System of multifunctional Jones matrix tomography of phase anisotropy in diagnostics of endometriosis

V.O. Ushenko[a], G.D. Koval[b] , Yu. O. Ushenko[a], L.Y. Pidkamin[a], M.I. Sidor[a], O. Vanchuliak[b], A.V. Motrich[a], M.P. Gorsky[a], I.Meglinskiy[c],

[a] Chernivtsi National University, 2 Kotsyubinsky Str., Chernivtsi, 58012, Ukraine
[b] Bukovinian State Medical University, Chernivtsi, 58000, Ukraine
[c] University of Oulu, P.O. Box 4500, Oulu, Finland

ABSTRACT

The paper presents the results of Jones-matrix mapping of uterine wall histological sections with second-degree and third-degree endometriosis. The technique of experimental measurement of coordinate distributions of the modulus and phase values of Jones matrix elements is suggested. Within the statistical and cross-correlation approaches the modulus and phase maps of Jones matrix images of optically thin biological layers of polycrystalline films of plasma and cerebrospinal fluid are analyzed. A set of objective parameters (statistical and generalized correlation moments), which are the most sensitive to changes in the phase of anisotropy, associated with the features of polycrystalline structure of uterine wall histological sections with second-degree and third-degree endometriosis are determined.

Keywords: Jones matrix, tomography, phase anisotropy, diagnostics

1. INTRODUCTION

In recent years in the field of biomedical optics a new basic approach in a well-tested diagnostic direction has been formed - Mueller-matrix polarimetry of biological tissues [1 - 13].

However, for non-depolarizing biological layers [5,6,14-28] more appropriate to apply the Jones-matrix formalism.

Our work consists in the study of the modulus and phase distributions of the Jones-matrix elements characterizing the optically anisotropic structure of uterine wall histological sections with second-degree and third-degree endometriosis using the statistical and correlation approaches. The aim of the research is to determine the objective criteria that ensure reliable differentiation of such objects and can be treated as the basis for the development of Jones-matrix diagnostics of non-depolarizing biological layers.

2. BRIEF THEORY

It is obtained an analytical expression for the resulting Jones matrix of a phase anisotropic transparent layer by modeling as a sequence of linearly and circularly birefringent layers in [18-28].

$$\{J\} = \begin{Vmatrix} j_{11} & j_{12} \\ j_{21} & j_{22} \end{Vmatrix} = \begin{Vmatrix} \cos U - i\dfrac{\delta \sin U}{2U} & -\zeta \dfrac{\sin U}{U} \\ \zeta \dfrac{\sin U}{U} & \cos U + i\dfrac{\delta \sin U}{2U} \end{Vmatrix}. \tag{1}$$

$$U^2 = N^2\theta^2 = \zeta^2 + \left(\frac{\delta}{2}\right)^2. \tag{2}$$

Expression (1) is an accurate analytical record of Jones-matrix elements of an optically anisotropic layer with linear (δ) and circular (ζ) birefringence.

In the approximation of weak phase fluctuations (1) can be rewritten as follows

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$$\begin{Vmatrix} j_{11} & j_{12} \\ j_{21} & j_{22} \end{Vmatrix} = \begin{Vmatrix} \left[\left(1+\zeta^{2}\right)-i\delta\right]_{11} & \left[2\zeta + i\zeta\delta\right]_{12} \\ \left[2\zeta + i\zeta\delta\right]_{21} & \left[\left(1+\zeta^{2}\right)+i\delta\right]_{22} \end{Vmatrix}. \qquad (3)$$

From Jones matrix (3) we obtain the analytical expressions for linear (δ) and circular (ζ)birefringence

$$\delta = 2tgArg\left(j_{12;21}\right). \qquad (4)$$

$$\zeta = \sqrt{1 - 0{,}5\frac{tg\left(Arg\left(j_{12;21}\right)\right)}{tg\left(Arg\left(j_{11;22}\right)\right)}}. \qquad (5)$$

Measurements of the elements of Jones matrix distributions were carried out according to the classical technique presented in [16].

3. ANALYSIS AND DISCUSSION OF EXPERIMENTAL DATA

Two groups of histological sections of the endometriosis uterine wall second-degree (sample 31 - group 1) and third-degree (sample 31) were studied.

The series of Fig. 1 - Fig. 4 represent maps (fragments 1), histograms (fragments (2)), autocorrelation functions (fragments (3)) and logarithmic dependences of power spectra (fragments (4)) extreme values distributions of Linear (δ)and circular (ζ)birefringence of the group 1 (Figure 1, Figure 3) endometrium histological sections and group 2 (Fig. 2, Fig. 4).

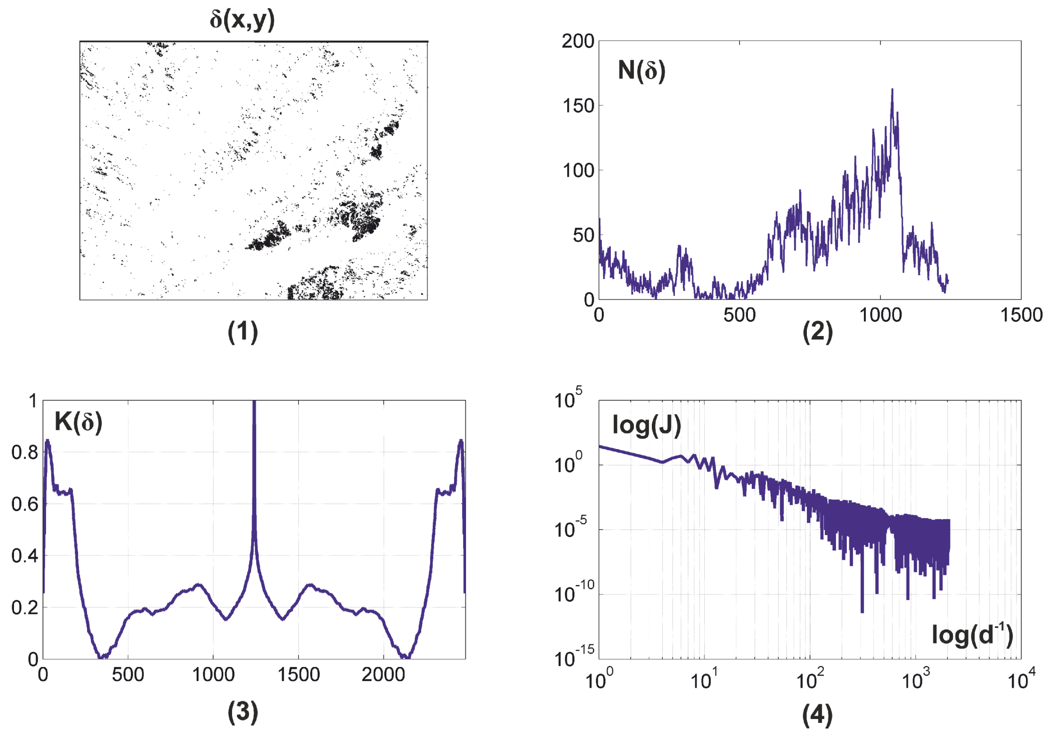

Figure 1. Statistical, correlation and fractal parameters of the group 1 of endometrium sample linear birefringence distributions.

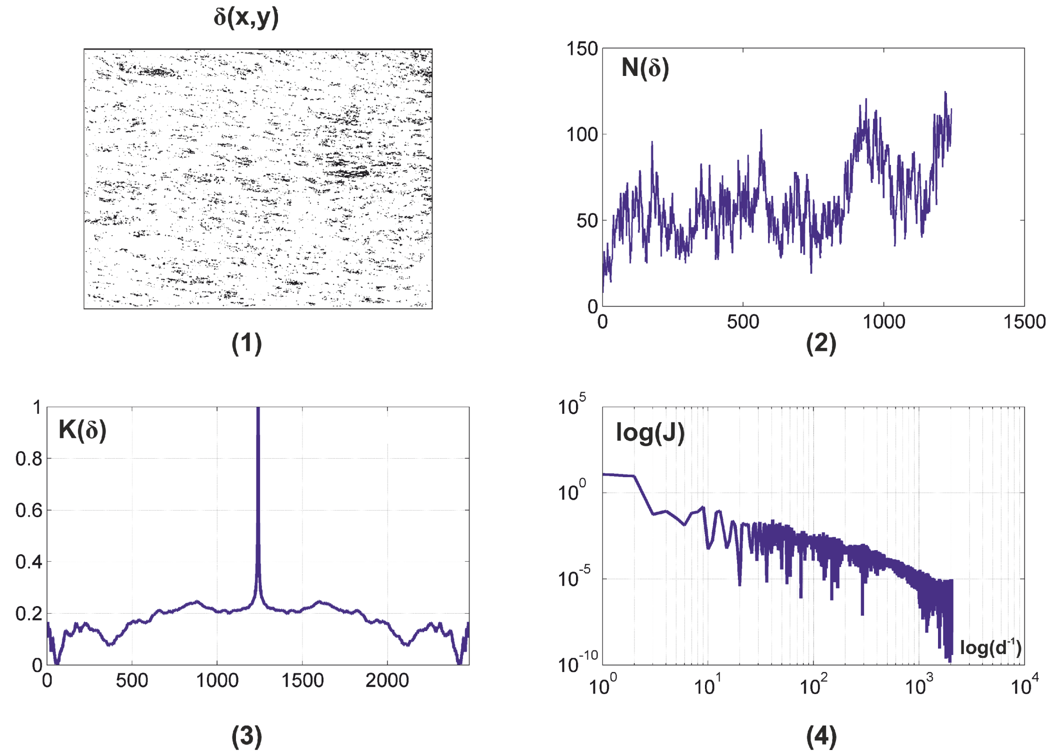

Figure 2. Statistical, correlation and fractal parameters of the group 2 of endometrium sample linear birefringence distributions.

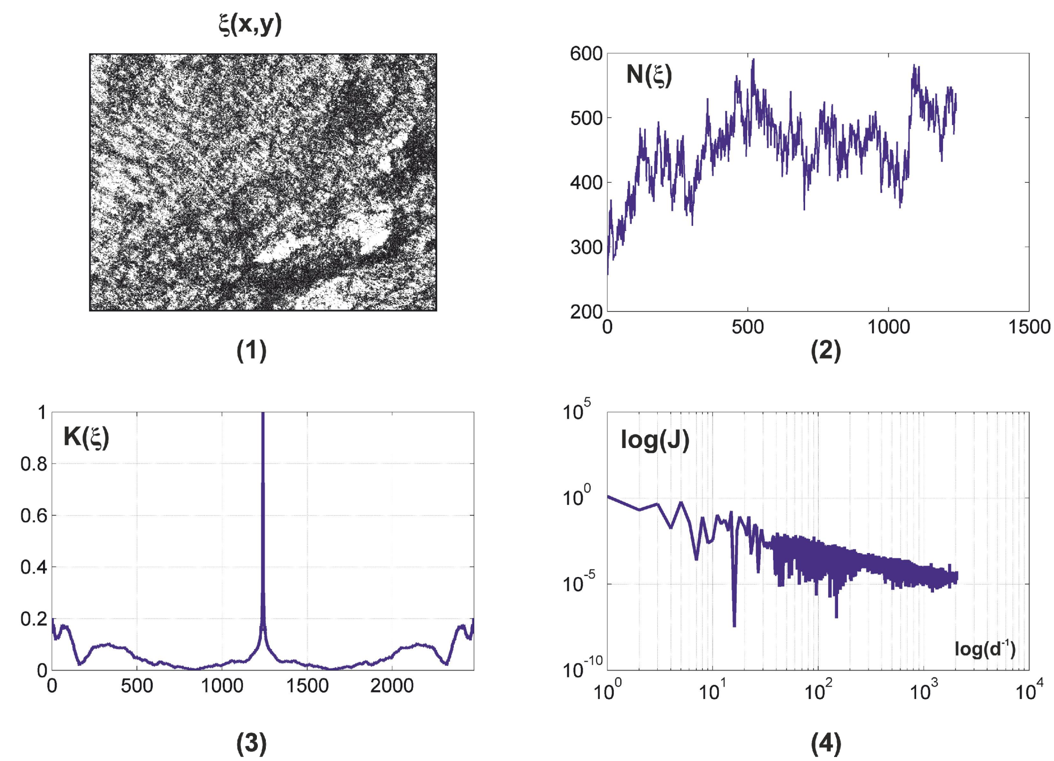

Figure 3. Statistical, correlation and fractal parameters of the group 1 of endometrium sample circular birefringence distributions.

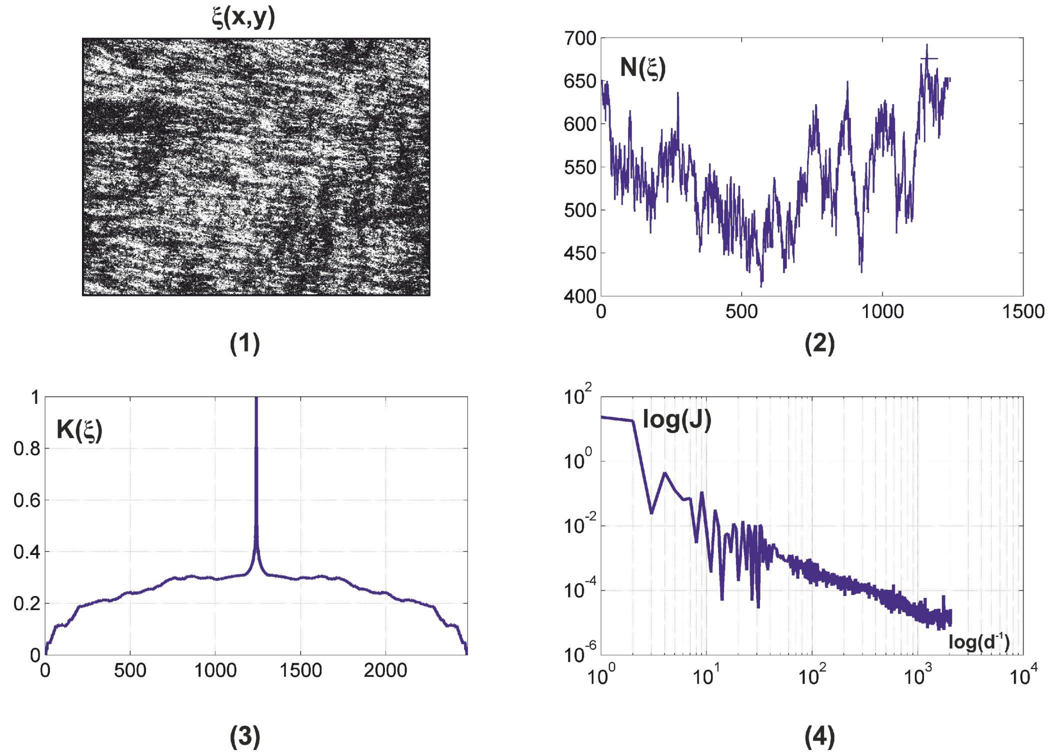

Figure 4. Statistical, correlation and fractal parameters of the group 2 of endometrium sample circular birefringence distributions.

In order to identify the sensitivity of the Jones matrix method of planar polycrystalline non-depolarizing layers mapping to changes of linear and circular birefringence the results obtained (Fig. 1 - Fig. 4) were compared by determining the set of statistical (statistical moments of the 1st - 4th orders [14]), correlation (correlation moments 2nd and 4th orders [15]) and fractal [16] parameters that characterize the distribution δ и ζ – Table 1.

Table 1. Statistical, correlation and fractal moments of linear and circular birefringence distributions

Z_i	Group 1		Group 2	
	δ	ζ	δ	ζ
Z_1	0,055	0,06	0,029	0,052
Z_2	0,029	0,08	0,017	0,06
Z_3	0,22	1,52	0,02	1,23
Z_4	1,35	3,17	0,77	1,94
$Z^k{}_2$	0.11	0.008	0.14	0,12
$Z^k{}_4$	1.88	2.44	1.02	3.89
D_f	0.19	0.25	0.23	0,33

The comparative analysis of data presented in Table 1 showed diagnostic sensitivity of a number of objective parameters:

- $\Delta Z_4(\delta) = 2{,}05;$
  $\Delta Z_4(\zeta) = 1{,}86;$

- $\Delta Z_4^k(\delta) = 1,79;$
  $\Delta Z_4^k(\zeta) = 1,66;$
- $\Delta D_f(\delta) = 1,55;$
  $\Delta D_f(\zeta) = 1,63.$

CONCLUSION

The Jones matrix model of differentiating the weak changes of phase anisotropy of the endometrium histological sections with different pathologies is suggested.
The coordinate distributions of the endometrium tissues linear and circular birefringence are experimentally determined.
Within the statistical, correlation and fractal analysis of coordinate distributions of linear and circular birefringence the objective parameters are determined that are most sensitive (statistical moments of the 3rd and 4th orders, generalized correlation moment of the 4th order) to changes of the phase anisotropy of optically thin endometrium biological tissue of different endometriosis pathology.

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