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ABSTRACT

It has been proposed the optical model of Jones-matrix description of mechanisms of optical anisotropy of polycrystalline films of human bile, namely optical activity and birefringence. The algorithm of reconstruction of distributions of parameters - optical rotation angles and phase shifts of the indicated anisotropy types has been elaborated. The objective criteria of differentiation of bile films taken from healthy donors and patients with cholelithiasis by means of statistic analysis of such distributions have been determined. The operational characteristics (sensitivity, specificity and accuracy) of Jones-matrix reconstruction method of optical anisotropy parameters were defined.

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

1. INTRODUCTION

The structure of biological layers can be considered as structurally inhomogeneous one[1-3]. Laser polarimetry was formed recently as a new separate approach within matrix optics [4-27].

This research is aimed on generalization of optical anisotropy of optically thin layers of bile films and the development of the method of Jones-matrix reconstruction of anisotropy parameters of polycrystalline networks in the task of cholelithiasis early diagnostics.

2. BRIEF THEORETICAL BACKGROUND

In this research we have utilized the model description of phase anisotropy[7,8,18-21] (optical activity and linear birefringence) of polycrystalline structure of films of biological fluids developed in[22-27].

We determined the following analytical algorithms for reconstructing the phase anisotropy parameters of such polycrystalline films.

$$\delta = \frac{2\arccos\left(R_{11}\cos\Theta_{11} + R_{22}\cos\Theta_{22}\right)}{1 + \dfrac{R_{12}\cos\Theta_{12} - R_{21}\cos\Theta_{21}}{R_{22}\cos\Theta_{22} - R_{11}\cos\Theta_{11}}}; \quad (1)$$

$$\theta = \frac{2\arccos\left(R_{11}\cos\Theta_{11} + R_{22}\cos\Theta_{22}\right)}{1 + \dfrac{R_{22}\cos\Theta_{22} - R_{11}\cos\Theta_{11}}{R_{12}\cos\Theta_{22} - R_{21}\cos\Theta_{11}}}. \quad (2)$$

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3. ANALYSIS AND DISCUSSION OF EXPERIMENTAL DATA

Two groups of polycrystalline bile films were investigated:

- Healthy donors (group 1) - 41 patients;
- Patients with cholecystitis (group 2) - 41 patients.

The measurements of coordinate distributions of Jones-matrix elements were performed in the polarymeter setup[21].

On the basis of (1)-(2) for each pixel of CCD-camera the parameters of phase (δ, θ) anisotropy were found. For objective assessment of histograms $N(q)$ of distributions $q \equiv \{\delta, \theta\}$ the set of statistical moments of the 1st-4th orders was determined[24].

The series of figures 1-4 present the results of the technique of Jones-matrix reconstruction parameters $q \equiv \{\delta, \theta\}$ of polycrystalline bile films of 1st group patients (fig. 1, fig. 3) and second one (fig.2, fig.4).

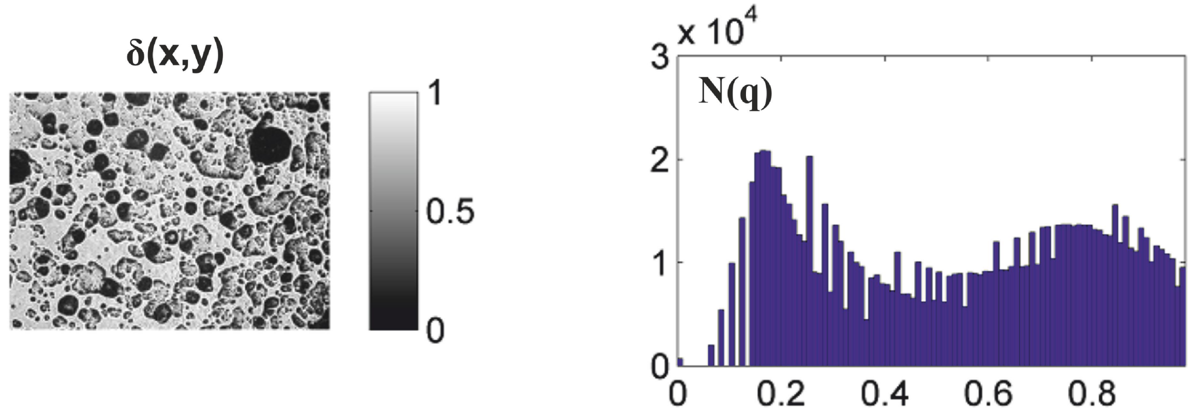

Figure 1. Coordinate distributions and the corresponding histogram of the values of phase shifts δ, formed by polycrystalline film of bile of donors.

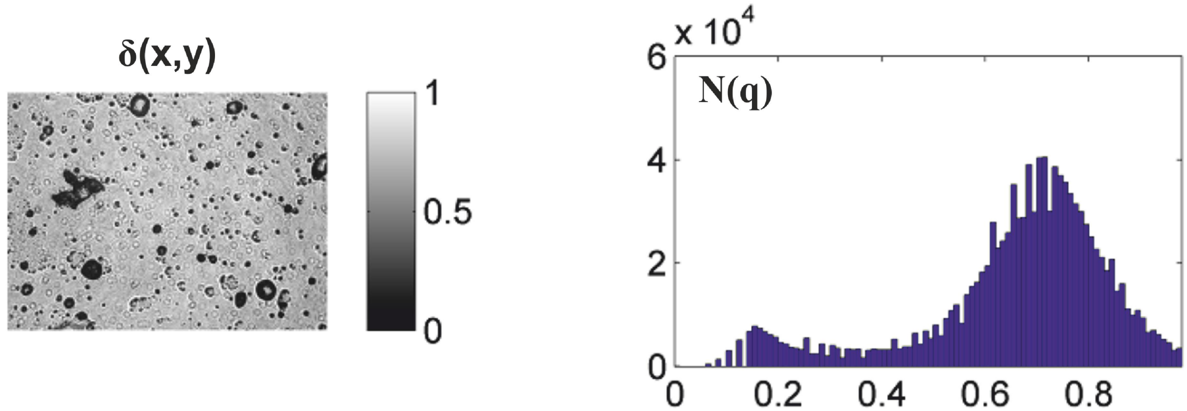

Figure 2. Coordinate distributions and the corresponding histogram of the values of phase shifts δ, formed by polycrystalline film of bile of patients with cholelithiasis

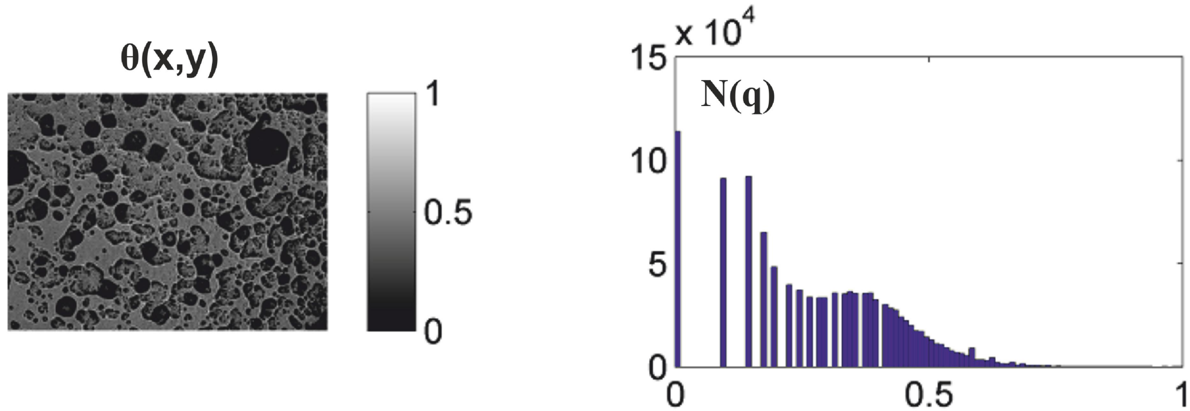

Figure 3. Coordinate distributions and the corresponding histogram of the values of phase shifts θ, formed by polycrystalline film of bile of donors.

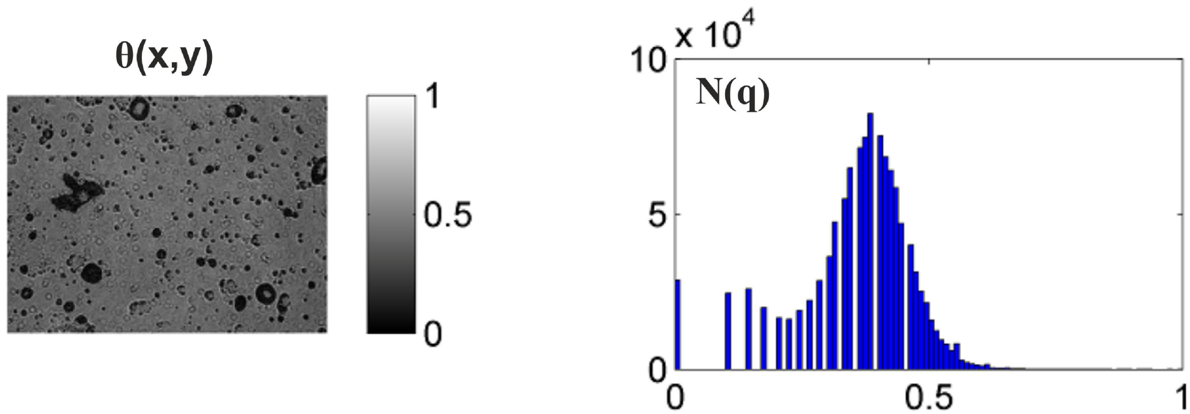

Figure 4. Coordinate distributions and the corresponding histogram of the values of phase shifts θ, formed by polycrystalline film of bile of patients with cholelithiasis.

3.1 Statistical intergroup analysis

For the possible clinical application of both methods the following was determined for each group of samples[29-31]:

- average (within group 1 and group 2) values of statistical moments $M_{i=1;2;3;4}(q)$, their standard deviations $\pm\sigma$ and histograms $M(R_i)$ - Table 1.

- 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 – Table 2.

Table 1. Average ($\overline{M}_{i=1;2;3;4}$) and standard deviations ($\pm\sigma$) of statistical moments $M_{i=1;2;3;4}$ of optical anisotropy distributions of bile films of groups 1 and 2

q	δ ($n=47$)		θ ($n=47$)	
	group 1	group 2	group 1	group 2
M_1	0.16 ± 0.0079	0.19 ± 0.013	0.079 ± 0.0073	0.11 ± 0.0011
M_2	0.19 ± 0.013	0.24 ± 0.015	0.14 ± 0.009	0.189 ± 0.0145
M_3	0.67 ± 0.053	0.43 ± 0.041	0.95 ± 0.088	0.54 ± 0.036
M_4	0.95 ± 0.085	0.46 ± 0.042	1.33 ± 0.15	0.77 ± 0.062

Table 2 presents the parameters of information value of polarization-phase method of Jones-matrix reconstruction of phase anisotropy of polycrystalline films of bile.

Table 2. Operational characteristics of the method of Jones-matrix reconstruction of polycrystalline structure of bile films

q	M_i	δ	θ
$Ac(Z_i)$	M_1	74%	79%
	M_2	83%	85%
	M_3	93%	91%
	M_4	92%	93%

The comparative analysis of operational characteristics of the method of Jones-matrix polarization reconstruction of polycrystalline structure of bile films revealed clinically optimal (highlighted in grey) parameters

$$\begin{cases}\delta \to M(\delta) \equiv \{Ac(R_{3;4}) = 92\% - 93\%\}; \\ \theta \to M(\theta) \equiv \{Ac(R_{3;4}) = 90\% - 93\%\}.\end{cases}$$

The obtained results enable to state a rather high level of accuracy of Jones-matrix polarization-phase tomography. According to the criteria of probative medicine[31] the parameters $M(\delta,\theta) \sim 90\% - 93\%$ correspond to high quality.

CONCLUSION

The model of generalized optical anisotropy and the technique of Jones-matrix reconstruction of optical anisotropy parameters of polycrystalline bile films has been proposed. By means of statistic analysis the interconnection between the statistical moments of the 1st-4th order of anisotropy parameters of bile films and the changes in it structure of healthy people and cholelithiasis patients were determined. It has been proved the efficiency of Jones-matrix reconstruction of optical anisotropy parameters of bile films in diagnostics of early stages of cholelithiasis.

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