Gozhenko Anatoliy I., Kuchma Igor L., Ruzhylo Sofiya V., Kovalchuk Galyna Y., Zukow Walery, Popovych Igor L. Role of the lipid peroxidation in immunomodulating effects of the nitrogenous metabolites in rats. Journal of Education, Health and Sport. 2021;11(4):144-156. eISSN 2391-8306. DOI http://dx.doi.org/10.12775/JEHS.2021.11.04.015
https://apcz.umk.pl/czasopisma/index.php/JEHS/article/view/JEHS.2021.11.04.015
https://zenodo.org/record/4897982

The journal has had 5 points in Ministry of Science and Higher Education parametric evaluation. § 8. 2) and § 12. 1. 2) 22.02.2019.

Received: 05.04.2021. Revised: 14.04.2021. Accepted: 28.04.2021.

ROLE OF THE LIPID PEROXIDATION IN IMMUNOMODULATING EFFECTS OF THE NITROGENOUS METABOLITES IN RATS

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Abstract

Background. We have previously shown that nitrogenous metabolites have immunomodulatory effects, but the question of mediators of the immunomodulation remains open. We hypothesized the mediating role of mediators of the autonomic nervous system and adaptation hormones as well as reactive oxygen species. Mediating role in the immunomodulation of neuroendocrine factors is analyzed in a previous article. The **aim** of this study is to analyze the relationships between the parameters of nitrogenous metabolites and lipid peroxidation as well as between latter and immune parameters subordinate modulations by nitrogenous metabolites. **Material and methods**. Experiment was performed on 60 healthy female Wistar rats. The plasma level and urinary excretion of the nitrogenous metabolites as well as parameters of lipid peroxidation (diene conjugates, malonic dyaldehid, superoxide dismutase, catalase) and neuroendocrine-immune complex were determined. **Results**. According to the canonical correlation analysis, the constellation of nitrogenous metabolites determines the state of lipid peroxidation by 38,8%. The latter, in turn, determines the constellation of immune parameters (subject to modulation by nitrogenous metabolites) by 61,4%. On the other hand, the coefficient of determination between nitrogenous metabolites and neuroendocrine parameters is 71,5%, and between the latter and immune status – 89,6%. Taken together, neuroendocrine parameters and lipid peroxidation parameters determine the pool of immune parameters subject to modulation by nitrogenous metabolites by 96,7%. It was previously shown that the coefficient of determination between nitrogenous metabolites and a number of immune parameters is 95,8%. **Conclusion**. The obtained results, taken together with the previous ones, prove that uric acid, bilirubin, urea and creatinine realize

their immunomodulatory effects both directly through receptors of immunocytes (aryl hydrocarbon, adenosine and TL) and with the participation of mediators of autonomic nervous and endocrine systems and lipid peroxidation.

Key words: uric acid, creatinine, urea, bilirubin, lipid peroxidation, ANS, hormones, immunity, relationships, rats.

INTRODUCTION

We have previously shown that nitrogenous metabolites have immunomodulatory effects, both in healthy rats [7,8,25] and in humans exposed to pathogenic influences [9,10,15,29]. The immunomodulatory effect of bilirubin is probably mediated through aryl hydrocarbon receptors, and uric acid through TL- and adenosine receptors of immune cells. The question of mediators of the immunomodulatory action of urea and creatinine remains open. Standing on the positions of the concepts of functional-metabolic continuum [6] and neuroendocrine immunomodulation [11,18-20,22,24,26-28,30-32] we hypothesized the mediating role of mediators of the autonomic nervous system and adaptive hormones. In an experiment on rats, we showed that the modulating effects of nitrogenous metabolites on neuroendocrine parameters are quite pronounced and almost identical in terms of bilirubin (R=0,603), creatinine (R=0,602), uric acid (R=0,599) and urea (R=0,586). Taken together, nitrogenous metabolites determine neuroendocrine parameters by 71,5% (R=0,845). Triiodothyronine, fascicular and medullar areas of the adrenal glands, vagal tone and calcitonin activity were the most susceptible to nitrogenous metabolites. In turn, neuroendocrine parameters determine the parameters of immunity, subject to exposure to nitrogenous metabolites, by 95,8% (R=0,979) [17]. Thus, immunomodulatory effects of nitrogenous metabolites are realized, perhaps, through the factors of the autonomic nervous and endocrine systems.

In a parallel study in this project, we showed that in patients with postradiation encephalopathia constellation of nitrogenous metabolites (primarily plasma urea and creatinine) determines the state of lipids peroxidation by 44,0% (R=0,663). The inclusion in factor structure of canonical correlation between the HRV markers of ANS and parameters of Immunity the parameters of lipids peroxidation increases the degree of determination from 89,6% (R=947) to 94,6% (R=0,973) [14,16]. Therefore, lipids peroxidation plays a role in the mechanism of the immunomodulatory effect of nitrogenous metabolites.

The **aim** of this study is to analyze the relationships between the parameters of nitrogenous metabolites and lipids peroxidation as well as between latter and immune parameters subordinate modulations by nitrogenous metabolites.

MATERIAL AND METHODS

Experiment was performed on 60 healthy female Wistar rats 220-300 g. Of these, 10 remained intact, while others received drinking water of various compositions during the week. The day after the completion of the drinking course in all rats assessed the state of autonomous regulation by the parameters of the HRV [2]. Animals were then placed in individual chambers with perforated bottom for collecting daily urine. The experiment was completed by decapitation of rats in order to collect as much blood as possible. The plasma levels of the hormones of adaptation were determined: corticosterone, triiodothyronine and testosterone (by the ELISA [12]); as well as parameters of lipids peroxidation: diene

conjugates (spectrophotometry of the heptane phase of the lipids extract [4]) and malonic dyaldehid (in the test with thiobarbituric acid [1]), antioxidant enzymes: superoxide dismutase erythrocytes (according to the degree of inhibition of reduction of nitroblue tetrazolium in the presence of N-methylphenazonium metasulphate and NADH [3,20]) and catalase plasma (at the rate of decomposition of hydrogen peroxide [13]). Electrolytes: calcium (by reaction with arsenase III), phosphates (phosphate-molybdate method), sodium and potassium (flamming photometry) were determined in plasma and daily urine. The analyzes were carried out according to the instructions described in the manual [5].

The analyzers “Tecan” (Oesterreich), “Pointe-180” ("Scientific", USA) and “Reflotron” (Boehringer Mannheim, BRD) were used with appropriate sets and a flamming spectrophotometer “СФ-47”.

According to the parameters of electrolyte exchange, hormonal activity was evaluated: parathyroid by coefficient $(Cap•Pu/Pp•Cau)^{0,25}$, calcitonin by coefficient $(Cau•Pu/Cap•Pp)^{0,25}$ and mineralocorticoid by coefficient $(Nap•Ku/Kp•Nau)^{0,25}$, based on their classical effects and recommendations by IL Popovych [11,26].

In the adrenal glands after weighing, the thickness of glomerular, fascicular, reticular and medullar zones was measured under a microscope [11,26].

Methods for determining nitrogenous metabolites and immune parameters are given in previous article [25].

Digital material is statistically processed on a computer using the software package "Statistica 20".

RESULTS AND DISCUSION

In the first stage, the screening of the links between nitrogenous metabolites, on the one hand, and the parameters of lipid peroxidation, on the other hand, was performed (Table 1).

Table 1. Correlation matrix for nitrogenous metabolites and Lipid Peroxidation parameters

Variable	Cr Ex	Cr P	Urea Ex	UA Ex	Bilir	Urea P	UA P
SOD	-0,21	0,35	-0,23	-0,03	-0,03	0,17	-0,23
Katalase	0,16	0,32	0,43	0,26	0,42	0,25	-0,04
MDA	-0,14	0,14	-0,07	0,23	0,10	-0,03	0,28
DC	-0,08	-0,11	0,11	0,10	-0,08	-0,24	0,41

Based on the obtained matrix, regression models were further created by stepwise exclusion to reach the maximum level of Adjusted R^2.

It was found that the activity of plasma Catalase is determined by nitrogenous metabolites by 29,9% (Table 2), and erythrocyte Superoxide dismutase by only 18,3% (Table 3).

Table 2. Regression Summary for Katalase Plasma
$R=0,589$; $R^2=0,347$; Adjusted $R^2=0,299$; $F_{(4,6)}=7,3$; $p<10^{-4}$

		Beta	St. Err. of Beta	B	St. Err. of B	$t_{(55)}$	p-level
Variables	r		Intercpt	0,060	0,017	3,51	0,001
Urea Excretion, µM/24h•100 g	**0,43**	0,360	0,115	0,00010	0,00003	3,13	0,003
Bilirubinemia, µM/L	**0,42**	0,280	0,117	0,0061	0,0026	2,39	0,020
Creatininemia, mM/L	**0,32**	0,391	0,201	0,547	0,281	1,94	0,057
Urea Plasma, mM/L	**0,25**	-0,206	0,202	-0,0032	0,0031	-1,02	0,313

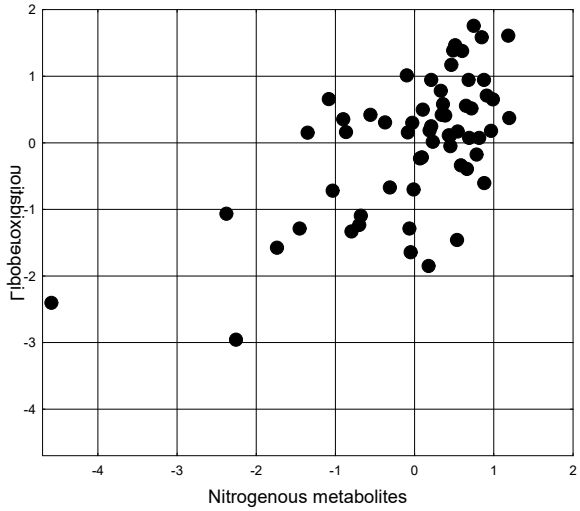
Table 3. Regression Summary for SOD Erythrocytes
R=0,488; R^2=0,239; Adjusted R^2=0,183; $F_{(4,6)}$=4,3; p=0,004

		Beta	St. Err. of Beta	B	St. Err. of B	$t_{(55)}$	p-level
Variables	r		Intercpt	55,2	4,70	11,8	10^{-6}
Creatininemia, mM/L	**0,35**	0,641	0,216	192,5	64,9	2,96	0,004
Urea Plasma, mM/L	**0,17**	-0,375	0,221	-1,232	0,727	-1,69	0,096
Urea Excretion, µM/24h•100 g	**-0,23**	-0,199	0,122	-0,011	0,007	-1,63	0,109
Uricemia, µM/L	**-0,23**	-0,142	0,126	-0,003	0,003	-1,13	0,262

Lipid peroxidation products are even less bound to nitrogenous metabolites. In general, nitrogenous metabolites determine the constellation of lipoperoxidation parameters by 38,8% (Table 4 and Fig. 1).

Table 4. Factor load on canonical roots of nitrogenous metabolites (left set) and Lipid Peroxidation parameters (right set)

Left set	**Root 1**
Urea Excretion, µM/24h•100 g	**-0,942**
Bilirubinemia, µM/L	**-0,432**
Uricemia, µM/L	**-0,248**
Creatininemia, mM/L	**0,132**
Right set	**Root 1**
Katalase, nM/h•mL	**-0,659**
Superoxide Dismutase, un/mL	**0,520**
Diene conjugates, E^{232}/mL	**0,070**
Malonic Dyaldehid, nM/mL	**0,065**



R=0,623; R^2=0,388; $\chi^2_{(20)}$=65; p=10^{-6}; Λ Prime=0,301
Fig. 1. Scatterplot of canonical correlation between the nitrogenous metabolites (X-line) and lipid peroxidation parameters (Y-line) in female rats

In the future, a matrix for Lipid Peroxidation and Immunity is created (Table 5).

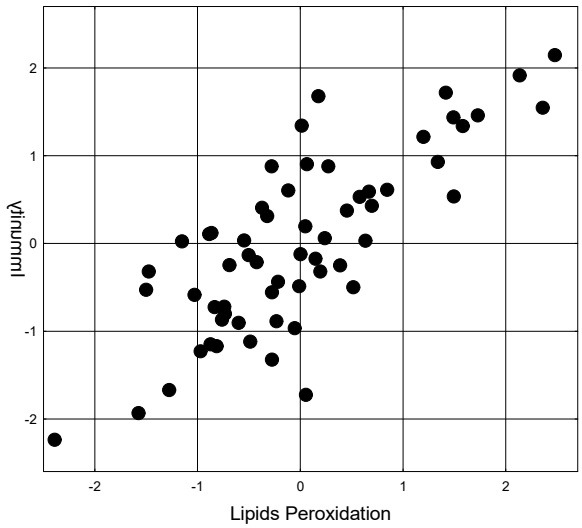
Table 5. Correlation matrix for Lipid Peroxidation and Immunity parameters (only subordinate modulations by nitrogenous metabolites are included)

Root Variable	Correlations			
	SOD	Katal	MDA	DC
MCN	0,029	0,253	0,334	0,184
PhIM	-0,205	-0,117	-0,025	-0,053
PhIN	-0,046	0,190	0,091	0,149
Spleen MI	-0,023	0,006	-0,050	-0,057
LbS	-0,027	0,373	0,112	0,216
MacPhaS	-0,041	-0,231	0,018	-0,156
MicPhaS	0,142	-0,222	-0,255	-0,105
EosS	-0,101	-0,150	0,022	-0,039
FibrS	-0,158	-0,110	-0,026	0,023
LCT	0,039	0,233	0,076	0,147
LbT	0,158	0,291	0,133	-0,066
RetT	-0,048	-0,138	-0,102	-0,009
EndT	-0,250	0,029	0,061	0,077
MacPhT	-0,209	0,208	-0,094	-0,104
HassT	-0,051	0,074	0,067	-0,028
StubN B	0,053	0,111	-0,023	0,001
Eos B	0,053	0,088	-0,236	-0,182
Mon B	0,101	-0,314	-0,475	-0,299
Leukoc B	0,211	-0,125	0,045	0,055
Th B	0,295	0,215	0,012	-0,050
NK B	0,036	-0,326	-0,381	-0,227
H LCG	-0,041	-0,320	-0,112	0,093
H SCG	-0,052	0,218	-0,043	-0,086

Canonical analysis shows that the constellation of lipid peroxidation parameters determines the constellation of immunity parameters subject to modulation by nitrogenous metabolites by 61,4% (Table 6 and Fig. 2).

Table 6. Factor load on canonical roots of Lipid peroxidation (left set) and Immunity (right set)

Left set	Root 1
Katalase, nM/h•mL	**0,668**
Malonic Dyaldehid, nM/mL	**0,643**
Diene conjugates, E^{232}/mL	**0,401**
Superoxide Dismutase, un/mL	**-0,478**
Right set	**Root 1**
Monocytes Blood, %	**-0,626**
Natural Killers Blood, %	**-0,525**
Microbial Count Neutrophils	**-0,437**
Entropy Leukocytogram	**-0,284**
Leukocytes Blood, 10^9/L	**-0,215**
Macrophages Spleen, %	**-0,141**
Eosinophiles Blood, %	**-0,127**
Th Lymphocytes Blood, %	-0,041
Eosinophiles Spleen, %	-0,029
Lymphoblastes Spleen, %	**0,384**
Macrophages Thymus, %	**0,245**
Endotheliocytes Thymus, %	**0,242**
Phagocytic Index Neutrophils, %	**0,241**
Reticulocytes Thymus, %	**0,229**
Lymphocytes Thymus, %	**0,204**
Lymphoblastes Thymus, %	**0,192**
Entropy Splenocytogram	**0,172**
Hassal's corpuscles Thymus, %	**0,138**
Stub Neutrophils Blood, %	0,076
Spleen Mass Index, g/100g	0,063
Phagocytic Index Monocytes, %	0,039
Fibroblastes Spleen, %	0,013



R=0,783; R^2=0,614; $\chi^2_{(76)}$=110; p=0,006; Λ Prime=0,096

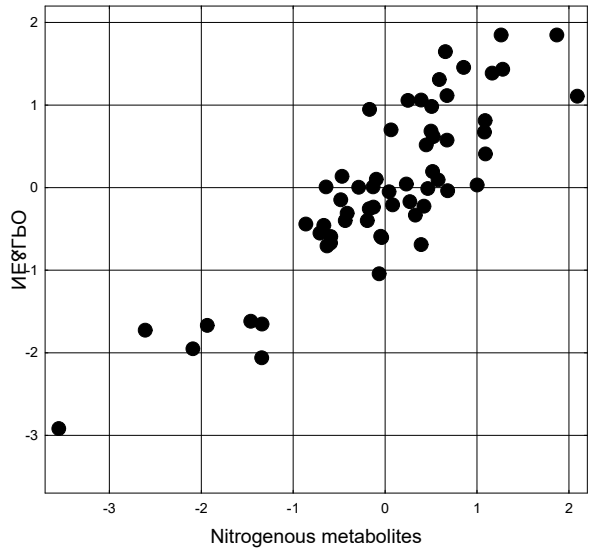
Fig. 2. Scatterplot of canonical correlation between the Lipids Peroxidation parameters (X-line) and Immunity parameters (Y-line) in female rats

As a result of the analysis of the canonical correlation between nitrogenous metabolites and all presumed mediators of their immunomodulatory effects, katalase, malonic dyaldehid and diene conjugates appeared in the constellation of parameters of the first neuroendocrine

root, subordinate to upregulation by bilirubin, uric acid, urea urine and creatinine plasma while downregulation by creatinine urine (Table 7 and Fig. 3).

Table 7. Factor load on first canonical roots of nitrogenous metabolites (left set) and neuroendocrine and lipid peroxidation parameters (right set)

Left set	**Root 1**
Bilirubinemia, µM/L	**-0,486**
Uricosuria, µM/24h•100 g	**-0,458**
Urea Excretion, µM/24h•100 g	**-0,422**
Uricemia, µM/L	**-0,181**
Creatininemia, mM/L	**-0,159**
Creatinineuria, µM/24h•100 g	**0,309**
Right set	**Root 1**
Triiodothyronine, nM/L	**0,747**
Fascicular ZAC, µM	**0,674**
Mineralocorticoid Activity	**0,414**
Testosterone, nM/L	**0,273**
Reticular ZAC, µM	**0,263**
Glomerular ZAC, µM	**0,170**
Medullar ZA, µM	**-0,657**
Katalase, nM/h•mL	**-0,494**
Calcitonin Activity	**-0,451**
MxDMn HRV, msec	**-0,408**
Malonic Dyaldehid, nM/mL	**-0,316**
Diene conjugates, E^{232}/mL	**-0,276**
Adrenals Mass, mg/100 g	**-0,118**



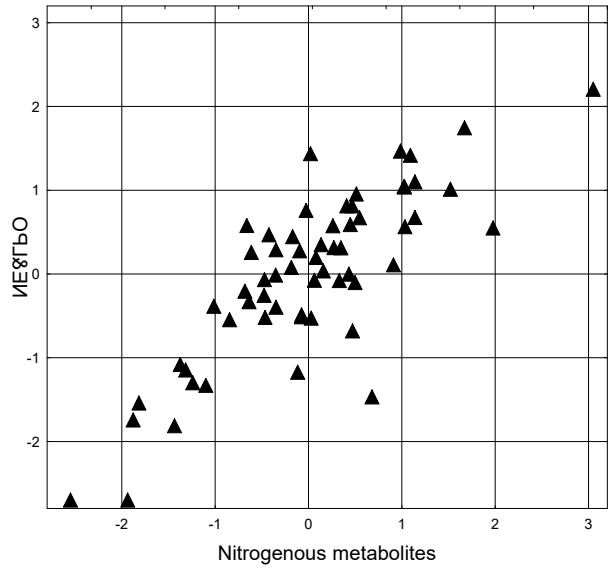
R=0,863; R^2=0,745; $\chi^2_{(112)}$=225; p<10^{-6}; Λ Prime=0,008

Fig. 3. Scatterplot of canonical correlation between the nitrogenous metabolites (X-line) and neuroendocrine and lipid peroxidation parameters (Y-line) in female rats. First pair of Roots

Instead, superoxide dismutase entered the factor structure of only the second neuroendocrine root, surrounded by parameters subject to downregulation by uric acid urine and urea plasma while upregulation by creatinine and bilirubin plasma (Table 8 and Fig. 4).

Table 8. Factor load on second canonical roots of nitrogenous metabolites (left set) and neuroendocrine and lipid peroxidation parameters (right set)

Left set	**Root 2**
Uricosuria, µM/24h•100 g	**-0,408**
Urea Plasma, mM/L	**-0,133**
Creatininemia, mM/L	**0,234**
Bilirubinemia, µM/L	**0,220**
Right set	**Root 2**
Parathyroid Activity	**-0,497**
Mineralocorticoid Activity	**-0,482**
Reticular ZAC, µM	**-0,179**
Medullar ZA, µM	**0,294**
Diene conjugates, E^{232}/mL	**0,228**
Fascicular ZAC, µM	**0,208**
Corticosterone, nM/L	**0,198**
Triiodothyronine, nM/L	**0,190**
Katalase, nM/h•mL	**0,170**
Adrenals Mass, mg/100 g	**0,157**
Superoxide Dismutase, un/mL	**0,138**
Malonic Dyaldehid, µM/L	**0,129**
MxDMn HRV, msec	**0,120**
Glomerular ZAC, µM	**0,101**



R=0,813; R^2=0,661; $\chi^2_{(90)}$=161; p<10^{-5}; Λ Prime=0,033

Fig. 4. Scatterplot of canonical correlation between the nitrogenous metabolites (X-line) and neuroendocrine and lipid peroxidation parameters (Y-line) in female rats. Second pair of Roots

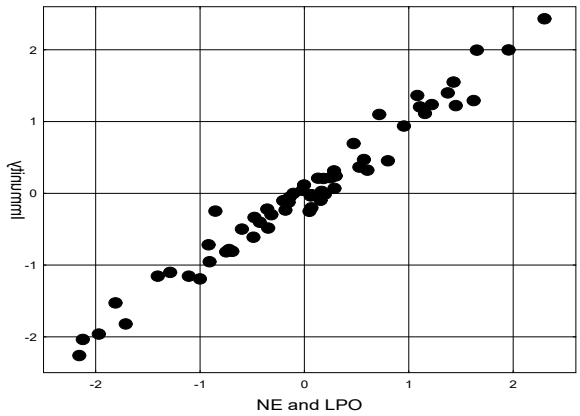
At the final stage, the analysis of the canonical correlation between all the presumed mediators of the immunomodulatory action of nitrogenous metabolites, on the one hand, and the constellation of immune parameters subject to the influence of the latter, on the other hand.

Two neuroendocrine-immune pairs of canonical roots are formed. The first pair of roots reflects the immunomodulatory effect, primarily of triiodothyronine and glucocorticoids, to a lesser extent - mineralocorticoids, androgens and parathyroid hormone, as well as, conversely, catecholamines, vagus, calcitonin, katalase, malonic dyaldehid and diene conjugates (Table 9).

The degree of determination of immunity is 96,7% (Fig. 5). Therefore, lipid peroxidation parameters increase neuroendocrine determination of immunity by only 0,9% [17].

Table 9. Factor load on first canonical roots of Neuroendocrine and Lipid peroxidation parameters (left set) and Immune parameters (right set)

Left set	**Root 1**
Triiodothyronine, nM/L	**0,953**
Fascicular ZAC, µM	**0,609**
Mineralocorticoid Activity	**0,339**
Reticular ZAC, µM	**0,310**
Parathyroid Activity	**0,216**
Testosterone, nM/L	**0,156**
Medullar Zone Adrenals, µM	**-0,427**
Katalase, nM/h•mL	**-0,404**
MxDMn HRV, msec	**-0,384**
Calcitonin Activity	**-0,344**
Malonic dyaldehid, nM/mL	**-0,313**
Diene conjugates, E^{232}/mL	**-0,233**
Right set	**Root 1**
Natural Killers Blood, %	**0,911**
Monocytes Blood, %	**0,893**
Macrophages Spleen, %	**0,272**
Phagocytic Index Monocytes, %	**0,253**
Reticulocytes Thymus, %	**0,229**
Hassal's corpuscles Thymus, %	**0,138**
Eosinophiles Spleen, %	**0,128**
Fibroblastes Spleen, %	**0,127**
Stub Neutrophils Blood, %	**0,076**
Spleen Mass Index, g/100g	**0,063**
Microbial Count Neutrophils	**-0,884**
Phagocytic Index Neutrophils, %	**-0,639**
Lymphoblastes Spleen, %	**-0,415**
Lymphocytes Thymus, %	**-0,286**
Lymphoblastes Thymus, %	**-0,247**
Th Lymphocytes Blood, %	**-0,187**
Entropy Splenocytogram	**-0,181**
Macrophages Thymus, %	**-0,112**
Eosinophiles Blood, %	**-0.071**



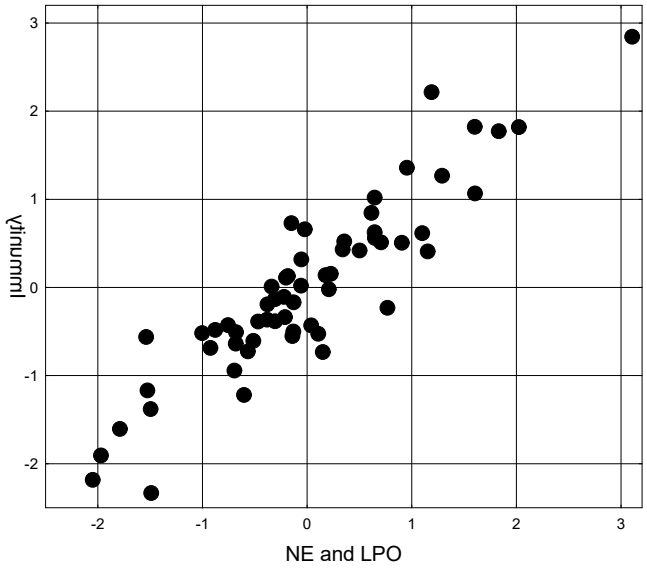
R=0,983; R^2=0,967; $\chi^2_{(345)}$=514; p<10^{-6}; Λ Prime<10^{-5}

Fig. 5. Scatterplot of canonical correlation between the Neuroendocrine and Lipid peroxidation parameters (X-line) and immune parameters (Y-line) in female rats. First pair of Roots

The second neuroendocrine root is poorly structured and reflects the modulating effect of vagus, parathyrin, calcitonin and corticosterone as well as diene conjugates and katalase, whith represent the root inversely, and steroid hormones as well as superoxide dismutase, which represent the root directly, on another constellation of immune parameters. The degree of determination of immunity is 83,4% (Table 10 and Fig. 6).

Table 10. Factor load on second canonical roots of Neuroendocrine and Lipid peroxidation parameters (left set) and Immune parameters (right set)

Left set	**Root 2**
MxDMn HRV, msec	**-0,490**
Parathyroid Activity	**-0,353**
Diene conjugates, E^{232}/mL	**-0,195**
Katalase, nM/h•mL	**-0,152**
Calcitonin Activity	**-0,144**
Corticosterone, nM/L	**-0,101**
Superoxide dismutase, un/mL	**0,354**
Glomerular ZAC, µM	**0,295**
Testosterone, nM/L	**0,260**
Mineralocorticoid Activity	**0,160**
Fascicular ZAC, µM	**0,144**
Right set	**Root 2**
Macrophages Spleen, %	**0,598**
Leukocytes Blood, 10^9/L	**0,358**
Th Lymphocytes Blood, %	**0,191**
Eosinophiles Spleen, %	**0,145**
Eosinophiles Blood, %	**0,056**
Microphages Spleen, %	**-0,251**
Endotheliocytes Thymus, %	**-0,241**
Phagocytic Index Monocytes, %	**-0,208**
Entropy Leukocytogram	**-0,202**
Fibroblastes Spleen, %	**-0,132**
Macrophages Thymus, %	**-0,104**



R=0,913; R^2=0,834; $\chi^2_{(308)}$=380; p=0,003; Λ Prime<10^{-4}

Fig. 6. Scatterplot of canonical correlation between the Neuroendocrine and Lipid peroxidation parameters (X-line) and immune parameters (Y-line) in female rats. Second pair of Roots

Therefore, lipid peroxidation parameters increase neuroendocrine determination of another pool immunity parameter by 10,5% [17].

It seems that nitrogenous metabolites modulate the activity of the autonomic nervous system, the adrenal, thyroid and parathyroid glands as well as lipid peroxidation, mediators which, in turn, have an immunomodulatory effect.

The obtained results, taken together with the previous ones, prove that uric acid, bilirubin, urea and creatinine realize their immunomodulatory effects both directly through receptors of immunocytes (aryl hydrocarbon, adenosine and TL) and with the participation of mediators of autonomic nervous and endocrine systems and lipid peroxidation [33,34].

CONFORMITY TO ETHICAL STANDARDS

Experiments on animals have been carried out in accordance with the provisions of the Helsinki Declaration of 1975, revised and supplemented in 2002 by the Directives of the National Committees for Ethics in Scientific Research.

The conduct of experiments was approved by the Ethics Committee of the Ukrainian Scientific Research Institute for Medicine of Transport. The modern rules for the maintenance and use of laboratory animals complying with the principles of the European Convention for the Protection of Vertebrate Animals used for scientific experiments and needs are observed (Strasbourg, 1985).

REFERENCES

1. Andreyeva LI, Kozhemyakin LA, Kishkun AA. Modification of the method for determining the lipid peroxide in the test with thiobarbituric acid [in Russian]. Laboratornoye Delo. 1988; 11: 41-43.
2. Baevskiy RM, Ivanov GG. Heart Rate Variability: theoretical aspects and possibilities of clinical application [in Russian]. Ultrazvukovaya i funktsionalnaya diagnostika. 2001; 3: 106-127.
3. Dubinina YY, Yefimova LF, Sofronova LN, Geronimus AL. Comparative analysis of the activity of superoxide dismutase and catalase of erythrocytes and whole blood from newborn children with chronic hypoxia [in Russian]. Laboratornoye Delo. 1988; 8: 16-19.
4. Gavrilov VB, Mishkorudnaya MI. Spectrophotometric determination of plasma levels of lipid hydroperoxides [in Russian]. Laboratornoye Delo. 1983; 3: 33-36.
5. Goryachkovskiy AM. Clinical Biochemistry [in Russian]. Odesa. Astroprint; 1998: 608 p.
6. Gozhenko AI. Functional-metabolic continuum [in Russian]. J of NAMS of Ukraine. 2016; 22 (1): 3-8.
7. Gozhenko AI, Smagliy VS, Korda IV, Badiuk NS, Zukow W, Popovych IL. Functional relationships between parameters of uric acid exchange and immunity in female rats. Actual problems of transport medicine. 2019; 4(58): 123–131.
8. Gozhenko AI, Smagliy VS, Korda IV, Badiuk NS, Zukow W, Popovych IL. Features of immune status in different states of uric acid metabolism in female rats. Journal of Education, Health and Sport. 2019; 9(12): 167-180.
9. Gozhenko AI, Smagliy VS, Korda IV, Badiuk NS, Zukow W, Kovbasnyuk MM, Popovych IL. Relationships between parameters of uric acid exchange and immunity as well as microbiota in patients with neuroendocrine-immune complex dysfunction. Journal of Education, Health and Sport. 2020; 10(1): 165-175.
10. Gozhenko AI, Smagliy VS, Korda IV, Badiuk NS, Zukow W, Kovbasnyuk MM, Popovych IL. Relationships between changes in uric acid parameters metabolism and parameters of immunity and microbiota in patients with neuroendocrine-immune complex dysfunction. Journal of Education, Health and Sport. 2020; 10(2): 212-222.
11. Gozhenko AI, Zukow W, Polovynko IS, Zajats LM, Yanchij RI, Portnichenko VI, Popovych IL. Individual Immune Responses to Chronic Stress and their Neuro-Endocrine Accompaniment. RSW. UMK. Radom. Torun; 2019: 200 p.

12. Instructions for use of a set of reagents for enzyme-linked immunosorbent assay of hormones in human blood [in Russian]. SPb. CJSC “Alcor Bio”; 2000.
13. Korolyuk MA, Ivanova MI, Mayorova IG, Tokarev VYe. The method for determining the activity of catalase [in Russian]. Laboratornoye Delo. 1988; 1: 16-19.
14. Kuchma IL, Gozhenko AI, Bilas VR, Huchko BY, Ponomarenko RB, Nahurna YV, Zukow W, Popovych IL. Relationships between parameters of nitrogenous metabolites and HRV in humans exposed to the factors of the accident at the Chornobyl nuclear power plant. Journal of Education, Health and Sport. 2021; 11(1): 253-268.
15. Kuchma IL, Gozhenko AI, Bilas VR, Ruzhylo SV, Kovalchuk GY, Nahurna YV, Zukow W, Popovych IL. Immunotropic effects of nitrogenous metabolites (creatinine, urea, uric acid and bilirubin) in humans exposed to the factors of the accident at the Chornobyl nuclear power plant. Journal of Education, Health and Sport. 2020; 10(12): 314-331.
16. Kuchma IL, Gozhenko AI, Flyunt ISS, Ruzhylo SV, Nahurna YV, Zukow W, Popovych IL. Role of the autonomic nervous system and lipoperoxidation in immunotropic effects of nitrogenous metabolites in patients with postradiation encephalopathia. Journal of Education, Health and Sport. 2021; 11(2): 145-155.
17. Kuchma IL, Gozhenko AI, Flyunt ISS, Ruzhylo SV, Kovalchuk GY, Zukow W, Popovych IL. Role of the neuroendocrine complex in immunotropic effects of nitrogenous metabolites in rats. Journal of Education, Health and Sport. 2021; 11(3): 212-230.
18. Kul’chyns’kyi AB**,** Kyjenko VM, Zukow W, Popovych IL. Causal neuro-immune relationships at patients with chronic pyelonephritis and cholecystitis**.** Correlations between parameters EEG, HRV and white blood cell count. Open Medicine. 2017; 12(1): 201-213.
19. Kul’chyns’kyi AB**,** Zukow W, Korolyshyn TA, Popovych IL. Interrelations between changes in parameters of HRV, EEG and humoral immunity at patients with chronic pyelonephritis and cholecystitis. Journal of Education, Health and Sport. 2017; 7(9): 439-459.
20. Lukyanchenko OI, Mel’nyk OI, Gozhenko OA, Zukow W, Popovych IL. Features of the HRV, endocrine and metabolic parameters in persons whose immune status is susceptible or resistant to chronic stress. Journal of Education, Health and Sport. 2020; 10(3): 177-187.
21. Makarenko YeV. A comprehensive definition of the activity of superoxide dismutase and glutathione reductase in red blood cells in patients with chronic liver disease [in Russian]. Laboratornoye Delo. 1988; 11: 48-50.
22. Mel’nyk OI, Struk ZD, Zukow W, Popovych IL. Vegetative, endocrine and metabolic accompaniments of individual immune responses to adaptogenic balneotherapy. Journal of Education, Health and Sport. 2019; 9(12): 207-229.
23. Morelli M, Carta AR, Kachroo A, Schwarzschild A. Pathophysiological roles for purines: adenosine, caffeine and urate. Prog Brain Res. 2010; 183: 183-208.
24. Nance DM, Sanders VM. Autonomic innervation and regulation of the immune system. Brain Behav Immun. 2007; 21(6): 736-745.
25. Popovych IL, Gozhenko AI, Kuchma IL, Zukow W, Bilas VR, Kovalchuk GY, Ivasivka AS. Immunotropic effects of so-called slag metabolites (creatinine, urea, uric acid and bilirubin) at rats. Journal of Education, Health and Sport. 2020; 10(11): 320-336.
26. Popovych IL, Gozhenko AI, Zukow W, Polovynko IS. Variety of Immune Responses to Chronic Stress and their Neuro-Endocrine Accompaniment. Scholars' Press. Riga; 2020: 172 p.
27. Popovych IL, Kul’chyns’kyi AB**,** Gozhenko AI, Zukow W, Kovbasnyuk MM, Korolyshyn TA**.** Interrelations between changes in parameters of HRV, EEG and phagocytosis at patients with chronic pyelonephritis and cholecystitis. Journal of Education, Health and Sport. 2018; 8(2): 135-156.
28. Popovych IL, Kul’chyns’kyi AB**,** Korolyshyn TA, Zukow W**.** Interrelations between changes in parameters of HRV, EEG and cellular immunity at patients with chronic pyelonephritis and cholecystitis. Journal of Education, Health and Sport. 2017; 7(10): 11-23.
29. Smagliy VS, Gozhenko AI, Korda IV, Badiuk NS, Zukow W, Kovbasnyuk MM, Popovych IL. Variants of uric acid metabolism and their immune and microbiota accompaniments in patients with neuroendocrine-immune complex dysfunction. Actual problems of transport medicine. 2020; 1(59): 114–125.
30. Sternberg EM. Neural regulation of innate immunity: a coordinated nonspecific host response to

pathogens. Nat Rev Immunol. 2006; 6(4): 318-328.
31. Thayer JF, Sternberg EM. Neural aspects of immunomodulation: Focus on the vagus nerve. Brain Behav Immun. 2010; 24(8): 1223-1228.
32. Tracey KJ. Physiology and immunology of the cholinergic antiinflammatory pathway. J Clin Invest. 2007; 117(2): 289-296.
33. Gozhenko A., Biryukov V., Gozhenko O., Zukow, W. Health as a space-time continuum. Journal of Education, Health and Sport, 2018; 8(11): 763-777. DOI: http://dx.doi.org/10.5281/zenodo.2657000.
34. Gozhenko A., Biryukov V., Muszkieta R., Zukow, W. Physiological basis of human longevity: the concept of a cascade of human aging mechanism. Collegium antropologicum, 2018; 42(2): 139-146.