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Azimuthally invariant Mueller-matrix mapping of biological optically anisotropic network

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ABSTRACT

A new technique of Mueller-matrix mapping of polycrystalline structure of histological sections of biological tissues is suggested. The algorithms of reconstruction of distribution of parameters of linear and circular dichroism of histological sections liver tissue of mice with different degrees of severity of diabetes are found. The interconnections between such distributions and parameters of linear and circular dichroism of liver of mice tissue histological sections are defined. The comparative investigations of coordinate distributions of parameters of amplitude anisotropy formed by Liver tissue with varying severity of diabetes (10 days and 24 days) are performed. The values and ranges of change of the statistical (moments of the 1st – 4th order) parameters of coordinate distributions of the value of linear and circular dichroism are defined. The objective criteria of cause of the degree of severity of the diabetes differentiation are determined.

Keywords: polarization; Fourier optics and signal processing; imaging systems; medical and biological imaging.

1. INTRODUCTION

The foundations of the traditional Müller-matrix polarimetry are set forth in a series of publications [1-13].

A new step was the basics of laser polarimetry of optically thin non-depolarizing layers creation [14-31].]. The question of studying the optical anisotropy of diffuse depolarizing layers remains open [32]. This work is aimed at the development and substantiation of the methods of Mueller-matrix mapping and 2D reconstruction of distribution of parameters of linear and circular dichroism of mice liver tissue with different degrees of severity of diabetes.

2. THEORY

The theoretical bases of Mueller matrix approach to describe the interaction of optical radiation with depolarizing layers are shown in a series of publications [24-31]. By averaging the generalization of this theory, we have found the relationships between the parameters of the amplitude anisotropy and the elements of the Muller matrix of the diffuse layer combinations

$$LD = \ln\left(\frac{M_{14}}{M_{41}}\right); \tag{1}$$

$$LD^{*} = \ln\left(\frac{M_{24}}{M_{42}}\right); \tag{2}$$

$$CB = \ln\left(\frac{M_{13}}{M_{31}}\right); \tag{3}$$

Here LD - linear dichroism for $\gamma = 0^{0}$; LD^{*} - linear dichroism for $\gamma = 45^{0}$; CD circular dichroism determined by the following relations:

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Therefore using the ideologies of differential data analysis of Mueller-matrix mapping allowed us to obtain a set of algorithms (equations (1) - (3)) of polarization reproduction of mean values of the parameters of amplitude anisotropy of biological layer polycrystalline component.

3. MATERIALS AND METHODS

Experimental investigations of Mueller matrix elements coordinate distributions were performed in the classical setup of polarimeter [14,15].

4. RESULTS AND DISCUSSION

As objects of investigation we chose the most frequently used histological sections (geometrical thickness $d = 30\mu m \div 35\mu m$) of biopsy of liver tissue of mice with different degrees of diabetes severity (10 days and 24 days) in multiple scattering regime is realized. In other words, such standard samples are appeared to be partly depolarizing (attenuation coefficient $\tau > 0.01 \approx 0.056 \div 0.078$) of laser radiation.

From the medical point of view two groups of мышей with the following diagnoses, prepared according to standard technique on the freezing microtome were formed:

- group 1 - diabetes duration 10 days;
- group 2 - diabetes duration 24 days.

The measured distributions $q \equiv \{M_{ik}\}$ were objectively analyzed within the statistical approach [16] – the set of statistical moments of the 1st-4th order was determined.

The data of Mueller-matrix dichroism tomography allowed us to estimate the polycrystalline structure of the myocardium samples in more detail (quantitatively) of Figs. 1-2 show the dichroism tomograms $\{\Delta\tau(m \times n);\ \Delta\chi(m \times m)\}$ and the histograms of the distribution of parameters of amplitude (relation (1), (3)) anisotropy of the mice liver histological sections obtained using this method.

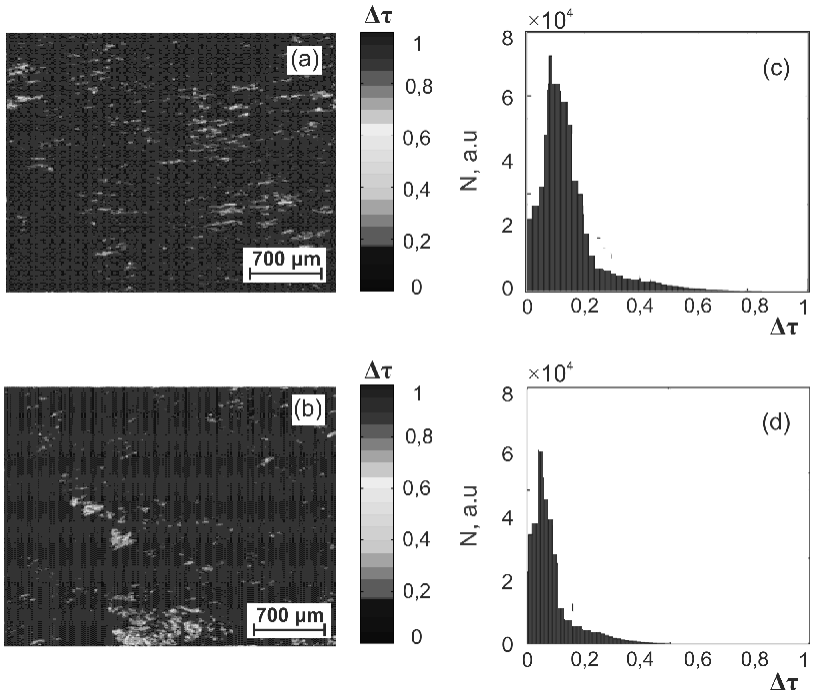

Fig. 1. Dichroism tomograms ((a),(b)) and histograms ((c),(d)) of the distributions $\Delta\tau(m \times n)$ of mice liver tissue histological sections from group 1 ((a),(c)) and group 2 ((b),(d)).

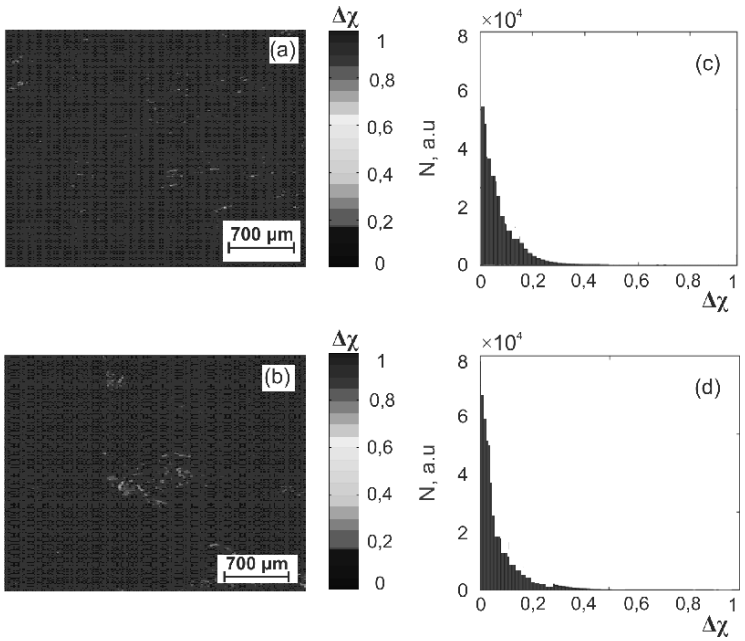

Fig. 2. Dichroism tomograms ((a),(b)) and histograms ((c),(d)) of the distributions $\Delta\chi(m\times n)$ of mice liver tissue histological sections from group 1 ((a),(c)) and group 2 ((b),(d)).

The differentiation between the group 1 and group 2 was determined by using of the following methodology [35-37]:

- within each set of values of statistical moments $Z_{i=1;2;3;4}$ we determined the average value $\tilde{Z}_{i=1;2;3;4}$ and standard deviation $\sigma_{i=1;2;3;4}$;
- differences between the statistical sets $Z_{i=1;2;3;4}$ were significant in the case when the average value $\tilde{Z}_{i=1;2;3;4}$ within the group 1 didn't "overlap" with the standard deviation $\sigma_{i=1;2;3;4}$ within group 2 and vice versa.
- for every statistical moments traditional for probative medicine operational characteristics: sensitivity ($Se=\frac{a}{a+b}100\%$), specificity ($Sp=\frac{c}{c+d}100\%$) and balanced accuracy ($Ac=\frac{Se+Sp}{2}$), where a and b are the number of correct and wrong diagnoses within group 2; c and d - the same within group 1 were determined.

The comparative analysis of the data obtained (Table 1) showed that the differences between the values of average $\tilde{Z}_{i=1;2;3;4}$ moments of all orders are statistically valid.

Table 1 Parameters of statistical structure of dichroism tomograms coordinate distributions.

Parameters	$\Delta\tau(m\times n)$		$\Delta\chi(m\times n)$	
	10 days	21 days	10 days	21 days
Z_1	0.093 ± 0.0072	0.052 ± 0.0043	0.071 ± 0.0053	0.069 ± 0.0044
Z_2	0.13 ± 0.0078	0.089 ± 0.0054	0.12 ± 0.0093	0.094 ± 0.0071
Z_3	1.12 ± 0.072	$0.78\pm 0.0.56$	1.39 ± 0.11	1.08 ± 0.091
Z_4	1.79 ± 0.14	1.02 ± 0.069	1.45 ± 0.11	1.23 ± 0.104

Table 2 presents the parameters of information value of method of dichroism tomography of optical anisotropy of histological sections of biopsy of mice liver tissue with different degrees of severity of diabetes.

Table 2 Operational characteristics of the method of Mueller-matrix tomography of optical anisotropy of histological sections of mice liver tissue with different degrees of severity of diabetes

Parameters	Z_i	$\Delta\tau(m\times n)$	$\Delta\chi(m\times n)$
$Ac(Z_i)$	Z_1	81%	64%
	Z_2	69%	67%
	Z_3	86%	74%
	Z_4	92%	71%

The obtained results enable to state a rather high level of accuracy of dichroism tomography. According to the criteria of probative medicine [31] the parameters $Ac(\Delta\tau) \sim 85\%$ correspond to good quality, while $Ac(\Delta\tau) > 90\%$ – to high quality.

CONCLUSION

The efficiency of the developed technique of Mueller-matrix tomography in the diagnostics of the mice liver tissue degree of diabetes severity was demonstrated.

The differentiation criteria between diabetic changes in mice liver tissue on the basis of the statistical (statistical moments of the 1st – 4th order) analysis of dichroism tomograms are defined.

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