

Statistical analysis of polarized images of biotissues for diagnose of their pathological changes

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This work is directed to the investigation of the scope of the technique of laser polarimetry of oncological changes of the human prostate tissue under the conditions of multiple scattering, which presents a more general and real experimental clinical situation. To compare the above mentioned scope of biotissue laser polarimetry on the first stage the research of human prostate tissue in the conditions of single scattering was performed. The analysis of the obtained results showed high diagnostic sensitivity of statistic moments of the 3rd and 4th orders of coordinate distributions of matrix elements of both types of biotissues to the changes of optical-geometric structure.

(Received February 08, 2010; accepted April 11, 2010)

Keywords: Polarization, Biological tissue, Statistical moments, Fractal, Anis

1. Introduction

The variety of real biological tissues (BT) possesses optically inhomogeneous structure. This makes the light-scattering important for a wide range of tasks being solved in biomedical optics. The field of radiation scattered by the BT bears the information on their properties. Such information is photometric, spectral, polarization and correlation characteristics of light oscillations [1, 2].

Traditional spectrophotometric methods of biomedical optics are completed with the techniques based on application of polarized radiation [3-7].

Application of lasers in biomedical optics caused the development of other direction of the research – the BT laser polarimetry based on both statistical and fractal analysis of polarizationally inhomogeneous object fields [8].

The results of the series of laser polarimetric investigation of optical and geometric parameters of the BT structure in the conditions of single scattering showed that the phase shifts between the orthogonally polarized components of laser radiation by optically uniaxial crystalline structures with two levels of morphological structure – the crystallite and morphological ones – are the reasons of forming the distributions of polarization states of object field of physiologically different biotissues [9-12]. Basing on this fact it is shown that polarization inhomogeneity of coherent fields of the BT crystallite components is determined by transforming the state of laser beam polarization by the ensemble of spatially oriented birefringent fibrils.

Application of statistical analysis of polarizationally inhomogeneous object fields enabled us to find the connection between the set of statistic moments of 1st-4th orders (that describe the surface microgeometry and the orientation-phase structure of the BT architectonics) and the ensemble of the corresponding statistic moments of

polarization maps – coordinate distributions of azimuths and the BT boundary field polarization ellipticities [13].

Fractal analysis of polarizationally inhomogeneous images showed that polarization properties of physiologically normal BT possess the fractal structure. For physiologically changed BT a stochastic or statistic distribution of polarization states is typical [14, 15].

Our work is directed to the investigation of the scope of the technique of laser polarimetry of oncological changes of the human prostate tissue under the conditions of multiple scattering, which presents a more general and real experimental clinical situation. To compare the above mentioned scope of BT laser polarimetry on the first stage the research of human prostate tissue in the conditions of single scattering was performed.

2. Optical modelling of polarization properties of multilayer tissues

Let's represent such an object (Fig. 1) as a set of sequentially located N-monolayers, polarization properties of each of them is characterized by the matrix $\{F\}_{i=1-N}$ of the kind [16]:

$$\{F\} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & f_{22} & f_{23} & f_{24} \\ 0 & f_{32} & f_{33} & f_{34} \\ 0 & f_{42} & f_{43} & f_{44} \end{pmatrix}. \quad (1)$$

In such a situation the Mueller matrix can generally be determined as a product of corresponding partial matrices

$$\{Z\} = \{F\}_N \{F\}_{N-1} \dots \{F\}_2 \{F\}_1. \quad (2)$$

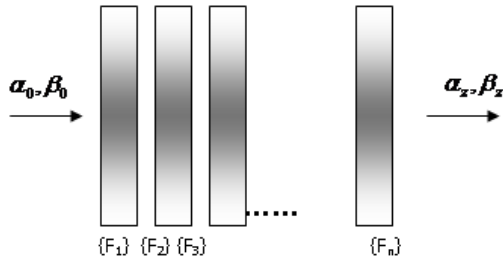


Fig. 1. Optical model of multilayer prostate tissue

The value of azimuth $\alpha_{\{z\}}$, ellipticity $\beta_{\{z\}}$ and intensity $I_{\{z\}}$ in each point of the image of such a layer is determined from the relations

$$\begin{cases} \alpha_{\{z\}} = Q(z_{ik}, S_i^0) = Q(\rho, \delta, \alpha_0, \beta_0); \\ \beta_{\{z\}} = G(z_{ik}, S_i^0) = G(\rho, \delta, \alpha_0, \beta_0); \\ I_{\{z\}} = R(\alpha_{\{z\}}, \beta_{\{z\}}) \end{cases} \quad (3)$$

3. Computer simulation of the structure of polarization images of the prostate tissue

To determine the efficiency of statistical differentiation of multilayer prostate tissue we performed the computer simulation of dependence of intensity distribution of it polarization images $I(0-0)$, $I(0-90)$ on the changes in orientation and phase structure of collagen net.

The architectonics of the healthy prostate tissue was simulated by sequentially located ($N=10$) optically thin layers of collagen fibrils, orientation ρ and phase δ of which are distributed (Fig. 2a, Fig. 2b) according to normal law with the following grading of the dispersion value σ_ρ :

$$\begin{aligned} \sigma_\rho^i &= \sigma_\rho^{i-1} + 0.05, i = 1, 2, \dots, 10; \\ \sigma_\delta^i &= \sigma_\delta^{i-1} + 0.05, i = 1, 2, \dots, 10. \end{aligned} \quad (4)$$

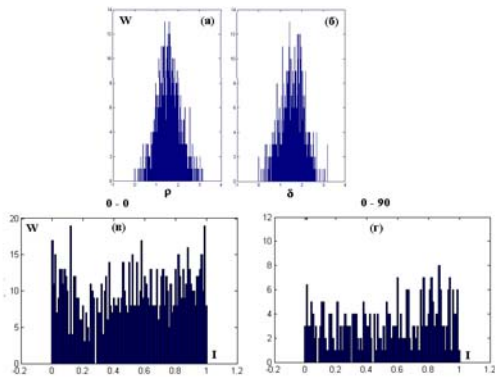


Fig. 2. Statistical structure of polarization images (c), (d) of the virtual multilayer tissue of the "A" type.

Architectonics of oncologically changed prostate tissue was simulated by two types of changes in orientation - phase structure.

The first type-orientation change. It was assumed that 4-7 layers of orientation distribution are distributed according to exponential law (Fig. 3a), that morphologically models the situation of forming the certain directions of growth of newly-formed collagen fibrils [10]

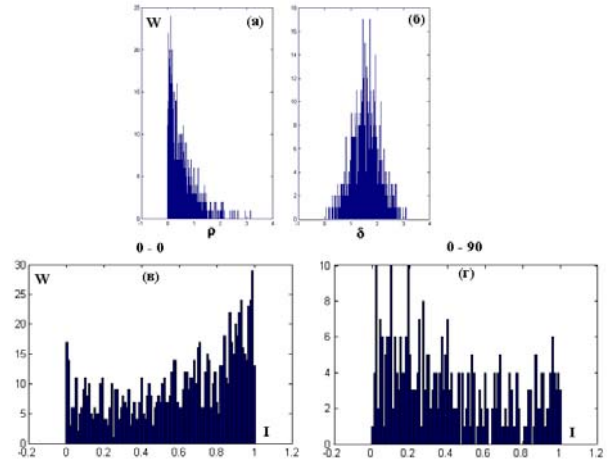


Fig. 3. Statistical structure of polarization images (c), (d) of virtually multilayer tissue of the "B" type.

Orientations of the rest of layers and phase shifts (Fig. 2b) of all layers of prostate tissue are similar to conditions.

The second type-phase change. It was assumed that 4-7 layers of phase distribution are distributed according to equal probability law (Fig. 3b), that morphologically models the situation of chaotic growth (excessiveness) of newly-formed collagen fibrils [12].

Orientations of all layers (Fig. 4a) and phase shifts of the rest of layers of prostate tissue are similar to conditions.

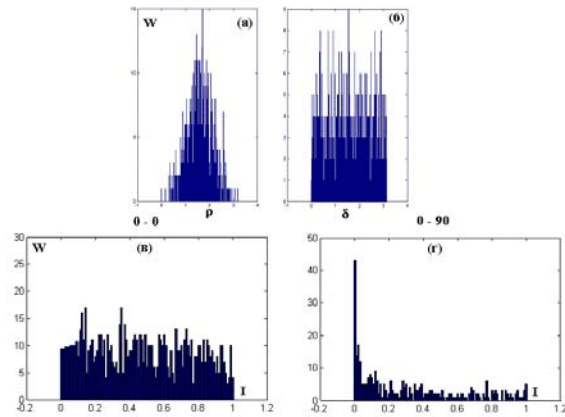


Fig. 4. Statistical structure of polarization images (c), (d) of virtually multilayer tissue of the "C" type.

Let's name such types of virtual biological tissues "A", "B", "C".

The series of Figs. 2-4 presents histograms of images distributions of tissues "A", "B", "C", obtained in coaxial (0-0) and crossed (0-90) polarizer and analyzer – fragments "c", "d" correspondingly.

Comparative analysis of the set of histograms $I(0-0)$, $I(0-90)$ of the sound tissue "A" virtual image shows their quite symmetric structure (Fig. 2 (c) and (d)). Pathological changes in polarization images of virtual biological tissues "B" and "C" show themselves in the asymmetry of intensity distributions (Figs. 3 and 4, fragments "c", "d"). Furthermore, such asymmetry is more distinctly observed for distributions $I(0-0)$, $I(0-90)$ (Figs. 3 (d) and 4 (d)).

Table 1 presents the values of statistic moments of intensity distributions of $I(0-0)$, $I(0-90)$ of the images of all types of virtual tissues "A", "B", "C".

Table 1. Statistics of the intensity of polarization images of virtually multilayer biological tissues

M_i	"A"		"B"		"C"	
	$I(0-0)$	$I(0-90)$	$I(0-0)$	$I(0-90)$	$I(0-0)$	$I(0-90)$
M	0,61	0,42	0,57	0,44	0,52	0,46
σ	0,26	0,35	0,25	0,33	0,22	0,31
A	0,29	0,56	0,95	2,73	0,95	6,73
E	0,23	0,43	0,64	1,27	0,53	1,03

Comparative analysis of the statistic moments values M_i of intensity distributions of the images of virtual biological tissues of all types showed that the difference between the values of average (M) and dispersion (σ) of distributions $I(0-0)$, $I(0-90)$, the intensities of images of all types of virtual tissues "A", "B", "C" are insufficient and lie within 5%-15%. Another situation is observed for statistical moments of higher orders. Thus, the values of the excess (E) of pathological tissues of the "B" and "C" type differ from the sound "A" by 2-3 times. The third statistic moment (A), the value of which increases by one order in comparison with similar statistic parameter of intensity distribution of the "A" type tissue image is the most sensitive to pathological changes in orientation-phase structure.

4. Experimental research and discussion

Histological sections of optically thick (reduction factor $\tau \approx 1,2$ geometrical thickness – 400 μm), layers of prostate tissue were used as the objects of investigation. Such choice of objects is conditioned by two factors. Firstly, their geometrical thickness corresponds to 10 thickness values of optically thin layers of prostate tissue. Secondly, modern technique of optical coherent tomography enables to obtain layer-by-layer images of biological tissue with the step ($\approx 20 - 40 \mu\text{m}$) in the depth up to $1000 \mu\text{m} \div 2000 \mu\text{m}$ [21], that approximately corresponds to our experimental conditions.

Polarization images of the healthy (a, b) and oncologically changed (c, d) prostate tissues obtained for coaxial (0-0) and crossed (0-90) polarizer 4 and analyzer 9 are presented in Fig. 5.

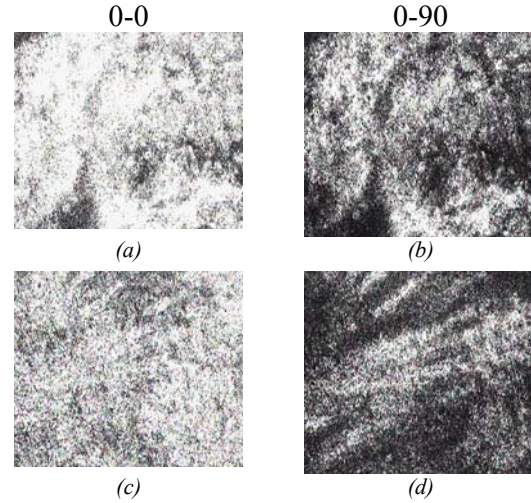


Fig. 5. Polarization images of optically thick prostate tissue layer

The results of fractal and statistic processing of experimentally obtained intensities distributions $I(0-0)$, $I(0-90)$ of the samples of healthy and oncologically changed human prostate tissue are illustrated in Figs. 6 and 7.

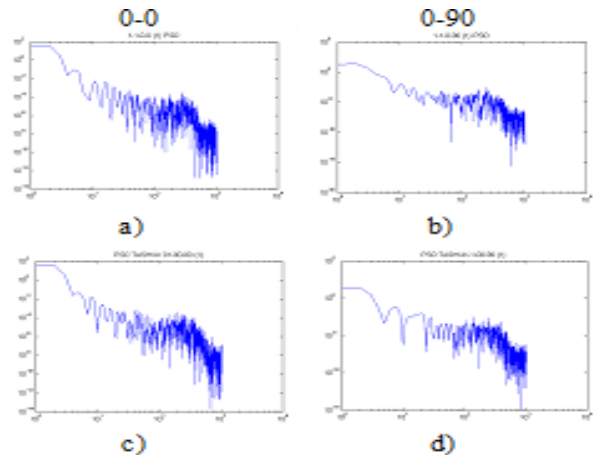


Fig. 6. Power spectra of intensity distributions of the prostate polarization images

Fractal analysis of coordinate of the intensity distributions of polarization images of the prostate tissue samples of both types proved their being statistic. Approximating curve $\Phi(z)$ of corresponding log-log dependencies $I(0-0)$,

$I(0-90)$ has no stable values of inclination angles within all the three decades of optical sizes recorded by the CCD-camera. Another situation is observed under the comparative analysis of the ensemble of statistic moments if the 1st -4th orders of

intensity distribution of polarization images of sound and oncologically changed prostate tissue (Fig. 7). It can be seen that the difference between the values of average (M) and dispersion (σ) of distributions $I(0-0)$, $I(0-90)$, the intensities of images of various types of prostate tissues are insufficient and are within 10%÷25%. The values of the excess (E) of intensity distribution of the images of oncologically changed prostate tissues differ from the similar parameter of a sound tissue by 1÷2 times. The third statistic moment (A) proved to be the most sensitive to pathological changes in orientation structure. Its value in the intensity distribution of polarization image $I(0-90)$ of oncologically changed tissue is 21 times higher if compared with the similar statistic parameter of the intensity distribution of the healthy tissue.

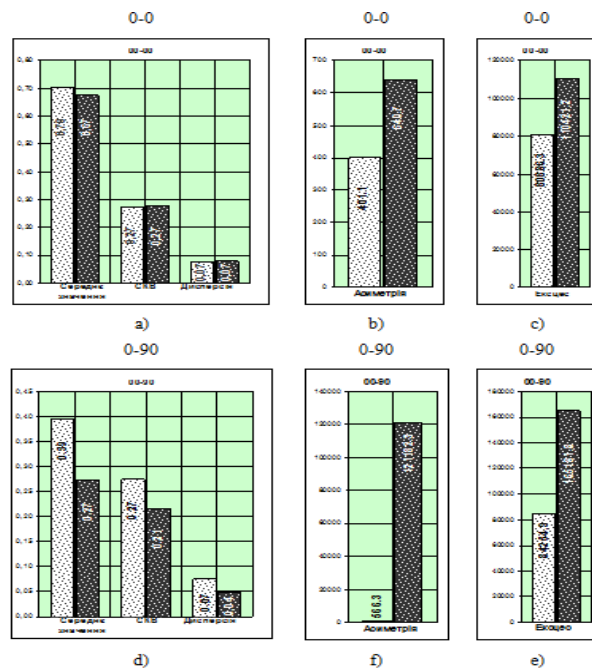


Fig. 7. Correlation between statistic moments of intensity distributions of polarization images

5. Conclusions

1. Fractal analysis of the structure of the images of optically thick layers of human prostate tissue proved to be inefficient for differentiation of its physiological state.

2. The statistic moments of the 3rd and 4th orders appeared to be most sensitive to pathological changes of orientation-phase structure of architectonics of prostate tissue. Their value (asymmetry of distribution $I(0-90)$) changes within the limits of two orders [20].

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