6.7. Jones-matrix tomography of biological tissues phase anisotropy in the diagnosis of uterus wall prolapse

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6.7.1. Theoretical basics and experimental realization of jones-matrix mapping of biological layers birefringence

6.7.1.1. Jones-matrix reconstruction of parameters of linear and circular birefringence

In the ground of this work it has been chosen the matrix approach for investigation of the structure of biological objects [1-14]. Theoretical backgrounds of the method of mapping of anisotropy parameters of polycrystalline component of biological layers are in details provided in the set of works [15 – 30].

In [14,15] it was suggested a new form of Jones matrices.

$$\{J\} = \left\| \begin{matrix} R_{11}(r)\exp\Theta_{11}(r) & R_{12}(r)\exp\Theta_{12}(r) \\ R_{21}(r)\exp\Theta_{21}(r) & R_{22}(r)\exp\Theta_{22}(r) \end{matrix} \right\|, \qquad (6.7.1)$$

Here matrix $\{J\}$ is written as real R_{ik} (modulus) and imaginary (phase angles) Θ_{ik} components. On this basis (6.7.1) in [1-3] obtain the algorithms of polarization reproduction of phase anisotropy parameters of optically thin birefringent layer

$$\delta = \frac{2\arccos(J_{11}+J_{22})}{1+\dfrac{J_{12}-J_{21}}{J_{22}-J_{11}}} = \frac{2\arccos(R_{11}\cos\Theta_{11}+R_{22}\cos\Theta_{22})}{1+\dfrac{R_{12}\cos\Theta_{12}-R_{21}\cos\Theta_{21}}{R_{22}\cos\Theta_{22}-R_{11}\cos\Theta_{11}}} \qquad (6.7.2)$$

$$\theta = \frac{2\arccos(J_{11}+J_{22})}{1+\dfrac{J_{22}-J_{11}}{J_{12}-J_{21}}} = \frac{2\arccos(R_{11}\cos\Theta_{11}+R_{22}\cos\Theta_{22})}{1+\dfrac{R_{22}\cos\Theta_{22}-R_{11}\cos\Theta_{11}}{R_{12}\cos\Theta_{22}-R_{21}\cos\Theta_{11}}} \qquad (6.7.3)$$

6.7.1.2. Experimental results of the method of birefringence mapping of biological layers

The measurements of coordinate distributions of Jones-matrix elements were performed in the setup (Fig.6.7.1).

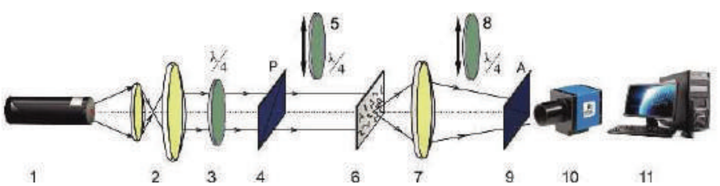

Fig.6.7.1. Optical scheme of experimental setup: 1 – He-Ne laser; 2 – collimator; 3 – stationary quarter-wave plate; 5, 8 – mechanically movable quarter-wave plates; 4, 9 – polarizer and analyzer respectively; 6 – object of investigation; 7 – optical system; 10 – CCD camera; 11 – PC.

Measurements of real R_{ik} and imaginary Θ_{ik} parts of Jones-matrix elements (relation (6.7.1)) were performed due to the standard technique [1-3].

As the object of investigation we used a histological section of skin derma. The main anisotropic structures of such an object are collagen fibrils with linear and circular birefringences. The values of such parameters are most adequately described by phase parameters δ (relation (6.7.1)) and θ (relation (6.7.2)) [1-3].

Fig. 6.7.2 presents the maps (fragments (1, 3)) and histograms (fragments (2, 4)) of the distributions of the values of phase shifts of linear (fragments (1, 2)) and circular (fragments (3, 4)) birefringences of the histological section of skin derma.

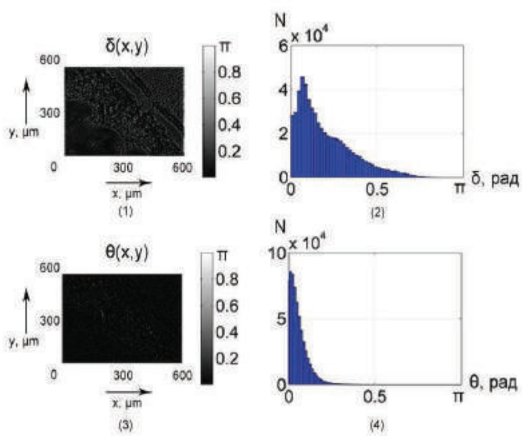

Fig. 6.7.2. Maps (fragments (1),(3)) and histograms (fragments (2, 4)) of the distributions of the values of phase shifts of linear (fragments (1, 2)) and circular (fragments (3, 4)) birefringences of the histological section of skin derma.

Table 6.7.1 presents the results of statistic analysis (statistical moments of the 1st-4th orders $Z_{i=1;2;3;4}$) of coordinate distributions of the phase shifts values of linear (relation (6.7.2)) and circular (relation (6.7.3)) birefringence of the histological section of skin derma.

Table 6.7.1. Statistical moments $Z_{i=1;2;3;4}$ of the distributions of MMI of anisotropy of skin derma tissue

$Z_{i=1;2;3;4}$	δ	θ
$Z_{i=1}$	0.14	0,09
$Z_{i=2}$	0,12	0.07
$Z_{i=3}$	0.71	1.27
$Z_{i=4}$	0.84	2.19

It was defined the individual sensitivity of the value of $Z_{i=1;2;3;4}$ to the peculiarities of MMI coordinate distributions of parameters of linear and circular birefringence of the skin derma tissue. Such a fact was chosen as the basic for applied biomedical usage of statistic analysis of coordinate distributions of linear and circular birefringence parameters.

6.7.2. Clinical application of jones-matrix mapping of birefringential diagnostics of pathologies of human internal organs

6.7.2.1. Objects of investigation

It was investigated two groups of samples of histological sections of biopsy of uterus wall tissue:

- normal - group 1 (32 samples);
- prolapse - group 2 (32 samples).

Histological sections were produced due to the standard technique on the freezing microtome.

Polycrystalline films of urine:

- normal – group 3 (32 samples);
- albuminuria - group 4 (32 samples).

6.7.2.2. Experimental results

The set of Figs. 6.7.3, 6.7.4 presents the results of mapping of phase parameters of linear (Fig. 6.7.3) and circular (Fig. 6.7.4) birefringence of histological sections of biopsy of patients from group 1 (fragments (1, 2)) and group 2 (fragments (3,4)).

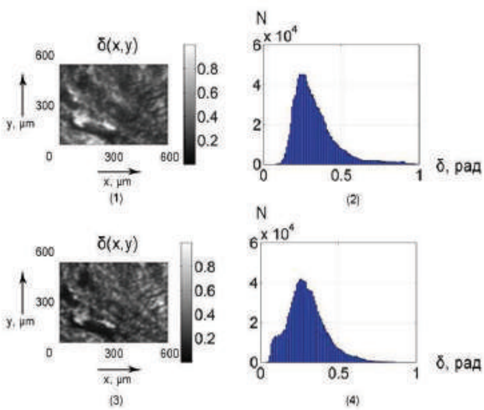

Fig. 6.7.3. Maps (fragments (1),(3)) and histograms (fragments (2, 4)) of the distributions of the values of phase shifts of linear (fragments (1, 2)) birefringence of the histological sections of uterus wall tissue of patients from group 1 (fragments (1),(2)) and group 2 (fragments (3),(4)).

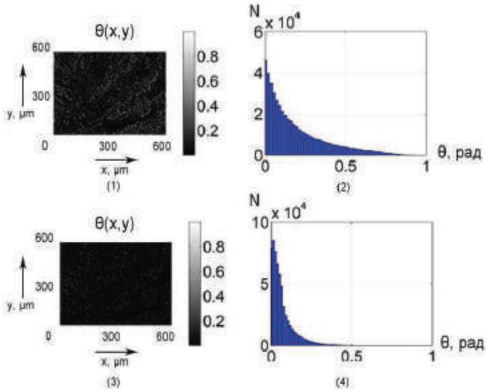

Fig. 6.7.4. Maps (fragments (1),(3)) and histograms (fragments (2, 4)) of the distributions of the values of phase shifts of circular (fragments (1, 2)) birefringence of the histological sections of uterus wall tissue of patients from group 1 (fragments (1),(2)) and group 2 (fragments (3),(4)).

For the possible clinical application of the Mueller matrix mapping method for each group of samples the operating characteristics, typical for evidence-based medicine [32-34] that determine the diagnostic power of the method are determined, namely – 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 – the number of correct and incorrect diagnoses within group 2; c and d – the same within group 1 – Table 2 and Table 3.

Table 6.7.2. Balanced accuracy of method of Jones-matrix mapping of linear and circular birefringence of uterus wall tissue

$Ac,\%$	δ	ϑ
$Z_{i=1}$	71%	68%
$Z_{i=2}$	73%	71%
$Z_{i=3}$	92%	84%
$Z_{i=4}$	95%	87%

It was reached a good ($Ac(\vartheta)=84\%-87\%$) and excellent ($Ac(\delta)=93\%-96\%$) level of balanced accuracy of the method of Jones-matrix mapping of linear and circular birefringence in the task of differentiation between normal tissue of the uterus wall and with prolapse.

Table 6.7.3. Balanced accuracy of method of Jones-matrix mapping of linear and circular birefringence of polycrystalline film of urine

$Ac,\%$	δ	ϑ
$Z_{i=1}$	71%	79%
$Z_{i=2}$	73%	84%
$Z_{i=3}$	83%	92%
$Z_{i=4}$	86%	94%

It was reached a good ($Ac(\delta)=83\%-86\%$) and excellent ($Ac(\theta)=92\%-94\%$) level of balanced accuracy of the method of Jones-matrix mapping of linear and circular birefringence in the task of differentiation between normal and albuminuria patients.

6.7.3.Conclusions

Short theoretical basics of the method of azimuthally invariant Jones-matrix mapping of the distribution of birefringence parameters (linear and circular birefringences) of polycrystalline structure of biological layers were provided.

It was demonstrated the results of experimental approbation of such method and defined the distributions of Jones-matrix invariants of linear and circular birefringence of skin derma tissue.

The differentiation of linear and circular birefringence was realized with good and excellent levels of balanced accuracy of differentiation between normal uterus wall tissue and with prolapse; normal and albuminuria patients.

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