

# Polarization Reconstruction of Fluctuations in the Parameters of the Phase Anisotropy of Biological Crystals Networks in Differentiation of Cerebral Infarction

M. Garazdyuk<sup>1</sup>, V. Bachinsky<sup>1</sup>, O. Vanchulyak<sup>1</sup>, A.Ushenko<sup>2</sup> Yu.Ushenko<sup>2</sup>, A.Dubolazov<sup>2\*</sup>, P.Gorodensky<sup>2</sup>, O.Yatsko<sup>2</sup>, Lin Bin<sup>3</sup>, Chen Zhebo<sup>3</sup>

<sup>1</sup> Bukovinian State Medical University, 3 Theatral Sq., Chernivtsi, Ukraine, 58000

<sup>2</sup> Chernivtsi National University, 2 Kotsiubynskyi Str., Chernivtsi, Ukraine, 58012

<sup>3</sup> Reasearch Institute of Zhejiang University-Taizhou, 38 Zheda Road, Hangzhou, People's Republic of China, Zhejiang Province, 310027

[a.dubolazov@chnu.edu.ua](mailto:a.dubolazov@chnu.edu.ua)

## ABSTRACT

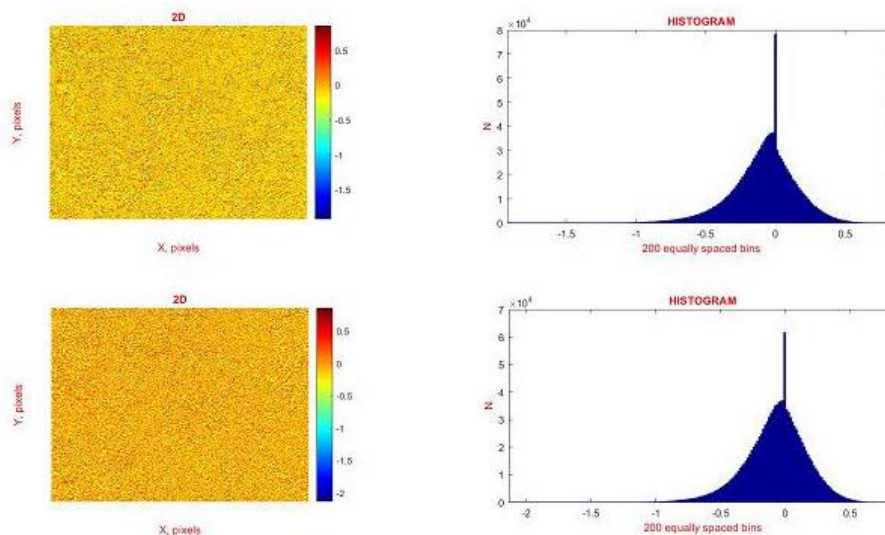
Our work consists the materials of the experimental determination of the set of maps and histograms of the magnitude distribution of the linear (DFLB) birefringence fluctuations for differential diagnosis and the formation of hemorrhages of traumatic origin, cerebral infarction ischemic and hemorrhagic genesis by diffuse tomography of the polycrystalline structure of brain histological sections .

**Keywords:** birefringence, polycrystalline structure, brain tissue, diagnostics.

## 1. Introduction

Cases of coronary heart disease (control group 1), traumatic hemorrhage (research group 2), cerebral infarction ischemic (research group 3), and hemorrhagic (research group 4) genesis were investigated.

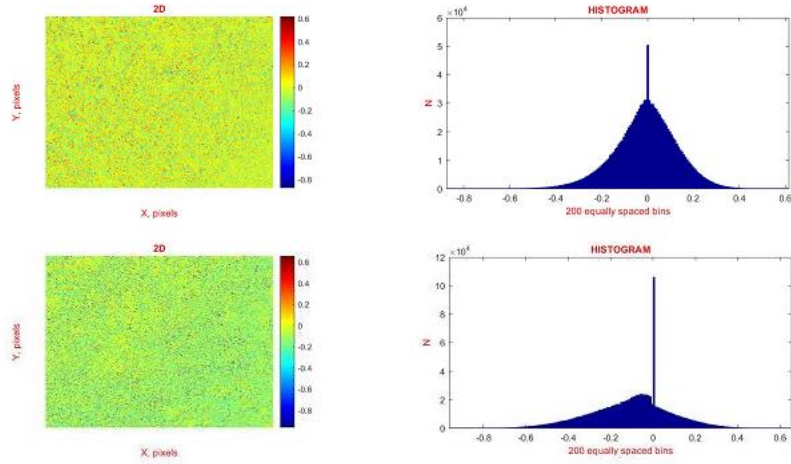
In Fig. 1 and Fig. 2 are shown the polarized-reproduced diffuse maps of DFLB (left column) and histograms (right column) of the distribution of the magnitude of fluctuations in the linear birefringence of histological sections of the brain of the deceased.



**Fig. 1.** Maps (left column) and histograms (right column) of the DFLB distribution of histological sections of the brain of the dead from group 1 (top row) and group 2 (bottom row).

From the analysis of diffuse tomography data<sup>1,2</sup> of the distribution of the magnitude of the fluctuations of linear birefringence, it was found:

- individual topographic structure of the distribution of fluctuations of linear birefringence of fibrillar networks of histological sections of the brain of deceased from all groups;



**Fig. 2.** Maps (left column) and histograms (right column) of the DFLB distribution of histological sections of the brain of the dead from group 3 (top row) and group 4 (bottom row).

- histograms of the distribution of the DFLB value of histological sections of the brain from all groups are characterized by different localization of the main extreme, ranges of scatter of random values, significant asymmetry and sharpness of the peak.

## 2. Methodology and theory of the method

A sample of brain tissue is taken from a corpse. Histological sections are irradiated with a low coherent semiconductor laser diode with a wavelength of 0.405  $\mu\text{m}$ ; four partial channels of laser probe beams with polarization azimuths are formed "0<sup>0</sup>"; "90<sup>0</sup>"; "45<sup>0</sup>"; and "rights circulation", project the image of histological sections of brain tissue into the plane of the digital photosensitive camera, for each channel of optical sensing, multi-parameter polarization filtering is implemented ("0<sup>0</sup>", "90<sup>0</sup>", "45<sup>0</sup>", "135<sup>0</sup>" "right circulation" and "left circulation"), measure a series of coordinate distributions of the intensity of digital laser images of histological sections of brain tissue, on this basis determine the coordinate distributions of the mean values of phase (linear and circular birefringence) and amplitude (linear and circular dichroism) anisotropy, calculate the statistical moments of the 1st - 4th orders of such distributions, determine the temporal dynamics of changes in their magnitude, and are used in differential diagnosis and determining the limitation of the formation of hemorrhages of traumatic origin, ischemic cerebral infarction and hemorrhagic origin.

The theoretical basis for using the method is the following data.

In<sup>1-7</sup>, polarization reproduction algorithms were obtained for the average values of the phase ( $\langle \Delta n_{0,90} \rangle$ ;  $\langle \Delta n_{45,135} \rangle$ ;  $\langle \Delta n_{\otimes, \oplus} \rangle$ ) and amplitude ( $\langle \Delta \mu_{0,90} \rangle$ ;  $\langle \Delta \mu_{45,135} \rangle$ ;  $\langle \Delta \mu_{\otimes, \oplus} \rangle$ ) anisotropy parameters of a partially depolarizing biological layer according to the values of the elements of the Mueller matrix.

Linear birefringence:

$$\langle \Delta n_{0,90} \rangle = \frac{\lambda}{2\pi r} \ln \left( \frac{f_{34}}{f_{43}} \right); \quad (1)$$

$$\langle \Delta n_{45,135} \rangle = \frac{\lambda}{2\pi r} \ln \left( \frac{f_{24}}{f_{42}} \right); \quad (2)$$

Circular birefringence:

$$\langle \Delta n_{\otimes;\oplus} \rangle = \frac{\lambda}{2\pi r} \ln \left( \frac{f_{23}}{f_{32}} \right); \quad (3)$$

Here  $\lambda$  is the wavelength;  $\Delta n_{0,90}$ ;  $\Delta n_{45,135}$  - the magnitude of birefringence for linearly polarized with azimuths  $0^\circ \div 90^\circ$  and  $45^\circ \div 135^\circ$  orthogonal components of the amplitude of the laser radiation;  $\Delta n_{CB}$  - birefringence value for circularly right- ( $\otimes$ ) and left ( $\oplus$ ) orthogonally polarized components of the amplitude of the laser radiation.

Linear dichroism

$$\langle \Delta \mu_{0,90} \rangle = \frac{\lambda}{2\pi r} \ln(f_{12}f_{21}); \quad (4)$$

$$\langle \Delta \mu_{45,135} \rangle = \frac{\lambda}{2\pi r} \ln(f_{13}f_{31}); \quad (5)$$

Circular dichroism

$$\langle \Delta \mu_{\otimes;\oplus} \rangle = \frac{\lambda}{2\pi r} \ln(f_{14}f_{41}) \quad (6)$$

here  $\Delta \mu_{0,90}$ ;  $\Delta \mu_{45,135}$ ;  $\Delta \mu_{\otimes;\oplus}$  - is the difference between the absorption coefficients  $\mu_0$ ;  $\mu_{90}$ ;  $\mu_{45}$ ;  $\mu_{135}$ ;  $\mu_{\otimes}$ ;  $\mu_{\oplus}$  of the linearly polarized with azimuths  $0^\circ \div 90^\circ$  and  $45^\circ \div 135^\circ$  and the circularly right- ( $\otimes$ ) and left ( $\oplus$ ) orthogonally polarized components of the amplitude of the laser radiation.

Thus, the differential approach to the analysis of data obtained by the direct Mueller matrix mapping method<sup>8-11</sup> made it possible to obtain a set of algorithms (relation (1) - (6)) for polarization reproduction of distributions of average values of linear and circular birefringence ( $\langle \Delta n_{0,90} \rangle$ ;  $\langle \Delta n_{45,135} \rangle$ ;  $\langle \Delta n_{\otimes;\oplus} \rangle$ ) and dichroism ( $\langle \Delta \mu_{0,90} \rangle$ ;  $\langle \Delta \mu_{45,135} \rangle$ ;  $\langle \Delta \mu_{\otimes;\oplus} \rangle$ ).

### 3. Results and discussion

The average values and mistakes of determining the set of statistical moments of the 1st - 4th orders of magnitude characterizing the distribution of the DFLB value are presented in table 1.

**Table 1.** Statistical moments of the 1st - 4th orders characterizing the distribution of the DFLB value of histological sections of the brain of groups 1 – 4

Parameters	Group 1	Group 2	Group 3	Group 4
$SM_1$	$0,08 \pm 0,0035$	$0,12 \pm 0,005$	$0,14 \pm 0,006$	$0,13 \pm 0,0055$
$SM_2$	$0,11 \pm 0,0045$	$0,16 \pm 0,007$	$0,21 \pm 0,009$	$0,17 \pm 0,0075$
$SM_3$	$0,41 \pm 0,019$	$0,33 \pm 0,015$	$0,27 \pm 0,012$	$0,21 \pm 0,009$
$SM_4$	$0,56 \pm 0,025$	$0,48 \pm 0,021$	$0,39 \pm 0,018$	$0,31 \pm 0,013$

The results of a statistical analysis of polarized-reconstructed maps of the magnitude of fluctuations of linear birefringence (table 1) found a statistically significant difference ( $P_{i=3;4}$ ) between the values of all statistical moments of the 3rd and 4th orders of magnitude characterizing the asymmetry and excess of the distributions of the magnitude of

the DFLB of histological sections of the brain for cases of coronary heart disease, hemorrhages of traumatic origin, cerebral infarction of ischemic and hemorrhagic genesis (control group 1 and research groups 2 to 4).

An information analysis of the strength of the method of diffuse tomography of linear birefringence of the fibrillar networks of the nervous tissue of brain samples revealed the following diagnostic effectiveness, which is illustrated by the data shown in Table 2.

**Table 2.** The specificity, sensitivity, accuracy of the DFLB method of histological sections of the brain

<b>Groups "1 – 2+3+4"</b>			
Parameters	Sensitivity, $Se$ ,%	Specificity, $Sp$ ,%	Accuracy, $Ac$ ,%
$SM_1$	<b>86</b>	<b>84</b>	<b>85</b>
$SM_2$	<b>92</b>	<b>90</b>	<b>91</b>
$SM_3$	<b>100</b>	<b>98</b>	<b>99</b>
$SM_4$	<b>100</b>	<b>97</b>	<b>98,5</b>
<b>Groups "2 – 3"</b>			
Parameters	Sensitivity, $Se$ ,%	Specificity, $Sp$ ,%	Accuracy, $Ac$ ,%
$SM_1$	<b>82</b>	<b>80</b>	<b>81</b>
$SM_2$	<b>84</b>	<b>82</b>	<b>83</b>
$SM_3$	<b>95</b>	<b>95</b>	<b>95</b>
$SM_4$	<b>95</b>	<b>95</b>	<b>95</b>
<b>Groups "2 – 4"</b>			
Parameters	Sensitivity, $Se$ ,%	Specificity, $Sp$ ,%	Accuracy, $Ac$ ,%
$SM_1$	<b>83</b>	<b>81</b>	<b>82</b>
$SM_2$	<b>82</b>	<b>80</b>	<b>81</b>
$SM_3$	<b>92</b>	<b>88</b>	<b>90</b>
$SM_4$	<b>92</b>	<b>88</b>	<b>90</b>
<b>Groups "3 – 4"</b>			
Parameters	Sensitivity, $Se$ ,%	Specificity, $Sp$ ,%	Accuracy, $Ac$ ,%
$SM_1$	<b>70</b>	<b>66</b>	<b>68</b>
$SM_2$	<b>68</b>	<b>64</b>	<b>66</b>
$SM_3$	<b>82</b>	<b>80</b>	<b>81</b>
$SM_4$	<b>81</b>	<b>79</b>	<b>80</b>

## Conclusions

The following strength parameters of the diffuse tomography method were experimentally established:

- satisfactory (average - 84% - 86%), good (dispersion - 90% - 92%) and excellent (asymmetry and excess - 97% - 100%) balanced accuracy of differentiation of histological sections of the brain of the "1" - "2 + 3 + 4" groups ;
- good ( $SM_3$ ;  $SM_4$  - 88% - 92%) balanced accuracy of intergroup differentiation of histological sections of the brain sections of the "2" - "4" groups;
- satisfactory (statistical moments of the 1st and 2nd orders - 80% - 82%) and excellent (statistical moments of the 3rd and 4th orders - 95%) balanced accuracy of intergroup differentiation of histological sections of the brain of the "2" - "3" groups ;

- unsatisfactory balanced accuracy of intergroup differentiation of histological sections of the brain of the "3" - "4" groups;

## References

- [1]. Ushenko, O. G., Grytsyuk, M., Ushenko, V. O., Bodnar, G. B., Vanchulyak, O., & Meglinskiy, I. (2018, January). Differential 3D Mueller-matrix mapping of optically anisotropic depolarizing biological layers. In *Thirteenth International Conference on Correlation Optics* (Vol. 10612, p. 106121I). International Society for Optics and Photonics.
- [2]. Toshitaka Kobata and Takanori Nomura, "Digital holographic three-dimensional Mueller matrix imaging," *Applied Optics* Vol. 54, No. 17, pp.5591-5596 (2015).
- [3]. Ushenko, A.G., Dubolazov, O.V., Bachynsky, V.T., Peresunko, A.P., Vanchulyak, O.Y., "On the feasibilities of using the wavelet analysis of mueller matrix images of biological crystals," (2010) *Advances in Optical Technologies*, 162832.
- [4]. Zabolotna, N.I., Wojcik, W., Pavlov, S.V., Ushenko, O.G., Suleimenov, B., "Diagnostics of pathologically changed birefringent networks by means of phase Mueller matrix tomography," (2013) *Proceedings of SPIE - The International Society for Optical Engineering*, 8698, 86980.
- [5]. Ushenko, A.G., "Correlation Processing and Wavelet Analysis of Polarization Images of Biological Tissues," (2001) *Optics and Spectroscopy* (English translation of *Optika i Spektroskopiya*), 91 (5), pp. 773-778.
- [6]. Ushenko, A.G., Ermolenko, S.B., Burkovets, D.N., Ushenko, Yu.A., "Polarization microstructure of laser radiation scattered by optically active biotissues," (1999) *Optika i Spektroskopiya*, 87 (3), pp. 470-474.
- [7]. Ushenko, A.G., Dubolazov, A.V., Ushenko, V.A., Novakovskaya, O.Y., "Statistical analysis of polarization-inhomogeneous Fourier spectra of laser radiation scattered by human skin in the tasks of differentiation of benign and malignant formations," (2016) *Journal of Biomedical Optics*, 21 (7), 071110.
- [8]. Bekshaev AY, Angelsky OV, Sviridova SV, Zenkova CY. Mechanical action of inhomogeneously polarized optical fields and detection of the internal energy flows. *Adv Opt Technol* 2011.
- [9]. Angelsky, O. V., Maksimyak, P. P., & Perun, T. O. (1993). Optical correlation method for measuring spatial complexity in optical fields. *Optics Letters*, 18(2), 90-92.
- [10]. Angelsky, O. V., Bekshaev, A. Y. A., Maksimyak, P. P., Maksimyak, A. P., & Hanson, S. G. (2018). Low-temperature laser-stimulated controllable generation of micro-bubbles in a water suspension of absorptive colloid particles. *Optics Express*, 26(11), 13995-14009.
- [11]. Angelsky, O. V. (2007). Optical correlation techniques and applications. *Optical correlation techniques and applications* (pp. 1-270)