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SINGULAR ANALYSIS OF MULLER-MATRIX IMAGING OF PHASE-INHOMOGENEOUS

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Анотація. Стаття присв’ячена дослідженню процесів трансформації лазерного випромінювання мережами біологічних кристалів із застосуванням підходів сингулярної оптики. Отримані результати виявлили чітку кореляцію між "характеристичними" значеннями координатних розподілів елементів матриці Мюллера (M_{ik} = 0, ±1) та поляризаційними сингулярностями (S- та C-точки) об’єктного поля мереж біологічних кристалів з наступною можливістю їх Мюллер-матричної селекції. Запропонована техніка Мюллер-матричної сингулярної діагностики патологічних змін жіночої репродуктивної сфери - міометрію.

Аннотация. Статья посвящена исследованию процессов трансформации лазерного излучения сетями биологических кристаллов с применением методик сингулярной оптики. Полученные результаты обнаружили четкую корреляцию между "характеристичными" значениями координатных распределений элементов матрицы Мюллера (M_{ik} = 0, ±1) и поляризационными сингулярностями (S- и C-точки) объектного поля сетей биологических кристаллов с последующей возможностью их Мюллер-матричной селекцией. Предложенная техника Мюллер-матричной сингулярной диагностики патологических изменений женской репродуктивной сферы - миометрия.

Annotation. The paper deals with investigating the processes of laser radiation transformation by biological crystals networks using the singular optics techniques. The results obtained showed a distinct correlation between the points of "characteristic" values of coordinate distributions of Mueller matrix (M_{ik} = 0, ±1) elements and polarization singularities (S- and C-points) of laser transformation of biological crystals networks with the following possibility of Mueller-matrix selection of polarization singularity. The technique of Mueller-matrix singular diagnostics of pathological changes of women's reproductive sphere tissue (myometrium) is proposed.

Key words: polarization, singular, crystal, biological tissue, statistics, Mueller matrix.

INTRODUCTION

Laser polarimetry [1-29] enabling to obtain information about optical anisotropy [1, 3, 14, 29] of biological tissues (BT) is an important direction of non-invasive diagnostics of organic phase-heterogeneous layers. For statistic analysis of such polarimetric information a model approach has been worked out based on the following conditions [1-4, 10-13, 15-17, 19, 29]:

- all the variety of human BT can be represented by four main types – connective, muscular epithelial, and neural tissues;
- morphological structure of any BT type is regarded as a two-component amorphous-crystalline one;
- the crystalline component or extracellular matrix is formed by the network of optically uniaxial birefringent protein (collagen, myosin, elastine, etc.) fibrils or biological crystals;
- the process of transformation of laser radiation polarization state by biological crystal is characterized by Jones $\{D\}$ and Mueller $\{M\}$ matrix operators of an optically uniaxial crystal [1-3, 6, 17, 20, 21, 23]

$$\{D\} = \begin{Vmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{Vmatrix} = \begin{Vmatrix} \cos^2\rho + \sin^2\rho\exp(-i\delta) & \cos\rho\sin\rho[1-\exp(-i\delta)] \\ \cos\rho\sin\rho[1-\exp(-i\delta)] & \sin^2\rho + \cos^2\rho\exp(-i\delta) \end{Vmatrix}. \quad (1)$$

$$\{M\} = \begin{Vmatrix} 1 & 0 & 0 & 0 \\ 0 & M_{22} & M_{23} & M_{24} \\ 0 & M_{32} & M_{33} & M_{34} \\ 0 & M_{42} & M_{43} & M_{44} \end{Vmatrix} = \begin{Vmatrix} 1 & 0 & 0 & 0 \\ 0 & \left(\cos^2 2\rho + \sin^2 2\rho \cos\delta\right) & \cos 2\rho \sin 2\rho (1-\cos\delta) & \left(\sin 2\rho \sin\delta\right) \\ 0 & \left(\cos 2\rho \sin 2\rho (1-\cos\delta)\right) & \left(\sin^2 2\rho + \cos^2 2\rho \cos\delta\right) & \left(\cos 2\rho \sin\delta\right) \\ 0 & \left(-\sin 2\rho \sin\delta\right) & \left(-\cos 2\rho \sin\delta\right) & \left(\cos\delta\right) \end{Vmatrix} . \quad (2)$$

Here ρ – direction of optical axis of biological crystal with birefringence index Δn, $\delta = {2\pi}/{\lambda}\,\Delta nl$ – phase shift between orthogonal components U_{0x}, U_{0y} of the amplitude of a probing laser beam with wave length λ.

A new approach to description of the BT laser images based on the analysis of coordinate distributions of polarization singularities became developed the above mentioned statistical [1-3, 14, 19, 28, 31]. Linearly (S-points) and circularly (C-points) polarized states of light oscillations belong to them. For S-points the direction of the electric-intensity vector's rotation is indefinite (singular). For a C-point the polarization azimuth of the electric intensity vector is indefinite.

The use of the fourth parameter of the Stokes vector appears to be a suitable and widely applied means of such singularities representation

$$V_4 = \begin{cases} 0 \leftrightarrow S; \\ \pm 1 \leftrightarrow C. \end{cases} \quad (3)$$

Investigation of laser images of the connective tissue layers revealed a developed network of polarization singularities [3, 28, 29], which was quantitatively estimated in the form of distribution of the amount of S- and C-points. By means of the analysis of the given distribution's statistical moments of the 1st-4th orders (the technique of polarization-correlation mapping $V_4(x,y)$) the criteria of diagnostics of oncological changes of uterus neck tissue were found.

It should be pointed out that singular approach is predominantly realized out of the analysis of the mechanisms of forming polarizationally heterogeneous laser images of BT by an extracellular matrix. Thus development of laser polarimetry techniques based on determination of singular interconnections "object – field" in order to find new methods of diagnostics of transformation of the BT extracellular matrix orientation-phase structure connected with pre-cancer changes of their physiological state is very important.

To solve such a problem we should revert to the analysis of optical properties of biological crystals' nets, comprehensively described by the Jones matrix though within a singular approach.

BRIEF THEORY OF THE SINGULAR APPROACH IN THE ANALYSIS OF THE BIOLOGICAL TISSUE BIREFRINGENT NETS

According to mathematical approach singularity of a complex matrix element d_{ik} is determined by the following terms

$$\begin{cases} \left(\operatorname{Re} d_{ik}\right)^2 + \left(\operatorname{Im} d_{ik}\right)^2 = 0, \\ tg\left[{\operatorname{Im}(d_{ik})}/{\operatorname{Re}(d_{ik})}\right] = \infty. \end{cases} \quad (4)$$

Taking into account (4) complex expressions of the Jones matrix elements (2) are transformed into the following analytical relations:

$$d_{11} \Leftrightarrow \begin{cases} \left(\cos^2\rho + \sin^2\rho\cos\delta\right)^2 + \sin^4\rho\sin^2\delta = 0, \\ \cos^2\rho + \sin^2\rho\cos\delta = 0. \end{cases} \quad (5)$$

$$d_{22} \Leftrightarrow \begin{cases} \left(\sin^2\rho + \cos^2\rho\cos\delta\right)^2 + \cos^4\rho\sin^2\delta = 0, \\ \sin^2\rho + \cos^2\rho\cos\delta = 0. \end{cases} \quad (6)$$

$$d_{12} = d_{21} \Leftrightarrow \begin{cases} 2\cos^2\rho\sin^2\rho\left(1+\cos\delta\right) = 0, \\ \cos\rho\sin\rho\left(1+\cos\delta\right) = 0. \end{cases} \quad (7)$$

It follows from (5) – (7) that singularities of matrix elements d_{ik} are caused by certain (characteristic) values of orientation ρ^* and phase δ^* parameters of the BT crystals' nets of the extracellular matrix

$$\begin{cases} \rho^* = 0^\circ, \quad 90^\circ; \\ \delta^* = 0^\circ, \quad 90^\circ, \quad 180^\circ. \end{cases} \tag{8}$$

On the other hand, relations (8) are the necessary terms for forming polarization singular states of the laser beam (S - ($\delta = 0^\circ, 180^\circ$) and C - ($\delta = \pm 90^\circ$) points) by optically coaxial birefringent crystal. It follows from the above mentioned that there is a direct theoretical interconnection between singularities of the Jones matrix elements of the biological crystal and polarization singularities in its laser image.

It should be noted that the use of Mueller matrix $\{M\}$ (relations (2) appear to be a more suitable tool for investigating polarization properties of the network of optically coaxial crystals.

Considering expressions (1), (2), (4) and (8) the characteristic values M^*_{ik} were defined that determine the S- and C-points in laser image of the extracellular matrix of the BT layer (Table 1). The analysis of the data given here resulted in:

- the values $M_{44} = 0$ and $V_4 = \pm 1$ determine the complete set of ±C-points ($\delta = \pm 90^\circ$);
- the complete set of S-points ($\delta = 0^\circ$) of the laser image is caused by the terms $M_{22} = M_{33} = M_{44} = 1$ and $V_4 = 0$.

Table 1

Interconnection between characteristic values of Mueller matrix M_{ik} elements of biological tissues and polarization singularities described by the fourth parameter of Stokes vector V_4

M_{ik}		"+S"-point ($\delta = 0$)	"-S"-point ($\delta = \pi$)	"+C"-point ($\delta = +\pi/2$)	"-C"-point ($\delta = -\pi/2$)	V_4
M_{22}	0	-	-	+ ($\rho = +\pi/4$)	+ ($\rho = -\pi/4$)	± 1
	1	+ ($\delta = 0$)	-	-	-	0
	-1	-	+ ($\delta = \pi$)	-	-	0
$M_{23} = M_{32}$	0	+ ($\rho = +\pi/4$)	+ ($\rho = -\pi/4$)	-	-	0
	1	-	-	+ ($\rho = +\pi/4$)	+ ($\rho = -\pi/4$)	$+1$
	-1	-	-	+ ($\rho = -\pi/4$)	+ ($\rho = +\pi/4$)	-1
$M_{24} = -M_{42}$	0	+ ($\rho = 0$)	+ ($\rho = \pi/2$)	-	-	0
	1	-	-	+ ($\rho = +\pi/4$)	+ ($\rho = -\pi/4$)	$+1$
	-1	-	-	+ ($\rho = -\pi/4$)	+ ($\rho = +\pi/4$)	-1
M_{33}	0	-	-	+ ($\rho = 0$)	+ ($\rho = 0$)	± 1
	1	+ ($\delta = 0$)	-	-	-	0
	-1	-	+ ($\delta = \pi$)	-	-	0
$M_{34} = -M_{43}$	0	+ ($\rho = +\pi/4$)	+ ($\rho = -\pi/4$)	-	-	0
	1	-	-	+ ($\rho = 0$)	+ ($\rho = +\pi/2$)	$+1$
	-1	-	-	+ ($\rho = +\pi/2$)	+ ($\rho = 0$)	-1
M_{44}	0	-	-	+ ($\rho = 0 \div \pi$)	+ ($\rho = 0 \div \pi$)	± 1
	1	+ ($\delta = 0$)	-	-	-	0
	-1	-	+ ($\delta = \pi$)	-	-	0

In addition to the above mentioned, the Mueller-matrix analysis enables to perform the sampling of polarization singularities of the laser image, formed by biological crystals with orthogonally oriented ($\delta = 0^\circ$, 90° and $\delta = 45^\circ$, 135°) optical axes to:

- "orthogonal" $\pm C$-points

$$\begin{cases} M_{33}=0, M_{34,43}=\pm 1 \quad - \quad \pm C-(\rho=0^{\circ},90^{\circ}), \\ M_{22}=0, M_{24,42}=\pm 1 \quad - \quad \pm C-(\rho=45^{\circ},135^{\circ}). \end{cases} \quad (9)$$

- "orthogonal" $S_{0;90}$ - and $S_{45;135}$ - points

$$\begin{cases} M_{24,42}=0 \quad - \quad S_{0^{\circ},90^{\circ}}-(\rho=0^{\circ},90^{\circ}), \\ M_{34,43}=0 \quad - \quad S_{45^{\circ},135^{\circ}}-(\rho=45^{\circ},135^{\circ}). \end{cases} \quad (10)$$

Thus, measuring the coordinate distributions of the characteristic values ($M_{ik}^{*}=0, \pm 1$) of the BT Mueller matrix elements enables not only to foresee the scenario ($M_{ik}^{*} \rightarrow V_{4}^{*}$) of forming the ensemble of polarization singularities ($V_{4}=0, \pm 1$) of its image, but also to additionally realize their differentiation, conditioned by the specificity of orientation structure of biological crystals.

SCHEME AND METHODS OF EXPERIMENTAL INVESTIGATIONS

The traditional optical scheme of polarimeter for measuring the elements of Mueller matrix of the BT histological sections was illustrated at [11].

Polarization analysis of the BT images was performed by means of polarizer 9 and quarter-wave plate 8 according to the following technique:

• within the section of illuminating laser beam the values array ($m \times n=800 \times 600$) of the Stokes vector $V_{j=1,2,3,4}$ parameters and elements of Mueller matrix $M_{ik}(m \times n)$ were determined according to the following algorithms

$$\begin{cases} V_{1}=I_{0}+I_{90}, \quad V_{2}=I_{0}-I_{90}, \quad V_{3}=I_{45}-I_{135}, \quad V_{4}=I_{\otimes}-I_{\oplus}, \\ M_{i1}=0.5\left[V_{i}^{(1)}+V_{i}^{(2)}\right], \quad M_{i2}=0.5\left[V_{i}^{(1)}-V_{i}^{(2)}\right], \quad M_{i3}=V_{i}^{(3)}-M_{i1}, \quad M_{i3}=V_{i}^{(4)}-M_{i1}, i=1,2,3,4. \end{cases} \quad (11)$$

• in each of the arrays $M_{ik}(m \times n)$ and $V_{4}(m \times n)$ coordinate distributions of characteristic (singular) values 0, ± 1/were determined.

At the first stage the interconnections ($M_{ik}^{*} \rightarrow V_{4}^{*}$) of matrix and polarization singularities were investigated on the example of histological section of healthy skin derma layer.

Fig. 1 represents coordinate distributions of matrix elements $M_{44,24,34}(m \times n)$ of histological section of skin derma and the fourth parameter $V_{4}(m \times n)$ of its image's Stokes vector with the characteristic values 0, ± 1 plotted on them (within the marked $100\,pix \times 100\,pix$ sampling plot).

It can be seen from the data obtained that there is direct correlation between the coordinate ($k, g \quad 1 \leq k \leq m, 1 \leq g \leq n$) positions of characteristic values of the matrix element M_{44}^{*} of skin derma and the network of S- and C-points of its laser image $\left\{M_{44}^{*}(k, g)=\begin{Bmatrix}0 \\ \pm 1\end{Bmatrix} \Leftrightarrow V_{4}^{*}(k, g)=\begin{Bmatrix}\pm 1 & - & \pm C \\ 0 & - & S\end{Bmatrix}\right\}$ (Fig. 1, fragments "a", "d").

Coordinate distributions of characteristic values of matrix elements $M_{24,42}^{*}(m, n)$, $M_{34,43}^{*}(m, n)$ and corresponding networks of "orthogonal" $S_{0,90}-$, $S_{45,135}-$ и $C_{0,90}-$, $C_{45,135}-$points (relations (8) and (9)) possess individual structure. Such peculiarities of singular networks of laser image of skin derma is obviously conditioned by the asymmetry of various directions ($\rho=0^{\circ}$, 90° and $\rho=45^{\circ}$, 135°) of orientation of optical axes of biological crystals in the plane of the investigated sample (Fig. 1, fragments "b", "c").

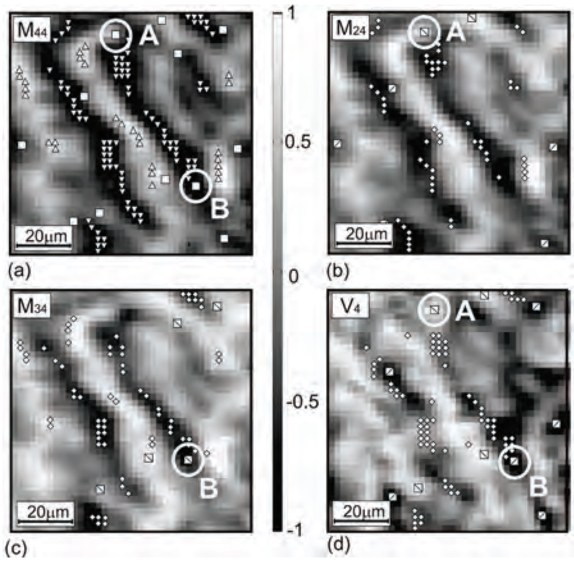

Fig. 1. Networks of characteristic values $M^{*}_{44,24,34}(m \times n)$ of matrix elements $M_{44,24,34}$ ("a", "b", "c") and singularities of polarization image of the skin derma layer histological section V_4 ("d"):

– "±C"-points (□) (M_{44} = 0);
– "+C"-points (⧅) ($M_{24,34}$ = +1, V_4 = +1);
– "-C"- points (⧄) ($M_{24,34}$ = –1, V_4 = –1);
– "+S"- points (Δ) (M_{44} = +1);
– "-S"- points (∇) (M_{44} = –1);
– "±S"- points (◊) ($M_{24,34}$ = 0, V_4 = 0).

Analytically substantiated and experimentally proven interconnections between the matrix and polarization singularities were used as the basis for Mueller-matrix singular diagnostics of oncological changes of the tissues of women's reproductive sphere.

MUELLER-MATRIX SINGULAR DIAGNOSTICS AND DIFFERENTIATION OF PATHOLOGICAL CHANGES OF THE TISSUES OF WOMEN'S REPRODUCTIVE SPHERE

Three groups of histological sections of the main tissue of women's reproductive sphere – myometrium – were used as the objects of investigation:

- biopsy of the sound tissue of women's reproductive sphere (type "**A**" – Fig. 2, "a");
- biopsy of the inflamed tissue (ectonia) (type "**B**" – Fig. 2, "b");
- biopsy of the tissue in the state of dysplasia (pre-cancer state) (type "**B**" – Fig. 2, "c").

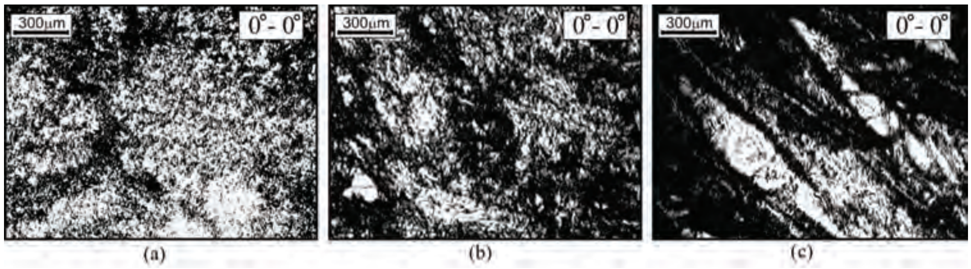

Fig. 2. Polarization images of women's reproductive sphere tissue – myometrium "**A**" ("a"), "**B**" ("b") and "**C**" ("c") – types in coaxial polarizer and analyzer

To determine the criteria of Mueller-matrix singular diagnostics of myometrium oncological state and differentiation of its severity degree the following technique was used:

- coordinate networks of characteristic values of matrix elements $M^{*}_{44,24,34}(m \times n) = 0$, ± 1 were scanned in the direction $x \equiv 1, \ \ldots, \ m$ with the step $\Delta x = 1$ pixel;
- within the obtained sampling $\left(1_{pix} \times n_{pix}\right)^{(k=1, \ 2, \ \ldots, \ m)}$ for coordinate distribution of the element $M_{44}(m \times n)$ the total amount ($N^{(k)}$) of characteristic points ($0, \pm 1$), which set (relation (7)) the complete

ensemble of singular points was calculated and the dependencies $N(x) \equiv (N^{(1)}, \quad N^{(2)}, \quad ..., \quad N^{(m)})$ were determined;

• distributions of the number of “orthogonal” singular $S-$ and $\pm C$ -points were determined according to the terms (9) and (10);

$$\begin{cases} \rho = 0^{\circ}, 90^{\circ} \Leftrightarrow N_{0,90}(x) = N_C(M_{34,43} = \pm 1) + N_S(M_{24,42} = 0), \\ \rho = 45^{\circ}, 135^{\circ} \Leftrightarrow N_{45,135}(x) = N_S(M_{34,43} = 0) + N_C(M_{24,42} = \pm 1). \end{cases} \tag{11}$$

• statistical moments of the 1st-4th orders of the obtained distributions of $N(x)$ amount of singularities were calculated according to the algorithms

$$Z_1 = \frac{1}{m \times n} \sum_{i=1}^{m \times n} |N(x)|, \quad Z_2 = \sqrt{\frac{1}{m \times n} \sum_{i=1}^{m \times n} [N(x)]^2}, \quad Z_3 = \frac{1}{Z_2^3} \frac{1}{m \times n} \sum_{i=1}^{m \times n} [N(x)]^3, \quad Z_4 = \frac{1}{Z_2^4} \frac{1}{m \times n} \sum_{i=1}^{m \times n} [N(x)]^4. \tag{12}$$

Fig. 3 – 4 show the networks of characteristic values $M^{*}_{44,24,34}(m \times n)$ of coordinate distributions of matrix elements $M_{44,24,34}(m \times n)$ of histological sections of myometrium tissues of “**A**”, “**B**”, “**C**” - types.

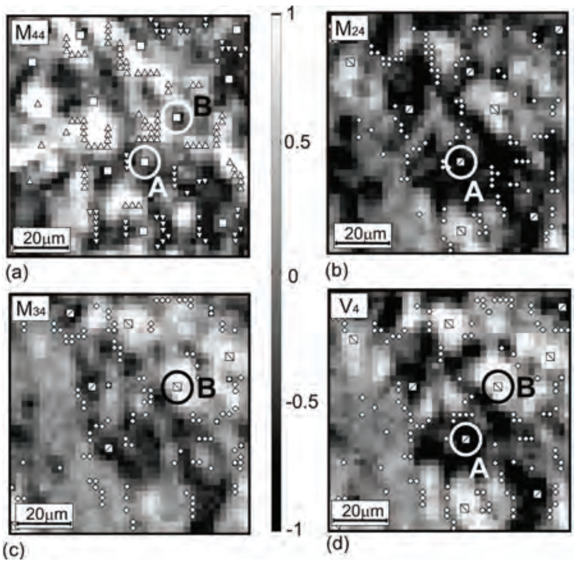

Fig. 3. Networks of characteristic values $M^{*}_{44,24,34}(m \times n)$ of matrix elements $M_{44,24,34}$ (“a”, “b”, “c”) and singularities of polarization image of myometrium histological section of “**A**”-type V_4 (“d”):

– “±C”- points (□) (M_{44} = 0);
– “+C”- points (⧅) ($M_{24,34}$ = +1, V_4 = +1);
– “-C”- points (⧄) ($M_{24,34}$ = –1, V_4 = –1);
– “+S”- points (Δ) (M_{44} = +1);
– “-S”- points (∇) (M_{44} = –1);
– “±S”- points (◊) ($M_{24,34}$ = 0, V_4 = 0)

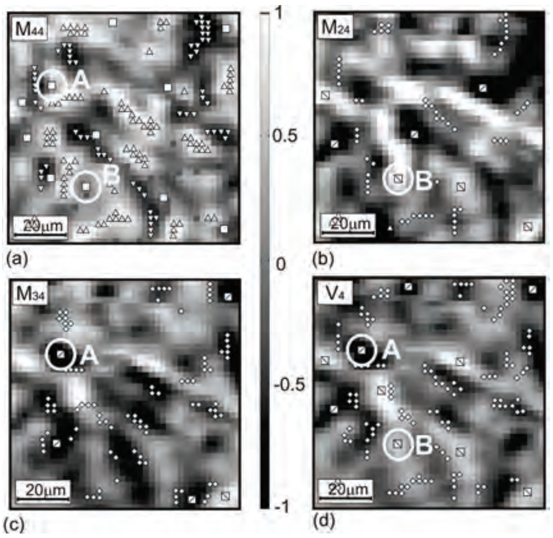

Fig. 4. Networks of characteristic values $M^{*}_{44,24,34}(m \times n)$ of matrix elements $M_{44,24,34}$ ("a", "b", "c") and singularities of polarization image of myometrium histological section of "**B**"-type V_4 ("d"):

– "±C"- points (□) (M_{44} = 0);
– "+C"- points (⧅) ($M_{24,34}$ = +1, V_4 = +1);
– "-C"- points (⧄) ($M_{24,34}$ = –1, V_4 = –1);
– "+S"- points (Δ) (M_{44} = +1);
– "-S"- points (∇) (M_{44} = –1);
– "±S"- points (◊) ($M_{24,34}$ = 0, V_4 = 0)

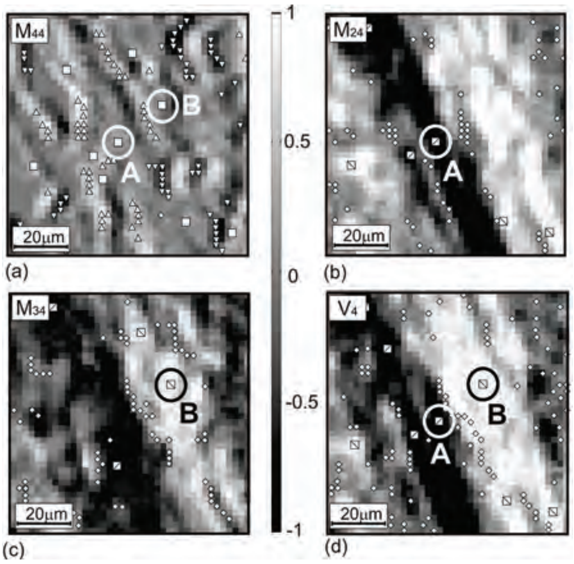

Fig. 5. Networks of characteristic values $M^{*}_{44,24,34}(m \times n)$ of matrix elements $M_{44,24,34}$ ("a", "b", "c") and singularities of polarization image of myometrium histological section of "**C**"-type V_4 ("d"):

– "±C"- points (□) (M_{44} = 0);
– "+C"- points (⧅) ($M_{24,34}$ = +1, V_4 = +1);
– "-C"- points (⧄) ($M_{24,34}$ = –1, V_4 = –1);
– "+S"- points (Δ) (M_{44} = +1);
– "-S"- points (∇) (M_{44} = –1);
– "±S"- points (◊) ($M_{24,34}$ = 0, V_4 = 0)

Fig. 6 illustrates the distributions of the number of singularities $N(x)$, $N_{0,90}(x)$, $N_{45,135}(x)$ of myometrium tissues of "**A**" (left column), "**B**" (central column), "**C**" (right column) types.

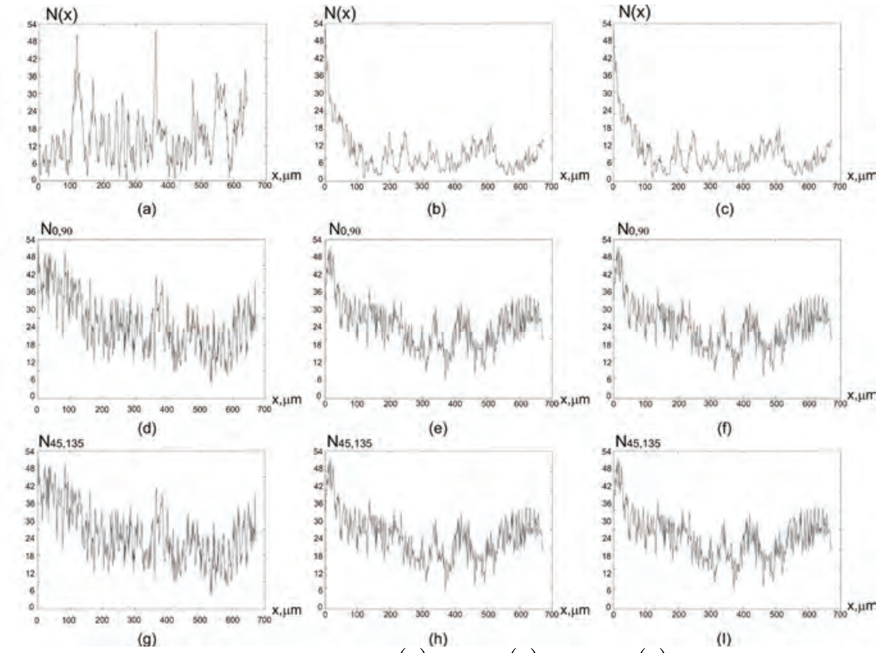

Fig. 6. Distributions of the amount of singularities $N(x)$, $N_{0,90}(x)$, $N_{45,135}(x)$ of myometrium tissues of "**A**"- (left column), "**B**"- (central column), "**C**" (right column)-types

The comparative analysis of the data obtained shows that:

- coordinate distributions of the elements $M_{44,24,34}(m \times n)$ of Mueller matrix of myometrium tissue of all types is characterized by individual (according to quantitative and topological structure) networks of singular points (Fig. 3 – 5);
- total amount of $\pm C$ -points ($M^{*}_{44}(m \times n) = 0$) sequentially increases for the samples of myometrium of "**A**", "**B**", "**C**" types (Fig. 3 – 5, fragments "a");
- dependencies $N_{0,90}(x)$ of the number of singular values of matrix elements (relations (8), (9)) for the samples of myometrium tissue of all types are similar in their structure (Fig. 6 "d", "e", "f");
- distributions $N_{45,135}(x)$ for the samples of myometrium tissue of "**B**"-type are characterized by sufficient increase (by 2-3 times) of the number of singular values in comparison with similar dependencies $N_{0,90}(x)$ (Fig. 6 "e", "h").

The obtained results can be connected with the increase of birefringence ($\Delta n \approx 1{,}5 \times 10^{-2}$) of collagen and myosin fibrils of pathologically changes myometrium of "**B**"– and "**C**"–types. Besides, at early stages (ectonia) (the directions of the growth of newly-formed fibrils are being formed. At dysplasia states such pathologically changed fibrils form specifically oriented network of biological crystals.

In terms of physics such morphological processes are manifested in the increase of probability of forming the $\pm C$ -points (myometrium samples of "**B**" and "**C**" – types), as well as in appearance of asymmetry between ranges of dependences values $N_{0,90}(x)$ and $N_{45,135}(x)$, which characterize the number of orthogonal S- and C- points, – Table 1.

In the end the comparative investigations of diagnostic efficiency of the potential of famous techniques of laser polarimetry $\left(Z_{1,2,3,4}\left(M_{44,34,24}(m \times n)\right)\right)$ [11]; polarization-correlation mapping $\left(Z_{1,2,3,4}\left(V_4(m \times n) = \begin{cases} 0, \\ \pm 1 \end{cases}\right)\right)$ [19, 20] and the technique of Mueller-matrix singular diagnostics $Z_{1,2,3,4}\left(N(x),\ N_{0,90}(x),\ N_{45,135}(x)\right)$ were suggested.

Table 2 presents statistical averaged values within the three groups of samples of myometrium tissue $\left(Z_{1,2,3,4}\left(M_{44,34,24}(m \times n)\right)\right)$; $\left(Z_{1,2,3,4}\left(V_4(m \times n) = \begin{cases} 0, \\ \pm 1 \end{cases}\right)\right)$ and $Z_{1,2,3,4}\left(N(x)\right),\ N_{0,90}(x),\ N_{45;135}(x)$.

Table 2

Values $\left(Z_{1,2,3,4}\left(M_{44,34,24}(m\times n)\right)\right)$, $\left(Z_{1,2,3,4}\left(V_4(m\times n)=\begin{cases}0,\\ \pm 1\end{cases}\right)\right)$ **and** $Z_{1,2,3,4}\left(N(x),\ N_{0,90}(x),\ N_{45;135}(x)\right)$ **statistically averaged within the three groups of myometrium tissue samples**

	Myometrium "**A**"-type (21 samples)			Myometrium "**B**"-type (21 samples)			Myometrium "**C**"-type (21 samples)		
$Z_{j=1,2,3,4}$	M_{44}	M_{34}	M_{24}	M_{44}	M_{34}	M_{24}	M_{44}	M_{34}	M_{24}
Z_1	*0,67± ±0.059*	*0,32± ±0.031*	*0,27± ±0.02*	*0,59± ±0.048*	*0,27± ±0.02*	*0,24± ±0.05*	*0,37± ±0.034*	*0,19± ±0.015*	*0,18± ±0.019*
Z_2	*0,51± ±0,046*	*0,29± ±0,019*	*0,26± ±0,021*	*0,57± ±0,05*	*0,23± ±0,013*	*0,21± ±0,01*	*0,28± ±0,023*	*0,21± ±0,018*	*0,17± ±0,015*
Z_3	*1,13± ±0,12*	*0,88± ±0,09*	*0,74± ±0,08*	*0,98± ±0,1*	*0,79± ±0,081*	*0,66± ±0,069*	*0,66± ±0,071*	*0,49± ±0,042*	*0,41± ±0,04*
Z_4	*3,15± ±0,32*	*2,11± ±0,29*	*2,27± ±0,31*	*2,84± ±0,24*	*1,79± ±0,18*	*1,87± ±0,17*	*1,57± ±0,14*	*1,07± ±0,1*	*1,12± ±0,11*

$Z_{j=1,2,3,4}$	A: $V_4=0$	A: $V_4=\pm1$	B: $V_4=0$	B: $V_4=\pm1$	C: $V_4=0$	C: $V_4=\pm1$
Z_1	0.12±0,079	0.24±0,038	0.15±0,067	0.28±0,068	0.18±0,071	0.29±0,076
Z_2	0.16±0,074	0.31±0,042	0.19±0,031	0.38±0,052	0.23±0,019	0.4±0,048
Z_3	0.70±0,052	0.92±0,086	0.93±0,094	1.12±0,101	1.27±0,112	1.72±0,123
Z_4	1.71±0,13	2.19±0,18	2.01±0,19	3.13±0,27	3.41±0,31	4.01±0,31

$Z_{j=1,2,3,4}$	A: $N(x)$	A: $N_{0,90}(x)$	A: $N_{45,135}(x)$	B: $N(x)$	B: $N_{0,90}(x)$	B: $N_{45,135}(x)$	C: $N(x)$	C: $N_{0,90}(x)$	C: $N_{45,135}(x)$
Z_1	*0,61±* ±0,052	*0,43±* ±0,038	*0,12±* ±0,034	*0,39±* ±0,05	*0,37±* ±0,042	*0,23±* ±0,048	*0,29±* ±0,039	*0,28±* ±0,036	*0,19±* ±0,038
Z_2	*0,75±* ±0,068	*0,82±* ±0,076	*0,15±* ±0,021	*0,36±* ±0,042	*0,69±* ±0,056	*0,46±* ±0,02	*0,31±* ±0,024	*0,55±* ±0,049	*0,23±* ±0,026
Z_3	*1,19±* ±0,15	*0,92±* ±0,01	*1,86±* ±0,19	*0,63±* ±0,051	*0,87±* ±0,07	*1,86±* ±0,19	*0,53±* ±0,041	*0,76±* ±0,062	*2,06±* ±0,21
Z_4	*1,99±* ±0,17	*2,31±* ±0,19	*2,32±* ±0,21	*1,01±* ±0,1	*2,07±* ±0,17	*8,45±* ±0,73	*0,8±* ±0,07	*1,87±* ±0,19	*2,91±* ±0,32

It follows from the data presented that:

- efficiency of laser polarimetry for diagnostics and differentiation of early oncological changes of myometrium tissue is insufficient – the difference between the values of statistical moments $\left(Z_{1,2,3,4}\left(M_{44,34,24}(m\times n)\right)\right)$ of samples "**A**", "**B**" and "**C**" - types is insufficient and does nor exceed 20% - 45%;
- the technique of polarization-correlation mapping is efficient for differentiation of optical properties of sound and oncologically changed myometrium tissue – asymmetry (Z_3) and excess (Z_4) of distribution of the number of singular points of "**A**"- and "**B**"-types of laser images differ by 1.53 and 2.15 times;
- the technique of Mueller-matrix singular diagnostics is efficient for differentiation of optical properties of all types of samples – statistical moments of the 3rd and 4th orders of distributions $N(x)$ for the samples "**A**", "**B**" and "**C**" – types differ by 1.7 and 2.5 times respectively.
- for distributions $N_{45,135}(x)$ of the amount of orthogonal singular $S_{45,135}$ - and $C_{45,135}$ points of myometrium tissue of "**A**" and "**B**" types the maximal difference (from 2.2 to 4.1 times) is observed between all statistical $Z_{j=1,2,3,4}$.

CONCLUSIONS

Analytical conditions of forming the singularity elements of Jones matrix of birefringent networks of biological tissues are determined. Correlation between the coordinate locations of characteristic points of 2D elements of Mueller matrix of optically thin layer of biological tissue and the network of S- and C-points in its laser image is defined. The potentiality of Mueller-matrix sampling of polarization singularities formed by biological crystals with orthogonally oriented ($\rho = 0^{\circ}$, 90° и $\rho = 45^{\circ}$, 135°) optical axes is shown. The efficiency of Mueller-matrix singular diagnostics not only for oncological changes of myometrium tissue but for differentiating their severity degree is demonstrated.

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