METABOLIC CHANGES IN THE EYE LENS IN THE PROGRESSION OF CATARACT

Chuprov A.D.[1,2], Notova S.V.[2], Marshinskaia O.V.[1], Kazakova T.V.[1]

[1] Orenburg branch of the S. Fyodorov Eye Microsurgery Federal State Institution (460047, Salmyshskaya str. 17, Orenburg, Russian Federation)
[2] Orenburg State University (Pobedy ave. 13, Orenburg 460018, Russian Federation)

Corresponding author:
Tatiana V. Kazakova,
e-mail: vaisvais13@mail.ru

ABSTRACT

Background. *Cataract is one of the main causes of decreased visual acuity in the world, and therefore scientists are continuing researches on the mechanisms of development of this ophthalmic pathology.*
The aim. *To study metabolic changes in a cloudy lens using an experimental model.*
Materials and methods. *The study was carried out on adult male Wistar rats (n = 60), which were divided into control (n = 30) and experimental (n = 30) groups. Experimental cataract were simulated by daily ultraviolet irradiation (λ = 300–350 nm) during 6 months for 20 minutes. At the months 2, 4 and 6 of the study, we carried out a biomicroscopic examination of the anterior eye of animals using a slit lamp to monitor the development of cataract. Lenses were collected to determine the content of stearoyl-coenzyme-A desaturases and melatonin using enzyme immunoassay.*
Results. *At the stage of initial cataract, the content of the stearoyl-coenzyme A desaturase was statistically significantly lower than the control values by 38 %; at the stage of immature cataract – by 30 %; at the stage of mature cataract – by 15.4 %. It was revealed that at the month 6 of the study, the concentration of melatonin in lens homogenates was 17 % lower when compared with the control. A statistically significant correlation was established between stearoyl-coenzyme A desaturase and melatonin (r = 0.32).*
Conclusion. *Melatonin and stearoyl-coenzyme A desaturase play an important role in a number of biochemical processes that ensure the proper functioning of the visual analyzer. Changes in the concentration of these biological molecules can play a key role in the pathogenesis of cataract and a number of other ophthalmic diseases.*

Key words: *stearoyl-coenzyme A desaturase, melatonin, cataract, fatty acids, eye lens*

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МЕТАБОЛИЧЕСКИЕ ИЗМЕНЕНИЯ В ХРУСТАЛИКАХ ГЛАЗА ПРИ ПРОГРЕССИРОВАНИИ КАТАРАКТЫ

Чупров А.Д.[1,2], Нотова С.В.[2], Маршинская О.В.[1], Казакова Т.В.[1]

[1] Оренбургский филиал ФГАУ «НМИЦ «МНТК «Микрохирургия глаза» имени академика С.Н. Фёдорова» Минздрава России (460047, г. Оренбург, ул. Салмышская, 17, Россия)
[2] ФГБОУ ВО «Оренбургский государственный университет» (460018, г. Оренбург, просп. Победы, 13, Россия)

Автор, ответственный за переписку: **Казакова Татьяна Витальевна,** e-mail: vaisvais13@mail.ru

РЕЗЮМЕ

Обоснование. *Катаракта является одной из основных причин снижения зрения в мире, в связи с чем, учёными активно продолжаются исследования по изучению механизмов развития данной офтальмопатологии.*
Цель исследования. *Изучить метаболические изменения в мутнеющем хрусталике на экспериментальной модели.*
Материалы и методы. *Работа была проведена на взрослых крысах-самцах линии Wistar (n = 60), которые были разделены на контрольную (n = 30) и опытную (n = 30) группы. Экспериментальная катаракта моделировалась путём ежедневного ультрафиолетового облучения (λ = 300–350 нм) в течение 6 месяцев по 20 минут. На 2-й, 4-й и 6-й месяцы исследования проводилось биомикроскопическое обследование переднего отдела глаза животных с помощью щелевой лампы для наблюдения за развитием катаракты; осуществлялся забор хрусталиков для определения содержания стеарил-коэнзим-А-десатураз и мелатонина методом иммуноферментного анализа.*
Результаты. *На стадии начальной катаракты содержание фермента стеарил-коэнзим-А-десатуразы было статистически значимо ниже контрольных значений на 38 %; на стадии незрелой катаракты – на 30 %; на стадии зрелой катаракты – на 15,4 %. Выявлено, что на 6-й месяц исследования концентрация мелатонина в гомогенатах хрусталиков была ниже на 17 % при сравнении с контролем. Установлено наличие статистически значимой корреляционной зависимости между стеарил-коэнзим-А-десатуразой и мелатонином (r = 0,32).*
Заключение. *Мелатонин и стеарил-коэнзим-А-десатуразы играют важную роль в ряде биохимических процессов, обеспечивающих правильное функционирование зрительного анализатора. Изменение концентрации данных биологических молекул может играть ключевую роль в патогенезе катаракты и ряда других офтальмологических заболеваний.*

Ключевые слова: *стеарил-коэнзим-А-десатуразы, мелатонин, катаракта, жирные кислоты, хрусталик глаза*

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INTRODUCTION

Cataract is one of the most common ophthalmological diseases and one of the leading causes of blindness along with glaucoma and age-related macular degeneration [1]. According to the World Health Organization, cataract accounts for 47 % of all eye diseases [2]. That is why understanding the underlying mechanisms of age-related changes in the structure and function of the ocular apparatus has become critically important for identifying new therapeutic targets and developing multimodal health strategies that meet the needs of the population.

A number of numerous studies devoted to the causes of cataracts have shown that cataracts are a multifactorial disease [3]. The main causes of this pathology include exposure to ultraviolet (UV) radiation. This is evidenced by epidemiological studies that have established a relationship between the medium-wave range of UV radiation (UVB, wavelength 290–315 nm), present in sunlight, and the formation of lens opacities [4]. There is an assumption that lens lipids of the eye are involved in the development of the disease, despite their small content (1 %). In particular, it is known that prolonged exposure to sunlight increases the risk of cataracts due to peroxidation of fatty acids that are part of the cell membrane of lens cells [5].

One of the actively studied enzymes involved in the regulation of fatty acid metabolism is membrane-bound stearyl-coenzyme A desaturase-1 (SCD1; EC 1.14.19.1). This enzyme catalyzes the reaction during which saturated fatty acids are converted into monounsaturated ones. As a rule, stearic and palmitic acids undergo desaturation reactions with the formation of oleic and palmitoleic acids, respectively [6]. It is known that the ratio of fatty acids, in particular stearic acid, to oleic acid affects the viscosity of the lipid bilayer of cell membranes. For this reason, SCD1 is vital for maintaining the structural integrity and fluidity of membranes. Foreign scientists have found that changes in the level of desaturases in humans and animals are associated with the development of ophthalmological pathologies [7, 8].

In addition, according to modern literature, the role of melatonin in the normal and pathological functioning of the visual system is actively discussed in ophthalmology [9, 10]. Melatonin is a hormone secreted by the pineal gland in accordance with the circadian rhythm and regulates chronobiological processes in the body, including endocrine and non-endocrine functions [11]. Other functions of melatonin are associated with the oxidation-reduction status of cells and tissues and include its antioxidant and anti-inflammatory properties [12]. It should be noted that melatonin is produced not only in the pineal gland – its synthesis has been found in many organs and tissues. Using specific antibodies to melatonin, its presence was found in almost all biological fluids, including cerebrospinal fluid, saliva, bile, amniotic fluid, breast milk and tear fluid [11]. Melatonin is also found in the structures of the eyeball – the ciliary body, lens and retina [13].

The working hypothesis of the study is based on the assumption that desaturases and melatonin participate in cataractogenesis. In this regard, the assessment of the levels of these enzymes in lens homogenates is a necessary step in the study of the visual analyzer functional state.

THE AIM OF THE STUDY

To study metabolic changes in a cloudy lens using an experimental model.

MATERIALS AND METHODS

The studies were conducted in the experimental biological clinic (vivarium) of the Federal Research Centre of Biological Systems and Agrotechnologies of the Russian Academy of Sciences and S. Fyodorov Eye Microsurgery Federal State Institution of the Ministry of Health of the Russian Federation. The experiment was performed on the Wistar rat model in accordance with the protocols of the Geneva Convention and the principles of good laboratory practice (National Standard of the Russian Federation GOST R 53434-2009), as well as according to the recommendations of The Guide for the Care and Use of Laboratory Animals (National Academy Press Washington, D.C. 1996). The design of the experiment was approved by the local Ethics Committee of the Federal Research Centre of Biological Systems and Agrotechnologies of the Russian Academy of Sciences (protocol No. 4 dated February 05, 2019).

For the experiment, 60 male rats weighing 180–200 g and aged 10 months were selected. Two groups were formed from the selected animals using the pair-analogue method: control ($n = 30$) and experimental ($n = 30$). Age-related cataracts were modeled in the animals of the experimental group by daily ultraviolet irradiation using a mercury gas discharge lamp DRL ($\lambda = 300–350$ nm). The exposure time was 20 minutes for 6 months.

The animals were kept on a standard diet (according to GOST R 50258-92), with free access to water and food, at a temperature of 22 ± 1 °C and 12-hour lighting.

At the 2nd, 4th and 6th months of the study, a biomicroscopic examination of the anterior segment of the animal's eye was performed using a BQ 900 slit lamp (Haag-Streit, Switzerland) to monitor the development of cataracts; the lenses were isolated and then homogenized on ice in sterile saline (in a ratio of 1:20 – 20 mg of tissue sample was added to 1 ml of the solution) to determine the content of stearyl-coenzyme-A desaturase and melatonin using an enzyme immunoassay and the Rat SCD (Stearoyl Coenzyme A Desaturase) Elisa Kit and Rat MT (Melatonin) Elisa Kit according to the instructions.

The obtained data were processed using the methods of variation statistics using the statistical package Statistica 10 (StatSoft Inc., USA). The compliance of the obtained data with the normal distribution law was checked using the Kolmogorov goodness-of-fit test. The hypothesis of the data belonging to the normal distribution was rejected in all cases with a probability of 95%, which justified the use of nonparametric procedures for processing statistical populations (Mann – Whitney U-test). The obtained data are presented as the median (Me) and the 25th and 75th centiles (Q25–Q75). The relationships between the parameters were assessed using the Spearman's rank correlation method.

RESULTS

According to biomicroscopic examination of the eyeball, no clinical signs of cataract development were detected in laboratory animals during the first month of ultraviolet irradiation. Only by the end of the 2nd month of ultraviolet exposure did the rats develop initial subcapsular cataract, characterized by heterogeneity of the lens fibers. In the 4th month of exposure, according to slit lamp analysis of the eye, signs of subcapsular cataract became more pronounced, and by the 6th month of irradiation, signs of mature cataract were observed in the animals – lens clouding was noted at the equator and in the center in all layers (fig. 1).

Analysis of the enzyme immunoassay results showed that in animals of the experimental group, the content of SCD1 in lens homogenates throughout the experiment was statistically significantly lower than in the control (fig. 2).

When comparing centile values, it was found that Q75 of the experimental group was lower than Q25 of the control group by 38 % ($p \leq 0.05$) at the initial cataract stage (2nd month of observation), by 30 % ($p \leq 0.001$) at the immature cataract stage (4th month), and by 15.4 % ($p \leq 0.05$) at the mature cataract stage (6th month). It should be noted that in the 4th month of the experiment, the range of SCD1 enzyme concentrations was the widest, while the 25th centile value was more than 2 times lower than the same indicator in the 2nd and 6th months of observation.

In the experimental group animals, the melatonin content in lens homogenates was stable throughout the experiment, but somewhat lower than in the control. However, against the background of the development of mature cataract (6th month), the melatonin concentration in the experimental group statistically significantly decreased relative to the control values: the median value was 17 % lower; Q75 of the experimental group was 5 % lower than Q25 of the control group ($p \leq 0.05$) (fig. 3).

The conducted correlation analysis allowed us to establish the presence of a positive moderate association between melatonin and SCD1 (r = 0.32; $p \leq 0.05$) in lens

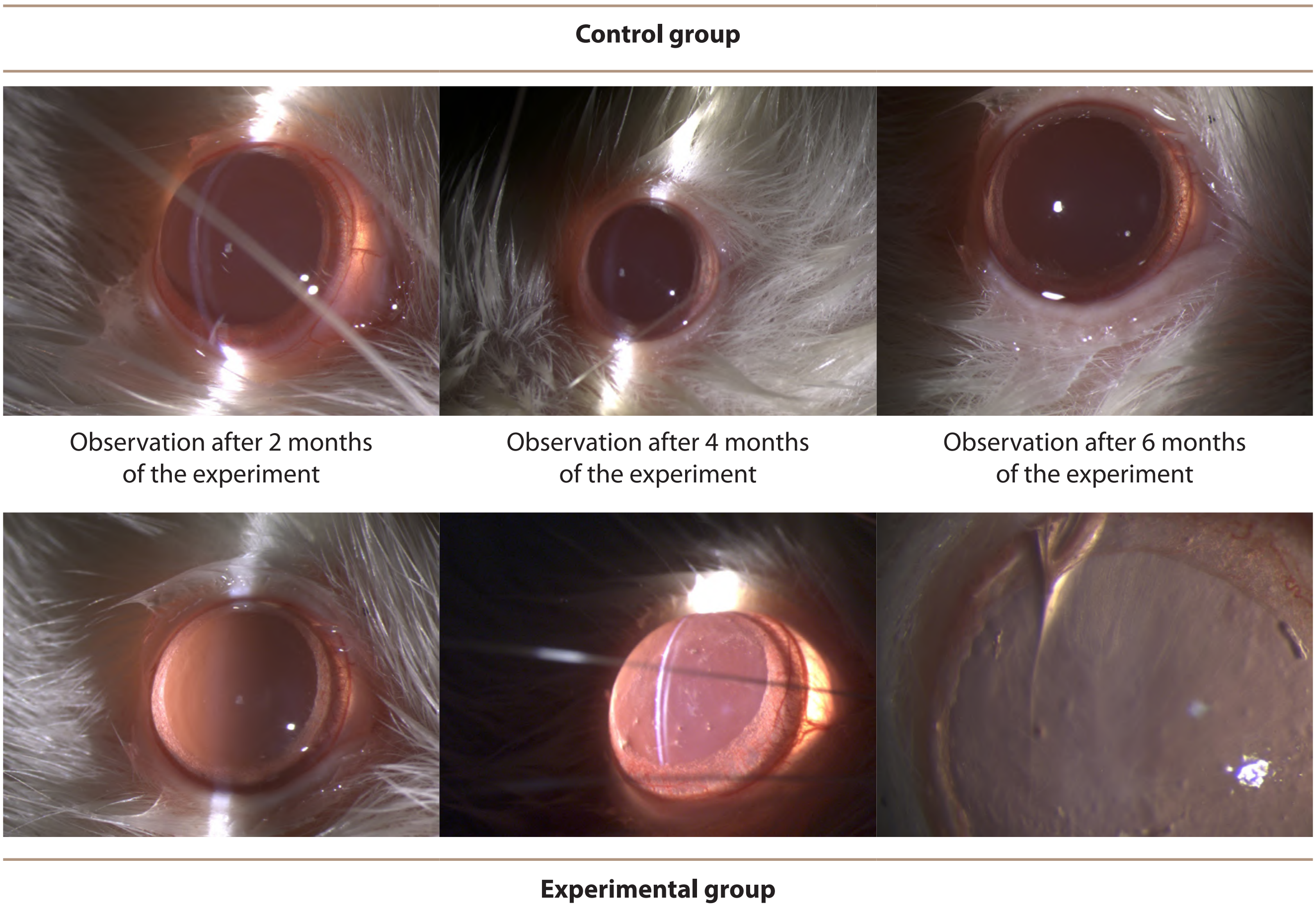

FIG. 1.
Biomicroscopy of the lens at the different stages of the experiment

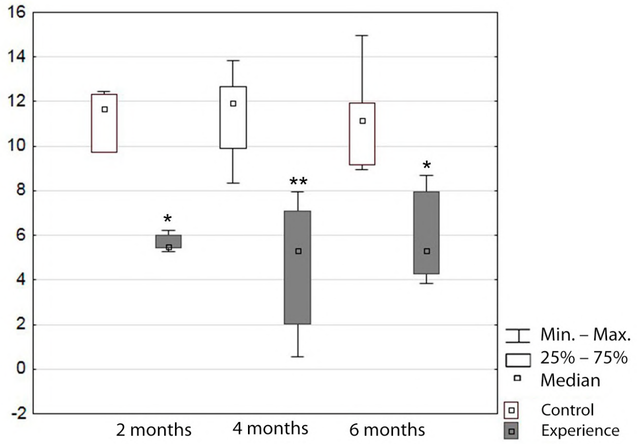

FIG. 2.
*Content of stearoyl-coenzyme A desaturase in eye lens homogenates: statistically significant difference between the experimental group and the control * – at p ≤ 0.05, ** – at p ≤ 0.01; data are presented as Me (Q25–Q75)*

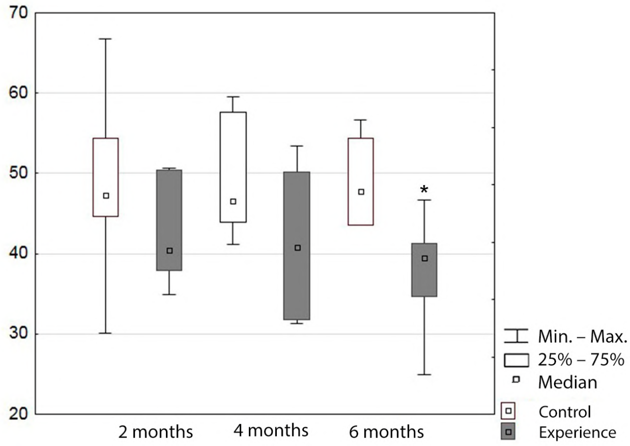

FIG. 3.
*Melatonin content in eye lens homogenates: * – statistically significant difference between the experimental group and the control at p ≤ 0.05; data are presented as Me (Q25–Q75)*

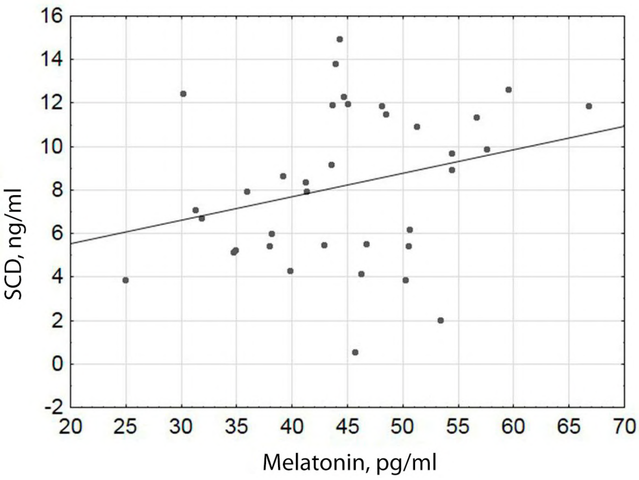

FIG. 4.
Correlation between melatonin and stearyl-coenzyme A desaturase in eye lens homogenates

homogenates (fig. 4). As can be seen from the presented graph, the higher the melatonin level, the higher the desaturase level.

DISCUSSION

The study found that after 2 months of ultraviolet irradiation, there was a statistically significant decrease in the SCD1 level in animal lens homogenates by more than 30 %. This fact may be due to the protective and compensatory body reaction aimed at ensuring the correct functioning of the system elements under conditions exceeding the adaptation norm, due to the reaction of the structures of the system itself [14]. As is known, the body maintains physiologically favorable membrane fluidity by changing the ratio of saturated and unsaturated fatty acids. Ultraviolet radiation promotes the activation of oxidation processes and the accumulation of photolysis products. Lipids containing unsaturated fatty acids are primarily subject to peroxidation. This is due to the fact that they contain a π-bond, which is less strong than a σ-bond and is more easily broken during chemical reactions [15]. As a result, there is a loss of phospholipids (phosphatidylcholines and phosphatidylethanolamines), which mainly include unsaturated fatty acids. In order to provide resistance to oxidation and maintain the transparency of the lens membranes, the acyl chains of phospholipids are saturated, and the content of lipids with residues of saturated fatty acids increases [16, 17]. Such processes provide relative physical and chemical stability of membranes, rigidity and resistance to peroxidation. This is the basis for the physiological compensatory decrease in the concentration of the SCD1 enzyme, which catalyzes the biosynthesis of unsaturated fatty acids. It should be noted that the established increase in the SCD1 content in the 6^{th} month of the experiment compared to the 2^{nd} and 4^{th} months may indicate adaptation processes in response to the stress factor, as well as the high metabolic flexibility of this enzyme. This is probably due to the fact that in the process of peroxidation, the fluidity of cell membranes decreases, but remains within a certain range due to the action of desaturases. On the other hand, it can be assumed that the activity of desaturase in lens cells is subject to cyclic changes, allowing to maintain a constant ionic composition in the cells and membrane potential, thereby preventing the development of cataracts [18, 19]. However, the results of studies by Chinese scientists show that SCD1 inhibition may be involved in cataractogenesis by changing the lipid composition of the lens [20]. In our previous studies, it was shown that against the background of cataract development, the content of saturated palmitic acid increases and the level of unsaturated linoleic acid decreases [21]. Such changes provide an increase in the "rigidity" of the membranes, which helps protect cells from oxidative stress. However, along with this, the ratio of saturated and unsaturated fatty acids changes, which leads to a violation of the fluidity and structural integrity of the lens cell membranes and, as a consequence, to the development of cataracts. Thus, chronic exposure to unfavorable environmental factors on the body, as a rule, causes stress in the regulatory mechanisms, which may result in a breakdown of compensatory reactions, leading to the so-called state of distress, against the background of which there is an imbalance in the regulatory systems of the body and the development of the disease. It is assumed that the violation of lipid metabolism and damage to cell membranes is the leading link in the process of changing the optical and physical properties of the lens.

The decrease in the melatonin level in the studied biosamples revealed during the experiment is entirely justified. As is known, in physiological concentrations, this hormone protects cells from oxidative stress by binding hydroxyl radicals that are formed during lipid peroxidation, as well as stimulating the expression of antioxidant genes and inhibiting the genes of prooxidant enzymes [22]. A number of experimental studies have shown that melatonin is able to suppress the development of cataracts [23–25]. For example, a study by Turkish scientists found that intraperitoneal administration of melatonin reduced the manifestations of oxidative stress and contributed to the restoration of the lens optical properties after UV irradiation [26]. Thus, a decrease in the concentration of this hormone in lens homogenates is due to the high production of active oxygen forms. The results of the study also indicate that the antioxidant system cannot cope with the progression of cataracts.

Of great interest is the fact that there is a direct correlation between the content of melatonin and SCD1 in lens cells. Perhaps this association is due to the fact that melatonin in this case acts, as described earlier, as a strong antioxidant with direct and indirect antioxidant properties [27]. Due to these properties of melatonin, the level of active oxygen species in lens cells decreases, due to which the SCD1 enzyme concentration increases and the ratio of saturated and unsaturated fatty acids is normalized, thereby restoring the functional activity of membranes. Thus, we assume that the higher the level of melatonin, the higher the degree of cell protection from oxidative stress, and, consequently, the higher the level of unsaturated fatty acids and desaturases. It is interesting to note that in 1981, D.F. Horrobin in the journal "Medical Hypotheses" identified melatonin as one of the factors regulating desaturases [28]. Thus, in the 2000s. Japanese scientists have shown that the introduction of melatonin to rats with type 2 diabetes mellitus contributed to the activity restoration of one of the enzyme isoforms – liver Δ-5-desaturase, which in turn led to the normalization of the ratio of fatty acids in the blood plasma and liver [29]. In addition, there is evidence that the activity of the enzymes of the isoenzymes Δ-5- and Δ-6-desaturases plays an important role in the expression and regulation of melatonin itself [30].

CONCLUSION

To summarize the study, it should be concluded that the enzyme stearyl-coenzyme-A desaturase and the hormone melatonin play an important role in a number of biochemical processes that ensure the proper functioning of the visual analyzer. The study noted that at the stage of initial cataract, the content of stearyl-coenzyme-A desaturase is statistically significantly lower than the control values by 38 %, at the stage of immature cataract – by 30 %, at the stage of mature cataract – by 15.4 %. It was found that during the mature cataract formation, the melatonin concentration in lens homogenates statistically decreases by 17 % when compared with the control. The presence of a statistically significant correlation between stearyl-coenzyme-A desaturase and melatonin ($r = 0.32$) was established. Changes in the concentration of these biological molecules may play a key role in the pathogenesis of cataracts and a number of other ophthalmological diseases.

Conflicts of interest

No potential conflict of interest relevant to this article reported.

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Information about the authors

Aleksandr D. Chuprov – Dr. Sc. (Med.), Professor, Director, Orenburg Branch of the S. Fyodorov Eye Microsurgery Federal State Institution; Head of the Department of Biomedical Engineering, Orenburg State University; e-mail: office@mail.ofmntk.ru, https://orcid.org/0000-0001-7011-4220

Svetlana V. Notova – Dr. Sc. (Med.), Professor, Professor at the Department of Biochemistry and Microbiology, Orenburg State University; e-mail: snotova@mail.ru, https://orcid.org/0000-0002-6378-4522

Olga V. Marshinskaia – Senior Research Officer, Orenburg branch of the S. Fyodorov Eye Microsurgery Federal State Institution; e-mail: m.olja2013@yandex.ru, https://orcid.org/0000-0002-5611-5128

Tatiana V. Kazakova – Senior Research Officer, Orenburg branch of the S. Fyodorov Eye Microsurgery Federal State Institution; e-mail: vaisvais13@mail.ru, https://orcid.org/0000-0003-3717-4533