Wavelet analysis of myocardium polarization images in problems of diagnostic of necrotic changes

Yu.O. Ushenko[a], O. Vanchuliak[b] , G.B. Bodnar[b], V.O. Ushenko[a], N. Pavlyukovich[b], O.V. Pavlyukovich[b], O. Antonyuk[b]

[a] Chernivtsi National University, 2 Kotsyubinsky Str., Chernivtsi, 58012, Ukraine

[b] Bukovinian State Medical University, Chernivtsi, 58000, Ukraine

ABSTRACT

The paper presents the results of polarization manifestations of small - and Large-scale phase anisotropy of dead in consequence of ischemic heart disease (IHD) and acute coronary insufficiency (ACI) people myocardial tissue structures To differentiate information, the wavelet analysis method is used. The resulting maps of the of the polarization-correlation parameters distributions (the phase of the two-point first and second parameters of the Stokes vector) are analyzed in the framework of statistical approach. On this basis, the criteria for differential diagnosis of IHD and ACI cases have been determined.

Keywords: polarization, wavelet analysis, diagnostic, necrotic changes.

1. INTRODUCTION

In the series of research works the possibility of polarimetry diagnostic [1-19] of optically anisotropic layers of biological tissues [20-22] and fluids [23-37] is demonstrated.

This research aims to study fundamental potentiality of ischemic heart disease and acute coronary insufficiency died patients myocardial tissue microscopic images wavelet analysis for polarization-correlation mapping.

2. THEORY OF THE METHOD

T.Setola, Ya.Tervo and A.T.Friberg [30,31] proposed 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 mutual spectral density matrix.

We have generalized this theory to the case of phase anisotropy of biological tissues. For this purpose, analytical expressions for the phase of the first and second complex two-point parameters of the Stokes vector are determined.

$$\begin{cases} ArgS_1 = arctg\left[\dfrac{\sin(\delta_2-\delta_1)}{ctg\rho_1 ctg\rho_2+\cos(\delta_2-\delta_1)}\right]. \end{cases} \quad (1)$$

$$\begin{cases} ArgS_2 = arctg\left[\dfrac{\sin(\delta_2-\delta_1)}{ctg\rho_1 ctg\rho_2-\cos(\delta_2-\delta_1)}\right]. \end{cases} \quad (2)$$

In the approximation of weak phase modulation, the expressions (1) - (2) acquire the following form

$$\begin{cases} ArgS_1 = arctg\left[\dfrac{(\delta_2-\delta_1)}{1+ctg\rho_1 ctg\rho_2}\right]. \end{cases} \quad (3)$$

Biosensing and Nanomedicine X, edited by Hooman Mohseni, Massoud H. Agahi, Manijeh Razeghi,
Proc. of SPIE Vol. 10352, 103520S · © 2017 SPIE · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2273752

$$\begin{cases} ArgS_2 = arctg\left[\dfrac{(\delta_2 - \delta_1)}{ctg\rho_1 ctg\rho_2}\right]. \end{cases} \quad (4)$$

It follows from the analysis of the obtained relations (5) - (6) that the SCP phase $Arg\left(S_{i=1;2;3;4}(\Delta x, \Delta y)\right)$ carries information about their birefringence ($\delta(x, y)$).

3. MATERIALS AND METHODS

Measurement of the coordinate distributions values is carried out in the experimental arrangement of Stokes-polarimeter, the optical scheme of which is shown in Fig. 1.

$Arg\left(S_{i=1}(\Delta x;\Delta y)\right)$ and $Arg\left(S_{i=2}(\Delta x;\Delta y)\right)$ were calculated by the following ratios

$$\begin{cases} ArgS_1 = arctg\left(\dfrac{\left[\sqrt{I_0(r_1)I_{90}(r_2)}\sin\delta_2 + \sqrt{I_0(r_2)I_{90}(r_1)}\sin\delta_1\right]}{\left[\sqrt{I_0(r_1)I_{90}(r_2)}\cos\delta_2 + \sqrt{I_0(r_2)I_{90}(r_1)}\cos\delta_1\right]}\right). \end{cases} \quad (5)$$

$$\begin{cases} ArgS_2 = arctg\left(\dfrac{\left[\sqrt{I_0(r_2)I_{90}(r_1)}\cos\delta_2 - \sqrt{I_0(r_1)I_{90}(r_2)}\cos\delta_1\right]}{\left[\sqrt{I_0(r_2)I_{90}(r_1)}\sin\delta_1 + \sqrt{I_0(r_1)I_{90}(r_2)}\sin\delta_2\right]}\right). \end{cases} \quad (6)$$

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 histological sections (geometrical thickness $l = 25\mu m \div 30\mu m$ $0.0093 \le \tau \le 0.0099$) of myocardium biological tissues of internals of two statistically significant (37 samples each) groups.

Histological sections of biological tissues of rat's internal were produced by the standard technique in freezing microtome.

5. EXPERIMENTAL RESULTS AND DISCUSSION

The coordinate distributions of the phase and the corresponding histograms of the phase of large-scale (Fig. 1) and small-scale (Fig. 2) polarization correlation parameters of the Stokes vector of images of the histological sections of the myocardium with IHD (fragments (1), (2)) and ACI (fragments (3) , (4)) were submitted.

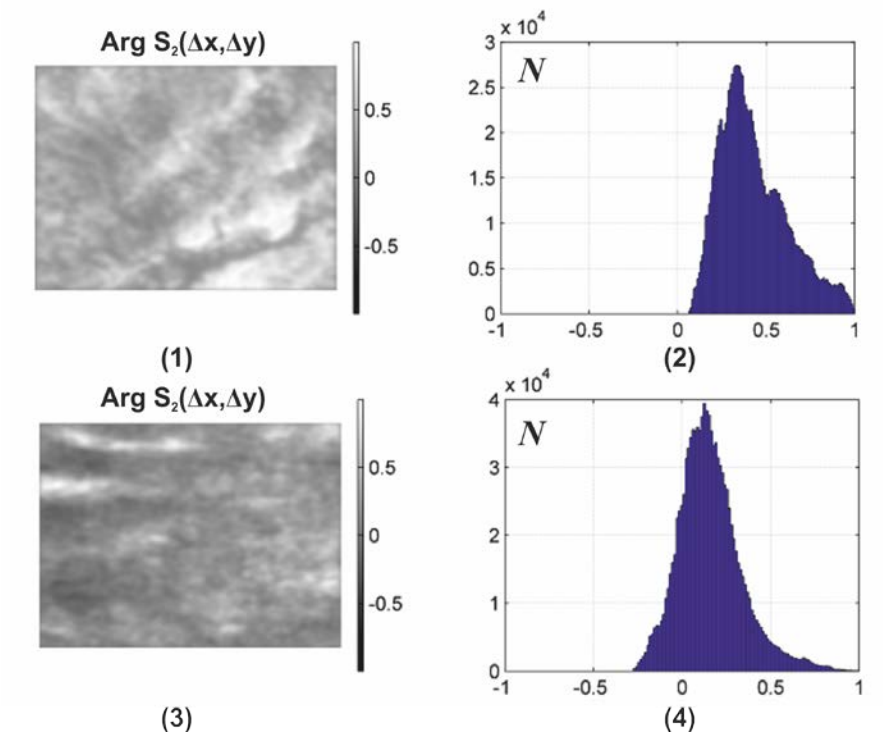

Figure 1. Polarization maps of the phase of the second parameter of the Stokes vector (fragments (1), (3)) and histograms of the corresponding distributions (fragments (2), (4)) of the large-scale birefringence structure of the histological sections of the myocardium with IHD (fragments (1), (2)) and ACI (fragments (3), (4)).

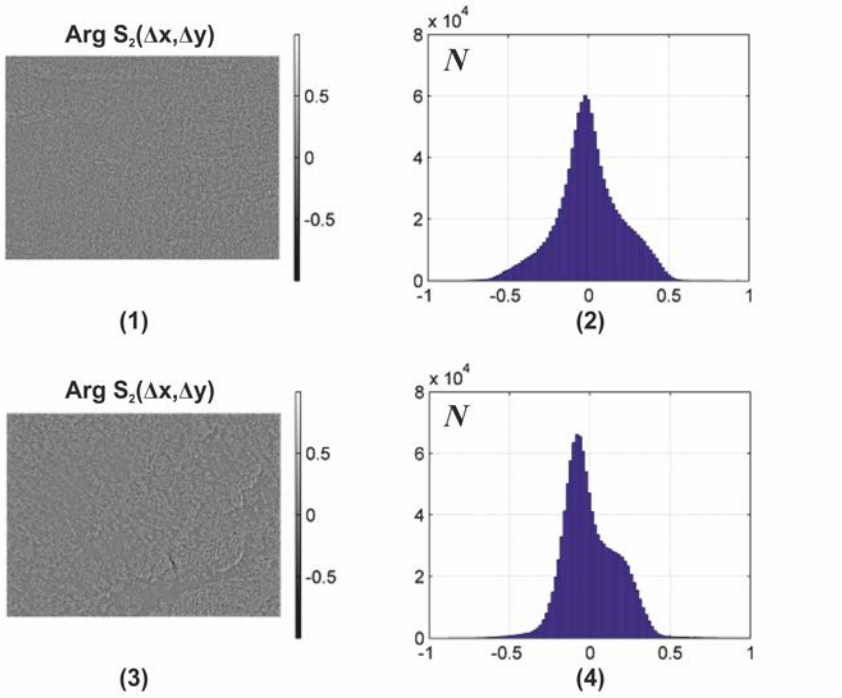

Figure 2. Polarization maps of the phase of the second parameter of the Stokes vector (fragments (1), (3)) and histograms of the corresponding distributions (fragments (2), (4)) of the low-scale birefringence structure of the histological sections of the myocardium with IHD (fragments (1), (2)) and ACI (fragments (3), (4)).

6. INTERGROUP STATISTICAL, CORRELATION AND FRACTAL ANALYSIS OF THE PHASE DISTRIBUTIONS OF SCP-MAPS

The results are presented in Table 1.

Table 1 Statistical parameters SCP phase maps

$Arg(S_2(\Delta x;\Delta y))$	IHD (low)	ACI (large)	IHD (low)	ACI (large)
Z_1	0.13 ± 0.0056	1.21 ± 0.015	0.23 ± 0.013	0.81 ± 0.054
Z_2	0.23 ± 0.015	0.33 ± 0.017	0.21 ± 0.014	0.28 ± 0.015
Z_3	0.43 ± 0.034	0.23 ± 0.017	0.87 ± 0.056	0.47 ± 0.035
Z_4	1.12 ± 0.033	1.21 ± 0.047	1.98 ± 0.096	1.79 ± 0.093

The analysis of the data presented in Table 1 showed:

• individual for each type of biological tissue values of statistical $Z_{i=1;2;3;4}$, parameters describing the coordinate distributions $Arg(S_2(\Delta x;\Delta y))$;

• the values of statistical moments of the 3rd ($Z_3(Arg(S_2))$) (by 2.15 – 3.6 times) and 4th ($Z_4(Arg(S_2))$) orders (by 1.23 – 2.56 times).

CONCLUSION

A new method of wavelet-analysis of the coordinate distributions of the phase of "two-point" Stokes-vector parameters of polarization-inhomogeneous images of histological sections of biological tissues of myocardium is suggested and analytically substantiated.

The comparative analysis of the objective statistical analysis of distributions of polarization Stokes-vector parameters of polarization-inhomogeneous images of histological sections under study demonstrated the excellent accuracy ($Ac \succ 90\%$) of differential diagnostics of changes in optical anisotropy of myocardium by the wavelet method.

REFERENCES

[1] Müller G.et al., Eds., "Medical Optical Tomography: Functional Imaging and Monitoring" Vol. IS11, SPIE Press, Bellingham, Washington (1993).

[2] Yao G., Wang L. V., "Two-dimensional depth-resolved Mueller matrix characterization of biological tissue by optical coherence tomography" Opt. Lett., V. 24, 537-539 (1999).

[3] Lu S., Chipman R. A., "Interpretation of Mueller matrices based on polar decomposition" J. Opt. Soc. Am. A., Vol. 13, 1106-1113 (1996).

[4] Tuchin V. V., Tranquillo R. T., [*Light scattering study of tissues*], Physics-Uspekhi 40(5), 495–515 (1997).

[5] Tower T. T., "Alignment Maps of Tissues: I. Microscopic Elliptical Polarimetry" Biophys. J. Vol. 81, 2954-2963 (2001).

[6] Tynes H. H. et al., "Monte Carlo and multicomponent approximation methods for vector radiative transfer by use of effective Mueller matrix calculations," Appl. Opt. 40(3), 400–412 (2001).

[7] Wang X., Wang L.-H., "Propagation of polarized light in birefringent turbid media: a Monte Carlo study" J. Biomed. Opt., Vol. 7, 279-290 (2002).

[8] Tuchin V. V. [*Handbook of optical biomedical diagnostics*], Bellingham, SPIE Press, 1110 p (2002).

[9] Ushenko A. G., Pishak V. P., “Laser Polarimetry of Biological Tissue: Principles and Applications”, in Handbook of Coherent-Domain Optical Methods: Biomedical Diagnostics, Environmental and Material Science edited by Valery V. Tuchin, Kluwer Academic Publishers, Vol. 1, 93-138 (2004).
[10] Tuchin V. V., Wang L., and Zimnyakov D. A`, [*Optical Polarization in Biomedical Applications*], New York, USA (2006).
[11] Wang L. V.and Wu H.-I., [*Biomedical Optics: Principles and Imaging*], Wiley-Interscience, Hoboken, New Jersey (2007).
[12] Ghosh N., Wood M. F. G. and Vitkin I. A., “Polarized light assessment of complex turbid media such as biological tissues via Mueller matrix decomposition,” in Handbook of Photonics for Biomedical Science, V.V. Tuchin, Ed., CRC Press, Taylor & Francis Group, London, 253–282 (2010).
[13] Angelsky O.V., Ushenko A.G., Ushenko Yu.A., Pishak V.P., Peresunko A.P., “Statistical, Correlation and Topological Approaches in Diagnostics of the Structure and Physiological State of Birefringent Biological Tissues” in Handbook of Photonics for Biomedical Science ed. by Valery V. Tuchin, CRC Press, Taylor&Francis group: Boca Raton, London, New York, 283-322 (2010).
[14] O.V. Angelsky, S.G. Hanson, P.P. Maksimyak, A.P. Maksimyak, C.Yu. Zenkova, P.V. Polyanskii, and D.I. Ivanskyi, "Influence of evanescent wave on birefringent microplates," Opt. Express 25, 2299-2311 (2017).
[15] Angelsky, O. V., Bekshaev, A. Ya., Maksimyak, P. P., Maksimyak, A. P., Hanson, S. G., Kontush, S. M., "Controllable generation and manipulation of micro-bubbles in water with absorptive colloid particles by CW laser radiation," Opt. Express 25, 5232-5243 (2017).
[16] Angelsky, O. V., Bekshaev, A. Ya., Maksimyak, P. P., Maksimyak, A. P., Hanson, S. G., Zenkova, C. Yu., “Self-diffraction of continuous laser radiation in a disperse medium with absorbing particles,” Optics Express 21(7), 8922-8938, (2013).
[17] Angelsky, O. V., Bekshaev, A. Ya., Maksimyak, P. P., Maksimyak, A. P., Hanson, S. G., Zenkova, C. Yu., ”Self-action of continuous laser radiation and Pearcey diffraction in a water suspension with light-absorbing particles,” Optics Express 22(3), 2267-2277, (2014).
[18] Angelsky, O. V., Bekshaev, A. Ya., Maksimyak, P. P., Maksimyak, A. P., Hanson, S. G., “Measurement of small light absorption in microparticles by means of optically induced rotation,” Optics Express 23(6), 7152-7163 (2015).
[19] Angelsky, O.V., Tomka, Y.Y., Ushenko, A.G., Ushenko, Y.G., Yermolenko, S.B., ”2-D tomography of biotissue images in pre-clinic diagnostics of their pre-cancer states,” Proc. SPIE., 5972, 158-162, (2005).
[20] Ushenko V. A., Gavrylyak M. S., ”Azimuthally invariant Mueller-matrix mapping of biological tissue in differential diagnosis of mechanisms protein molecules networks anisotropy” Proc. SPIE 8812, Biosensing and Nanomedicine VI, 88120Y (September 11, 2013).
[21] Ushenko V. O. “Two-dimensional Mueller matrix phase tomography of self-similarity birefringence structure of biological tissues” Proc. SPIE 8487, Novel Optical Systems Design and Optimization XV, 84870W (October 19, 2012).
[22] Ushenko V. A., Pavlyukovich N. D., Trifonyuk L., “Spatial-Frequency Azimuthally Stable Cartography of Biological Polycrystalline Networks” International Journal of Optics , Volume 2013, Article ID 683174, 7 pages (2013).
[23] Ushenko Yu. A., Ushenko V. A., Dubolazov A. V., Balanetskaya V. O. and Zabolotna N. I., “Mueller-matrix diagnostics of optical properties of polycrystalline networks of human blood plasma” Optics and Spectroscopy, Volume 112, Issue 6, 884-892 (June 2012).
[24] Ushenko Yu. A., Dubolazov A. V., Balanetskaya V. O., Karachevtsev A. O., Ushenko V. A., “Wavelet-analysis of polarization maps of human blood plasma” Optics and Spectroscopy, Volume 113, Issue 3, 332-343 (September 2012).
[25] Ushenko V. O., “Spatial-frequency polarization phasometry of biological polycrystalline networks” Optical Memory and Neural Networks, Volume 22, Issue 1, 56-64 (March 2013).
[26] Ushenko V. A., Dubolazov O. V., Karachevtsev A. O., “Two wavelength Mueller matrix reconstruction of blood plasma films polycrystalline structure in diagnostics of breast cancer” Applied Optics, Vol. 53, Issue 10, B128-B139 (2014).
[27] Ushenko A.G., Pashkovskaya N.V., Dubolazov O.V., Ushenko Yu.A., Marchuk Yu.F. and Ushenko V.A., “Mueller matrix images of polycrystalline films of human biological fluids,” Romanian reports in physics. 67(4), 1467-1479 (2015).

[28] Prysyazhnyuk V. P., Ushenko Yu. A., Dubolazov A. V., Ushenko A. G. and Ushenko V. A., "Polarization-dependent laser autofluorescence of the polycrystalline networks of blood plasma films in the task of liver pathology differentiation," Appl. Opt. 55, B126-B132 (2016).
[29] Dubolazov A. V., Pashkovskaya N. V., Ushenko Yu. A., Marchuk Yu. F., Ushenko V. A. and Novakovskaya O. Yu., "Birefringence images of polycrystalline films of human urine in early diagnostics of kidney pathology"Appl. Opt. 55, B85-B90 (2016).
[30] Tervo J., Setala T., Friberg A., "Degree of coherence for electromagnetic fields," Opt. Express 11, 1137-1143 (2003).
[31] Tervo J., Setala T., Friberg A., "Two-point Stokes parameters: interpretation and properties," Optics Letters 34(20), 3074-3076 (2009).
[32] Ushenko Yu. A., Gorskii M. P., Dubolazov A. V., Motrich A. V., Ushenko V. A. and Sidor M. I., "Spatial-frequency Fourier polarimetry of the complex degree of mutual anisotropy of linear and circular birefringence in the diagnostics of oncological changes in morphological structure of biological tissues" Quantum Electron, Volume 42(8) (2012).
[33] Angelsky, O.V., Besaha, R.N., Mokhun, A.I., Mokhun, I.I., Sopin, M.O., Soskin, M.S., "Singularities in vectoral fields," Proc. SPIE, 40-54, (1999).
[34] Polyanskii, V.K., Angelsky, O.V., Polyanskii, P.V., "Scattering-induced spectral changes as a singular optical effect," Optica Applicata 32 (4), 843-848, (2002).
[35] Ushenko Yu. A., Bachynsky V. T., Vanchulyak O. Ya., Dubolazov A. V., Garazdyuk M. S. and Ushenko V. A., "Jones-matrix mapping of complex degree of mutual anisotropy of birefringent protein networks during the differentiation of myocardium necrotic changes," Appl. Opt. 55, B113-B119 (2016).
[36] Cassidy, "Basic concepts of statistical analysis for surgical research," Journal of Surgical Research 128, 199-206 (2005).
[37] Davis C. S., [*Statistical methods of the analysis of repeated measurements*], New York: Springer-Verlag (2002).
[38] A. Petrie, B. Sabin, [*Medical Statistics at a Glance*], pp. 157, Blackwell Publishing (2005).