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Polarization correlometry of microscopic images and polycrystalline networks of biological layers necrotic changes

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ABSTRACT

The work is aimed at the development and experimental testing of the polarization-correlation method for the analysis of the polycrystalline structure of biological layers. introduced a new parameter-complex degree of mutual anisotropy. the statistical (statistical moments of the 1st – 4th orders) structure of the distributions of the values of the cdma module of spatially structured fibrillar networks of histological sections of the myocardium that died due to mechanical asphyxia and heart attack was experimentally studied.

Keywords: correlometry; polarization; biological tissue; diagnostics; microscopic images, mechanical asphyxia, heart attack

1. INTRODUCTION

The proposed work lies within the broad area of biomedical diagnostics using laser radiation. One of the most important areas is methods and systems for detecting pathological and necrotic changes in biological objects. Such as trauma, age of injury, degenerative tissue changes, forensic medicine, postmortem tissue changes, substance brain, hematoma, cerebral infarction or stroke[1-3].

This work contains the results of: the analytical justification of polarization-correlation mapping of histological sections of biological tissues by using "two-point" parameters - the complex degree of mutual anisotropy (CDMA) and CDMA - differentiation of necrotic changes in the optical anisotropy of histological sections of the myocardium[4-6].

2. THE OPTICAL SCHEME OF THE CDMA SYSTEM - MAPPING OF OPTICALLY ANISOTROPIC NETWORKS OF HISTOLOGICAL SECTIONS OF BIOLOGICAL TISSUES

Fig. 1 shows the optical design of the CDMA - mapping of optically anisotropic networks of histological sections of biological tissues[7,10,11].

To determine the values of the CDMA module, the results presented in[1-3] can be applied

$$W(r_1,r_2)=\frac{\{d_{11}(r_1,r_2)+d_{12}(r_1,r_2)+d_{21}(r_1,r_2)+d_{22}(r_1,r_2)\}^2}{I(r_1)I(r_2)}, \quad (1)$$

where $d_{ik}(r_1, r_2)$ – the generalized matrix elements of the following form:

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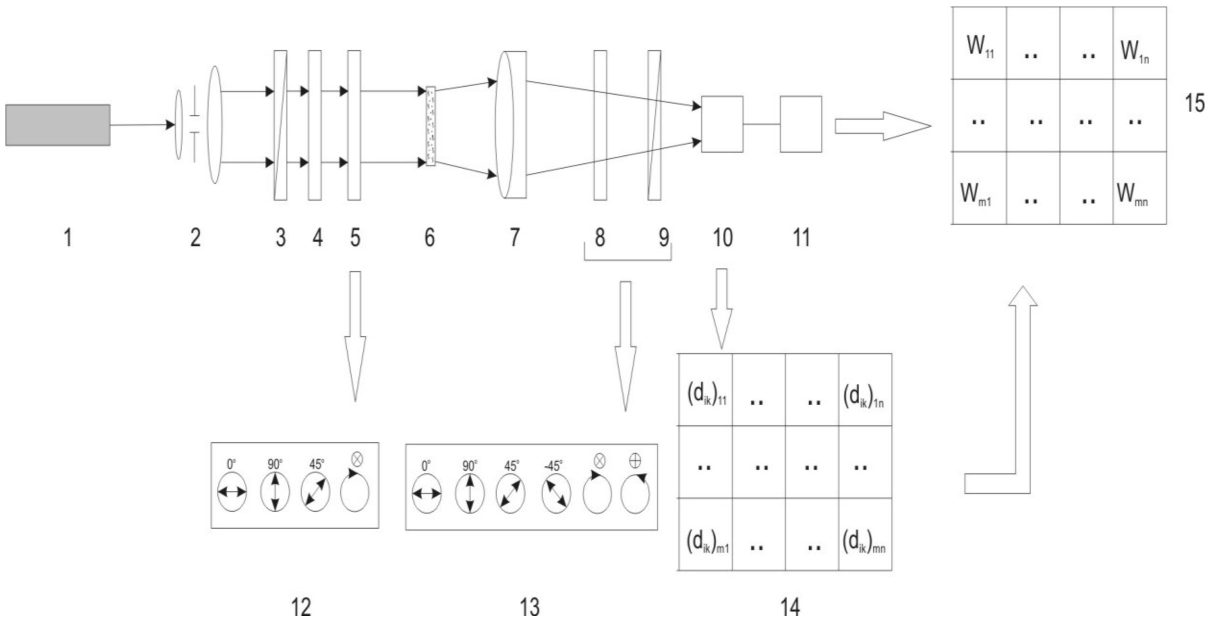

Figure 1. The optical scheme of CDMA - mapping of biological layers.

$$\begin{cases} d_{11}(r_1,r_2) = d_{11}(r_1)d_{11}(r_2); \\ d_{12}(r_1,r_2) = d_{12}(r_1)d_{12}(r_2); \\ d_{21}(r_1,r_2) = d_{21}(r_1)d_{21}(r_2); \\ d_{22}(r_1,r_2) = d_{22}(r_1)d_{22}(r_2), \end{cases} \quad (2)$$

where d_{ik} – complex elements of the Jones matrix $\{D\}$

The experimental measurement of the real component R_{ik} of complex elements d_{ik} is based on the classical approach proposed in[12]. The values of R_{ik} are measured in the following way. Irradiate sample 6 (Fig. 1) with a linearly polarized laser light beam 1 with azimuth $\alpha_0 = 0°$ – the functional sequence of the change in polarization states, provides a filter that consists of quarter-wave plates 3, 5 and polarizer 4, illustrates fragment 12. Next, rotate the transmission axis of the polarizer-analyzer 9 (in the absence of a quarter-wave plate 8) by the angles $\Theta = 0°$, $\Theta = 90°$ and measure the intensity of the transmitted radiation $I_0^0; I_{90}^0$ – the functional sequence of changes in the polarization states is provided by a polarization analyzer, which consists of a quarter-wave plate 8 and polarizer 9, illustrates fragment 13[13,14]; irradiate sample 6 with a linearly polarized light beam with azimuth of $\alpha_0 = 90°$. Rotate the axis of transmission of the polarizer by the angles $\Theta = 0°$, $\Theta = 90°$ and measure the intensity of the transmitted radiation $I_0^{90}; I_{90}^{90}$. Calculate for each pixel of the digital camera 10 the actual components R_{ik} of the elements of the Jones matrix – fragment 14, according to the following equation:

$$\begin{cases} R_{11} = \sqrt{I_0^0}; \\ R_{12} = \sqrt{I_{90}^0}; \\ R_{21} = \sqrt{I_0^{90}}; \\ R_{22} = \sqrt{I_{90}^{90}}. \end{cases} \quad (3)$$

Next, calculate by Eq. (1)–(3) for each pixel of the digital camera the value of the CDMA module – fragment 15[8,9]. The obtained coordinate distributions polarization-correlation CDMA maps $W(m \times n)$ were analyzed within the framework of the statistical approach - the values of the statistical moments of the 1st - 4th orders were calculated using the following algorithms[14,15].

$$Q_1 = \frac{1}{N}\sum_{j=1}^{N} W_j; \;\; Q_2 = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(W^2\right)_j}; \;\; Q_3 = \frac{1}{Q_2^3}\frac{1}{N}\sum_{j=1}^{N}\left(W^3\right)_j; \;\; Q_4 = \frac{1}{Q_2^4}\frac{1}{N}\sum_{j=1}^{N}\left(W^4\right)_j, \qquad (4)$$

where N is the total number of pixels of the digital camera 11 (Fig. 1)

3. DIAGNOSTIC FEATURES OF CDMA MAPPING

The results of studies on the possibility of polarization-correlation differentiation of changes in birefringence of myosin myocardial networks due to necrotic changes in the myocardium are presented[10]. Fig.2 shows the polarization-correlation CDMA maps $W(m \times n)$ (left parts) and histograms $N(W)$ (right parts) of the distributions of the values of the CDMA module in the plane of histological sections of the myocardium that died due to mechanical asphyxia (upper row) and heart attack (lower row)[16]. The results of the comparative analysis of the averaged (within the respective groups of samples) values of the statistical moments characterizing the two-dimensional distribution of the values of the CDMA module are shown in Table 1. The results of the accuracy determining of polarization-correlation mapping method of samples with necrotic changes in myocardial tissue are presented in Table 2.

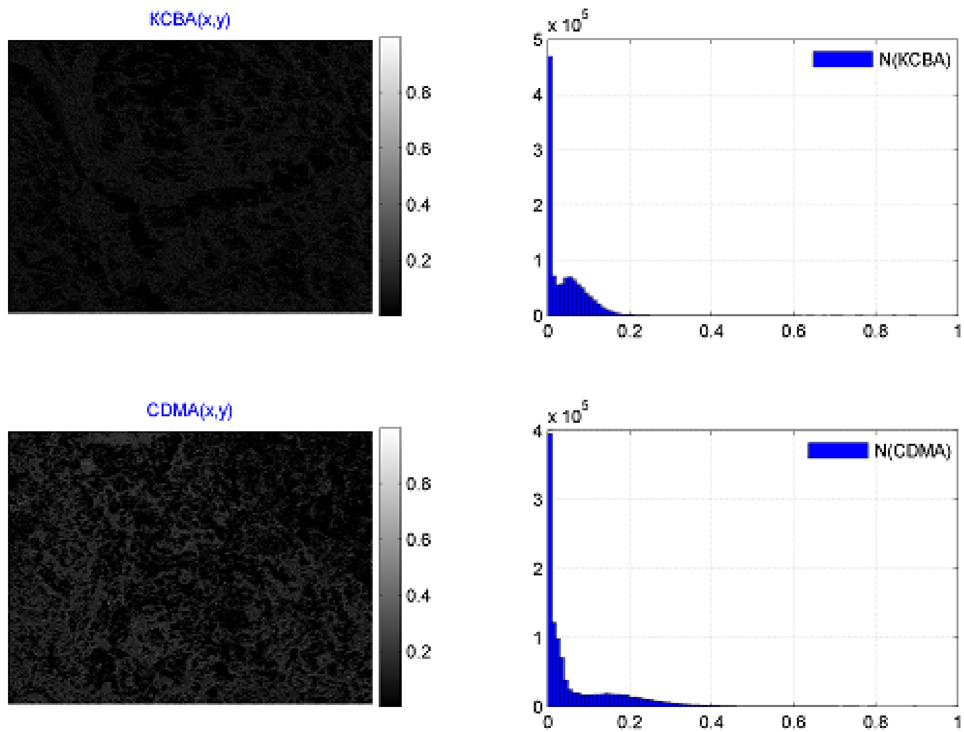

Figure 2. CDMA maps (left parts) and histograms (right parts) of the distribution of CDMA module values in microscopic images of histological sections of the myocardium that died from mechanical asphyxia (top line) and heart attack (bottom line).

From the analysis of statistical moments of the 1st – 4th order $Q_{i=1;2;3;4}$, which characterize the coordinate distributions of the values of the modulus of the polarization-correlation parameter CDMA of histological sections of the myocardium of both types, the following main differences are revealed[17]. First, for both causes of death, there is a significant difference between the values of all four statistical moments $Q_{i=1;2;3;4}(W)$ and $Q_{i=1;2;3;4}(W^*)$. The second, for necrotic changes caused by a heart attack, there is a decrease in average ($Q_1(W)\downarrow$) and dispersion ($Q_2(W)\downarrow$).

Third, for the case of mechanical asphyxia - the values of statistical moments increase $Q_3(W^*)\uparrow$ and $Q_4(W^*)\uparrow$. The revealed scenarios can be associated with a different effect of necrotic changes on the birefringence of myosin fibrillar networks.

Table 1. Statistical moments $Q_{i=1;2;3;4}$ that characterize the distribution of the values of the CDMA module of histological sections of the dead myocardium due to mechanical asphyxia (W) and heart attack (W^*)

$Q_{i=1;2;3;4}$	W	W^*
$Q_{i=1}$	0.12 ± 0.017	0.07 ± 0.009
$Q_{i=2}$	0.19 ± 0.025	0.11 ± 0.018
$Q_{i=3}$	1.09 ± 0.16	1.48 ± 0.021
$Q_{i=4}$	1.63 ± 0.23	2.12 ± 0.29

Table 2. The balanced accuracy value of differential diagnosis of myocardium necrotic changes

$Q_{i=1;2;3;4}$	Acc, %
$Q_{i=1}$	83
$Q_{i=2}$	84
$Q_{i=3}$	90
$Q_{i=4}$	86

For the deceased due to a heart attack, there is a morphological destruction of the myocardial fibrillar network. Optically, this is manifested in a decrease in birefringence. As a result, the probability of formation of CDMA module values other than extreme decreases. As a result, the dispersion decreases and, conversely, the average, asymmetry and excess values $W = 0$ increase, characterizing the distribution of this correlation parameter of the histological section of the necrotic altered myocardium. The expansion of the range of variation of random values of the CDMA module in the plane of the birefringent network of the histological section of the deceased myocardium due to mechanical asphyxiation is associated with a high level of birefringence of the myosin network of this sample $Q_1(W)\downarrow$; $Q_2(W)\uparrow$; $Q_3(W)\downarrow$; $Q_4(W)\downarrow$. The data presented in Table 1 made it possible to establish the criteria for intergroup differences in the values of statistical moments of the 1st – 4th orders that characterize the polarization-correlation CDMA maps $W(m\times n)$ of histological sections of the myocardium of both types

$$W(m \times n) \Leftrightarrow \begin{cases} \Delta M_1 = 1.22; \ \ \Delta M_2 = 1.26; \\ \Delta M_3 = 1.34; \ \ \Delta M_4 = 1.36. \end{cases} \quad (5)$$

The results revealed the sensitivity of all four statistical moments to necrotic changes in the optical anisotropy of polycrystalline myosin networks of the myocardium. At the same time, the highest level of balanced accuracy was achieved $Acc(W)$ = 80% – 87%.

4. CONCLUSIONS

Based on the correlation approach to the description of polarization-inhomogeneous laser fields, a comparative study of the method of analysis of polycrystalline optically anisotropic networks of histological sections of biological tissues by using polarization-correlation parameters - a complex degree of mutual anisotropy (CDMA).

The methodology for determining the coordinate distributions of the values of the CDMA module of optically thin biological layers with spatially ordered and disordered along the directions of the optical axes of birefringent fibrillar networks was experimentally tested.

Objective parameters, the most sensitive to changes in optical anisotropy, have been established — statistical moments of the first and fourth orders characterizing the distribution of the values of the CDMA module of polycrystalline networks of histological sections of biological tissues.

The statistical (statistical moments of the 1st – 4th orders) structure of the distributions of the values of the CDMA module of spatially structured fibrillar networks of histological sections of the myocardium that died due to mechanical asphyxia and heart attack was experimentally studied. The most sensitive parameters were revealed - a complete set of four statistical moments characterizing the coordinate distribution of the values of the CDMA module. At the same time, the highest level of balanced accuracy was achieved $Acc(W)$ = 84% – 90%.

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