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ABSTRACT

A new method of Stokes correlometry of polarization-inhomogeneous images of biological layers is presented. Analytic relations are determined for the modulus of complex parameters of the Stokes vector. A technique for measuring the coordinate distributions of the magnitude of the two-point modulus of the Stokes vector is proposed. Objective criteria for differentiating the optical anisotropy of polycrystalline urine films of healthy donors and patients with albuminuria have been found. An excellent level of balanced accuracy of differential diagnostics has been achieved.

Keywords: Stokes vector, biological tissues, diagnostics, polarimetry.

1. INTRODUCTION

The main theoretical positions of laser polarimetry of optically anisotropic biological layers are given in a series of publications [1-29].

This research aims to study fundamental potentiality of the new Stokes-polarimetry approach to polarization-correlation mapping of microscopic images of polycrystalline layers of urine by determining the coordinate distributions of "two-point" Stokes vector parameters, which were theoretically introduced for the first time by T.Setola, Ya.Tervo and A.T.Friberh [30,31.] As an applied aspect the possibility of differential Stokes-polarimetry diagnostics [32-38] of the change of optical anisotropy of the urine films of healthy donors and patients with albuminuria will be discussed.

2. THEORY OF THE METHOD

To describe the correlation structure of the stationary distributions of the fields of complex amplitudes of laser light converted by optically anisotropic biological layers, one can use the following mutual spectral density matrix [30,31]

$$W_{i,j}(r_1,r_2) = E_i^*(r_1)\cdot E_j(r_2), i,j = x,y \quad (1)$$

Here r_1 and r_2 - the coordinates of the neighboring points in the field of laser radiation.

Relations for the analytic description of the module of two-point parameters of the Stokes vector were found

$$S_1 = W_{xx}(r_1,r_2) + W_{yy}(r_1,r_2);$$
$$S_2 = W_{xx}(r_1,r_2) - W_{yy}(r_1,r_2);$$
$$S_3 = W_{xy}(r_1,r_2) + W_{yx}(r_1,r_2);$$
$$S_4 = i\left[W_{yx}(r_1,r_2) + W_{xy}(r_1,r_2)\right]:$$

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$$|S_1| = \sqrt{\left[1 + tg^2\rho_1 tg^2\rho_2 + 2tg\rho_1 tg\rho_2 \cos(\delta_2 - \delta_1)\right]}; \tag{2}$$

$$|S_2| = \sqrt{\left[1 + tg^2\rho_1 tg^2\rho_2 - 2tg\rho_1 tg\rho_2 \cos(\delta_2 - \delta_1)\right]}; \tag{3}$$

$$|S_3| = \sqrt{\left[1 + ctg^2\rho_2 tg^2\rho_1 - 2ctg\rho_2 tg\rho_1 \cos(\delta_2 - \delta_1)\right]}; \tag{4}$$

$$|S_4| = \sqrt{\left[1 + ctg^2\rho_2 tg^2\rho_1 + 2ctg\rho_2 tg\rho_1 \cos(\delta_2 - \delta_1)\right]}; \tag{5}$$

Here $\left|S_{i=1;2;3;4}\right|$ - modulus.

3. MATERIALS AND METHODS

Measurement of the coordinate distributions of the values of $\left|S_{i=3}(\Delta x;\Delta y)\right|$ and $\left|S_{i=4}(\Delta x;\Delta y)\right|$ was carried out in the experimental arrangement of Stokes-polarimeter [9,13,17] and were calculated by the following ratios

$$|S_3| = \sqrt{\begin{array}{l}\left[\sqrt{I_0(r_1)I_{90}(r_2)}\cos\delta_2 + \sqrt{I_0(r_2)I_{90}(r_1)}\cos\delta_1\right]^2 + \\ + \left[\sqrt{I_0(r_1)I_{90}(r_2)}\sin\delta_2 - \sqrt{I_0(r_2)I_{90}(r_1)}\sin\delta_1\right]^2\end{array}}; \tag{6}$$

$$|S_4| = \sqrt{\begin{array}{l}\left[\sqrt{I_0(r_2)I_{90}(r_1)}\sin\delta_1 + \sqrt{I_0(r_1)I_{90}(r_2)}\sin\delta_2\right]^2 + \\ + \left[\sqrt{I_0(r_2)I_{90}(r_1)}\cos\delta_2 + \sqrt{I_0(r_1)I_{90}(r_2)}\cos\delta_1\right]^2\end{array}} \tag{7}$$

$$\delta(r) = arctg\left[\left(\frac{S_4(r)S_2(r)}{S_3(r)}\right)\left(\frac{1 + \frac{I_{90}(r)}{I_0(r)}}{1 - \frac{I_{90}(r)}{I_0(r)}}\right)\right]. \tag{8}$$

Here I_0 and I_{90} - the intensities at the orientation of transmission plane of polarizer 0^0 and 90^0; δ_i - phase shifts between the orthogonal components of the amplitude of the laser radiation in the points with coordinates r_1 and r_2.

4. BRIEF DESCRIPTION OF THE RESEARCH OBJECTS

Optically thin (attenuation coefficient $\tau \prec 0.01$) samples of polycrystalline layers of urine (geometrical thickness $l = 10\mu m \div 15\mu m$ $0.0079 \le \tau \le 0.0083$) of biological tissues of internals of two statistically significant (39 samples each) groups of patients – healthy ones and those with albuminaria.

5. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 1 - Fig. 4 show the SCP-maps of the modulus $\left|S_{i=3}(\Delta x;\Delta y)\right|$ values distribution (Fig. 1, Fig. 3) and $\left|S_{i=4}(\Delta x;\Delta y)\right|$ (Fig. 2, Fig.4) of microscopic images urine films of healthy donors (Fig. 1, Fig. 3) and patients with albuminuria (Fig. 2, Fig. 4).

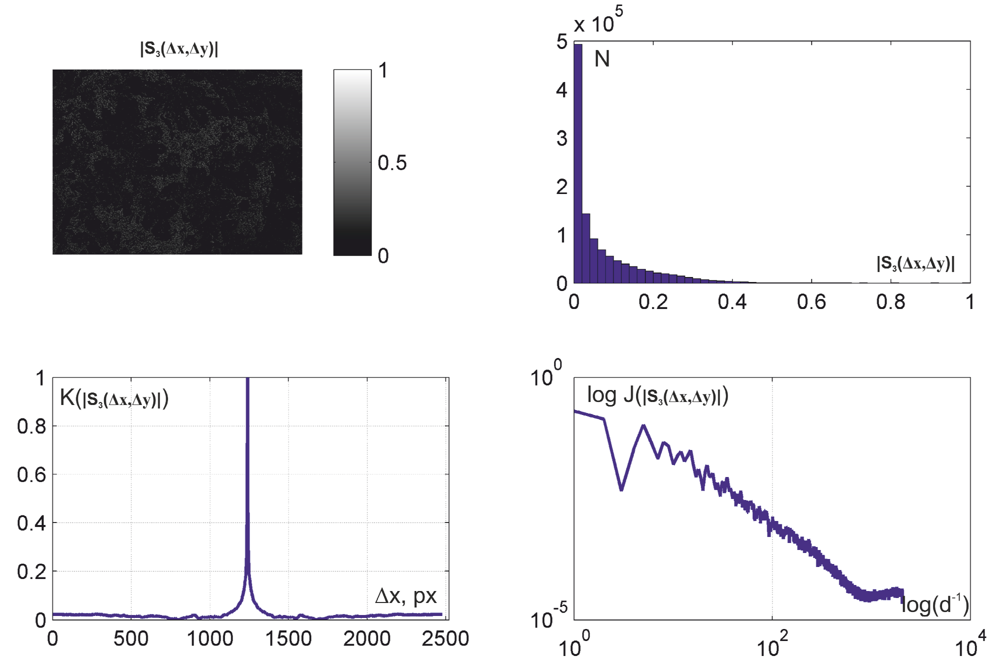

Figure 1. Maps (coordinate distributions (1), histograms (2), autocorrelation functions (3), logarithmic dependences of power spectra (4) of SCP modulus $\left|S_{i=3}(\Delta x;\Delta y)\right|$ of polarization-inhomogeneous images of urine films of healthy donors.

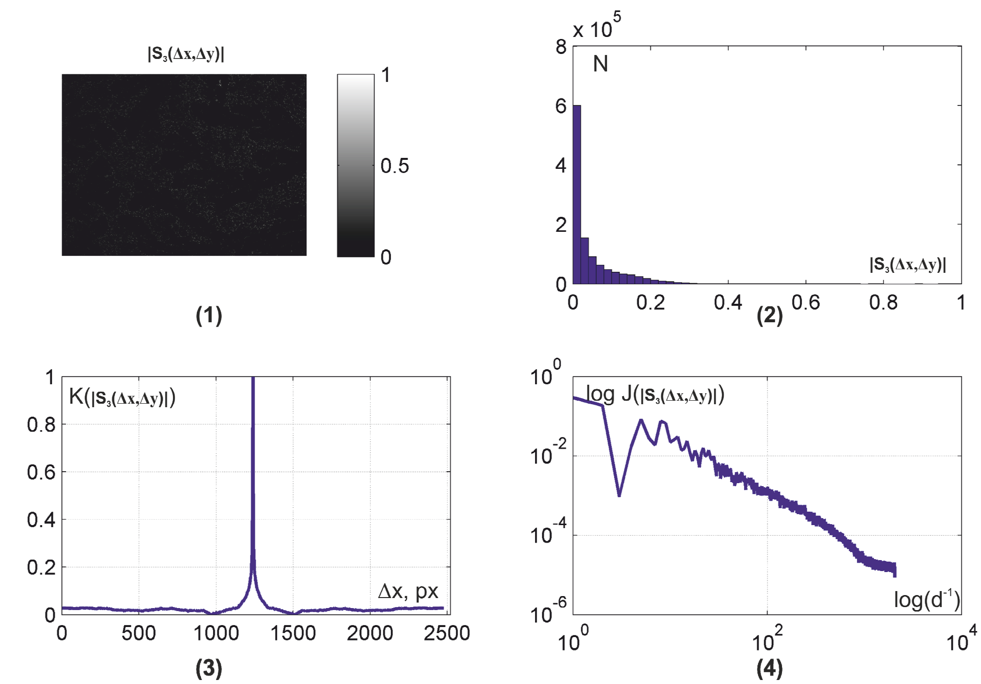

Figure 2. Maps (coordinate distributions (1), histograms (2), autocorrelation functions (3), logarithmic dependences of power spectra (4) of SCP modulus $\left|S_{i=3}(\Delta x;\Delta y)\right|$ of polarization-inhomogeneous images of polycrystalline layers of urine of patients with albuminuria

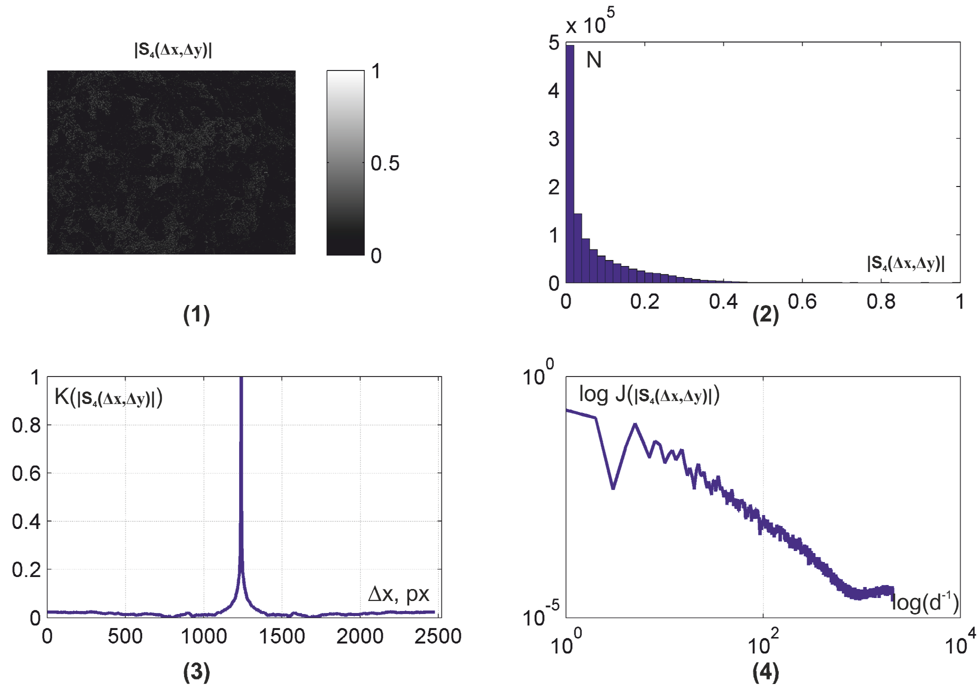

Figure 3. Maps (coordinate distributions (1), histograms (2), autocorrelation functions (3), logarithmic dependences of power spectra (4) of SCP modulus $\left|S_{i=4}(\Delta x;\Delta y)\right|$ of polarization-inhomogeneous images of urine films of healthy donors

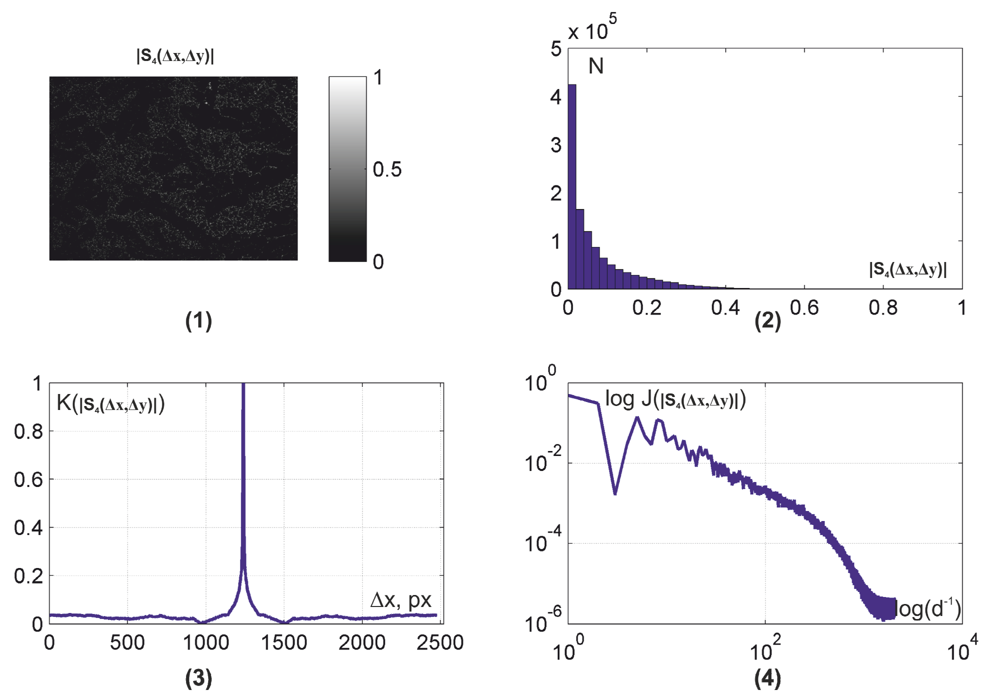

Figure 4. Maps (coordinate distributions (1), histograms (2), autocorrelation functions (3), logarithmic dependences of power spectra (4) of SCP modulus $\left|S_{i=4}(\Delta x;\Delta y)\right|$ of polarization-inhomogeneous images of polycrystalline layers of urine of patients with albuminuria

The potentiality of Stokes-correlometry differentiation of the two groups of polycrystalline layers of urine is quantitatively illustrated by the data presented in Table 1.

Table 1 Statistical, correlation and fractal parameters of SCP modulus maps of polarization-inhomogeneous images of polycrystalline layers of urine

Parameters	$\left\|S_{i=3}(\Delta x, \Delta y)\right\|$		$\left\|S_{i=4}(\Delta x, \Delta y)\right\|$	
Condition	Normal $(n=39)$	Albuminuria $(n=39)$	Normal $(n=39)$	Albuminuria $(n=39)$
Z_1	$0{,}037 \pm 0{,}0029$	$0{,}019 \pm 0{,}0011$	$0{,}77 \pm 0{,}031$	$0{,}081 \pm 0{,}054$
Z_2	$0{,}011 \pm 0{,}0013$	$0{,}008 \pm 0{,}0006$	$0{,}26 \pm 0{,}018$	$0{,}086 \pm 0{,}0089$
Z_3	$1{,}13 \pm 0{,}14$	$3{,}37 \pm 0{,}26$	$0{,}79 \pm 0{,}065$	$2{,}27 \pm 0{,}29$
Z_4	$3{,}12 \pm 0{,}25$	$7{,}41 \pm 0{,}59$	$0{,}92 \pm 0{,}079$	$3{,}35 \pm 032$
Z_2^k	$0{,}073 \pm 0{,}0055$	$0{,}13 \pm 0{,}008$	$0{,}065 \pm 0{,}006$	$0{,}093 \pm 0{,}0087$
Z_4^k	$2{,}14 \pm 0{,}18$	$0{,}92 \pm 0{,}079$	$1{,}56 \pm 0{,}14$	$0{,}82 \pm 0{,}063$
D^f	$0{,}24 \pm 0{,}019$	$0{,}18 \pm 0{,}014$	$0{,}35 \pm 0{,}024$	$0{,}24 \pm 0{,}019$

The data analysis revealed the following differences between the set of objective parameters that characterize the maps of SCP-modulus of polarization-inhomogeneous images:

- ΔZ_1 = 1.61 – 7.81 times; ΔZ_2 = 1.68 – 2.81 times; ΔZ_3 = 2.58 – 3,2 times; ΔZ_4 = 2.12 – 4.48 times;
- ΔZ_2^k = 1.45 – 1.65 times; ΔZ_4^k = 1.78 – 2.43 times;
- ΔD^f = 1.24 – 1.44 times.

The complex study found significantly greater accuracy of the methods of Stokes-correlometry in the differentiation of weak changes in optical anisotropy of of healthy donors and patients with albuminuria ($90\% \le \max Ac \le 92\%$).

CONCLUSION

A new method of Stokes-correlometry – determination of the coordinate distributions of the modulus of "two-point" Stokes-vector parameters of polarization-inhomogeneous images of healthy donors and patients with albuminuria – is suggested and analytically substantiated.
Within the statistical, correlation and fractal analysis the objective criteria characterizing the SCP-maps of polarization-inhomogeneous microscopic images of two groups of healthy donors and patients with albuminuria are determined.
The comparative analysis of the objective statistical, correlation and fractal analysis of distributions of polarization "single-point" azimuth and ellipticity and "two-point" Stokes-vector parameters of polarization-inhomogeneous images of of healthy donors and patients with albuminuria under study demonstrated the excellent accuracy ($Ac \succ 90\%$) of differential diagnostics of changes in optical anisotropy of rat's internal organs tissues by the Stokes-correlometry method.

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