PROCEEDINGS OF SPIE

Fifteenth International Conference on Correlation Optics

Oleg V. Angelsky
Editor

13–16 September 2021
Chernivtsi, Ukraine

Organized by
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Volume 12126

Proceedings of SPIE 0277-786X, V. 12126

Fifteenth International Conference on Correlation Optics, edited
by Oleg V. Angelsky, Proc. of SPIE Vol. 12126, 1212601
© 2021 SPIE · 0277-786X · doi: 10.1117/12.2626737

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Author(s), "Title of Paper," in *Fifteenth International Conference on Correlation Optics*, edited by Oleg V. Angelsky, Proc. of SPIE 12126, Seven-digit Article CID Number (DD/MM/YYYY); (DOI URL).

ISSN: 0277-786X
ISSN: 1996-756X (electronic)

ISBN: 9781510651289
ISBN: 9781510651296 (electronic)

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time)
SPIE.org

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Forensic medical assessment of cerebral infarction, hemorrhagic hemorrhages of traumatic genesis and determination of the duration of their formation methods of spectral-selective laser-induced direct polarization-phase tomography

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ABSTRACT

The structural-logical diagram and research design by the methods of polarization-phase tomography of linear dichroism of the polycrystalline structure [1-5] of histological sections of the brain are presented. Differential diagnosis of the formation of hemorrhages of traumatic genesis, cerebral infarction of ischemic and hemorrhagic genesis by the method of differential Mueller-matrix mapping of amplitude anisotropy - linear dichroism maps (ALD) of histological brain sections and operational characteristics of the method of their statistical analysis.

Differential diagnosis of the prescription of the formation of hemorrhages of traumatic genesis, cerebral infarction, ischemic and hemorrhagic genesis by the method of differential Mueller-matrix mapping of amplitude anisotropy - temporal dynamics of changes in the statistical structure of ALD maps of histological brain sections.

Keywords: polarization, optical anisotropy, linear dichroism, Mueller's matrix, statistical moments of the 1st-4th orders, hemorrhages of traumatic origin, cerebral infarction of ischemic and hemorrhagic genesis.

1. STRUCTURAL AND LOGICAL DIAGRAM OF POLARIZATION-PHASE TOMOGRAPHY OF THE POLYCRYSTALLINE STRUCTURE OF HISTOLOGICAL SECTIONS OF BRAIN

Histological sections of the brain of the deceased			
Control group deceased (group 1)	Hemorrhage of traumatic genesis (group 2)	Cerebral infarction of ischemic genesis (group 3)	Cerebral infarction of hemorrhagic genesis (group 4)
Mueller-matrix mapping of maps of elements of 1st order differential matrix [6,7]			
Algorithms for reconstructing the distributions of average values of parameters of amplitude anisotropy			
Linear dichroism maps (ALD)			
Statistical analysis of ALD maps			
Average values and standard deviations of the magnitude of the statistical moments of the 1st - 4th orders, which characterize the coordinate distributions of the ALD value			
Criteria for differential diagnosis of samples of histological sections of the brain of the deceased from groups 1 - 4			
Time dynamics of changes in the value of statistical moments of the 1st - 4th orders, which characterize the coordinate distributions of the ALD value			
Duration of formation of hemorrhages of traumatic genesis, cerebral infarction of ischemic and hemorrhagic genesis by methods of polarization-phase tomography [8-12]			

Fig. 1. Structural and logical diagram of polarization-phase tomography of histological sections of the brain

Fifteenth International Conference on Correlation Optics, edited by Oleg V. Angelsky, Proc. of SPIE Vol. 12126, 1212621

2. DIFFERENTIAL DIAGNOSIS OF THE FORMATION OF HEMORRHAGES OF TRAUMATIC GENESIS, CEREBRAL INFARCTION ISCHEMIC AND HEMORRHAGIC GENESIS BY THE METHOD OF POLARIZATION-PHASE REPRODUCTION OF LINEAR DICHROISM

A series of fragments in Fig. 2 shows the results of studying the coordinate (fragments (1), (3), (5), (7)) and histograms (fragments (2), (4), (6), (8)) distributions of the linear dichroism value of fibrillar networks of the nervous brain tissue with various types of pathology.

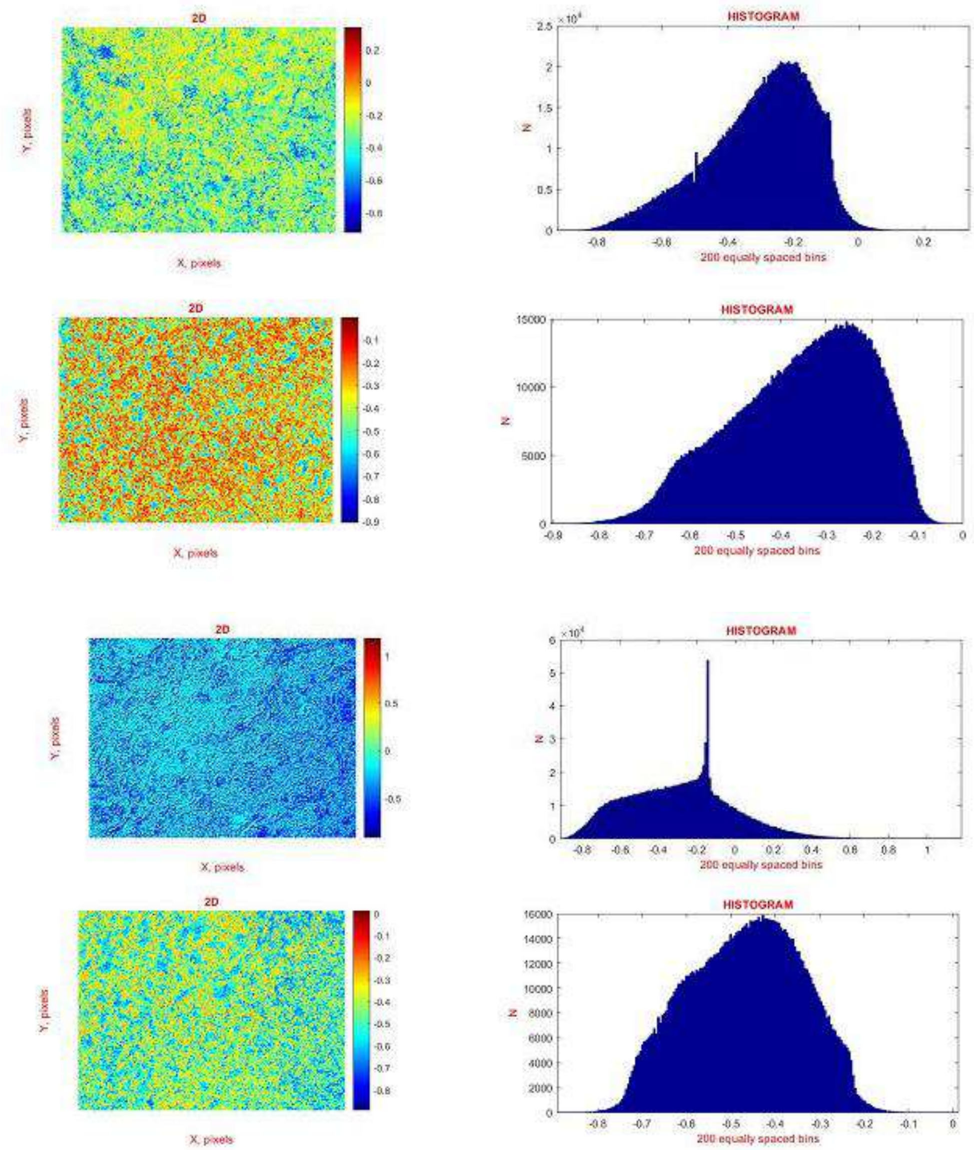

Fig. 2. Maps ((1), (2), (3), (4)) and histograms ((4), (5), (6), (7)) of the distribution of the ALD value of histological sections of the brain of the deceased from group 1 ((1), (5)), group 2 ((2), (6)), group 3 ((3), (7)) and group 4 ((4), (8)).

Analysis of polarization-reconstructed ALD maps revealed:

- individual topographic structure of all ALD maps of histological sections of the nervous tissue of the brain of the deceased from groups 1 - 4 (Fig. 2, fragments (1), (3), (5), (7));

- The histograms characterizing the distributions of the linear dichroism value of the fibrillar networks of the brain nervous tissue samples from the control 1 and research groups 2 - 4 are characterized by maximum differences in the average value SM_1, the spread of random values (dispersion SM_2), significant skewness (SM_3) and sharpness (kurtosis SM_4) of the peak (Fig. 5.4, fragments (2), (4), (6), (8)).

Table 1 presents the data of the statistical analysis of ALD maps - the mean values and errors ($\pm\Omega$) for determining the set of statistical moments of the 1st - 4th orders $SM_{i=1-4}$, characterizing the distributions of the linear dichroism value of the nervous tissue of the brain.

Table 1 Statistical moments of the 1st - 4th orders, characterizing the distributions of the ALD value of histological sections of the brain of groups 1 – 4

Parameters	Group 1	Group 2	Group 3	Group 4
SM_1	$0,18 \pm 0,008$	$0,24 \pm 0,011$	$0,31 \pm 0,014$	$0,39 \pm 0,017$
p_1		$p \prec 0,05$	$p \prec 0,05$	$p \prec 0,05$
p_2		$p \prec 0,05$		$p \prec 0,05$
p_3		$p \prec 0,05$	$p \prec 0,05$	
p_4		$p \prec 0,05$		
SM_2	$0,33 \pm 0,015$	$0,39 \pm 0,018$	$0,45 \pm 0,021$	$0,51 \pm 0,023$
p_1		$p \prec 0,05$	$p \prec 0,05$	$p \prec 0,05$
p_2		$p \prec 0,05$		$p \prec 0,05$
p_3		$p \prec 0,05$	$p \prec 0,05$	
p_4		$p \prec 0,05$		
SM_3	$0,65 \pm 0,031$	$0,77 \pm 0,035$	$0,91 \pm 0,042$	$1,11 \pm 0,052$
p_1		$p \prec 0,05$	$p \prec 0,05$	$p \prec 0,05$
p_2		$p \prec 0,05$		$p \prec 0,05$
p_3		$p \prec 0,05$	$p \prec 0,05$	
p_4		$p \prec 0,05$		
SM_4	$0,53 \pm 0,023$	$0,91 \pm 0,041$	$0,79 \pm 0,036$	$1,18 \pm 0,051$
p_1		$p \prec 0,05$	$p \prec 0,05$	$p \prec 0,05$
p_2		$p \prec 0,05$		$p \prec 0,05$
p_3		$p \prec 0,05$	$p \prec 0,05$	
p_4		$p \prec 0,05$		

The results of statistical analysis of the data of polarization-phase tomography of linear dichroism maps shown in Table 1 illustrate the statistically significant difference ($p_{i=1;2;3;4} \prec 0,05$) between the mean values of all statistical moments of the 1st - 4th orders, which are determined within all representative samples of histological sections of the brain.

3. OPERATIONAL CHARACTERISTICS OF THE METHOD OF STATISTICAL ANALYSIS OF ALD MAPS OF HISTOLOGICAL BRAIN SECTIONS

By tomographic reproduction of ALD maps, the following parameters of the operational characteristics of force (sensitivity, specificity and balanced accuracy) of this method of reconstruction of the polycrystalline component of the nervous tissue of the brain were established:

- good (average SM_1 and dispersion SM_2 - 85% - 92% spread of ALD values) and excellent (statistical moments of higher orders $SM_3; SM_4$, which determine the skewness and sharpness of the peak of ALD distributions - 98% - 100%) balanced accuracy of differentiation of a set of representative samples of histological sections of the brain of group "1 "-" 2 + 3 + 4 ";
- satisfactory (average SM_1 and dispersion SM_2 - 80% - 84% of the spread of ALD values) and excellent ($SM_3; SM_4$ - 95% - 97%) balanced accuracy of intergroup differentiation of histological sections of the brain of group "2" (traumatic hemorrhage) - "4" (cerebral infarction of ischemic genesis) , as well as intergroup differentiation of histological sections of the brain of group "2" (traumatic hemorrhage) - "3" (cerebral infarction of hemorrhagic genesis);
- good ($SM_{3;4}$ - 90% - 94%) balanced accuracy of intergroup differentiation of histological sections of the brain of group "3" - "4".

Table2 Specificity, sensitivity, accuracy of the method of statistical analysis of ALD maps of histological brain sections

Groups"1 – 2+3+4"			
Parameters	Sensitivity, Se,%	Specificity, Sp,%	Accuracy, Ac,%
SM_1	$a = 86; b = 14$	$c = 85; d = 15$	$n = 100$
	86	**85**	**85,5**
SM_2	$a = 92; b = 8$	$c = 90; d = 10$	$n = 100$
	92	**90**	**91**
SM_3	$a = 100; b = 0$	$c = 98; d = 2$	$n = 100$
	100	**98**	**99**
SM_4	$a = 100; b = 0$	$c = 98; d = 2$	$n = 100$
	100	**98**	**99**
Groups "2 – 3"			
Parameters	Sensitivity, Se,%	Specificity, Sp,%	Accuracy, Ac,%
SM_1	$a = 82; b = 18$	$c = 80; d = 20$	$n = 100$
	82	**80**	**81**
SM_2	$a = 84; b = 16$	$c = 81; d = 19$	$n = 100$
	84	**81**	**82,5**
SM_3	$a = 96; b = 4$	$c = 95; d = 5$	$n = 100$
	96	**95**	**95,5**
SM_4	$a = 97; b = 3$	$c = 95; d = 5$	$n = 100$
	97	**95**	**96**
Groups "2 – 4"			
Parameters	Sensitivity, Se,%	Specificity, Sp,%	Accuracy, Ac,%
SM_1	$a = 83; b = 17$	$c = 81; d = 19$	$n = 100$
	83	**81**	**82**
SM_2	$a = 85; b = 15$	$c = 83; d = 17$	$n = 100$

	85	**83**	**84**
SM_3	$a=97; b=3$	$c=95; d=5$	$n=100$
	97	**95**	**96**
SM_4	$a=96; b=4$	$c=95; d=5$	$n=100$
	96	**95**	**95,5**
Groups “3 – 4”			
Parameters	Sensitivity, Se,%	Specificity, Sp,%	Accuracy, Ac,%
SM_1	$a=80; b=20$	$c=78; d=22$	$n=100$
	80	**78**	**79**
SM_2	$a=78; b=22$	$c=77; d=23$	$n=100$
	78	**77**	**77,5**
SM_3	$a=92; b=8$	$c=90; d=10$	$n=100$
	92	**90**	**91**
SM_4	$a=94; b=16$	$c=92; d=8$	$n=100$
	94	**92**	**93**

4. DIFFERENTIAL DIAGNOSIS OF THE AGE OF THE FORMATION OF HEMORRHAGES OF TRAUMATIC GENESIS, CEREBRAL INFARCTION OF ISCHEMIC AND HEMORRHAGIC GENESIS BY THE METHOD OF REPRODUCING ALD DISTRIBUTIONS

In fig. 3 - fig. 5 shows maps (fragments (1), (3)) and histograms of distributions (fragments (2), (4)) of the magnitude of circular birefringence of samples of histological sections of the nervous tissue of the brain of the deceased of all groups.

Tables 3 - 5 show the results of a statistical analysis of temporary changes in necrotic changes in the structure of ALD maps of the nervous tissue of the brain of the deceased within the representative samples of samples from group 2 (table 3), group 3 (table 4) and group 4 (table 5) with different AOD (antiquity of onset of death).

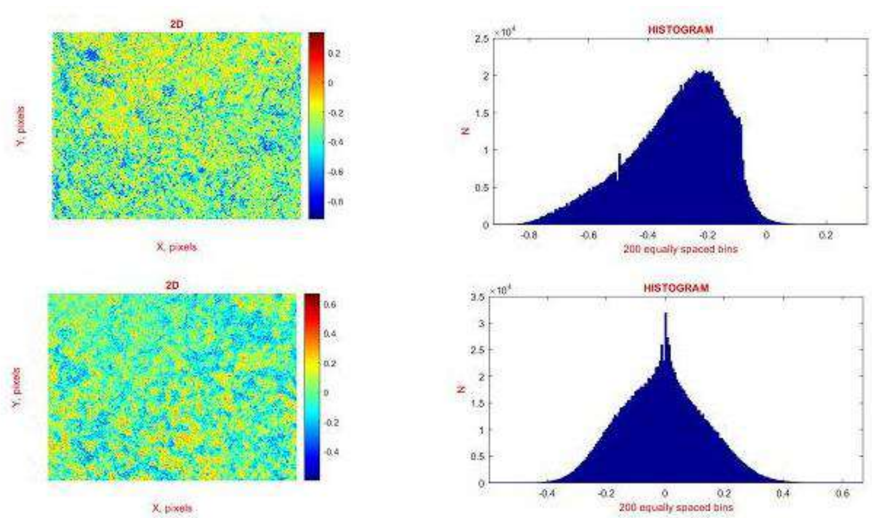

Fig. 3. Maps ((1), (2)) and histograms ((3), (4)) of the distribution of the ALD value of histological sections of the brain of the deceased from group 2 for AOD 6 hours. ((1), (3)) and AOD 24 hours ((2), (4)).

Table 3 Time dynamics of changes in the statistical moments of the 1st - 4th orders characterizing the distributions of the ALD value of histological brain sections of the deceased from group 2

T, **hours**	**6**	**12**	**18**	**24**	**48**
SM_1	$0{,}24 \pm 0{,}008$	$0{,}22 \pm 0{,}007$	$0{,}205 \pm 0{,}006$	$0{,}19 \pm 0{,}005$	$0{,}16 \pm 0{,}005$
p	$p \prec 0{,}05$				
SM_2	$0{,}41 \pm 0{,}014$	$0{,}37 \pm 0{,}013$	$0{,}35 \pm 0{,}013$	$0{,}33 \pm 0{,}012$	$0{,}25 \pm 0{,}01$
p	$p \prec 0{,}05$				
SM_3	$0{,}91 \pm 0{,}034$	$1{,}39 \pm 0{,}054$	$1{,}63 \pm 0{,}072$	$1{,}87 \pm 0{,}088$	$2{,}83 \pm 0{,}11$
p	$p \prec 0{,}05$				
SM_4	$0{,}78 \pm 0{,}031$	$1{,}33 \pm 0{,}059$	$1{,}58 \pm 0{,}065$	$2{,}79 \pm 0{,}11$	$2{,}91 \pm 0{,}12$
p	$p \prec 0{,}05$				
T, **hours**	**72**	**96**	**120**	**144**	**168**
SM_1	$0{,}11 \pm 0{,}004$	$0{,}08 \pm 0{,}003$	$0{,}09 \pm 0{,}004$	$0{,}08 \pm 0{,}003$	$0{,}07 \pm 0{,}003$
p	$p \prec 0{,}05$		$p \succ 0{,}05$		
SM_2	$0{,}17 \pm 0{,}006$	$0{,}11 \pm 0{,}004$	$0{,}12 \pm 0{,}004$	$0{,}11 \pm 0{,}004$	$0{,}12 \pm 0{,}004$
p	$p \prec 0{,}05$		$p \succ 0{,}05$		
SM_3	$3{,}73 \pm 0{,}31$	$4{,}51 \pm 0{,}32$	$4{,}66 \pm 0{,}32$	$4{,}12 \pm 0{,}31$	$4{,}39 \pm 0{,}31$
p	$p \prec 0{,}05$		$p \succ 0{,}05$		
SM_4	$3{,}98 \pm 0{,}23$	$4{,}71 \pm 0{,}25$	$4{,}88 \pm 0{,}26$	$4{,}56 \pm 0{,}22$	4.39 ± 0.21
p	$p \prec 0{,}05$		$p \succ 0{,}05$		

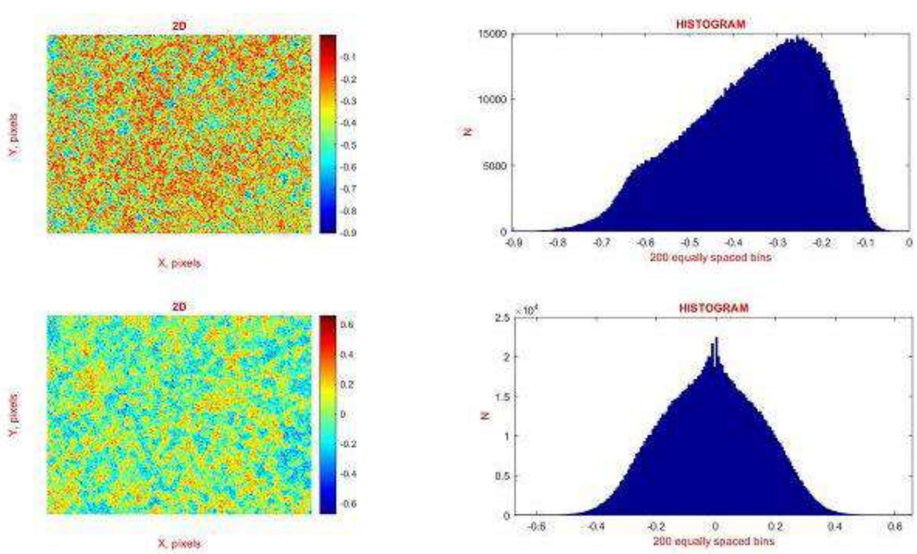

Fig. 4. Maps ((1), (2)) and histograms ((3), (4)) of the distribution of the ALD value of histological sections of the brain of the deceased from group 3 for AOD 6 hours. ((1), (3)) and AOD 24 hours ((2), (4)).

Table 4 Time dynamics of changes in the statistical moments of the 1st - 4th orders, characterizing the distribution of the ALD value of histological brain sections of the deceased from group 3

T, **hours**	**6**	**12**	**18**	**24**	**48**
SM_1	$0,15\pm$	$0,137\pm$	$0,13\pm$	$0,12\pm$	$0,1\pm$
p	$p \prec 0,05$				
SM_2	$0,31\pm$	$0,28\pm$	$0,26\pm$	$0,25\pm$	$0,205\pm$
p	$p \prec 0,05$				
SM_3	$0,71\pm$	$1,06\pm$	$1,23\pm$	$1,41\pm$	$2,11\pm$
p	$p \prec 0,05$				
SM_4	$0,63\pm$	$1,06\pm$	$1,27\pm$	$1,48\pm$	$2,03\pm$
p	$p \prec 0,05$				
T, **hours**	**72**	**96**	**120**	**144**	**168**
SM_1	$0,07\pm$	$0,05\pm$	$0,06\pm$	$0,05\pm$	$0,04\pm$
p	$p \prec 0,05$		$p \succ 0,05$		
SM_2	$0,13\pm$	$0,08\pm$	$0,09\pm$	$0,08\pm$	$0,07\pm$
p	$p \prec 0,05$		$p \succ 0,05$		
SM_3	$2,79\pm$	$3,35\pm$	$3,44\pm$	$3,13\pm$	$3,27\pm$
p	$p \prec 0,05$		$p \succ 0,05$		
SM_4	$3,19\pm$	$3,81\pm$	$3,99\pm$	$3,73\pm$	$3,88\pm$
p	$p \prec 0,05$		$p \succ 0,05$		

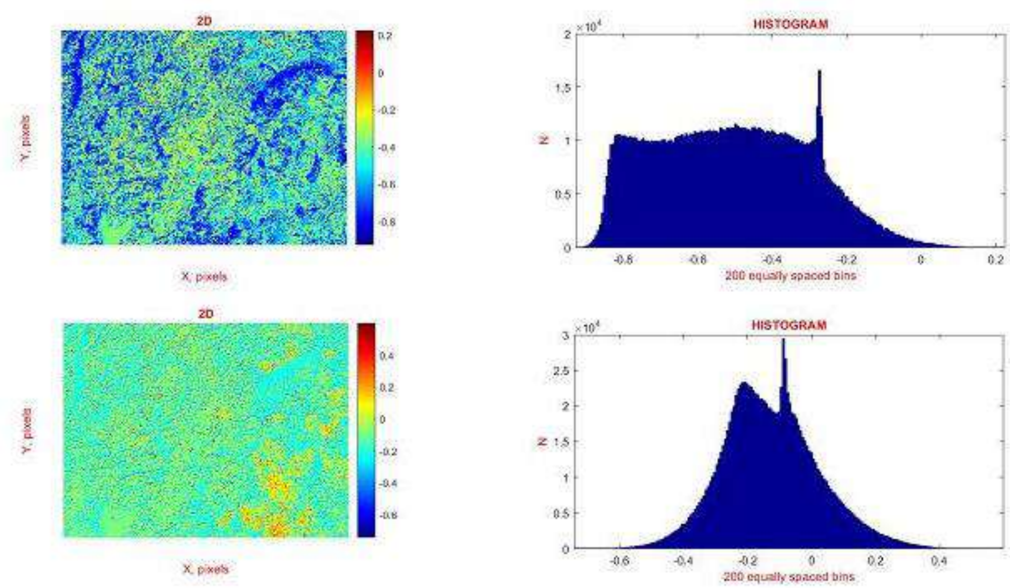

Fig. 5. Maps ((1), (2)) and histograms ((3), (4)) of the distribution of the ALD value of histological sections of the brain of the deceased from group 4 for AOD 6 hours. ((1), (3)) and AOD 24 hours ((2), (4)).

Table 5 Time dynamics of changes in the statistical moments of the 1st - 4th orders, characterizing the distribution of the ALD value of histological brain sections of the deceased from group 4

T, hours	6	12	18	24	48
SM_1	$0,21 \pm 0,006$	$0,192 \pm 0,005$	$0,18 \pm 0,005$	$0,17 \pm 0,004$	$0,14 \pm 0,003$
p			$p \prec 0,05$		
SM_2	$0,36 \pm 0,009$	$0,33 \pm 0,008$	$0,31 \pm 0,007$	$0,285 \pm 0,006$	$0,23 \pm 0,005$
p			$p \prec 0,05$		
SM_3	$0,69 \pm 0,021$	$1,09 \pm 0,029$	$1,31 \pm 0,033$	$1,52 \pm 0,055$	$2,34 \pm 0,16$
p			$p \prec 0,05$		
SM_4	$0,83 \pm 0,026$	$1,36 \pm 0,034$	$1,63 \pm 0,043$	$1,89 \pm 0,049$	$2,96 \pm 0,17$
p			$p \prec 0,05$		
T, hours	**72**	**96**	**120**	**144**	**168**
SM_1	$0,095 \pm 0,003$	$0,07 \pm 0,0025$	$0,08 \pm 0,003$	$0,07 \pm 0,003$	$0,09 \pm 0,004$
p	$p \prec 0,05$			$p \succ 0,05$	
SM_2	$0,16 \pm 0,004$	$0,09 \pm 0,003$	$0,1 \pm 0,004$	$0,09 \pm 0,003$	$0,08 \pm 0,003$
p	$p \prec 0,05$			$p \succ 0,05$	
SM_3	$3,17 \pm 0,16$	$3,51 \pm 0,17$	$3,57 \pm 0,17$	$3,43 \pm 0,16$	$3,51 \pm 0,17$
p	$p \prec 0,05$			$p \succ 0,05$	
SM_4	4,03 ± 0,1`9	$4,88 \pm 0,21$	$4,99 \pm 0,22$	$4,76 \pm 0,21$	$4,94 \pm 0,22$
p	$p \prec 0,05$			$p \succ 0,05$	

From the analysis of the results of statistical processing of the topographic structure of tomograms of linear dichroism of fibrillar networks of histological sections of the brain (Fig. 3 - Fig. 5) of the deceased from all groups, one can see a large temporal dynamics of necrotic destruction of the nervous tissue. In accordance with this, there is a faster temporal decrease in the absolute values and the range of scatter of the linear dichroism value with increasing AOD time (Fig. 3 - Fig. 5, fragments (2), (4)).

The following regularities of the scenario of temporary changes in the topographic structure of the ALD maps have been established:

- an increase in the magnitude of the range of temporal linear changes in the values of statistical moments of the 1st - 4th orders, characterizing the distributions of the magnitude of the linear dichroism of fibrillar networks of histological sections of the nervous tissue of the brain of the deceased from all groups up to 24 hours;
- the accuracy of the AOD determination is 30 min. ± 5 min.

CONCLUSIONS

1. The design of forensic differentiation of cases of cerebral infarction, hemorrhagic hemorrhages of traumatic genesis and determination of the age of their formation by means of experimental testing of methods of polarization-phase tomography of optical anisotropy, investigated on the basis of the developed structural-logical scheme, has been substantiated.

2. The following parameters of the strength of the method of polarization-phase tomography were experimentally established:

- Linear dichroism - good (SM_1 and SM_2 - 85% - 92%) and excellent ($SM_3; SM_4$ - 98% - 100%) balanced accuracy of differentiation of a set of representative samples of histological brain sections of group "1" - "2 + 3 + 4";

satisfactory (SM_1 and SM_2 - 80% - 84%) and excellent ($SM_3;SM_4$ - 95% - 97%) balanced accuracy of intergroup differentiation of histological sections of the brain of group "2" - "4", as well as intergroup differentiation of histological sections of the brain of group "2" - "3" "; good ($SM_{3;4}$ - 90% - 94%) balanced accuracy of intergroup differentiation of histological sections of the brain of the group "3" - "4";

3. By temporarily monitoring the change in the magnitude of the statistical moments of the 1st - 4th orders, which characterize the polarization-reproduced maps of the set of mechanisms of optical anisotropy of the polycrystalline structure of the nervous tissue, the following parameters of the differential determination of the duration of the formation of cases of cerebral infarction, hemorrhagic hemorrhages of traumatic genesis were determined:

- tomography of the distributions of the linear dichroism value of histological sections of the brain – AOD 24 hours, accuracy 30 min. ± 5 min.

FUNDING

Current research supported by the National Research Foundation of Ukraine (Project 2020.02/0061)

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Polarization mapping of laser-induced monospectral fields of optically anisotropic fluorophores in forensic diagnostics of the age of the formation of damage to human organs

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ABSTRACT

The paper presents the results of experimental testing of methods for azimuthal-invariant polarization mapping of laser-induced microscopic images of fluorophores in histological sections of the liver of deceased; time monitoring of changes in the magnitude of statistical moments of the 1st - 4th orders characterizing the distributions of the azimuth and ellipticity of polarization of microscopic images of histological sections of the liver with different age of damage; determination of the diagnostic efficiency (time interval and accuracy) of establishing the age of damage to human internal organs by digital histological methods of mapping maps of azimuth and ellipticity of polarization of microscopic images of samples of histological sections of the brain, liver and kidney, as well as myocardium and lung tissue.

Keywords: polarization, azimuth, ellipticity, microscopic image, statistical moments of the 1st - 4th orders, histological sections, biological tissues, damages

1. INTRODUCTION

The methodology and technique of polarization mapping of microscopic images of biological preparations are presented in detail and comprehensively in numerous publications of the scientific schools [1-8].

The obtained results of polarization mapping revealed information (diagnostic) relationships between:

- maps of polarization azimuth and concentration of optically active molecular compounds (fluorophores) of biological tissues and fluids of human organs;
- maps of ellipticity of polarization and the degree of ordering (crystallization) of fibrillar networks of biological preparations.

However, at present, these digital methods of polarizing microscopy are practically absent in histological studies for determining the age of damage to human internal organs..

The aim of the study is to develop a set of objective forensic criteria for expanding the functionality and improving the accuracy of establishing the age of damage to human internal organs according to the data of a multiparametric digital histological study of liver tissue through the integrated use of polarization mapping of the polycrystalline structure of fluorophores of prototypes based on a statistical analysis of the temporal dynamics of their change [9-15].

2. MATERIALS AND METHODS

The following groups were formed (control group with those who died from coronary artery disease and experienced with different age of damage) of experimental samples of histological sections of internal organs (brain, liver, kidney, as well as myocardium and lung tissue) of a person.

Fifteenth International Conference on Correlation Optics, edited by Oleg V. Angelsky, Proc. of SPIE Vol. 12126, 1212622
 · doi: 10.1117/12.2616662