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Медицина є прикладом інтеграції багатьох наук. Наукові дослідження у сучасній медицині на основі досягнень фізики, хімії, біології, інформатики та інших наук відкривають нові можливості для вивчення процесів, які відбуваються в живих організмах, та вимагають якісних змін у підготовці медиків. Науково-практична інтернет-конференція «**Розвиток природничих наук як основа новітніх досягнень у медицині**» покликана змінювати свідомость людей, характер їхньої діяльності та стимулювати зміни у підготовці медичних кадрів. Вміле застосування сучасних природничо-наукових досягнень є запорукою подальшого розвитку медицини як галузі знань.

Конференція присвячена висвітленню нових теоретичних і прикладних результатів у галузі природничих наук та інформаційних технологій, що є важливими для розвитку медицини та стимулювання взаємодії між науковцями природничих та медичних наук.

Комп'ютерна верстка:
Марія ІВАНЧУК

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У збірнику подані матеріали науково-практичної інтернет-конференції «Розвиток природничих наук як основа новітніх досягнень у медицині». У статтях та тезах представлені результати теоретичних і експериментальних досліджень.

Матеріали подаються в авторській редакції. Відповідальність за достовірність інформації, правильність фактів, цитат та посилань несуть автори.

Для наукових та науково-педагогічних співробітників, викладачів закладів вищої освіти, аспірантів та студентів.

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МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ, ПРОГНОЗУВАННЯ ТА СТАТИСТИЧНІ МЕТОДИ ОБРОБКИ РЕЗУЛЬТАТІВ У МЕДИЦИНІ

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Some biophysical methods for the assessment of bile homeostasis by chronic cholecystitis and diabetes mellitus type 2

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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. 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.

Key words: chronic cholecystitis, diabetes mellitus type 2, laser polarimety.

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, 3, 4].

The main information for these methods is obtained from coordinate distributions of polarization azimuths $\alpha(x,y)$ and ellipticity $\beta(x,y)$ (polarization maps) with the following correlation (auto- and mutually correlation functions [1, 2]) and fractal (fractal dimensions [7, 8]) 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 $\tau \le 0{,}1$) 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.

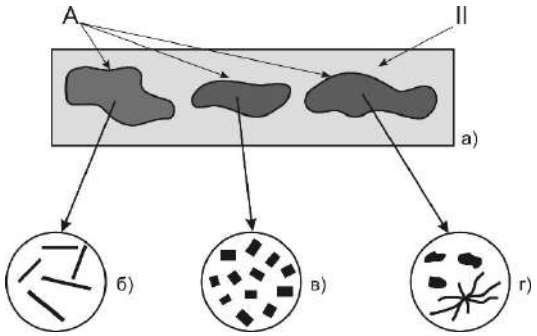

Fig. 1. On the analysis of bile optical model as (I) – anisotropic (A) fluid.

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): “attenuation” (Fig. 2a) – 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 ($\alpha_0 = const$); “birefringence” (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 – $\alpha_0 \to \alpha$.

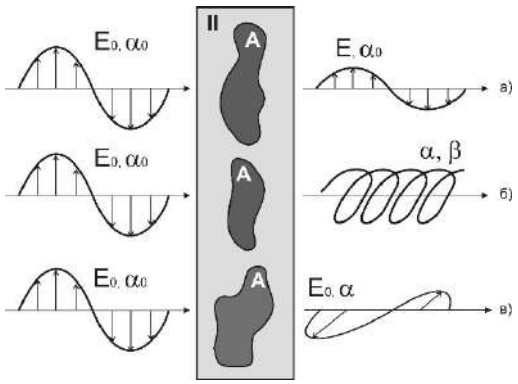

Fig. 2. Main mechanisms of transformation of laser radiation parameters by bile.

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

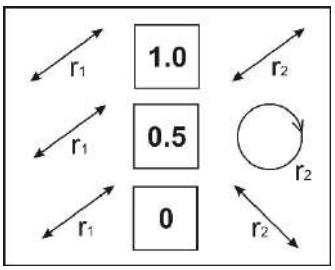

Fig. 3. Polarization correlation structure of the bile sample laser image.

It is shown [1, 6] 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 [9] 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) [1, 5, 8]. 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 $I_{\min}\begin{pmatrix} r_{11},\ldots r_{1m} \\ \ldots\ldots\ldots \\ r_{n1},\ldots r_{nm} \end{pmatrix}; I_{\max}\begin{pmatrix} r_{11},\ldots r_{1m} \\ \ldots\ldots\ldots \\ r_{n1},\ldots r_{nm} \end{pmatrix}$ of human bile layers images for each separate pixel (mn) of CCD-camera were determined, as well as rotation angles $\theta\begin{pmatrix} r_{11},\ldots r_{1m} \\ \ldots\ldots\ldots \\ r_{n1},\ldots r_{nm} \end{pmatrix}\left(I\begin{pmatrix} r_{11},\ldots r_{1m} \\ \ldots\ldots\ldots \\ r_{n1},\ldots r_{nm} \end{pmatrix} \equiv \min \right)$ 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, 7]

$$\alpha\begin{pmatrix} r_{11},\ldots r_{1m} \\ \ldots\ldots\ldots \\ r_{n1},\ldots r_{nm} \end{pmatrix} = \theta\left(I(r_i) \equiv \min\right) - \frac{\pi}{2};$$
$$\beta\begin{pmatrix} r_{11},\ldots r_{1m} \\ \ldots\ldots\ldots \\ r_{n1},\ldots r_{nm} \end{pmatrix} = arctg\,\frac{I(r_i)_{\min}}{I(r_i)_{\max}}. \quad (1)$$

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

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

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 (50 patients); cholelithiasis patients with diabetes mellitus type 2 – group 3 (50 patients).

Results. 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.

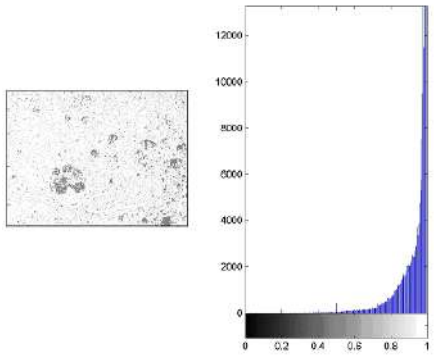

Fig. 4. Coordinate distribution (a) and histogram of values (a) of mutual polarization $V(x,y)$ degree if a healthy patient's bile layer (group 1).

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 ($D(V=0{,}5)=2{,}11;\Omega(V=0{,}5)=0{,}16$) 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.

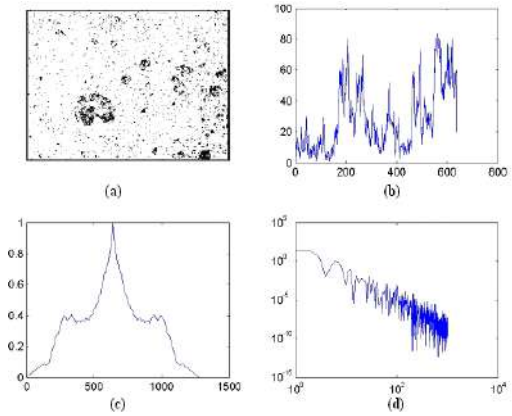

Fig. 5. Autocorrelation function (c) and log-log dependencies (d) of the amount of values $V=0{,}5$ (b) in the coordinate distribution $V(x,y)$ (a) of a healthy patient's bile layer (group 1).

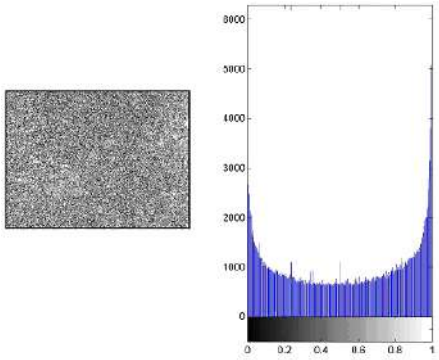

Fig. 6. Coordinate distribution (a) and histogram of the values (a) of mutual polarization degree $V(x,y)$ of bile layer of chronic cholecystitis patient (group 2).

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

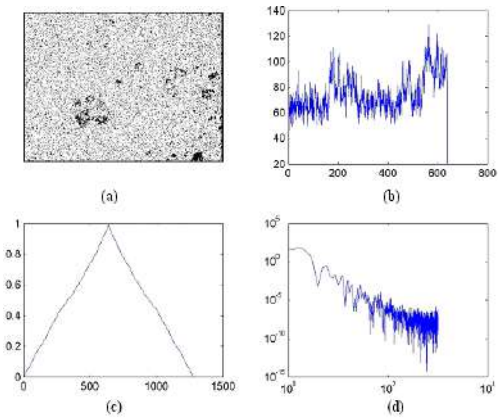

Fig. 7. Autocorrelation function (c) and log-log dependencies (d) of the amount of values $V=0{,}5$ (b) in the coordinate distribution $V(x,y)$ (a) of bile layer of chronic cholecystitis patient (group 2).

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

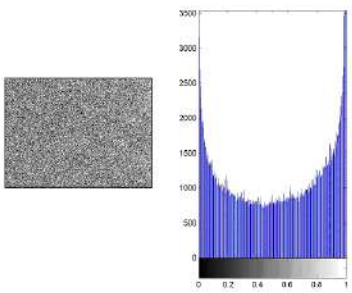

Fig. 8. Coordinate distribution (a) and histogram (a) of the values of mutual polarization degree $V(x,y)$ of bile layer of diabetes mellitus type 2 patients (group 3).

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 %.

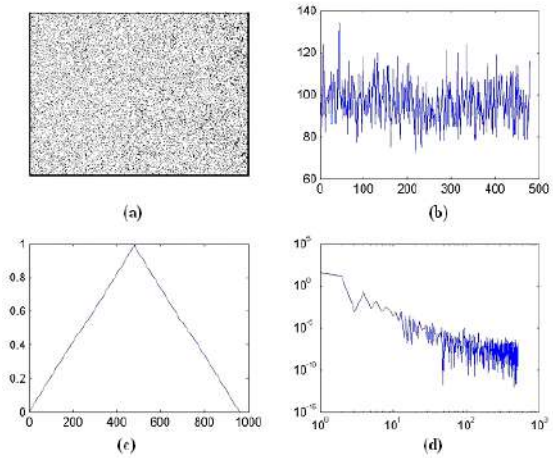

Fig. 9. Autocorrelation function (c) and log-log dependencies (d) of the amount of values $V = 0{,}5$ (b) in the distribution $V(x,y)$ (a) of bile layer of diabetes mellitus type 2 patients (group 3).

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.

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
$M_1(V=0,5)$	$0,09\pm0,008$	$0,21\pm0,027$	$0,32\pm0,019$
$M_2(W=0,5)$	$0,26\pm0,031$	$0,13\pm0,023$	$0,12\pm0,019$
$M_3(W=0,5)$	$0,11\pm0,021$	$1,28\pm0,41$	$4,26\pm0,58$
$M_4(W=0,5)$	$0,09\pm0,009$	$2,12\pm0,52$	$5,29\pm0,0096$

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.

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
$S(V=0,5)$	$0,15\pm0,038$	$0,22\pm0,042$	$0,29\pm0,036$
$\Omega(V=0,5)$	$0,17\pm0,048$	$0,24\pm0,069$	$0,38\pm0,089$

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.

References

1. Angelsky OV, Ushenko AG, Ushenko YG. Complex degree of mutual polarization of biological tissue coherent images for the diagnostics of their physiological state. *J Biomed Opt.* 2005 Nov-Dec;10(6):060502.

2. Angelsky OV, Ushenko AG, Ushenko YG, Tomka YY. Polarization singularities of biological tissues images. *J Biomed Opt.* 2006 Sep-Oct;11(5):054030.

3. Baumann B, Woehrer A, Ricken G, Augustin M, Mitter C, Pircher M, Kovacs GG, Hitzenberger CK. Visualization of neuritic plaques in Alzheimer's disease by polarization-sensitive optical coherence microscopy. *Sci Rep.* 2017 Mar 6;7:43477.

4. Borovkova M, Trifonyuk L, Ushenko V, Dubolazov O, Vanchulyak O, Bodnar G, Ushenko Y, Olar O, Ushenko O, Sakhnovskiy M, Bykov A, Meglinski I. Mueller-matrix-based polarization imaging and quantitative assessment of optically anisotropic polycrystalline networks. *PLoS One.* 2019 May 16;14(5):e0214494.

5. Dubolazov AV, Pashkovskaya NV, Ushenko YA, Marchuk YF, Ushenko VA, Novakovskaya OY. Birefringence images of polycrystalline films of human urine in early diagnostics of kidney pathology. *Appl Opt.* 2016 Apr 20;55(12):B85-90.

6. Ushenko AG, Angelsky PO, Sidor M, Marchuk YF, Andreychuk DR, Pashkovskaya NV. Spatial-frequency selection of complex degree of coherence of laser images of blood plasma in diagnostics and differentiation of pathological states of human organism of various nosology. *Appl Opt.* 2014 Apr 1;53(10):B172-80.

7. Ushenko YA. Concerted spatial-frequency and polarization-phase filtering of laser images of polycrystalline networks of blood plasma smears. *J Biomed Opt.* 2012 Nov;17(11):117005.

8. Ushenko YA, Trifonyuk LY, Dubolazov AV, Karachevtsev AO. Fourier-domain Jones-matrix mapping of a complex degree of mutual anisotropy in differentiation of biological tissues' pathological states. *Appl Opt.* 2014 Apr 1;53(10):B205-14.

9. Ushenko YO, Dubolazov OV, Karachevtsev AO, Gorsky MP, Marchuk YF. Wavelet analysis of Fourier polarized images of the human bile. *Appl Opt.* 2012 Apr 1;51(10):C133-9.