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Possibilities of laser polarimetric diagnostics of umbilical blood and capillary maternal blood

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umbilical cord blood;
capillary maternal blood;
diseases of the kidneys and urinary tract of a pregnant woman.

Abstract

A comparative analysis of the two types of samples showed differences in values of the statistical moments of the 3rd and 4th orders. In particular, the statistical moment of the 3rd order (asymmetry) is 2.5 times greater and the 4th parameter (kurtosis) is 2.5 times greater for the blood samples of newborns without pathological changes than the similar parameter for the blood samples of newborns with pathological changes. Fractal analysis showed the transformation of the distribution of power spectra from fractal for coordinate distributions of the Muller matrix element for blood samples without pathology to multifractal (fractal dimensions D_1=1.66, D_2= 2.90 and D_3= 0.56) of blood samples with pathology.

The diagnostic sensitivity of the statistical moments of the coordinate distributions of the orientation-phase elements of the Muller p34 matrix of higher orders (3rd and 4th) to structural changes occurring in blood samples of mothers of newborns with a normal physiological state and with pathological changes was revealed. In particular, with pathological changes, the statistical moments of the third order (asymmetry) decrease by 3.5 times, and accordingly, the statistical moment of the fourth order (kurtosis) increases by 2.5 times. The spread of the values of the statistical moments within the two groups did not exceed 5-10% of corresponding average values. The diagnostic possibilities of statistical and fractal analysis of the coordinate distributions of the elements of the Mueller matrix of blood samples of different physiological states of newborns and their mothers have been demonstrated.

Fractal and statistical analysis of the coordinate distributions of the orientational elements of the Mueller matrix p_{33} are diagnostically sensitive when examining the blood of newborns. For maternal blood samples, the statistical analysis of the orientational-phase elements of the Muller p_{34} matrix (increase in the statistical moments of the 3rd and 4th orders with pathological changes) is diagnostically sensitive.

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Можливості лазерної поляриметричної діагностики пуповинної крові і капілярної крові матері

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Ключові слова:
лазерна поляриметрія; матриця Мюллера; пуповинна кров; капілярна кров матері; захворювання нирок та сечовивідних проток вагітної.

Анотація
Порівняльний аналіз двох типів зразків показав відмінності у статистичних моментах 3-го та 4-го порядків елемента матриці p_{33}, зокрема для зразків крові новонароджених без патологічних змін статистичний момент 3-го порядку (асиметрія) в 2,5 разів більший за аналогічний параметр для зразків крові новонароджених з патологічними змінами, 4-ий параметр (ексцес) в 2,5 рази більший для зразків крові новонароджених без патології у порівнянні з аналогічними параметрами для зразків крові новонароджених з патологією. Фрактальний аналіз показав трансформацію розподілу спектрів потужності з фрактального для кординатних розподілів елементу матриці Мюллера p_{33} для зразків крові без патології в мультифрактальний (фрактальні розмірності D_1=1,66, D_2= 2,90 та D_3= 0,56) зразків крові з патологією.

Виявлено діагностичну чутливість статистичних моментів 3-го та 4-го порядків координатних розподілів орієнтаційно-фазових елементів матриці Мюллера p_{34} до структурних змін які відбуваються в зразках крові матерів новонароджених з нормальним фізіологічним станом та з патологічними змінами. Зокрема при патологічних змінах статистичні моменти третього порядку (асиметрія) зменшується в 3,5 рази, а відповідно статистичний момент четвертого порядку (ексцес) збільшується в 2,5 рази. Розкид значень статистичних моментів в межах двох груп не перевищував 5-10%. Продемонстровано діагностичні можливості статистичного та фрактального аналізу координатних розподілів елементів матриці Мюллера зразків крові різного фізіологічного стану новонароджених та їх матерів.

При дослідженні крові новонароджених діагостично чутливими є фрактальний та статистичний аналіз координатних розподілів орієнтаційних елементів матриці Мюллера p_{33}. Для зразків крові матерів діагностично чутливим є статистичний аналіз орієнтаційно-фазових елементів матриці Мюллера p_{34} (збільшення статистичних моментів 3-го та 4-го порядків при патологічних змінах).

Contents

Introduction

The vector approach to the research physiological state created a foundation, of the morphological structure and in particular, for the development of model ideas about the structures of biological tissues [1-3]. Biological tissue is considered as a two-component amorphous-crystalline structure-matrix. The amorphous component - fats, lipids, unstructured proteins, etc. is polarization-isotropic (optically inactive) [4, 5]. The crystalline component - collagen proteins, myosin, etc. are spatially oriented birefringent protein fibrils.

The properties of each individual fibril are modeled optically by an uniaxial crystal, the direction of the axis of which coincides with the direction of stacking in the plane of the biological tissue, the birefringence index is determined by its substance. A higher level of organization of biological tissue is an architectural grid formed by differently oriented birefringent beams [6, 7].

Within the framework of this model, it was possible to explain the mechanisms of formation of polarization heterogeneity of the objective fields of biological tissue of various types [8, 9]. The method of polarization visualization of the architectural structure of biological tissue of various morphological types allows for statistical analysis of coordinate distributions of polarization parameters of scattered laser radiation fields [10-12].

The aim of the study

Estimate laser polarimetry as diagnostic technique to analyze the umbilical cord blood of the newborn and the capillary maternal blood.

Research material and methods

Experimental samples were prepared according to the standard method in the form of smears on optically homogeneous glass, which were then dried at room temperature. Differentiation of the polarization properties of blood smears: umbilical cord blood of newborns (n = 20) and capillary blood of their normal mothers (n = 20), umbilical cord blood of a newborn (n = 20) and capillary blood of mothers who, according to clinical data, had pathology. Obtaining a sample of blood smears from healthy pregnant women and maternal pathology of kidney and urinary tract diseases in pregnant women were determined in the gynecological hospital of Chernivtsi by the ultrasound method based on the general analysis of the maternal blood. Previously, on the basis of protocols for the examination of pregnant women in the gynecological department of Chernivtsi, a selection of healthy pregnant women and diseases of the kidneys and urinary tract in pregnant women was made. The selection of patients was carried out based on a prior written agreement with pregnant women for the analysis of umbilical cord blood of their newborns and capillary maternal blood.

Illumination of samples of polycrystalline networks of blood is carried out in parallel

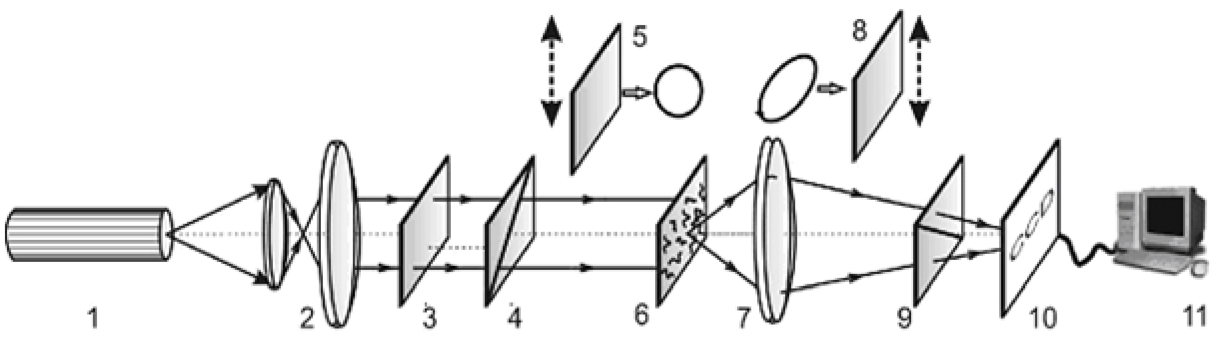

Fig. 1. Optical scheme of the polarimeter: 1 – He-Ne laser; 2 – collimator; 3 – stationary quarter-wave plate; 5, 8 – mechanical moving quarter-wave plates; 4, 9 – polarizer and analyzer, respectively; 6 – research object; 7 – micro lens; 10 – CCD camera; 11 – personal computer.

($D = 2x10^3$ μm) with a low-intensity ($W = 5.0$ mW) He-Ne laser beam ($\lambda = 0.6328$ μm) (Fig. 1).

The polarization illuminator consists of quarter-wave plates 3, 5 and a polarizer 4, which ensures the formation of a laser beam with an arbitrary azimuth and ellipticity of polarization.

For the processing of laser images of biological samples, statistical and fractal methods of analysis of the distributions of the elements of the Mueller matrix of optically anisotropic biological tissues were used. Statistical moments of the 1st-4th orders that characterize the distribution p_{ik}, were calculated using the following ratios:

$$Z_1 = \frac{1}{Q}\sum_{j=1}^{Q}\left|p_{ik}\right|_j, \quad Z_2 = \sqrt{\frac{1}{Q}\sum_{j=1}^{Q}\left((p_{ik})_j Z_1\right)^2},$$

$$Z_3 = \frac{1}{Z_2^3}\frac{1}{Q}\sum_{j=1}^{Q}(p_{ik})_j^3, \quad Z_4 = \frac{1}{Z_2^4}\frac{1}{Q}\sum_{j=1}^{Q}(p_{ik})_j^4,$$

where Q is the number of pixels of the CCD camera.

The coordinates of the distribution of the elements of the Mueller matrix of blood samples were evaluated within the limits of statistical and fractal approaches.

Fractal analysis of distributions was carried out by determining logarithmic dependencies $\log J(p_{ik})-\log(d^{-1})$ of power spectra, where d^{-1} – spatial frequencies determined by the range of changes in the size of the structural elements of the polycrystalline network. The calculated logarithmic dependences were approximated by the method of least squares, the fractal dimension was determined by the formula $D = 3 - \mathrm{tg}\,\eta$, where η – angle of inclination of linear part of graph.

The classification of coordinate distributions $p_{ik}(x,y)$ was carried out in accordance with the following criteria:

•$p_{ik}(x,y)$ – fractal or self-similar provided $\eta = const$ within 2-3 decades of changes in geometric dimensions d;

•$p_{ik}(x,y)$ – multifractal, provided that there are several constant angles of inclination $\eta_{j=1,2,..} = const$;

•$p_{ik}(x,y)$ – statistical or random provided $\eta \neq const$ for the entire change interval of d.

Results and discussion

The analysis of the optical properties of polycrystalline protein networks, which are formed by blood plasma amino acids, as well as formed blood elements, is based on the following model:

• blood plasma is considered as a two-component isotropic-anisotropic structure;

• the optically anisotropic component is a protein fraction consisting of optically uniaxial birefringent crystals of the amino acids albumin and globulin;

• the polarization properties of such biological crystals are characterized by the Mueller matrix;

• elements of the Mueller matrix p_{ik} planar network layer (N) of crystalline aminoacids and formed elements are determined by the superposition of partial matrix operators.

Statistical and fractal analysis of Mueller matrix images of biological crystal networks.

Fig.2 shows histological images of umbilical cord blood of a newborn and capillary maternal blood in normal and pathological conditions.

Fig.3 and Fig.4 shows polarization images of crystallite samples of umbilical cord blood of a newborn (a) and capillary maternal blood (b) with pathological changes for co-axial ($\theta = 0°$) and the cross ($\theta = 90°$) transmission planes of the analyzer and polarizer. Corresponding polycrystalline networks of blood are illustrated by a eries of laser images obtained in coaxial ($\theta = 0°$) and transmission planes of the polarizer

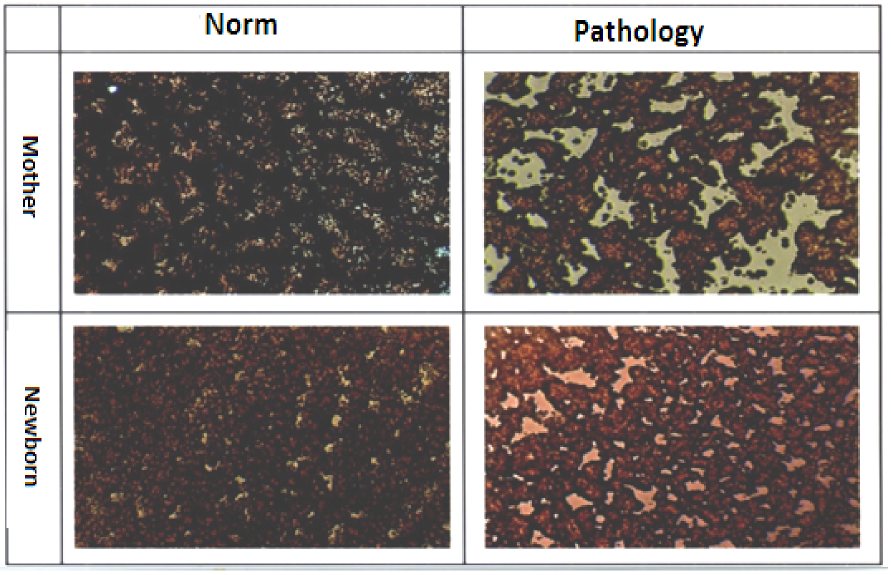

Fig. 2. Histological image of blood smears. Increased 60^x: capillary blood of the mother and umbilical cord blood of the newborn in normal conditions and in case of maternal pathology (according to ultrasound).

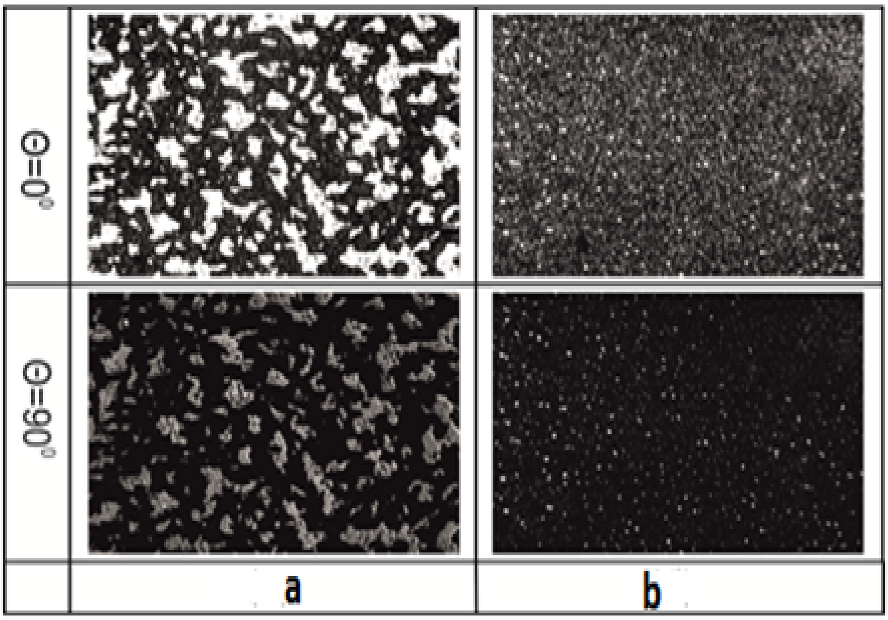

Fig. 3. Polarization images of crystallite samples of umbilical cord blood of a newborn (a) and capillary blood of the mother (b) without pathological changes for co-axial (θ = 0°) and the cross (θ = 90°) transmission planes of the analyzer and polarizer.

and the analyzer, the crossed ones (θ = 90°).

Comparative analysis of laser images revealed a different coordinate structure of these samples. For the optically anisotropic component of the blood samples of a healthy person, they are spatially ordered in several directions. The blood of newborns with pathological changes in the mother's blood contains globulin crystals that are more disordered in the directions of the optical axes (Fig. 5 a, b).

The subject of statistical and fractal analysis were two types of Mueller matrix images $p_{ik}(m \times n)$ umbilical cord blood of the newborn and capillary maternal blood in the norm and pathology of the mother. The first type is the coordinate distribution of the diagonal elements of the Mueller matrix

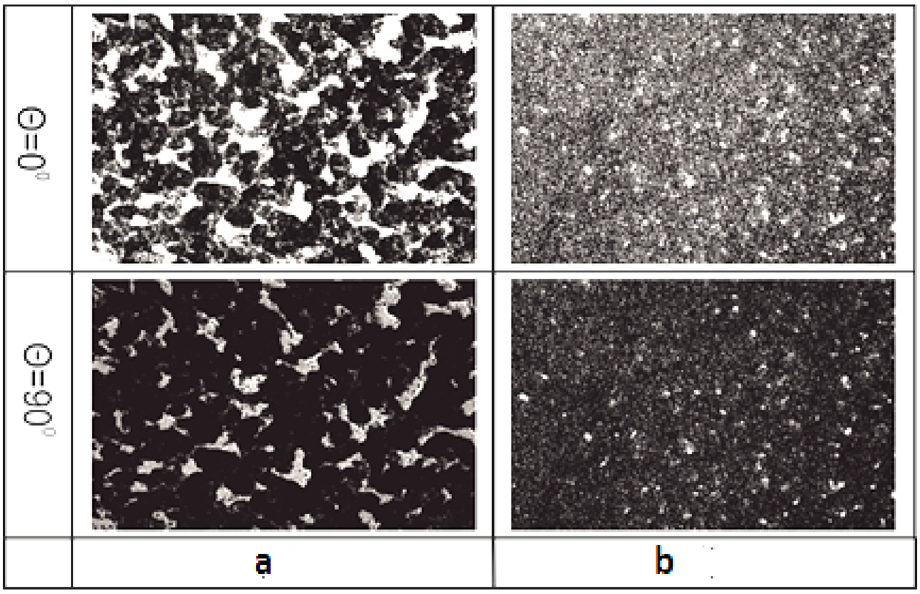

Fig. 4. Polarization images of crystallite samples of umbilical cord blood of a newborn (a) and capillary maternal blood (b) with pathological changes for co-axes (θ = 0°) and the cross (θ = 90°) transmission planes of the analyzer and polarizer.

$p_{33}(m \times n)$, characterizing the degree of transformation of the laser wave polarization azimuth by amino acid crystals whose optical axes are oriented in two mutually perpendicular directions ρ=45°↔135° ($p_{33}(m \times n)$), in accordance. In this sense, we will call such matrix elements «orientational».

A comparative analysis of the two

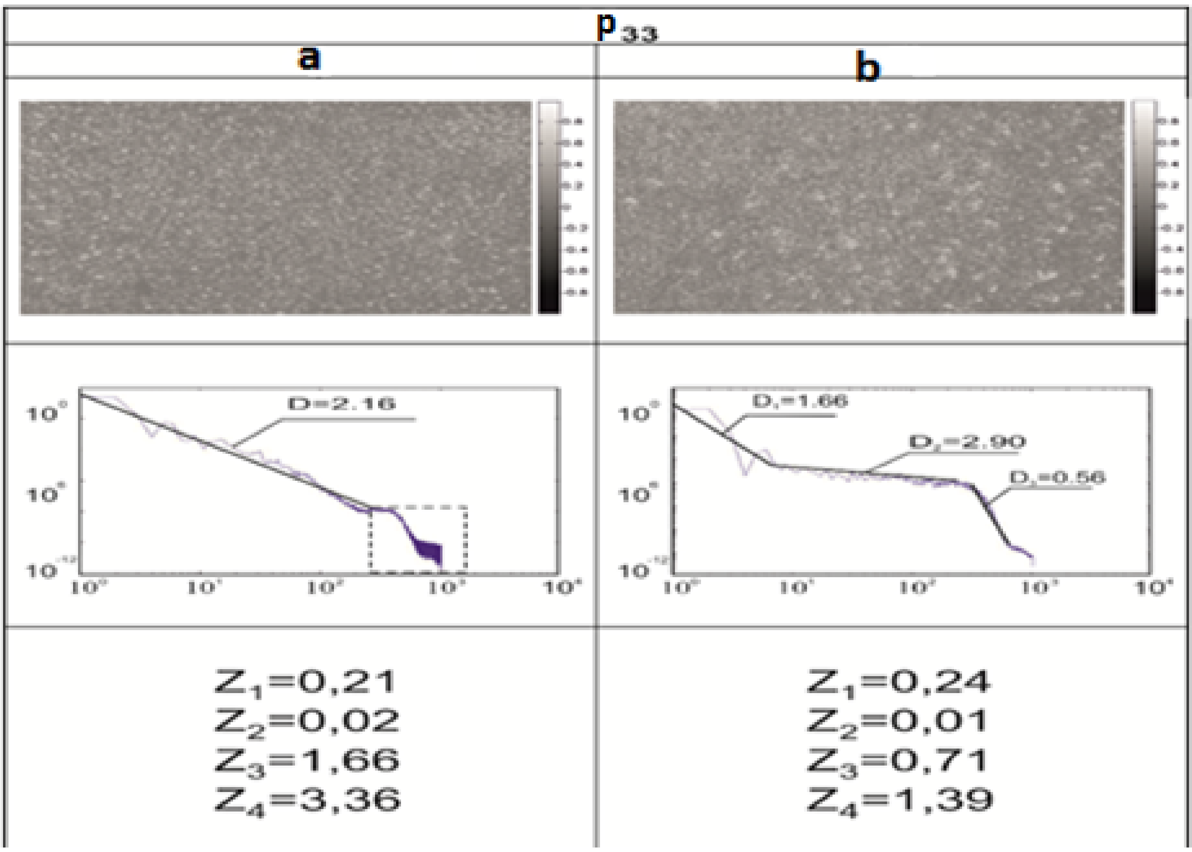

Fig. 5. Coordinate distribution, power spectra and statistical moments of the Mueller matrix element p_{33} blood samples of a newborn without pathological changes (a) and with pathological changes (b).

types of samples showed differences in the statistical moments of the 3rd and 4th orders, in particular, for the blood samples of newborns without pathological changes, the statistical moment of the 3rd order (asymmetry) is 2.5 times greater than the similar parameter for the blood samples of newborns with pathological changes, the 4th parameter (kurtosis) is 2.5 times greater for blood samples of newborns without pathology compared to similar parameters for blood samples of newborns with pathology.

Fractal analysis showed the transformation of the distribution of power spectra from fractal (fractal dimension) for coordinate distributions of the Mueller matrices element p_{33} for blood samples without pathology to multifractal (fractal dimensions D_1=1.66, D_2= 2.90 and D_3= 0.56) for samples blood with pathology.

The table shows the statistical parameters of the coordinate distributions of the orientation-phase elements of the Mueller' matrix p_{34} for the group of blood samples of mothers of newborns without pathological changes and, accordingly, with pathological changes.

Table

Statistical moments of the 1st-4th orders of orientational-phase elements p_{34} Mueller matrices of blood samples of different physiological states

Z_i	Norm (20 samples)	Pathological changes (20 samples)
Z_1	0.29±0.02	0.31±0.03
Z_2	0.03±0.006	0.02±0.009
Z_3	1.49±0.08	0.39±0.04
Z_4	2.44±0.11	6.15±0.23

The comparative analysis of the data presented in the table revealed the diagnostic sensitivity of the statistical moments of the coordinate distributions of the orientation-phase elements of the Mueller matrix (p_{34}) of higher orders (3rd and 4th) to structural changes that occur in blood samples of mothers of newborns with a normal physiological state and with pathological changes.

In particular, with pathological changes, the statistical moments of the third order (asymmetry) decrease by 3.5 times, and accordingly, the statistical moment of the fourth order (kurtosis) increases by 2.5 times. The spread of the values of the statistical moments within the two groups did not exceed 5-10%.

Conclusion

The diagnostic possibilities of statistical and fractal analysis of the coordinate distributions of the elements of the Mueller matrix of blood samples of different physiological states of newborns and their mothers have been demonstrated. In particular, when examining the blood of newborns, fractal and statistical analysis (transformation of fractality into multifractality, reduction of statistical moments of the 3rd and 4th orders) of the coordinate distributions of the orientational elements of the Mueller matrix p_{34} are diagnostically sensitive p_{33}. For maternal blood samples, the statistical analysis of the orientational-phase elements of the Mueller matrix (increase in the statistical moments of the 3rd and 4th orders with pathological changes) is diagnostically sensitive.

Compliance with Ethics Requirements:
The authors declare no conflict of interest regarding this article.
The authors declare that all the procedures and experiments of this study respect the ethical standards in the Helsinki Declaration of 1964, as revised in 2013, as well as the national law.
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