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SOME PECULIARITIES OF THE METHOD POLARIZATION SELECTION OF LASER IMAGES IN DIAGNOSTICS POLYCRYSTAL STRUCTURE BILE LAYERS OF HUMAN

Key words: *chronic cholecystitis, chholelithiazis, diabetes mellitus type 2, laser polarimetry.*

Abstract. *The research is focused on the analysis of potentiality of diagnostics and differentiation of cholelithiasis of patients with chronic cholecystitis and diabetes mellitus type 2 by means of new technique of polarization correlometry of human bile layers laser images. The techniques of laser polarimetry diagnostics of optical anisotropic structure have become widely spread among optical diagnostic methods of human biological tissues. A number of techniques of early diagnostics and differentiation of pathological changes in biological tissues structure, connected with their degenerative-dystrophic and oncological changes were developed. Biological fluids are much more accessible for direct laboratory analysis if compared with traumatic techniques of the biological tissue biopsy. In terms of the above mentioned the task of searching new additional parameters for laser diagnostics of biological fluids' optical anisotropic structure appears to be topical. There was investigated a new technique of estimating the structure of laser images based on measuring coordinate distributions of mutual polarization degree is suggested that characterizes the homogeneity of optically isotropic and optically anisotropic components in biochemical composition of bile. The statistical (mean, dispersion, asymmetry and excess), correlation (correlation area of distribution of mutual polarization degree values) and fractal (dispersion of extremes of log-log dependencies of power spectra of mutual polarization degree values distribution) criteria of polarization-correlation diagnostics of cholelithiasis latent course and its stages differentiation on the background of chronic cholecystitis, diabetes mellitus type 2 and complex pathology are determined and substantiated.*

Introduction

Among the methods of optical diagnostics of human biological tissues the techniques of laser polarimetry diagnostics of their optical anisotropic structure became widely spread [1-18].

The main information for these methods is obtained from coordinate distributions of polarization azimuths α (x,y) and ellipticity β (x,y) (polarization maps) with the following correlation (auto- and mutually correlation functions [3, 4]) and fractal (fractal dimensions [1, 8, 17, 18]) analysis.

As a result, several techniques of early diagnostics and differentiation of pathological changes in biological tissue (BT) structure with their degenerative, dystrophic and oncological changes were developed.

Besides, there is a widely spread group of optically anisotropic biological objects, for which the techniques of laser polarimetry diagnostics are not efficient enough. Optically thin (attenuation coefficient $\tau \leq 0,1$) layers of different biological fluids (bile, urine, liquor, synovial fluid, blood plasma, etc.) belong to such objects. Biological fluids are much more accessible for direct laboratory analysis if compared with traumatic techniques of the BT biopsy.

Material and methods

Optically, bile is a multicomponent phase-inhomogeneous fluid containing three basic fractions (Fig. 1).

Optically isotropic fraction – optically homogeneous micellar solution (I – Fig. 1a) with a small number of cylindrical epithelium cells, leukocytes, leukocytoids, mucus.

Optically anisotropic fraction – liquid-crystalline phase (A – Fig. 1a) consisting of the ensemble of liquid crystals of three types: needle crystals of fatty acids (CFA–Fig.1b), crystals of cholesterol monohydrate (CCM–Fig.1c); crystals of calcium bilirubinate (CCB – Fig.1d).

Optically crystalline fraction – solid crystalline phase formed due to dendritic and disclination mechanisms of crystallization.

At transmission of a laser wave through the layer of such a complex phase inhomogeneous fluid the following mechanisms of its parameters transformation are realized (Fig. 2).

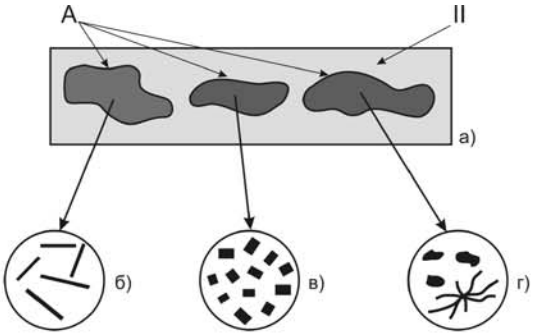

Fig. 1. On the analysis of bile optical model as (I) – anisotropic (A) fluid. Explanations are in the text

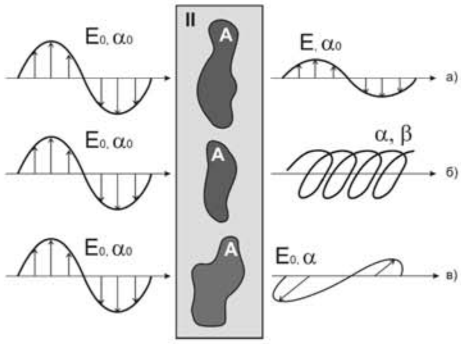

Fig. 2. Main mechanisms of transformation of laser radiation parameters by bile. "Attenuation" – decrease of the amplitude E_0 to E due to absorption of laser radiation by biochemical components of isotropic component while maintaining the polarization state ($\alpha_0 = const$). "Bbirefringence" (Fig. 2b) – transformation of linearly polarized laser radiation by liquid crystals into elliptically polarized laser radiation – $\alpha_0 \to \alpha; \beta$. "Dichroism" (Fig. 2c) – rotation of polarization plane of laser radiation by the crystalline fraction – $\alpha_0 \to \alpha$

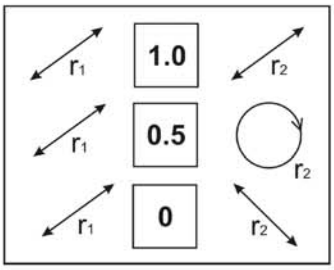

Fig. 3. Polarization correlation structure of the bile sample laser image

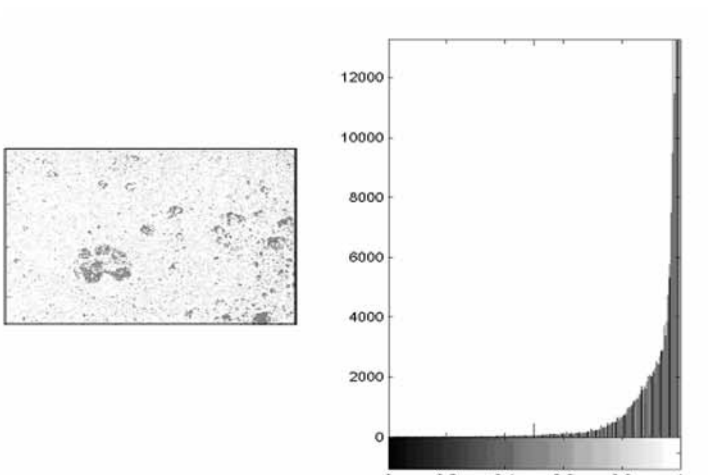

Fig. 4. Coordinate distribution (a) and histogram of values (a) of mutual polarization $V(x, y)$ degree if a healthy patient's bile layer (group 1)

Complex, multiparametric polarization distribution of laser images of bile layers requires additional analysis – correlation comparison of polarization states consistency degree ($\left\{\begin{matrix}\alpha_1(r_1)\leftrightarrow\alpha_2(r_2);\\ \beta_1(r_1)\leftrightarrow\beta_2(r_2).\end{matrix}\right.$) in various points with coordinates r1; r2 (Fig. 3).

It is shown [2, 11] that for various points of the plane of image of biological object with the same polarization states V (x,y)=1,0; for the points with the linear and circular polarization states V (x,y)=0,5; for the points with orthogonal polarization states V (x,y)=0.

It was determined [18] that the above mentioned "2-point" parameter V (x,y) of laser images of phase-inhomogeneous layers is much more sensitive to the changes in their structure in comparison with the techniques of investigation of intensity coordinate distribution (classical microscopic image), polarization (polarization image) and phases (phase image) [7, 9, 10]. That is why this technique's testing to the study of interconnections of bile optical properties with different types of pathologies of sick patients appears to be topical.

The technique of determining the parameter of mutual polarization complex degree consists in the following procedure [3, 4]:

1. By rotating the transmission plane of polarizer within the rotation angle θ 0^0–180^0 the arrays of minimal and maximal intensity levels $I_{\min}\begin{pmatrix}r_{11},\dots r_{1m}\\ \dots\dots\dots\\ r_{n1},\dots r_{nm}\end{pmatrix}; I_{\max}\begin{pmatrix}r_{11},\dots r_{1m}\\ \dots\dots\dots\\ r_{n1},\dots r_{nm}\end{pmatrix}$ of human bile layers images for each separate pixel (mn) of CCD-camera were determined , as well as rotation angles $\left(\theta\begin{pmatrix}r_{11},\dots r_{1m}\\ \dots\dots\dots\\ r_{n1},\dots r_{nm}\end{pmatrix}\left(I\begin{pmatrix}r_{11},\dots r_{1m}\\ \dots\dots\dots\\ r_{n1},\dots r_{nm}\end{pmatrix}\equiv\min\right)\right)$ corresponding to them.

2. The coordinate distributions (polarization maps) of polarization states in the plane of human bile samples images were calculated by such relations [2, 13]

$$\alpha\begin{pmatrix}r_{11},\dots r_{1m}\\ \dots\dots\dots\\ r_{n1},\dots r_{nm}\end{pmatrix}=\theta(I(r_i)\equiv\min)-\frac{\pi}{2};$$

$$\beta\begin{pmatrix}r_{11},\dots r_{1m}\\ \dots\dots\dots\\ r_{n1},\dots r_{nm}\end{pmatrix}=arctg\frac{I(r_i)_{\min}}{I(r_i)_{\max}}.$$

(1)

3. The value of complex degree of mutual polarization $V(r;r+\Delta r)$ of human bile samples' laser images was calculated by the following relation

$$V(r;r+\Delta r)=\frac{2\left\{I_0I_{90}\cos\left[\arcsin\left(\cos 2\alpha/tg2\beta\right)\right]\right\}(r)}{\left(I_0^2(r)+I_{90}^2(r)\right)\left(I_0^2(r+\Delta r)+I_{90}^2(r+\Delta r)\right)}\ \text{x}$$

$$\text{x}\left\{I_0I_{90}\cos\left[\arcsin\left(\cos 2\alpha/tg2\beta\right)\right]\right\}(r+\Delta r)$$

. (2)

Laser images of three groups of bile samples of the patients of different pathological state:

- healthy patients – group 1 (20 patients);
- patients with cholelithiasis and chronic cholecystitis – group 2 (30 patients);
- cholelithiasis patients with diabetes mellitus type 2 – group 3 (30 patients).

Results of investigation and discussion

The coordinate distribution and histogram of random values of V(x,y) parameter of polarizationally-inhomogeneous laser image of bile layer laser image of a healthy patient are presented in Fig. 4.

It can be seen from the obtained data that the laser image of a healthy patient's bile layer is characterized with a high homogeneity of polarization parameters – the number of values V(x,y) =1 is by three orders higher than the other, non-zero values of mutual polarization degree.

In other words, in biochemical structure of this bile layer the optically isotropic component prevails.

Correlation (b) fractal (c), structure of distribution (a) and the amount (b) of values of parameter V(x,y)=0,5 characterizing the liquid crystalline component of bile of patients from group 1 are presented in Fig. 5.

It was determined that the set of values V(x,y)=0,5 is fractal ($D(V=0{,}5)=2{,}1$ 1;$\Omega(V=0{,}5)=0{,}16$) with correlation area $S(V=0{,}5)=0{,}16$ great enough.

It can be seen from the analysis of histograms of random values of mutual polarization degree of the laser image of bile layer of chronic cholecystitis patient that the number of values $V(x,y)=0{,}5$ (liquid crystalline fraction) amount to 15 % of the number of values $V(x,y)=1{,}0$ characterizing the images of optically isotropic component.

The corresponding statistical (b), correlation (c) and fractal (d) parameters of coordinate distributions $V=0{,}5$ (a) are presented in Fig.6.

It was determined for liquid crystalline fraction of bile layer that the set of values $V(x,y)=0{,}5$ is

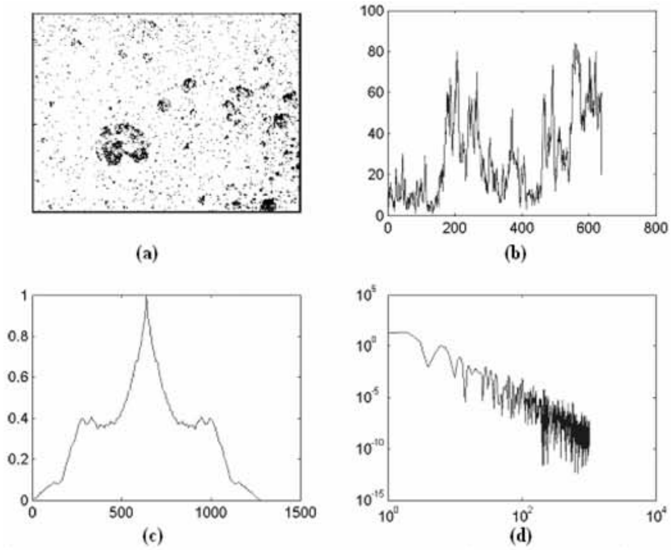

Fig. 5. Autocorrelation function (c) and log-log dependencies (d) of the amount of values $V = 0{,}5$ (b) in the coordinate distribution $V(x, y)$ (a) of a healthy patient's bile layer (group 1)

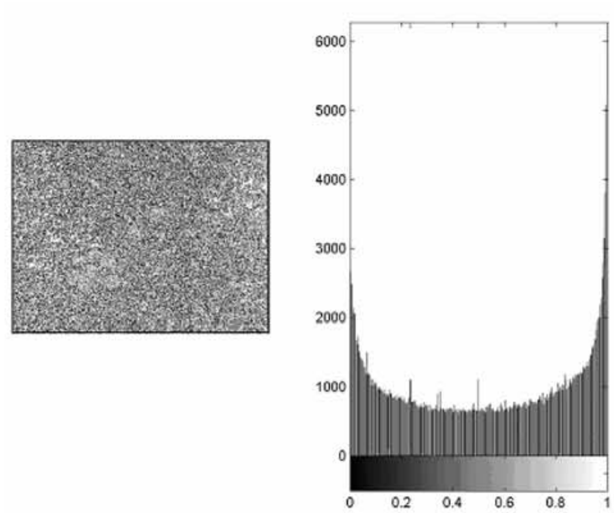

Fig. 6. Coordinate distribution (a) and histogram of the values (a) of mutual polarization degree $V(x, y)$ of bile layer of chronic cholecystitis patient (group 2)

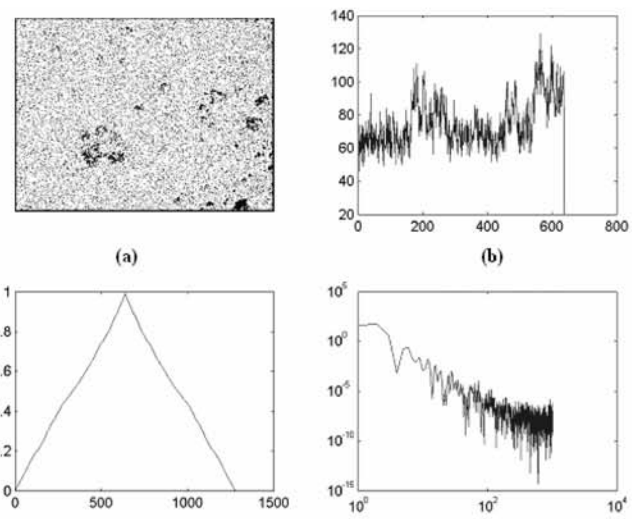

Fig. 7. Autocorrelation function (c) and log-log dependencies (d) of the amount of values $V = 0{,}5$ (b) in the coordinate distribution $V(x, y)$ (a) of bile layer of chronic cholecystitis patient (group 2)

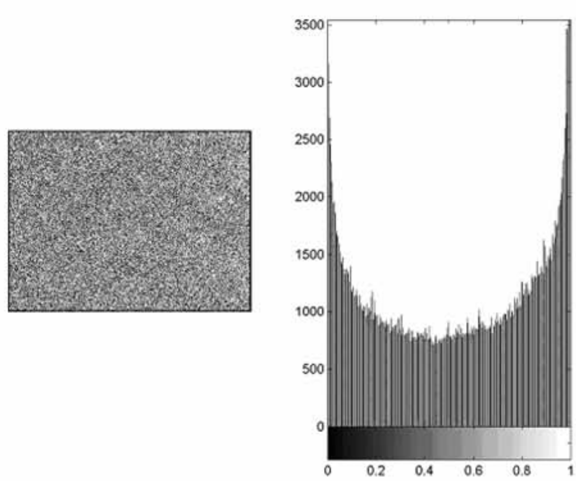

Fig. 8. Coordinate distribution (a) and histogram (a) of the values of mutual polarization degree $V(x,y)$ of bile layer of diabetes mellitus type 2 patients (group 3)

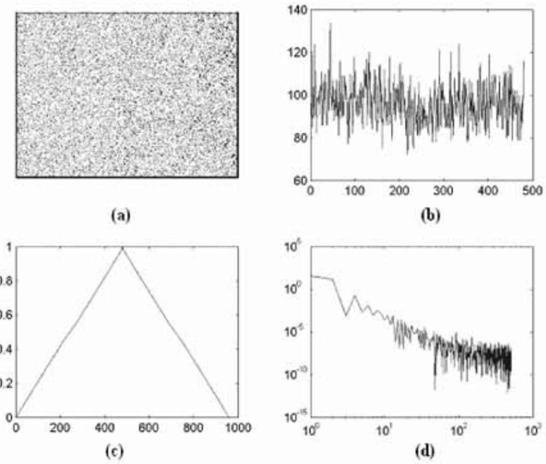

Fig. 9. Autocorrelation function (c) and log-log dependencies (d) of the amount of values $V = 0,5$ (b) in the distribution $V(x,y)$ (a) of bile layer of diabetes mellitus type 2 patients (group 3)

Table 1

Statistical moments of the 1st-4th orders of distributions $V(x,y) = 0,5$ of bile layers of all groups of patients

Parameters	Group 1	Group 2	Group 3
$M_1(V = 0,5)$	$0,09 \pm 0,008$	$0,21 \pm 0,027$	$0,32 \pm 0,019$
$M_2(W = 0,5)$	$0,26 \pm 0,031$	$0,13 \pm 0,023$	$0,12 \pm 0,019$
$M_3(W = 0,5)$	$0,11 \pm 0,021$	$1,28 \pm 0,41$	$4,26 \pm 0,58$
$M_4(W = 0,5)$	$0,09 \pm 0,009$	$2,12 \pm 0,52$	$5,29 \pm 0,0096$

Table 2

Correlation ($S(V = 0,5)$) and fractal ($\Omega(V = 0,5)$) parameters of $V(x,y) = 0,5$ distributions of bile layers of all groups of patients

Parameters	Group 1	Group 2	Group 3
$S(V = 0,5)$	$0,15 \pm 0,038$	$0,22 \pm 0,042$	$0,29 \pm 0,036$
$\Omega(V = 0,5)$	$0,17 \pm 0,048$	$0,24 \pm 0,069$	$0,38 \pm 0,089$

fractal ($D(V=0{,}5)=2{,}03;\Omega(V=0{,}5)=0{,}21$) with maximally great correlation area $S(V=0{,}5)=0{,}24$.

The following peculiarities are typical for polarization-correlation structure of laser images of bile layers of diabetes mellitus type 2 patients (Fig. 8, Fig. 9).

The extreme values of distribution $V(x,y)$ of bile layer of a patient from group 3, corresponding to sampling $V=0{,}5$, increase and amount to 45% - 50 %.

The correlation area and dispersion of extremes distribution of log-log dependency of power spectra of the number of extreme values of mutual polarization degree $V=0{,}5$ of the laser image of bile layer of the patient with complex pathology are as follows: $S(V=0{,}5)=0{,}25$ and

$D(V=0{,}5)=1{,}93;\Omega(V=0{,}5)=0{,}29$.

The following parameters of values distribution of liquid-crystalline sampling ($V(x,y)=0{,}5$) of mutual polarization degree of laser images of human bile layers belong to the basic criteria of diagnosing cholelithiasis latent course and differentiating its pathology types:

- statistical moments ($M_{i=1;2;3;4}(V)$) of distribution of mutual polarization degree values $V(x,y)=0{,}5$;
- correlation areas $S(V=0{,}5)$ of distribution of mutual polarization degree values $V(x,y)=0{,}5$;
- dispersions $\Omega(V)$ of extremes distribution of log-log dependencies of power spectra of parameters $V(x,y)=0{,}5$ values.

The ensemble of data about the values of diagnostic parameters $M_{k=1;2;3;4}(V=0{,}5)$ is presented in Table 1.

The obtained data about the coordinate distributions of mutual polarization degree of laser images of bile of all groups of healthy and sick patients prove that the statistical analysis of dependencies of the number of values of $V(x,y)=0{,}5$ sampling (liquid-crystalline phase) of bile layers laser images enable to reliably diagnose the latent course of cholelithiasis with both chronic cholecystitis and diabetes mellitus type 2.

The difference between statistical moments $M_k(W)$ of laser images of test group patients' bile (group 1) and the patients with various pathologies (groups 2 and 3) – mean (increasing by 2.7 – 3.5 times); dispersion (decreasing by 2.5 – 3.3 times); asymmetry (increasing by 3.3 – 5.4 times) and excess (increasing by 4.5 – 6.1 times) – are determined.

Thus, it can be stated that statistical moments' $M_{k=1;2;3;4}(V=0{,}5)$ investigation enables to perform reliable differentiation of the patients from groups 2 and 3.

Comparative data of correlation and fractal parameters of extreme values $V(x,y)=0{,}5$ distribution of laser images of all groups of patients are presented in Table 2.

The data about correlation and fractal structure of extreme values $V(x,y)=0{,}5$ distributions of mutual polarization degree indicate that the value of correlation area $S(V=0{,}5)$ and power spectra dispersion $\Omega(V=0{,}5)$ of mutual polarization degree distributions enable to reliably diagnose the latent course of cholelithiasis together with different pathology types. Correlation area $S(V=0{,}5)$ increases by 1,7-1,9 times. Dispersion $\Omega(V=0{,}5)$ increases by 1,6-2,1 times.

Thus it can be stated that the ensemble of correlation and fractal criteria of laser polarization diagnostics of not only cholelithiasis appearance but also its differentiation on the background of chronic cholecystitis and diabetes mellitus type 2 are experimentally determined and substantiated for practical application.

Conclusions

1. A new technique of estimating the structure of laser images based on measuring coordinate distributions of mutual polarization degree is suggested that characterizes the homogeneity of optically isotropic and optically anisotropic components in biochemical composition of bile.

2. The statistical (mean, dispersion, asymmetry and excess), correlation (correlation area of distribution of mutual polarization degree values) and fractal (dispersion of extremes of log-log dependencies of power spectra of mutual polarization degree values distribution) criteria of polarization-correlation diagnostics of cholelithiasis latent course and its stages differentiation on the background of chronic cholecystitis, diabetes mellitus type 2 and complex pathology are determined and substantiated.

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ДЕЯКІ ОСОБЛИВОСТІ МЕТОДУ ПОЛЯРИЗАЦІЙНОЇ СЕЛЕКЦІЇ ЛАЗЕРНИХ ЗОБРАЖЕНЬ У ДІАГНОСТИЦІ ПОЛІКРИСТАЛІЧНОЇ СТРУКТУРИ ШАРІВ ЖОВЧІ ЛЮДИНИ

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Резюме. Дана робота спрямована на дослідження можливостей діагностики і диференціації холелітіазу на тлі хронічного холециститу та цукрового діабету типу 2 шляхом використання нового методу поляризаційної селекції лазерних зображень шарів жовчі людини. Серед методів оптичної діагностики біологічних тканин людини широко розповсюдження набули методи лазерної поляриметричної діагностики їх оптико-анізотропної структури. У результаті розроблена низка методик ранньої діагностики та диференціації патологічних змін структури біологічних тканин, пов'язаних з їх дегенеративно-дисторофічними та онкологічними змінами. Біологічні рідини значно більш доступніші для безпосереднього лабораторного аналізу у порівняні із травматичними методами біопсії біологічних тканин. Враховуючи даний факт, актуальним є пошук нових додаткових параметрів лазерної діагностики біологічних рідин, їх оптико-анізотропної структури. Запропоновано новий метод оцінювання структури лазерних зображень на основі вимірювання координатних розподілів ступеня взаємної поляризації, який характеризує однорідність оптико-ізотропного та оптико-анізотропного компонентів у біохімічному складі жовчі. Установлені та обгрунтовані статистичні (середнє, дисперсія, асиметрія, та ексцес), кореляційні (кореляційна площа розподілів значень ступеня взаємної поляризації) і фрактальні (дисперсія екстремумів log-log залежностей спектрів потужностей розподілів значень ступеня взаємної поляризації) критерії поляризаційно-кореляційної діагностики латентного перебігу холелітіазу і диференціації стадій хронічного холециститу, цукрового діабету типу 2 та поєднання патологій.

Ключові слова: хронічний холецистит, холелітіаз, цукровий діабет типу 2.

НЕКОТОРЫЕ ОСБЕННОСТИ МЕТОДА ПОЛЯРИЗАЦИОННОЙ СЕЛЕКЦИИ ЛАЗЕРНЫХ ИЗОБРАЖЕНИЙ В ДИАГНОСТИКЕ ПОЛИКРИСТАЛИЧЕСКОЙ СТРУКТУРЫ СЛОЕВ ЖЕЛЧИ ЧЕЛОВЕКА

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Резюме. Даная работа направлена на исследование возможностей диагностики и дифференциации холелитиаза на фоне хронического холецистита и сахарного диабета типа 2 путем использования нового метода поляризационной селекции лазерных изображений слоев желчи человека. Среди методов оптической диагностики биологических тканей человека широкое распространение получили методы лазерной поляриметрической диагностики их оптико-анизотропной структуры. В результате разработан перечень методик ранней диагностики и дифференциации патологических изменений структуры биологических тканей, связанных с их дегенеративно-дистрофическими и онкологическими изменениями. Биологические жидкости значительно более доступные для непосредственного лабораторного анализа в сравнении с травматическими методами биопсии биологических тканей. Учитывая данный факт, актуальным является поиск новых дополнительных параметров лазерной диагностики биологических жидкостей, их оптико-анизотропной структуры. Предложен новый метод оценивания структуры лазерных изображений на основе измерения координатных распределений степени взаимной поляризации, который характеризует однородность оптико-изотропного и оптико-анизотропного компонентов в биохимическом составе желчи. Определены и обоснованы статистические (среднее, дисперсия, асимметрия и эксцесс), корреляционные (корреляционная площадь распределения значений степени взаимной поляризации) и фрактальные (дисперсия экстремумов log-log зависимостей спектров мощностей распределений значений степени взаимной поляризации) критерии поляризационо-кореляционой диагностики латентного течения холелитиаза и дифференциации стадий хронического холецистита, сахарного диабета типа 2 и сочетанных патологий.

Ключевые слова: хронический холецистит, холелитиаз, сахарный диабет типа 2.

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