo documentation using a SONY-H9 digital camera. Semi-thin sections with a thickness of 1-2 μm were made on an ultramicrotome LKB-3 (Sweden). They were stained with methylene blue.

The results of the study

As the results of our study showed, the structure of the spleen in animals of the intact and control groups corresponded to the species norm. The organ is surrounded by a capsule. The parenchyma is made of white and red pulp (*Figure 1*). The white pulp contains splenic lymphoid nodules and lymphoid periarterial sheaths. The red pulp is a place of blood deposition, contains venous sinuses and splenic cords. This is where the destruction of spent erythrocytes and other blood cells takes place. Morphometric indicators are presented in Tables 1, 2 (*Table 1*; *Table 2*).

Splenic lymphoid nodules consist of a periarterial, mantle, marginal zone and a germinal center. In the splenic cords, B-lymphocytes are transformed into plasma cells, and monocytes into macrophages. The lymphoid component of the spleen includes small, middle, and large T- and B-lymphocytes, macrophages, and plasma cells. All cells have a typical structure (*Figure 2*).

After four weeks of the experiment, both male and female rats showed signs of antigenic stimulation on histological preparations of the spleen, as evidenced by hyperplasia of the lymphoid component of the spleen, in particular. the intensity of the formation of germinal centers increased, the processes of proliferation and differentiation of lymphoid cells increased (*Figure 3*).

A large number of active macrophages and apoptically changed cells are observed on histological sections of spleen preparations. The number of cells with signs of mitosis decreased. The venous sinuses of the spleen are enlarged and full of blood, accumulating hemosiderin. The cytoplasm of active macrophages is filled with drops of hemosiderin (*Figure 4*).

The vessels of the hemomicrocirculatory channel also undergo changes. Arteries with a thickened wall, probably due to edema, their lumen is full of blood. Degeneratively changed erythrocytes are located around the vessels. The veins have a deformed shape, are dilated, the lumen is also full of blood. The venous sinuses in the red pulp are enlarged and contain accumulations of hemosiderin.

It was established by the morphometric method that the relative area of the white pulp of the spleen after four weeks of the experiment increases in comparison with the intact group of animals by only 1.4% in male rats and by 0.91% in female rats. The relative area of lymphoid nodules of the spleen decreases by 1.95% and 1.25%, respectively. The relative area of lymphoid periarterial sheaths decreased by 4.65% and 2.6%. The relative area of the red pulp of the spleen is only 0.49% and 0.33% less than the parameters of the intact group of animals (*Table 1*; *Table 2*).

The relative area of the mantle and marginal zones on the histological preparation of the spleen section is 0.98% in male rats and 1.36% in female rats less than the indicator of the intact group of animals, the germinal center increases compared to the intact group of animals by 15.21% and 14.91% ($p<0.001$), the periarterial zone is only 0.88% more in male rats and 2.93% less in female rats than the indicator of the intact group of animals. The outer diameter of the central arteries after four weeks of the experiment increases and is 44.94% and 40.25%, respectively, significantly ($p<0.001$) more than the parameters of the intact group of animals.

The inner diameter of the central arteries decreases and is 3.11% and 2.58% less than the indicator in animals of the intact group (*Tables 1*; *Table 2*).

After four weeks of the experiment, during the electron microscopic study of the spleen of white male and female rats of reproductive age, many active macrophages were found, their cytoplasm is loaded with fragments of the nucleus of other cells, parts of "undigested" formed blood elements, and contains numerous phagosomes. The proportion of reticular cells and connective tissue fibers both in the splenic trabeculae and in the splenic cords has increased, the walls of the splenic sinuses are thickened (*Figure 5*). The reticular cells' nucleus is elongated, the contour of the nuclear envelope is uneven, tortuous, the processes of the cell envelope are thinned.

Blood capillaries are filled with erythrocytes, arranged in a "coin column", presumably due to the narrowing of the lumen, which is associated with edema of the wall. Endotheliocyte nucleus in the wall of hemocapillaries are also enlarged, swollen, the basement membrane is thickened, signs of perivascular edema are revealed (*Figure 6*).

Discussion

After four weeks of daily exposure to monosodium glutamate, an immunoinducing effect is observed with increased proliferation of activated lymphocytes and their subsequent differentiation into plasma cells. This is the morphological prerequisite for increased synthesis of immunoglobulins. We think that all the changes mentioned by us are the primary reaction of the immune organs to the daily administration of monosodium glutamate. Signs of edema of the parenchyma of lymph nodes are that the intercellular space is expanded and contains vacuole-like structures.

It has been described in the literature that under conditions of exposure to a high-calorie diet, the main changes in visceral adipose tissue occurred due to a change in the relative population of immune cells, which resulted in a higher percentage of macrophages, dendritic cells, and CD8+ T cells. A high-calorie diet had a greater effect on visceral adipose tissue than on subcutaneous In the visceral lymph node, as a result of the development of obesity, the populations of cells that suppress immune function are reduced and the populations of those that regulate/activate the immune response are increased (*Magnuson et al., 2017*).

The authors in their research showed that a high-calorie diet, compared to a normal standard diet, reduced the expression of CD20, a surface molecule present on B cells that plays an important role in the immune response and produces IL-10 mainly in the spleen. Moreover, splenocyte proliferation stimulated by T-cell and B-cell mitogens was significantly lower in obese subjects (*Gotoh et al., 2017*).

The authors found that acute irradiation of the spleen using the inverse intensity modulated radiotherapy source axis distance irradiation technique had a protective effect on rats with traumatic brain injury. The spleen of the rats was precisely irradiated by a 6 MV X-ray with a total dose of 8 Gy. Initiation of splenic irradiation four hours after traumatic brain injury reduced splenic inflammatory response, alleviated brain edema, and improved behavioral scores (*Huang et al., 2021*).

When studying the distribution of connective tissue fibers in the spleen of diabetic rats and rats treated with vitamin C, the accumulation of collagen fibers was found in the splenic

trabeculae, in the capsule and around the central artery and venous sinuses of the spleen. There was thickening of the splenic trabeculae due to fibrosis, not edema as in our case. Reticular fibers accumulated in both the white and red pulp of the spleen. A partial rupture of elastic fibers in the arterial wall was observed. A slight thickening of the reticular fibers was found in the group of animals corrected with vitamin C, and the elastic fibers maintained their integrity and were better organised than in the group of animals with diabetes (*Ozerkan, 2021*).

Similar changes were found by the authors when studying the effect of Nano-Cu, an additive to animal feed. It is a potential antibacterial and growth-promoting material that can be used as an additional additive to animal feed. However, with the widespread use of nano-Cu, the risk of developing their unknown toxic side effects is becoming increasingly likely. The study revealed nano-Cu induced obvious spleen damage and oxidative-inflammatory and immune changes associated with activation of several pro-inflammatory responses, oxy/antioxidants and modulation of CD3+CD4+/CD3+CD8+T cell subtypes in rat spleen. Nano-Cu is more immunotoxic than conventional Cu sources, so it is not suitable as a long-term animal feed additive (*Xerong et al., 2019*).

The literature mentions that the spleen decreases in size after a stroke in rodents. Splenectomy two weeks before ischemic and hemorrhagic stroke in mice and rats shows a reduction in infarct volumes. Proinflammatory mediators are also increased in the spleen and subsequently in the brain after stroke (*Seifert & Offner, 2018*).

Prospects for further development are related to the study of histological, morphometric and ultrastructural changes in the spleen of rats under conditions of long-term exposure to monosodium glutamate and correction.

Conclusions

As a result of a study conducted on male and female rats of reproductive age, it was found that even short-term daily exposure to monosodium glutamate, namely four weeks, causes changes in the structural organization of the spleen. An immunoinducing effect is observed with increased proliferation of activated lymphocytes and their subsequent differentiation into plasma cells. There is a significant increase in the relative area of the germinal centers of splenic lymphoid nodules and the outer diameter of the central artery of the spleen. The share of active macrophages, apoptically changed cells increases. The red pulp is full-blooded, filled with hemosiderin.

Conflict of interest

The authors declare no conflict of interest.

References:

Bautista, R. J. H., Mahmoud, A. M., Konigsberg, M., Guerrero N., & Guerrero, L. D. (2019). Obesity: Pathophysiology, monosodium glutamate-induced model and anti-obesity medicinal plants. *Biomedicine & Pharmacotherapy*, *111*, 503-516. https://doi.org/10.1016/j.biopha.2018.12.108

Begay, V., Cirovic, B., Barker, A. J., Klopfleisch, R., Hart, D. W., Bennett, N. C., & Lewin, G. R. (2022). Immune competence and spleen size scale with colony status in the naked mole-rat. *Open Biology*, *12*, 210292. https://doi.org/10.1098/rsob.210292

Bhandari, U. (2018). Effect of embelin in monosodium glutamate induced obesity in male neonatal Wistar rats. *Atherosclerosis Supplements*, *32*, 138. https://doi.org/10.1016/j.atherosclerosissup.2018.04.423

Bibik, E. Y., Shipilova, N. V., & Demenko, A. V. (2018). Melatonin as an effective pharmacocorrector of alimentary obesity resulting from a long-therm excessive of intake of palm oil. *Research Result: Pharmacology and Clinical Pharmacology*, *4*(1), 51-58.

Buchan, L., Aubin Ch., Fisher, A. L., Hellings, A., Castro, M., Al-Nakkash, L., Broderick, T. L., & Plochocki, J. H. (2018). High-fat, high-sugar diet induces splenomegaly that is ameliorated with exercise and genistein treatment. *BMC Research Notes*, *11*, 752-758. https://doi.org/10.1186/s13104-018-3862-z

Camacho, S, & Ruppel, A. (2017). Is the calorie concept a real solution to the obesity epidemic? *Glob Health Action*, *10*(1), 1289650. https://doi.org/10.1080/16549716.2017.1289650

Coppey, L., Shevalye, H., Obrosov, A., Davidson, E., & Yorek, M. (2018). Determination of peripheral neuropathy in high-fat diet fed low-dose streptozotocin-treated female C57Bl/6J mice and Sprague-Dawley rats. *Diabetes Investigation*, *9*(5), 1033-1040. https://doi.org/10.1111/jdi.12814

Escobedo, N., & Oliver, G. (2017). The lymphatic vasculature: Its role in adipose metabolism and obesity. *Cell Metabolism*, *26*(4), 598-609. https://doi.org/10.1016/j.cmet.2017.07.020

Farias, T. S. M., Cruz, M. M., Sa, R. C. C., Severi, I., Perugini, J., & Senzacqua, M. (2019). Melatonin supplementation decreases hypertrophic obesity and inflammation induced by high-fat diet in mice. *Front Endocrinology*, *10*, 750. https://doi.org/10.3389/fendo.2019.00750

Finlayson, G. (2017). Food addiction and obesity: unnecessary medicalization of hedonic overeating. *Nature Reviews. Endocrinology*, *13*(8), 493-498. https://doi.org/10.1038/nrendo.2017.61

Gotoh, K., Fujiwara, K., Anai, M., Okamoto, M., Masaki, T., Kakuma, T., & Shibata, H. (2017). Role of spleen-derived IL-10 in prevention of systemic low-grade inflammation by obesity. *Endocrine*, *64*, 375-378. https://doi.org/10.1507/endocrj.EJ17-0060

Habashy, N. H., Kodous, A. S., & Abu-Serie, M. M. (2021). Targeting ROS/NF-$\varkappa$B signaling pathway by the seedless black Vitis vinifera polyphenols in CCl_4-intoxicated kidney, lung, brain, and spleen in rats. *Scientific Reports*, *11*, 16575. https://doi.org/10.1038/s41598-021-96008-0

Huang, X., Lu, Y., Li, L., Sun, T., Jiang, X., Li, M., & Zhang, T. (2021). Protective effect of acute splenic irradiation in rats with traumatic brain injury. *Neuroreport*, *32*(8), 711-720. https://doi.org/10.1097/WNR.0000000000001650

Magnuson, A. M., Regan, D. P., Fouts, J. K., Booth, A. D., Dow, S. W., & Foster, M. T. (2017). Diet-induced obesity causes visceral, but not subcutaneous, lymph node hyperplasia via increases in specific immune cell populations. *Cell Proliferation*, *50*(5), 12365. https://doi.org/10.1111/cpr.12365

Ozerkan, D., Ozsoy, N., Cebesoy, S., & Ozer, C. (2021). Distribution of spleen connective tissue fibers in diabetic and vitamin C treated diabetic rats. *Biotechnic & Histochemistry*, *96*(5), 347-353. https://doi.org/10.1080/10520295.2020.1795718

Seifert, H. A., & Offner, H. (2018). The splenic response to stroke: from rodents to stroke subjects. *Neuroinflammation*, *15*, 195. https://doi.org/10.1186/s12974-018-1239-9

Xerong, Z., Luo, J., Tang, H., Zhao, L., Xu, M., Wang, Y., Yang, X., Chen, H., Li, Y., Ye, G., Shi, F., Lv, Ch., & Jing, B. (2019). The toxic effects and mechanisms of nano-Cu on the spleen of rats. *International Journal of Molecular Sciences*, *20*(6), 1469. https://doi.org/10.3390/ijms20061469

Appendix

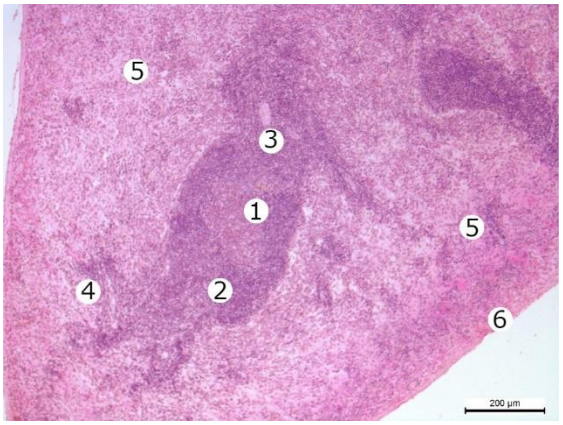

Figure 1. A fragment of the spleen of a white male rat from the intact group of animals. Staining with hematoxylin and eosin. Approx. ×100. Designation: 1 – germinal center of the lymphoid nodule; 2 – mantle and marginal zones of the lymphoid nodule; 3 – the central artery of the spleen; 4 – lymphoid periarterial sheath; 5 – red pulp; 6 – capsule of the spleen

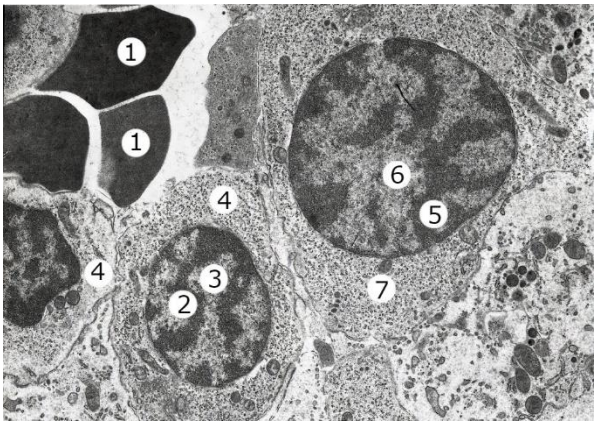

Figure 2. Electron-microscopic organization of a fragment of the red pulp of the spleen of a white male rat of the intact group of animals. Electron micrograph. Approx. ×8000. Designation: 1 – erythrocytes; 2 – heterochromatin and euchromatin (3) in the nucleus of a small lymphocyte; 4 – cytoplasm of a small lymphocyte; 5 – heterochromatin and euchromatin (6) in the nucleus of a middle lymphocyte; 7 – cytoplasm of a middle lymphocyte

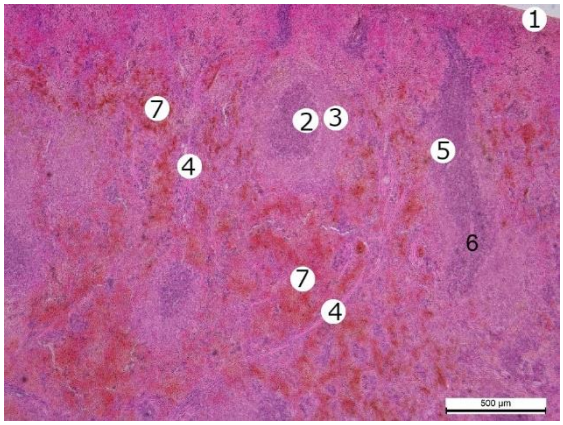

Figure 3. A fragment of the spleen of a white male rat after four weeks of monosodium glutamate exposure. Staining with hematoxylin and eosin. Approx. ×50. Designation: 1 – capsule of the spleen; 2 – germinal center of the lymphoid nodule; 3 – mantle and marginal zones of the lymphoid nodule; 4 – splenic trabeculae; 5 – lymphoid periarterial sheath; 6 – pulpal artery; 7 – full blood red pulp

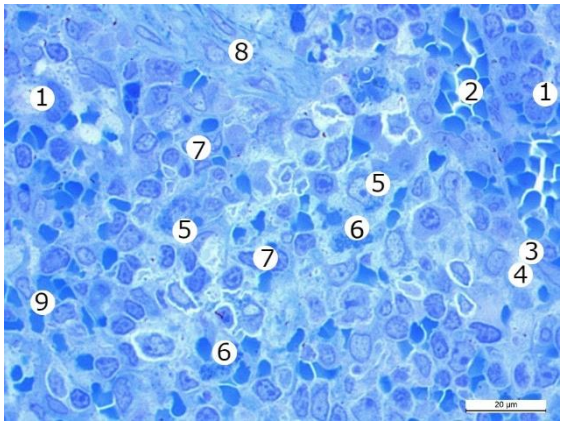

Figure 4. A fragment of the red pulp of the spleen of a white male rat after four weeks of monosodium glutamate exposure. Semi-thin cut. Staining with methylene blue. Approx. ×1000. Designation: 1 – polysegmened neutrophil; 2 – accumulation of erythrocytes in the splenic sinus; 3 – reticular cell; 4 – perivascular edema; 5 – "active" macrophage; 6 – apoptically changed macrophage, overloaded with hemosiderin residues; 7 – accumulation of lymphocytes; 8 – splenic trabeculae; 9 – erythrocytes in the thickness of the red pulp

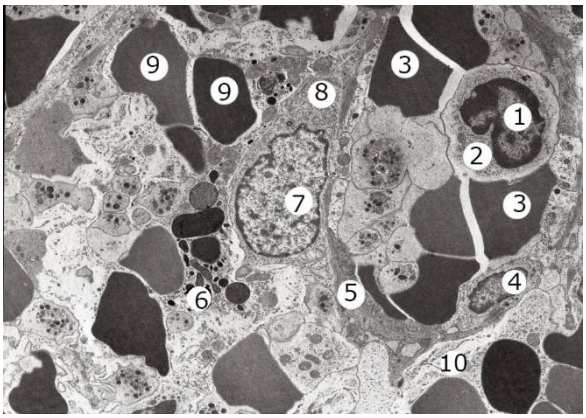

Figure 5. Electron-microscopic organization of a red pulp fragment of the spleen of a white female rat after four weeks of monosodium glutamate exposure. Electron micrograph. Approx. ×4000. Designation: 1 – nucleus and cytoplasm (2) of a small lymphocyte in the lumen of the splenic sinus; 2 – erythrocytes in the lumen of the splenic sinus; 4 – the nucleus of the interdigitating cell in the wall of the splenic sinus; 5 – thickened wall of the splenic sinus; 6 – osmiophilic inclusions; 7 – nucleus and cytoplasm (8) of a reticular cell; 9 – erythrocytes outside the sinus; 10 – perivascular edema

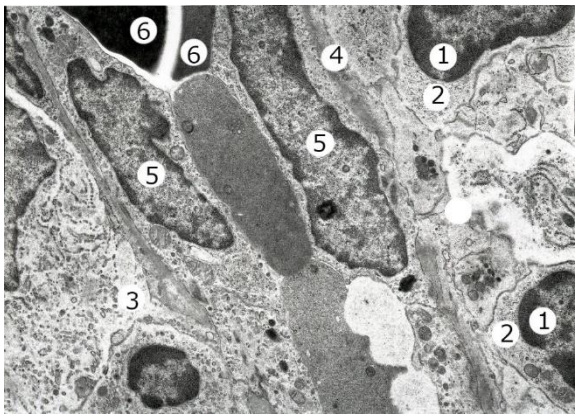

Figure 6. Electron-microscopic organization of a fragment of the white pulp of the spleen of a white male rat after four weeks of monosodium glutamate exposure. Electron micrograph. Approx. ×6000. Designation: 1 – lymphocyte nucleus and cytoplasm; 3 – perivascular edema; 4 – thickened basal membrane of the hemocapillary; 5 – swollen endotheliocyte nucleus in the blood capillary wall; 6 – erythrocytes in the lumen of a blood capillary

Table 1. Morphometric parameters of the structural components of the spleen of the studied male rats (M ± m)

Parameter, units of measurement	A group of animals		
	Intact	Experimental	
		M ± m	p
The relative area of the white pulp of the spleen, %:	25.78 ± 1.18	26.14 ± 0.9	p>0.05
– lymphoid periarterial sheaths	2.15 ± 0.04	2.05 ± 0.05	p>0.05
– lymphoid nodules:	23.63 ± 1.09	24.09 ± 0.64	p>0.05
mantle and marginal zones	17.34 ± 1.06	17.17 ± 0.52	p>0.05
germinal center	4.01 ± 0.31	4.62 ± 0.19	p<0.001
periarterial zone	2.28 ± 0.09	2.3 ± 0.1	p>0.05
The relative area of the red pulp of the spleen, %	74.22 ± 1.33	73.86 ± 1.2	p>0.05
The outer diameter of the central artery of the spleen, d_1, μm	14.02 ± 0.51	20.32 ± 0.45	p<0.001
Internal diameter of the central artery of the spleen, d_2, μm	6.11 ± 0.31	5.92 ± 0.22	p>0.05

Table 2. Morphometric parameters of the structural components of the spleen of the studied female rats (M ± m)

Parameter, units of measurement	A group of animals		
	Intact	Experimental	
		M ± m	p
The relative area of the white pulp of the spleen, %:	26.38 ± 1.02	26.62 ± 0.98	p>0.05
– lymphoid periarterial sheaths	2.31 ± 0.06	2.25 ± 0.04	p>0.05
– lymphoid nodules:	24.07 ± 1.11	24.37 ± 0.72	p>0.05
mantle and marginal zones	17.59 ± 1.15	17.35 ± 0.61	p>0.05
germinal center	4.09 ± 0.39	4.7 ± 0.18	p<0.001
periarterial zone	2.39 ± 0.12	2.32 ± 0.12	p>0.05
The relative area of the red pulp of the spleen, %	73.62 ± 1.4	73.38 ± 1.2	p>0.05
The outer diameter of the central artery of the spleen, d_1, μm	14.21 ± 0.62	19.93 ± 0.39	p<0.001
Internal diameter of the central artery of the spleen, d_2, μm	6.21 ± 0.29	6.05 ± 0.27	p>0.05