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Research Article

### THE STUDY OF MODIFICATIONS OF GENOMIC DNA IN ENDOTOXEMIA

**Trofimov A.V., Trofimov V.A., Sidorov D.I., Kadimaliev D.A., Vlasov A.P.**

Federal state budgetary educational institution of higher education «N.P. Ogarev Mordovia State University», Bolshevistskaya Str. 68, Saransk 430005, Russia

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**Abstract:**

*Background & objectives.* Endogenous intoxication and, as a consequence, the development of multi-organ failure are extreme forms of the pathological process and require immediate and radical repairing, therefore, the study of the molecular mechanisms of the pathogenesis of endogenous intoxication syndrome is a topical issue. The aim of the study is to look into the DNA modifications during endotoxic "pollution" of the body and to understand the mechanisms of development of dysregulation processes mediated by structural changes in DNA.

*Methods.* The rate of endogenous intoxication was assessed by determining the generally accepted laboratory-clinical and biochemical parameters. The mononuclear cell fraction was collected by gradient centrifugation on Ficoll-Paque™ ( $\rho=1,077$ ). The isolation of DNA from blood mononuclear cells was performed by using Laura-Lee Boodram. UV-spectroscopic assays of DNA solutions were carried out using a spectrophotometer UV-3600 Shimadzu (Japan). The IR Fourier spectra of DNA preparations were recorded on IRPrestige-21 SHIMADZU spectrometer (Japan) in the range of  $400\text{ cm}^{-1}$  -  $4000\text{ cm}^{-1}$ .

*Interpretation & conclusions.* The paper is concerned with the study of changes in biochemical composition and structure of genomic DNA of mononuclear cells of venous blood in patients with endogenous intoxication. The FT-IR spectra of genomic DNA of patients' venous blood mononuclear cells reveal that the band at a frequency of  $1337\text{ cm}^{-1}$ , characterising the fluctuations of  $\text{CH}_2$ -group and sugar-base bonds, shifts to a higher frequency. The absorption band at  $1491\text{ cm}^{-1}$ , reflecting the movement of purine atoms and corresponding to  $\text{C}=\text{N}$  guanine bond, becomes wider and has a more pronounced character. The absorption intensity increases at a frequency of  $863\text{ cm}^{-1}$ , characteristic of the type of twisting in N-type sugars. The intensity of the band  $1086\text{ cm}^{-1}$ , capturing the symmetric vibrations of the  $\text{O}=\text{P}=\text{O}$  stroma bonds decreases. The corresponding alterations in the spectrum point to changes in the mutual orientation of DNA phosphate groups, which is consequent to the topical untwisting of the double helix, redistribution of hydrogen bonds, the appearance of bends on it, resulting in changes in DNA spatial structure, and the increased proportion of DNA in the A-form. UV spectra of the DNA of the experimental samples showed a slight shift of the maximum and a small hyperchromic effect. The observed changes in the spatial structure of DNA may be attributed to the accumulation (penetration) of products in the DNA microenvironment, including those of toxic ones, formed due to impaired balance of biochemical reactions during intoxication. In its turn, changes in the conformation of DNA can be the cause of disorders of genetic processes, including those of gene expression and, as a consequence, lead to the development of dysregulation processes in patients' bodies.

**Key words:** endogenous intoxication, DNA configuration, DNA conformation, Fourier infrared spectroscopy, UV spectroscopy, reactive oxygen intermediate, lipid peroxidation.

**Corresponding author:**

**Trofimov V.A.,**

Mordovian state University. N.P. Ogarev Mordovia state University Ministry of education and science of the Russian Federation 430005, Saransk, Russia

QR code



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**INTRODUCTION:**

Endogenous intoxication and, as a consequence, the development of multi-organ failure are extreme forms of the pathological process and require immediate and radical repairing, therefore, the study of the molecular mechanisms of the pathogenesis of endogenous intoxication syndrome is a topical issue [1,2].

Endogenous intoxication syndrome is characterized by accumulation of toxic endotoxins in tissues and biological fluids, organs damage, disruption of the functional systems of the body due to ischemia, necrotic cell death, release of microorganisms, their metabolic products and decay from the focus of invasive infection into the body, impaired excretion of endotoxins from the body and secondary toxic aggression.

Endotoxins are the metabolites accumulating in large quantities in the tissues of the body, modified cytotoxic biomolecules, free radicals, including reactive oxygen and nitrogen intermediates having a high reaction activity.

The most important triggers for the development of the pathological process leading to the development of endogenous intoxication are free radicals, which are formed in excess in the body during various pathological processes induced, in particular, by inflammation and ischemia. The involvement of new biomolecules, including proteins and lipids in the free radical process coupled with poor antioxidant activity in the body leads to deep destructive changes in the cells and tissues of the body, the development of dysregulation processes, which ultimately aggravates the pathological process in the body and leads to the development of multi-organ failure [3,4].

DNA, like other important structural and functional biomolecules of the body - proteins and lipids, is also exposed to various oxidative modifications, but changes in the DNA covalent structure are offset by enzymes of the body's repair system [5,6]. However, endogenous intoxication nourishes all necessary conditions for the "long-term" presence of structural changes in the genomic DNA that can affect the DNA functional activity and the implementation of genetic processes, primarily gene transcription.

This paper presents the results of an experimental study of modifications that occur in genomic DNA of mononuclear cells in venous blood of patients with endogenous intoxication syndrome.

The aim of the study is to look into the DNA modifications during endotoxic "pollution" of the body and to understand the mechanisms of development of dysregulation processes mediated by structural changes in DNA.

**METHODS OF RESEARCH:**

In laboratory studies were used samples of venous blood of 15 patients with endotoxicosis syndrome against the background of acute pancreatitis, after giving patient informed consent. The examined group: age –  $48,3 \pm 2,1$  years, men – 7 (46,7%), women – 8 (53,3%). Control blood 10 samples were obtained from 15 to 60 years. Studies conducted in the period: January – May 2019.

The rate of endogenous intoxication was assessed by determining the generally accepted laboratory-clinical and biochemical parameters [7].

To determine nuclease activity isolated genomic DNA was used as the substrate of the reaction. Hydrolysis was carried out in the presence of  $MgCl_2$ , incubated at  $37^\circ C$  during 2 hours.

The mononuclear cell fraction was collected by gradient centrifugation on Ficoll-Paque™ ( $\rho=1,077$ ). The received ring of mononuclear cells was taken to clean eppendorf-type test tubes and cleansed from ficoll impurities by phosphate-saline buffer (PBS) and concentrated in Hanks' solution. Cell viability was determined by the amount of penetration of stain into the cells (1% of trypan blue or 5% eosin solution).

The isolation of DNA from blood mononuclear cells was performed by using Laura-Lee Boodram technique [8]. The cells were lysed with 10% of sodium dodecyl sulfate, then dispensed with 20% of proteinase K and incubated at  $55^\circ C$  during 2 hours. Proteins were salted out with 5,3 M NaCl solution. To deposit DNA in the supernatant cold isopropanol was used. The DNA precipitate was washed with 70% ethanol and resuspended in 0,1 M Tris-HCl, pH 8.5.

UV-spectroscopic assays of DNA solutions (maximum absorption at  $\lambda_{260}$ ), quantitative determination of medium-mass molecules ( $\lambda_{280}$  and  $\lambda_{254}$  nm), diene conjugates in the extracted heptane-isopropanol mixture (1:1, by volume) of lipid fractions ( $\lambda_{232}$  and  $\lambda_{220}$  nm) were carried out using a spectrophotometer UV-3600 Shimadzu (Japan).

The DNA precipitate was lyophilized by freeze-drying FreeZone Plus. The DNA preparation was mixed with KBr to form pills. The IR Fourier spectra of DNA preparations were recorded on IRPrestige-21 SHIMADZU spectrometer (Japan) in the range of  $400\text{ cm}^{-1}$  -  $4000\text{ cm}^{-1}$ .

The obtained findings were statistically processed by the method of variation statistics using the Student t-test.

### RESULTS:

The experiments utilised patients' blood with acute endotoxemia, which is a complication of patients with acute pancreatitis, accompanied by significant changes in the biochemical and blood cell composition (Fig.1).

The content of the average mass molecules – oligopeptides with molecular masses in the range between 500 - 5000 Da (MFM:  $\lambda_{280}$  and  $\lambda_{254}$ ) in patients' blood exceeded the normal values ( $249,2 \pm 19,08$  and  $296,4 \pm 22,17$  relative units  $\times 10^{-3}$ , respectively) on average by 240% and 233% ( $p < 0,05$ ), which is a characteristic sign of the development of endogenous intoxication.

In the blood of endogenously intoxicated patients, the content of lactic and pyruvic acids was increased by 252% and 169% compared to the control samples ( $0,25 \pm 0,022$  and  $0,035 \pm 0,003$  mmol/g protein, respectively) ( $p < 0,05$ ). As it was shown above in the blood of patients with endogenous intoxication, there is a more significant increase in the content of lactic acid in comparison with increased concentration of pyruvic acid, which points to the development of toxic enzymopathy. Also blood plasma of patients with endogenous intoxication, has a high activity of DNase equal to  $240,2 \pm 2,36$  activity units/l.

One of the indicators of molecular instability in the body is a high level of lipid peroxidation. In patients with endogenous intoxication syndrome, the content of the primary products of lipid peroxidation – diene conjugates (DC) on average exceeded the normal values ( $0,45 \pm 0,01$  rel.units/mg. of lipids) by 3,3 times, and TBA-reactive substances, which include malonaldehyde, exceeded the control parameters ( $4,5 \pm 0,5$  nmol/ml) by an average of 220% ( $p < 0,05$ ).

To study the properties of genomic DNA, we utilised the blood of endogenously intoxicated patients whose core biochemical parameters (markers) were higher or lower than the corresponding normal values.

By using spectral methods of analysis in IR and UV regions of the spectrum we studied structural modifications of genomic DNA (changes in chemical structure, conformations, packing density) in endogenous intoxication

Analysis of absorption spectra of control and experimental samples in the IR region (Fig. 1) showed the presence of DNA-specific bands in the frequency range  $2960 - 2850\text{ cm}^{-1}$  <sup>(A)</sup>,  $1500 - 1250\text{ cm}^{-1}$  <sup>(B)</sup>, and  $1150 - 750\text{ cm}^{-1}$  <sup>(C)</sup>, which are usually attributed to the bands caused by vibrations in the bonds of  $\text{CH}_2$ -groups, bonds between the bases and sugars (the fluctuation region of the groups in the sugar-phosphate backbone of DNA) and symmetrical vibrations in the bonds of phosphate groups  $-\text{PO}_2$ , respectively [9, 10]. At the same time, the IR spectra of the genomic DNA in the control and experimental samples differed by the intensity of absorption of characteristic bands and the shift of absorption bands.

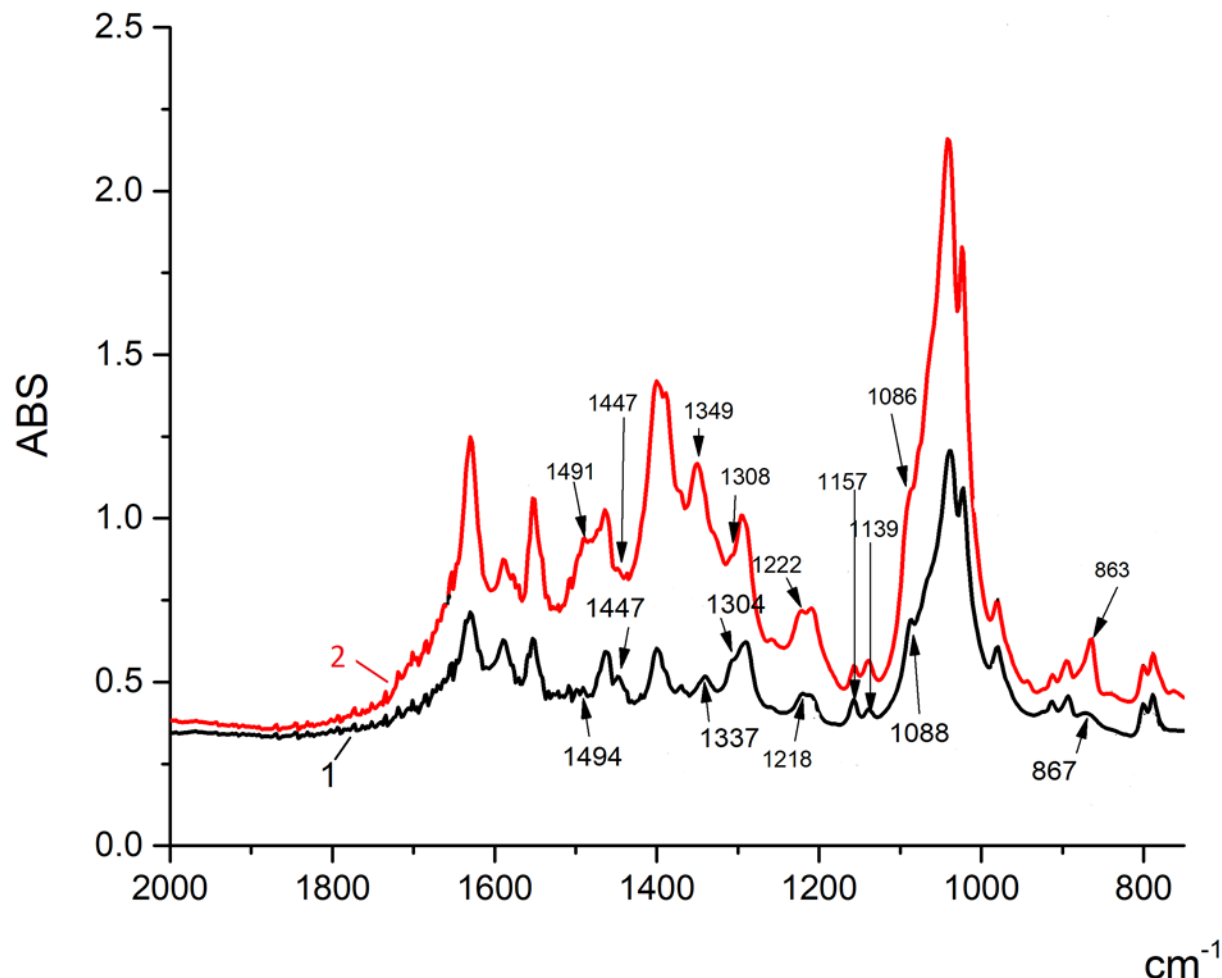


Fig 1. IR-spectra changes in DNA of donors' blood (1) as opposed to patients with endogenous intoxication syndrome (2)

Of particularly note are changes in the IR-spectrum of the DNA blood of patients with the syndrome of endogenous intoxication in the areas  $1500-1250\text{ cm}^{-1}$  and  $1150-750\text{ cm}^{-1}$ , as they may indicate rearrangements in the sugar phosphate backbone of the DNA, associated in particular with changes in efficiency of the ionic interactions between the functional groups of separate molecular fragments, which maintain a specific DNA conformation [11, 12].

As it can be seen from Fig. 1, experimental samples, as opposed to control samples, in the range between  $1500-1250\text{ cm}^{-1}$ , have a decreased absorption intensity in the region  $1447\text{ cm}^{-1}$  and  $1308\text{ cm}^{-1}$ , an increased intensity and shifting of the band at a frequency of  $1337\text{ cm}^{-1}$ , characterizing the vibrations of  $-\text{CH}_2$  group, the vibrations of deoxyribose-nitrogen base bonds, glycoside dihedral angles into the region of

higher frequencies -  $1349\text{ cm}^{-1}$ . The absorption band of genomic DNA of patients with endogenous intoxication  $1491\text{ cm}^{-1}$ , reflecting the movements of purine atoms and the corresponding C=N guanine bond [13, 14], is getting wider and has a more obvious character.

In the region  $1150-800\text{ cm}^{-1}$ , where we have vibrations of the sugar-phosphate backbone, noticeable shifts of the absorption bands are not observed. At the same time, the absorption intensity caused by symmetric vibrations of the bonds in the group O=P=O at frequencies  $1086\text{ cm}^{-1}$ ,  $1157\text{ cm}^{-1}$  and  $1222\text{ cm}^{-1}$  decreases, and increases at a frequency of  $1139\text{ cm}^{-1}$  and the absorption intensity at a frequency of  $863\text{ cm}^{-1}$ , characteristic of n-type sugars increases significantly.

It is known that the spatial structure of DNA is polymorphic, that is, it is able to take different conformations, including three main types of structures – A-, B- and Z- forms. For each of these forms in the IR spectra there are so-called marker absorption bands, which can tell us about the geometry of the DNA macromolecule, the possible transitions between conformations, the stability of the structure [9, 10, 15]. Normally, the DNA isolated from the control samples is mainly represented by the B-form: absorption bands are observed at frequencies of 970, 896 and 837  $\text{cm}^{-1}$ , characteristic of DNA in the B-form [11] and partially in the A-form – absorption band at a frequency of 863  $\text{cm}^{-1}$  [15, 16].

As it was shown above, in DNA, isolated from samples, the band shifts at a frequency of 1337  $\text{cm}^{-1}$  (vibrations of methylene radicals) to the region of higher frequencies - 1349  $\text{cm}^{-1}$ , as well as there is a noticeable increase in the absorption intensity at a frequency of 863  $\text{cm}^{-1}$ , (absorption band regular of the type of twisting in n-type sugars -C3'-endo/anti, 870-865  $\text{cm}^{-1}$ , marker of A-form) [10]. In addition, the intensity of the 1086  $\text{cm}^{-1}$  band related to the symmetric vibrations of the bonds of O=P=O backbone decreases [11, 13]. Such changes in the spectrum point to changes in the mutual orientation of the DNA phosphate groups, which is a consequence of the local unwinding of the double helix, the redistribution of hydrogen bonds between the nitrogen bases, the appearance of bends in it, resulting cumulatively in a change in the spatial structure of DNA. In genomic DNA, isolated from the blood of

patients with endogenous intoxication syndrome, most likely, there is a relative increase in the proportion of DNA in the A-form. According to the literature, under physiological conditions (low salt concentration, high degree of hydration), the dominant structural type of DNA is a B-form. An A-form is formed under conditions of lesser hydration and a higher ion content. Apparently, during evident endotoxemia, a complex of conditions is formed under which DNA modification occurs, consisting in structural changes and conformational rearrangements.

One of the methods of detecting changes in the structure of DNA molecules is the record of absorption spectra in the UV region. Firstly, by absorption ratio at wavelengths of 260 nm and 280 nm ( $\lambda_{260}/\lambda_{280}$ ) one can estimate the purity of the DNA preparation. The preparation is considered pure if the ratio of 260 nm/280 nm is approximately 1,8 for DNA. Secondly, by changing the nature of absorption at a wavelength of 260 nm, one can judge the stability of the bonds between complementary pairs, ensuring the maintenance of the necessary DNA conformation [17]. Intensive absorption of nucleic acids in the UV region of the spectrum is caused by purine and pyrimidine bases. Absorption spectra of select bases merge into one wide band and give a characteristic absorption of DNA with a maximum absorption at  $\lambda=260$  nm.

Our studies have shown that the UV spectra of genomic DNA isolated from donors blood and patients with endogenous intoxication syndrome are different (Fig 2).

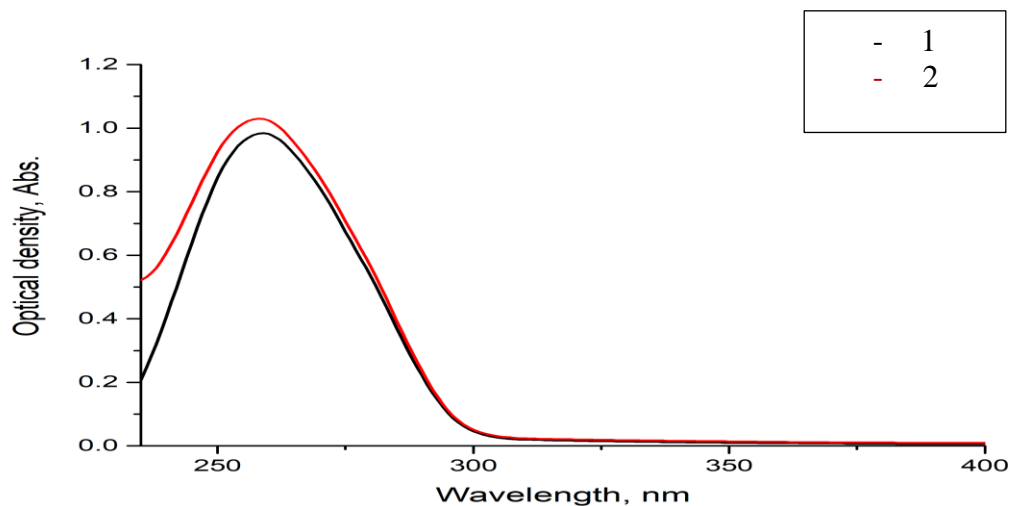


Fig 2. UV spectra of DNA from donors' blood (1) against patients with the syndrome of endogenous intoxication (2)

Figure 2 shows that in the UV absorption spectra of DNA, the absorption ratio at wavelengths of 260 nm and 280 nm of control and experimental samples lies within 1,8, which indicates a sufficiently high purity of the isolated macromolecules. At the same time, in the DNA spectra of the experimental samples there is a relative displacement of the maximum and a slight hyperchromic effect.

Quantum-mechanical calculations show that the intense absorption of light by purine and pyrimidine bases at 260 nm is linked with p-p and to a certain extent with n-p transitions. The optical properties of chromophore groups depend on the conformation of DNA. The phenomenon associated with an increased optical density is called the hyperchromic effect, and vice versa, the reduced absorption of native DNA preparations - hypochromic effect. Such changes in the spectra may also be attributed to changes in the DNA structure of blood cells in patients with endogenous intoxication syndrome.

We would like to emphasize that DNA spatial structure disorders can be the result of accumulation (penetration) of products, including those of toxic ones, in the nucleic acid microenvironment, formed as a result of impaired balance of biochemical reactions during intoxication. In its turn, changes in the DNA conformation can be the cause of disruption of genetic processes, including gene expression and, as a consequence, lead to the development of dysregulation processes in the body of patients.

### DISCUSSION:

During various inflammatory conditions, one of the undesirable stages of the disease is the development of endogenous intoxication syndrome and, as a consequence, the development of multi-organ failure.

During endogenous intoxication, toxic endotoxins accumulate in the body, causing aggravation of the patient's condition and the formation of this condition, that requires timely diagnosis and immediate repair.

According to the obtained findings during the development of endogenous intoxication syndrome in patients' blood cells there occur changes in the structure of genomic DNA.

The changes in the genomic DNA spatial structure in the syndrome of endogenous intoxication can also be revealed through changes in the UV spectra of DNA samples, observed as a slight shift of the maximum and a small hyperchromic effect.

The observed changes in the UV spectrum of the DNA medicine isolated from the blood of patients with endogenous intoxication syndrome are usually attributed to the binding of metal ions to the DNA molecule at N7 guanine position [18]. Such binding leads to destabilization of hydrogen bonds between complementary pairs, and with a significant number of such binding sites, there is a disruption of base-stacking, accompanied by a hyperchromic effect in the DNA absorption spectrum [19].

A number of papers have shown [17, 20, 21] that the saturation of DNA solutions with oxygen leads to an increased absorption with a maximum at  $\lambda_{260}$ . Such hyperchromism is attributed to one-electron oxidation of DNA by singlet oxygen [22] and the formation of its complex with superoxide anion,  $\text{DNA}+\bullet\text{O}_2^-$ , by a product of singlet oxygen reduction.

It is known that singlet molecular oxygen initiates some biological processes that lead to oxidative stress, accompanied by hyperproduction of reactive oxygen species, which can damage nucleic acid molecules. DNA is one of the main targets for reactive oxygen species, which have genotoxicity and lead to mutations. Modification of DNA effected by singlet oxygen is expressed almost exclusively as oxidation of purines. Whereas OH-radical, effectively interacting with deoxyribose, purine and pyrimidine bases leads to more serious changes in the DNA structure. Oxidized purines and pyrimidines are products of the induced damages that are very common in DNA under oxidative stress [22].

It was noted above that during endogenous intoxication syndrome, the concentration of lipid peroxidation products (LPP) increases in patients' blood, and accumulation of acids creates prerequisites for reducing the pH values.

The initiators of LPO are reactive oxygen intermediates. In particular, singlet oxygen can be formed following the interaction of hydroxyl radicals with superoxide anion radicals, which in turn can be formed as a response to high concentrations of ions, for instance  $\text{K}^+$ , and contribute to the development of a vicious circle of free-radical modification of biomolecules, cells and tissues damage.

In the course of lipid peroxidation a variety of cytotoxic products accumulates, including aldehydes. In particular, malondialdehyde (MDA) is formed as a result of peroxidation of fatty acids containing three or more double bonds (linolenic and arachidonic acids, respectively). The reaction of MDA with primary

amines leads to the formation of Schiff bases. MDA can bind to the DNA nitrogenous bases, leading to a cross-linking of DNA chains, therefore MDA is assigned to the role of a mutagenic, genotoxic and carcinogenic compound [23, 24].

Earlier we have shown that under conditions of increased activity of lipid peroxidation, cells respond by modification of chromatin lipids, coupled with changes in the amount of separate lipids and degree of their oxidation [25].

Therefore, on the basis of research findings and data of scientific literature it can be assumed that in severe forms of inflammatory diseases accompanied by endogenous intoxication, hyperproduction of reactive oxygen species, intensification of free radical processes, including lipid peroxidation, impairs the barrier and regulatory properties of the nucleus membranes, resulting in penetration of excess ions and other strange to karyoplasm substances penetrate karyoplasm, local changes in pH of the medium and in degree of hydration.

The interaction of reactive oxygen species with DNA, most likely and primarily with the nitrogen guanine bases, leads to modification of the macromolecule structure and conformational rearrangements: as evidenced by the change in the vibrations of methylene groups, vibrations in the sugar-base bond groups, changes in glycosidic dihedral angles (band shift at a frequency of  $1337\text{ cm}^{-1}$  into the region of higher frequencies –  $1349\text{ cm}^{-1}$ ), changes in vibrations of the C=N guanine bond (shift and increase in the absorption band at  $1491\text{ cm}^{-1}$ , reflecting the movements of purine atoms) [13,14]. These changes to a certain degree are provoked by interaction of lipid peroxidation products with nitrogen bases.

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