DOI: 10.17816/KMJ2021-486

The effect of substance P on blood serum glycoproteins under technogenic rotating electric fields in animals with different stress resistance profiles

T.S. Vorontsova*, N.N. Vasileva, L.S. Isakova

Izhevsk state medical Academy, Izhevsk, Russia

Abstract

Aim. To study the effect of substance P on the blood serum glycoproteins in experimental animals with different stress-resistance profiles under technogenic rotating electric field.

Methods. The level of sialic acids, mucoproteins, fucose, and α-L-fucosidase was determined in the blood serum of 72 noninbred white male rats before (control) and on the 10th and 20th day of exposure to a technogenic rotating electric field (REF), as well as under the combination of technogenic rotating electric field and substance P injection at the same time. To determine the stress resistance, the animals were tested using the "open field" method. Animals were divided into groups based on the tests' data obtained: stress-resistant, not stress-resistant and ambivalent.

Results. On the 10th day of technogenic rotating electric field action, the level of sialic acids, fucose, and α-L-fucosidase activity increased in all animals. The concentration of mucoproteins tended to decrease. On the 20th day, the sialic acids content remained elevated compared with the control in all groups. The content of mucoproteins decreased in stress-resistant, not stress-resistant and restored to the control level in ambivalent compared with those on the 10th day. On the 20th day, fucose concentration reached control values in stress-resistant and ambivalent animals and decreased in not stress-resistant. On the 10th day of the combined exposure, the concentration of sialic acids, mucoproteins, fucose, α-L-fucosidase was reduced in all animals compared with the 10th day of technogenic rotating electric field action. On the 20th day of the combined exposure, the values of the studied parameters remained reduced in all groups of animals compared with those on the 20th day of isolated technogenic rotating electric field action.

Conclusion. The substance P injection limits the effects of technogenic rotating electric field on the metabolism of carbohydrate-containing biopolymers in blood serum in all groups of animals, as can be seen by a decrease in the level of sialic acids, fucose, and low enzymatic activity of α-L-fucosidase under combined exposure.

Keywords: technogenic rotating electric field, stress, stress resistance, carbohydrate-containing biopolymers, sialic acids, mucoproteins, fucose, α-L-fucosidase, substance P.

For citation: Vorontsova T.S., Vasileva N.N., Isakova L.S. The effect of substance P on blood serum glycoproteins under technogenic rotating electric fields in animals with different stress resistance profiles. *Kazan Medical Journal.* 2021; 102 (4): 486–493. DOI: 10.17816/KMJ2021-486.

Background. The intensity of adverse effects on the human body from various stress factors in the environment has increased significantly in recent years. Although numerous studies on the influence of the electromagnetic field on the human body have already been conducted [1, 2], the fast growing global techno-industrial progress has given way to new types of stressful influences such as the technogenic rotating electrical field (REF), which still needs further studies. So far, available literature has focused on the effects of technogenic REF on the hormonal and reproductive systems of the body [3–5].

Previous studies have recognized the damaging potential of stress and its effect due to the activity ratio of endogenous stress-implementing and stress-limiting systems of the body [6]. The former includes the activation of the sympathoadrenal, pituitary-adrenal, and thyroid axes, forming a stress reaction and an adaptive response. The latter includes a number of central brain structures, as well as regulatory neuropeptides such as opioid peptides, substance P, and delta sleep-inducing peptide [6, 7].

Substance P plays as important role in various regulatory processes that help organisms to

For correspondence: solnoshko@udm.ru Received 23.11.2020; accepted 27.04.2021.

adapt [8]. It is widespread in both the central and peripheral nervous systems as well as in cells of other organs (e.g., immunocompetent cells, liver cells, and lung cells). Additionally, it is present in all body fluids such as blood and cerebrospinal fluid [9].

According to literature, the central role of substance P (formed in the hypothalamus and tonsil of the cerebellum) during the formation of a stress reaction is to inhibit the secretion of corticotropin-releasing hormones, prevent stress adrenal hypertrophy [8], mitigate stress hypertensive response [6], and enhance emotional stress resistance [10]. Additionally, substance P has a peripheral effect: it synthesizes and releases catecholamines from the adrenal glands, thereby reducing the release of these hormones under stress [11, 12].

Other studies have established that under stress conditions, animals are either predisposed to disorganization of various physiological functions or are resistant to stress. The open field test serves as a method to predict the individual resistance of rats to emotional stress. This test evaluates the behavior of animals, which is a complex response formed based on genetics, age, gender, and other components, which can be used as a prognostic criterion for individual stress resistance [13–17].

Carbohydrate-containing biopolymers in the blood serum carry out the functions of intercellular interaction, stabilize and protect biologically active compounds from premature proteolysis, bind and neutralize viruses and bacteria, and mark blood cells for binding to lectins [17–20].

To date, only a few experimental works have focused on the metabolism of carbohydrate-containing biopolymers under various stressful influences. Ever since H. Selye described the development of "stressful" stomach ulcers, some researchers have paid special attention to the peculiarities of the exchange of sialoglycoproteins in the mucous secretion composition, which acts as a barrier in the gastrointestinal tract organs [21, 22]. However, none have studied the effects of REF on the metabolism of carbohydrate-containing biopolymers.

We aim to study the components of carbohydrate-containing biopolymers in the blood serum of experimental animals with different stress resistance under technogenic REF conditions, as well as after the administration of substance P.

Materials and methods of research. We used 72 sexually mature white outbred male rats (weight: 180–220 g, age: 12–15 weeks) for this study since they lack the genetically determined stability of a particular system of internal organs [12]. We kept the animals (10–12 animals per cage) in the vivarium of the Izhevsk State Medical Academy (certified by the State Veterinary Service of the Udmurt Republic) at an air temperature of 20°C–22°C with artificial lighting (light from 8:00 to 20:00, and darkness from 20:00 to 8:00). We provided the rodents dry combined feed.

We performed the study protocol and sacrifice of animals in accordance with the bioethics principles of the International Guiding Principles for Biomedical Research Involving Animals (1985) and Order of the Ministry of Health of the Russian Federation (No. 708n dated 08/23/2010 "On Approval of the Rules of Laboratory Practice"). Additionally, we obtained the permission to conduct the experiment from the local ethical committee of the Izhevsk State Medical Academy (No. 607 dated 05/22/2018).

We used the "open field" method to test the rats and determine their stress resistance before the start of the study [14, 23] (a circular platform with a diameter of 90 cm, divided into 19 central and 18 peripheral sectors, bounded by walls 40 cm high, illuminated with a 100 W lamp from above). During testing, we recorded behavioral indicators, namely the horizontal and vertical motor activities, latent period of the first movement, latent period of reaching the center, the number of squares crossed, the number of struts, grooming time, and vegetative parameters (number of boluses).Moreover, we used the RATTEST software package (Russia) to register and analyze the behavioral tests [15, 24].

To calculate the activity index, we divided the sum of the number of intersected peripheral and central sectors, peripheral and central struts, as well as the objects studied by the sum of the latent periods of the first movement and reaching the center of the open field [14].

We divided the animals into three groups depending on the results: stress-susceptible (K_{sus} = 0.30–0.70, SS), ambivalent (K_{amb} = 0.8–1.99, SA), and stress-resistant (K_{res} = 2.00–5.00, SR) animals.

We exposed all animals to a technogenic REF (patent for a useful model No. 166292 "A device for studying the effect of a rotating electrical field on biological objects"). We assembled the REF equipment based on a physical model of a power transmission line (transformer, electrodes, capacitor, and resistor). We also used the voltage between the electrodes as a reference voltage. With respect to this reference voltage, a second voltage with a phase shift ($\alpha = 45°$) was formed by means of a phase-shifting chain formed by a series-connected capacitor and a resistor. This was also applied to the electrodes. The REF was formed between the electrodes, and its physical action was determined by the superposition of two orthogonal fields with amplitude values of the intensity at 30.5 and 75.9 V/m. The fields varied according to a sinusoi-

Table 1. Components of carbohydrate-containing biopolymers and α-L-fucosidase in the blood serum of rats after exposure to a rotating electrical field (REF)

Groups		Sialic acids, mmol/L	Mucoproteins, mg/dL	Fucose, mg%	α-L-fucosidase, U/L
Control (n = 18)	SR (n = 6)	26.65 [25.9; 27.4]	128.7 [126.4; 128.6]	6.5 [6.1; 6.75]	71 [71; 72]
	SS (n = 6)	23.65 [23.4; 23.7]	150.4 [149.3; 151.6]	8.7 [8.2; 9]	50.5 [49.7; 51]
	SA (n = 6)	23 [21.2; 24.1]	140 [139.4; 141.2]	7.25 [6.9; 7.5]	54.5 [53.5; 57.5]
REF, day 10 (n = 18)	SR (n = 6)	30.6 [30.5; 31]*	121.3 [120.4; 122]*	7.25 [7.2; 7.4]*	145.5 [145.1; 145.8]*
	SS (n = 6)	29.4 [29.2; 29.5]*	135.6 [134.6; 136.1]*	10.8 [10.6; 11]*	129.25 [129; 129.8]*
	SA (n = 6)	27.1 [27; 27.3]*	134.1 [133.4; 134.4]*	10 [9.75; 10.1]*	134.4 [133.4; 135]*
REF, day 20 (n = 18)	SR (n = 6)	29.7 [29.1; 30.4]*	110.1 [109.4; 111.6]*	6.5 [6.2; 6.75]*	113.3 [110; 115.1]*
	SS (n = 6)	29 [28.5; 29.5]*	149.3 [148.3; 149.8]*	5.5 [5.4; 5.6]*	123.8 [123.5; 124]*
	SA (n = 6)	28.4 [28.3; 28.5]*	142.2 [141.8; 142.5]*	8.5 [7.8; 8.8]*	133 [132.5; 133.7]*

Note: statistical significance of the difference in indicators *$p < 0.05$, determined using the Kruskal–Wallis H-test.

dal law with a frequency of 50 Hz while power was supplied from an AC network (220 V). We found a space in the REF equipment (relative to the unit center), limited along the X, Y, and Z axes, where the uniformity of the electric-field intensity was the greatest. We placed the experimental animals inside the unit every day before midday for 60 min for 10 and 20 days.

On the other hand, the control group consisted of animals (n = 18) which were placed in the unit while the network is disconnected.

Additionally, we determined the level of sialic acids (Sialotest, Russia), mucoproteins (a set of reagents from Hospitex Diagnostics, Russia), fucose (a set of reagents from Panreac Life Sciences, Spain), and α-L-fucosidase (a set of reagents from DIRUI, China) in the blood serum before exposure to REF, on days 10 and 20 of the study.

Moreover, we studied the combined effect of REF exposure and the administration of substance P (Sigma, USA). We administered substance P intraperitoneally at a dose of 25 μg/kg, dissolved in 1 ml of 0.9% sodium chloride solution every other day for 20 days. The control group received intraperitoneal injections of 1 ml of 0.9% sodium chloride solution every other day for 20 days.

We performed the statistical processing of three independent groups for one quantitative trait using the Kruskal–Wallis H-test. We also used the nonparametric Mann–Whitney test (Statistica 6.0) for pairwise comparison of samples. The differences between the samples were considered significant at $p < 0.05$. We presented the data in the form of a median and quartiles Me (Q_1–Q_3).

Results. On day 10 of REF exposure, we noted an increase in the sialic acid concentration, the main carbohydrate components of glycoproteins that occupy the terminal position in glycoconjugates, in the blood serum of all animals (Table 1) [17]. Also, the excess of this indicator compared with that in the control group was 16% ($p = 0.02$) in SR rats, 25% ($p = 0.019$) in SS rats, and 18% ($p = 0.02$) in SA rats. The high level of total sialic acid in the blood serum of animals exposed to REF indicated intensive catabolism of carbohydrate-containing biopolymers.

The concentration of mucoproteins, which represent a fraction of glycoproteins, decreased on day 10 in all groups of animals compared with that in the control.

The high level of fucose, which is one of the terminal carbohydrates in glycoproteins, indicated the intensive metabolism of carbohydrate-containing biopolymers after exposure to REF [20]. While the level of fucose increased to a greater extent in SS and SA animals by 25% ($p = 0.02$), this indicator increased by 11% in SR animals ($p = 0.028$). On the other hand, we noted an increase in the activity of α-L-fucosidase, which indicated an increased catabolism of fucose-containing glycoproteins. The enzyme activity in SS animals exceeded the values of the control group by 2.6 times ($p = 0.019$), by 2.4 times in SA rats ($p = 0.02$), and by 2 times in SR rats ($p = 0.019$).

On day 20, the sialic acid concentration in the blood serum of all experimental animals remained elevated compared with that in the control group. Additionally, this indicator did not have significant differences in SR and SS animals compared with data on day 10. The mucoprotein content continued to decrease in SR animals compared with data on day 10 in SR animals (by 9%, $p = 0.021$); however, this indicator returned to control values in SS and SA animals. On the other hand, fucose concentration on day 20 reached control values in SR and SA animals but decreased in SS animals, compared with data on day 10 of stress exposure (by 47%, $p = 0.019$) and with data in the control (by 34%,

Table 2. Components of carbohydrate-containing biopolymers and α-L-fucosidase in the blood serum of rats in the combined rotating electrical field (REF) exposure and the substance P administration

Groups		Sialic acids, mmol/L	Mucoproteins, mg/dL	Fucose, mg%	α-L-fucosidase, U/L
Control + NaCl 0.9% (n = 18)	SR (n = 6)	26.2 [26; 26.3]	129 [128.7; 129.4]	6.1 [6; 6.3]	70.5 [70; 71.25]
	SS (n = 6)	23.4 [23.1; 23.7]	148.2 [148; 148.6]	8.5 [8.37; 8.62]	49 [48.75; 49.25]
	SA (n = 6)	24 [23.9; 24.2]	141.5 [141.2; 141.7]	9 [9; 9.12]	57.5 [56.75; 57]
REF for 10 days + substance P (n = 18)	SR (n = 6)	21.5 [21.4; 21.6]*°	110.2 [109.8; 110.4]*°	2.8 [2.65; 3]*°	42.35 [42.3; 42.42]*°
	SS (n = 6)	19.5 [19; 21.4]*°	124.8 [122.7; 125.6]*	2.1 [2.1; 2.25]*°	37.5 [37.2; 37.5]*°
	SA (n = 6)	21.4 [21.4; 21.5]*°	126.2 [125.1; 127.3]*°	2.25 [2; 2.5]*°	41 [40.9; 41.05]*°
REF for 20 days + substance P (n = 18)	SR (n = 6)	23 [22.9; 23.2]*°	102 [101.6; 102.4]*°	2.66 [2.5; 2.7]*°	41.4 [41.3; 41.6]*°
	SS (n = 6)	21.5 [21.3; 21.6]°*	122.6 [121.1; 126.6]*°	2.5 [2.5; 2.5]*°	38 [37.9; 38.2]*°
	SA (n = 6)	21.5 [21.4; 21.6]*°	125.4 [125; 125.9]*°	2.1 [2; 2.25]*°	41.1 [41; 41.12]*°

Note: statistical significance of the difference in indicators *$p < 0.05$, determined using the Kruskal–Wallis H-test; °$p < 0.05$ when compared with the effect of REF at the same time using the Mann–Whitney test.

$p = 0.02$). Additionally, we noted a 24% decrease in the activity of α-L-fucosidase in SR rats ($p = 0.019$) as compared with data on day 10 of REF exposure. The enzyme activity did not reach the control level in any group of animals.

In terms of combined exposure (REF + substance P), we recorded a decrease in sialic acid concentration in all groups on day 10 of the experiment (Table 2), as opposed to increase in concentration during REF exposure alone. Furthermore, results revealed a decrease in sialic acid levels in SR and SA animals compared with those in the control (by 22%, $p = 0.021$ and 11%, $p = 0.021$, respectively) and compared with data from REF exposure alone (by 24%, $p = 0.02$ and 29%, $p = 0.019$, respectively). This indicator was 48% lower in SS rats ($p = 0.02$) compared with data on day 10 of REF exposure. The same did not have significant differences with the control.

As in the case of REF exposure, the levels of mucoproteins in all groups of animals decreased compared with those in the control values (by 17% in SR rats ($p = 0.02$), by 19% in SS rats ($p = 0.02$), and by 12% in SA rats ($p = 0.02$)). It should be noted that the level of mucoproteins in the SR and SA groups was significantly lower than in the case of REF exposure alone during the same period of the experiment.

While fucose levels in the blood serum increased in the REF exposure alone, fucose levels significantly decreased by 2–4 times in all groups of animals in the combined exposure and administration. Additionally, we recorded a significant decrease in the fucose concentration compared with control values (by 55% in SR rats ($p = 0.017$), by 74% in SS rats ($p = 0.019$), and by 75% in SA rats ($p = 0.017$)).

On the other hand, α-L-fucosidase activity decreased during the combined exposure and substance P administration, as opposed to the decreased activity during REF exposure alone. The decrease in α-L-fucosidase activity in SR rats was 41% ($p = 0.02$) compared with that in the control group and 71% ($p = 0.02$) compared with that in the REF exposure alone; it was 24% and 71% ($p = 0.02$), respectively, in SS rats and 29% and 69% ($p = 0.02$), respectively, in SA animals.

On day 20 of the combined exposure and administration, the values of the studied parameters still decreased in all groups compared with data on day 20 of REF exposure alone. Consequently, the sialic acid concentration was lower in SS rats by 27% ($p = 0.019$). The sialic acid level in the SR and SA groups was also lower but did not have significant differences. The mucoprotein level during the administration of substance P in combination with REF exposure was also significantly lower than that during REF exposure alone in the same period of the experiment. The fucose concentration remained reduced in all groups when compared with that on day 20 REF exposure alone (by 2.5 times in SR ($p = 0.02$), by 2.2 times in SS ($p = 0.019$), by 4 times in SA animals ($p = 0.02$)). Similarly, the α-L-fucosidase activity was also reduced (by 63% in SR ($p = 0.021$) and by 69% in SS and SA animals ($p = 0.02$).

It is worth noting that during the entire experiment, the administration of substance P not only limited the stress effects of REF exposure, but also caused an opposite reaction in terms of the metabolism of carbohydrate-containing biopolymers in the blood serum.

Discussion. Results showed that during technogenic REF exposure, the metabolism of carbohydrate-containing biopolymers in the blood serum is disrupted prevalently in the decomposition processes. Consequently, we recorded the greatest

changes in the SS group of animals on day 10 of the study. These results are consistent with data obtained from previous experimental stress models.

Previous works have demonstrated that prolonged repeated immobilization and metabolic stress caused by experimental diabetes mellitus could intensify the catabolism of sialoglycoproteins in the blood plasma [21, 25, 26]. These manifestations may have been due to an increase in the desialation of oligosaccharide chains of plasma sialoglycoproteins, since most of these complexes are responsible for the formation of acute phase proteins, immune complexes, and surface membrane structures that send transmembrane signals to the cell.

In 1936, Hans Selye described the stress syndrome, in which influences from physical, chemical, biological, psychogenic, and social origins are capable of causing a stress response in the body. Although physical stress caused by REF exposure has a specific effect on the body, it also leads to changes that are typical of any stress. Contrary to the enhanced function of the hypothalamic-pituitary-adrenal axis, the synthesis of glucocorticoids, which are allosteric inhibitors of glucosamine synthetase, increased. This could inhibit the production of glucosamine precursors in the synthesis of carbohydrate-containing biopolymers [27, 28]. As synergists of glucocorticoids, catecholamines regulate carbohydrate and protein metabolisms by activating the adenylate cyclase. They also enhance the catabolism of carbohydrate-containing biopolymers [25, 26, 29].

It should be noted that the severity of the decay processes of carbohydrate-containing biopolymers in the blood serum decreased on day 20 of REF exposure, as shown by the normalization of fucose concentration and the decrease in α-L-fucosidase activity, as well as the normalization of mucoprotein levels in the blood serum of SS and SA animals. The persistence of a low mucoprotein level in SR animals may be associated with a longer upkeep of glucocorticoids in the blood, as noted in other studies on stress effects in SR animals [22, 26]. Evidently, the adaptation and stabilization phases of the metabolism of carbohydrate-containing biopolymers initiate during stress exposure.

The administration of substance P inhibited the catabolic effects of REF exposure on carbohydrate-containing biopolymers in the blood serum, as evidenced by the decrease in sialic acid and fucose levels, as well as the low enzymatic activity of α-L-fucosidase. However, we could not confidently determine the intensity of glycoconjugate anabolism because the levels of glycoproteins, particularly of mucoproteins, in the blood plasma remained low. This implies that intensive biosynthesis and accumulation of carbohydrate-containing biopolymers took place primarily in the liver, which serves as the main "supplier" for peripheral blood.

Based on previous literature [7, 11, 30], a number of endogenous peptides such as substance P are involved in neurochemical mechanisms that increase resistance to emotional stress. The role of substance P is manifested in the regulation of catecholamine metabolism in the central nervous system during stress. The normalization of catecholamine levels in the brain is considered as one of the key factors in emotional stress resistance [10].

Emotional stress is known to disrupt the permeability of the blood-brain barrier, enabling substances in the bloodstream to affect the structure of the central nervous system [31].

The mechanisms of stress reactions caused by REF exposure are apparently comparable with the mechanisms of emotional stress development. The intraperitoneal administration of substance P may have promoted the activation of both peripheral and central NK-1 receptors of tachykinins. Since substance P can inhibit the stress-induced activity of the hypothalamic-pituitary-adrenal system [30], we assume that the partial elimination of changes in the studied parameters of glycoproteins and the restoration of the balance of metabolic processes of their biopolymers are precisely associated with the decrease in the catabolism of glucocorticoids and adrenaline.

CONCLUSIONS

1. Exposure to REF, which serves as an experimental model of stress, causes significant changes in the content of carbohydrate-containing biopolymers in the blood serum of animals.

2. On day 10 of REF exposure, the levels of sialic acids, fucose, and α-L-fucosidase increased in stress-resistant, stress-susceptible, and ambivalent rats, while mucoprotein concentration decreased, which is characteristic of the predominance of catabolic processes. We noted the greatest changes in individuals not resistant to stress.

3. By day 20 of REF exposure, the intensity of the decomposition processes of carbohydrate-containing biopolymers decreased, as shown by the restoration fucose concentration to control levels, the decrease in α-L-fucosidase activity, and the normalization of mucoprotein levels in the blood serum of stress-susceptible and ambivalent animals.

4. The administration of substance P in all groups of animals limited the effects of REF exposure on the metabolism of carbohydrate-containing biopolymers in the blood serum, as shown by the decrease in sialic acid level and fucose concen-

tration and low enzymatic activity of α-L-fucosidase under combined exposure and administration.

Author contributions. T.S.V. conducted the research, was responsible for collecting and analyzing the results; N.N.V. participated in the analysis of the results; L.S.I. was the project supervisor.
Funding. The study had no external funding.
Conflict of interest. The authors declare no conflict of interest.

REFERENCES

1. Kostryukova N.K., Gudkov A.B., Karpin V.A., Lavkina E.S. Biological effects of superweak magnetic fields. Literature review. *Ekologiya cheloveka.* 2004; (3): 55–59. (In Russ.)

2. Pryakhin E.A. Adaptive reactions under the influence of electromagnetic factors. *Vestn. ChGPU.* 2006; (6): 136–145. (In Russ.)

3. Shchepina T.P., Nekrasova D.A., Egorkina S.B. The influence of low frequency rotating field on reproductive potential of experimental animal. *Zdorove naseleniya i sreda obitaniya.* 2014; (8): 53–55. (In Russ.)

4. Zajnaeva T.P., Yegorkina S.B. The impact of the low-frequency rotating electric field on the "mother-placenta-fetus" system in rats with various prognostic stress resistance. *Ekologiya cheloveka*. 2016; (8): 3–7. (In Russ.) DOI: 10.33396/1728-0869-2016-8-3-7.

5. Zajnaeva T.P., Yegorkina S.B. The system mother-placenta-fetus in the technogeneous rotating electric field in rats with various prognostic stress resistance. *Vestnik novykh meditsinskikh tekhnologiy. Elektronnoe izdanie.* 2016; (2): 156–160. (In Russ.) DOI: 10.12737/19641.

6. Pshennikova M.G. The phenomenon of stress. Emotional stress and its role in pathology. *Patologicheskaya fiziologiya i eksperimentalnaya terapiya.* 2000; (2): 24–31. (In Russ.)

7. Sudakov K.V., Umryukhin P.E. *Sistemnye osnovy emotsional'nogo stressa.* (System bases of emotional stress.) M.: GEOTAR Media. 2010; 112 p. (In Russ.)

8. Egorkina S.B, Eliseeva E.V. Opioid peptides as neuromodulators of adaptive processes. *Bulletin of Udmurt University. Biology & earth sciences.* 2010; (3): 25–27. (In Russ.)

9. Mantyh P.W. Neurobiology of substance P and the NK1 receptor. *J. Clin. Psychiatry.* 2002; 63 (11): 6–10. PMID: 12562137.

10. Yumatov E.A. *Psikhofiziologiya emotsiy i emotsional'nogo napryazheniya studentov.* (Psychophysiology of emotions and emotional tension of students.) M.: ITRK. 2017; 198 p. (In Russ.)

11. Pshennikova M.G. Hereditary efficiency of stress-limiting systems as a factor of the resistance to stress-induced disorders. *Uspekhi fiziologicheskikh nauk.* 2003; 34 (3): 55–67. (In Russ.)

12. Schank J.R., Ryabinin A.E., Giardino W.J., Ciccocioppo R., Heilig M. Stress related neuropeptides and addictive behaviors: Beyond the usual suspects. *Neuron*. 2012; 76 (1): 192–208. DOI: 10.1016/j.neuron.2012.09.026.

13. Vasilyeva N.N., Bryndina I.G. The role of individual stress resistance in realization of immobilization and zoosocial stress effects on pulmonary surfactant system. *Rossiyskiy fiziologicheskiy zhurnal im. I.M. Sechenova.* 2012; 98 (7): 871–878. (In Russ.)

14. Koplik E.V. Method for determining the criterion of rat resistance to emotional stress. *Vestnik novykh meditsinskikh tekhnologiy.* 2002; 9 (1): 16–18. (In Russ.)

15. Mayorov O.Yu. Assessment of individual typological features of behavior and stability of intact white male rats based on the factor model of the normal ethological spectrum of indicators in the open field test. *Clinical Informatics and telemedicine*. 2011; 7 (8): 21–32. (In Russ.)

16. Pertsov S.S., Koplik E.V., Simbirtsev A.S., Kalinichenko L.S. Influence of IL-1β on the behavior of rats under weak stress load when testing in an open field. *Byulleten eksperimentalnoy biologii i meditsiny.* 2009; (11): 488–490. (In Russ.)

17. Wiederschain G.Ya. Glycobiology: progress, problems and perspectives. *Biokhimiya*. 2013; 78 (7): 877–900. (In Russ.)

18. Bauer J., Osborn H.M.I. Sialic acids in biological and therapeutic processes: opportunities and challenges. *Future Med. Chemistry.* 2015; 7 (16): 2285–2299. DOI: 10.4155/fmc.15.135.

19. Bohm S., Schwab I., Lux A., Nimmerjahn F. The role of sialic acid as a modulator of the anti-inflammatory activity of IgG. *Semin. Immunopathol*. 2012; 34 (3): 443–453. DOI: 10.1007/s00281-012-0308-x.

20. Varki A. Sialic acids in human health and disease. *Trendsin Mol. Med*. 2008; 14 (8): 351–360. DOI: 10.1016/j.molmed.2008.06.002.

21. Grebenkina E.P., Minaeva E.V. Stress implementing influence of neurogenic stress on nonspecific element of the immune response, sialoglycoprotein and collagen indices. *Zdorove, demografiya, ekologiya finno-ugorskikh narodov.* 2015; (4): 25–26. (In Russ.)

22. Protasova S.V., Butolin E.G., Oksuzyan A.V. Metabolism of carbohydrate-containing biopolymers in liver and gastric mucosa of rats with experimental diabetes and varying stress resistance. *Saharnyy diabet*. 2010; (1): 10–12. (In Russ.) DOI: 10.14341/2072-0351-6010.

23. Pertsov S.S. Catecholamines of the adrenal glands of August and Wistar rats under acute emotional stress. *Byulleten eksperimentalnoy biologii i meditsiny.* 1997; 123 (6): 645–648. (In Russ.)

24. Permyakov A.A., Eliseeva E.V. *Analiz povedencheskikh reaktsiy u eksperimental'nykh zhivotnykh s razlichnoy stressoustoychivost'yu.* (Analysis of behavioral reactions in experimental animals with different stress resistance.) Izhevsk: Knigograd. 2017; 127 p. (In Russ.)

25. Lekomtsev I.V., Naumova N.G., Logvinenko S.V. Indicators of sialoglycoprotein exchange in blood plasma of rats with experimental diabetes. *Proceedings of the Izhevsk state medical academy.* 2000; (38): 25. (In Russ.)

26. Protasova S.V., Butolin E.G., Oksuzyan A.V. Dynamics of changes in the content of carbohydrate-containing biopolymers in the blood of rats under long-term stress effects of various genesis. *Vyatskiy meditsinskiy vestnik.* 2008; (1): 81–83. (In Russ.)

27. Smith T. Glucocorticoid regulation of glucosaminoglycan synthesis in cultured human skin fibroblasts: evidence for a receptor-mediated mechanism involved effects on specific *de novo* protein synthesis. *Metabolism*. 1988; 37 (2): 179–184. DOI: 10.1016/S0026-0495(98)90015-4.

28. Varki A., Lowe J.B. *Essentials of Glycobiology*. 2nd ed. NY: Cold Spring Harbor Laboratory Press. 2009; 784 p.

29. Kunizhev S.M., Andrusenko S.F., Denisova E.V. *Glikoproteiny. Mediko-biologicheskie funktsii, svoystva, vydelenie i primenenie.* (Glycoproteins. Medico-biological functions, properties, selection and application.) M.: University book. 2016; 140 p. (In Russ.)

30. Danilov G.E., Myagkov A.V., Bryndina I.G., Vasilieva N.N. *Rol' stress-protektornykh struktur mozga v regulyatsii vistseral'nykh funktsiy.* (The role of stress-inducing brain structures in the regulation of visceral functions.) M.: RAMN publishing house. 2004; 144 p. (In Russ.)

31. Esposito B. Corticotropin-releasing hormone and brain mast cells regulate blood-brain-barrier permeability by acute stress. *J. Pharmacol*. 2002; (303): 1061–1066. DOI: 10.1124/jpet.102.038497.