Evolution of Mueller Matrix Images of the Myometrium for the Optical Anisotropy Oncological Changes

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***Abstract* — The optical model of polycrystalline networks of myometium is suggested. The results of investigating the interrelation between the values correlation (correlation area, asymmetry coefficient and autocorrelation function excess) and fractal (dispersion of logarithmic dependencies of power spectra) parameters are presented. They characterize the distributions of Mueller matrix elements in the points of laser images of myometrium histological sections. The criteria of differentiation of death coming reasons are determined.**

***Index Terms* — biological tissue, correlation function, correlation area, correlation moments, Mueller matrix, power spectra.**

I. INTRODUCTION

Three types of Mueller matrix elements $Z_{ik}(m \times n)$ of myometrium tissue can be defined [1-5].

The first type – coordinate distributions of the values of diagonal Mueller matrix elements $Z_{22;33}(m \times n)$ characterizing the transformation degree of polarization azimuth of laser wave, myosin fibrils, optical axes of which are oriented in two mutually transverse directions $\rho = 0^0 \leftrightarrow 90^0$ ($Z_{22}(m \times n)$) and $\rho = 45^0 \leftrightarrow 135^0$ ($Z_{33}(m \times n)$), correspondingly. In this sense such matrix elements will be called "orientation" one.

The second type – coordinate distributions of diagonal matrix element $Z_{44}(m \times n)$, the value of which is determined by phase shifts between the orthogonal components of laser wave amplitude appearing due to birefringence of myosin fibrils substance. In this sense the element of Mueller matrix will be called "phase" one.

The third type – coordinate distributions of non-diagonal Mueller matrix elements $Z_{23;24;34}(m \times n)$, characterizing the mechanisms of mutual transformations of linear polarization into the elliptical one, and vice versa. Such an ensemble of Mueller matrix elements will be called "orientation-phase" ones.

This research is focused on the search for possibilities of diagnostics of death coming due to acute coronary insufficiency by means of determining correlation and fractal parameters characterizing the distributions of phase" $Z_{44}(m \times n)$ Mueller matrix elements of myometrium tissue histological sections.

II. DIAGNOSTIC POTENTIALITY OF CORRELATION AND FRACTAL ANALYSIS OF DISTRIBUTIONS OF THE "PHASE" MUELLER MATRIX ELEMENT OF MYOMETRIUM TISSUE

The results of experimental investigations of coordinate $Z_{44}(m \times n)$ – fragments (a), (b); statistical $h(Z_{44})$, – fragments (c), (d); correlation $K(Z_{44})$, – fragments (e), (f) and fractal $\log J(Z_{44}) - \log d^{-1}$, – fragments (g), (h) structure of Mueller matrix phase elements Z_{44} of of myometrium of the heaths patients – group 1 (left column) and sick patients - group 2 are illustrated by Fig. 1.

The data obtained (Fig. 2) show that coordinate distributions $Z_{44}(m \times n)$ (fragments (a), (b)) of group 1 or group 2 myometrium tissues are random and statistical (fragments (c), (d)). This is verified by the fact of rapid decrease of autocorrelation functions $K(Z_{44})$ (fragments (e), (f)) and absence of the stable inclination of approximating curves to dependencies $\log J(Z_{44}) - \log d^{-1}$ (fragments (g), (h))

Correlation and fractal structure of phase elements Z_{44} distribution determined for two groups of myometrium samples (group 1– $q = 29$ and group 2 - $q = 21$) are illustrated by the values and change ranges of correlation area $S(Z_{44})$; dispersion $Q_2(Z_{44})$ and excess $Q_4(Z_{44})$ and statistical moments $M_{j=1;2;3;4}(J(Z_{44}))$ - Table 1.

The comparative analysis of values and change ranges of correlation parameters $S(Z_{44})$, $Q_2(Z_{44})$, $Q_4(Z_{44})$ and statistical moments of the 1st-4th order

$M_{j=1;2;3;4}(Z_{44})$, characterizing logarithmic dependencies of power spectra of phase elements Z_{44} distributions of myometrium Mueller matrix within the two groups group 1 and group 2 did not reveal any objective possibility to differentiate such cases. The change ranges of correlation and fractal parameters values for different groups of myometrium with group 1 and group 2 overlap.

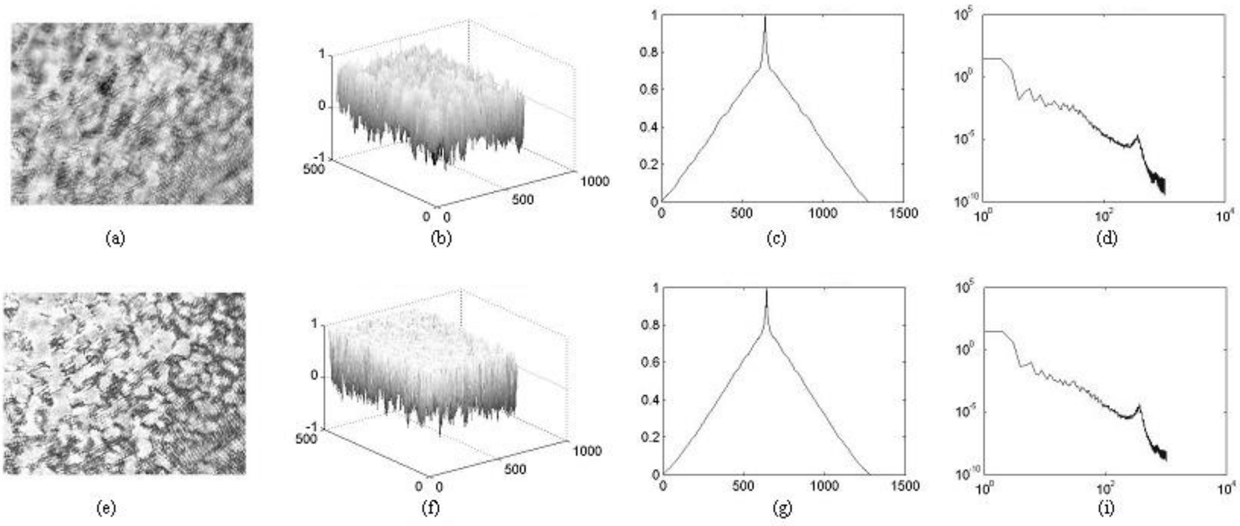

Fig. 1. Statistical, correlation and fractal parameters of myometrium phase element Z_{44} distributions.

To find more sensitive diagnostic criteria, the correlation and fractal structure of dependencies $N(Z_{44}=0) \equiv N_0$ (Fig. 2) and $N(Z_{44}=1) \equiv N_1$ (Fig. 3) was studied.

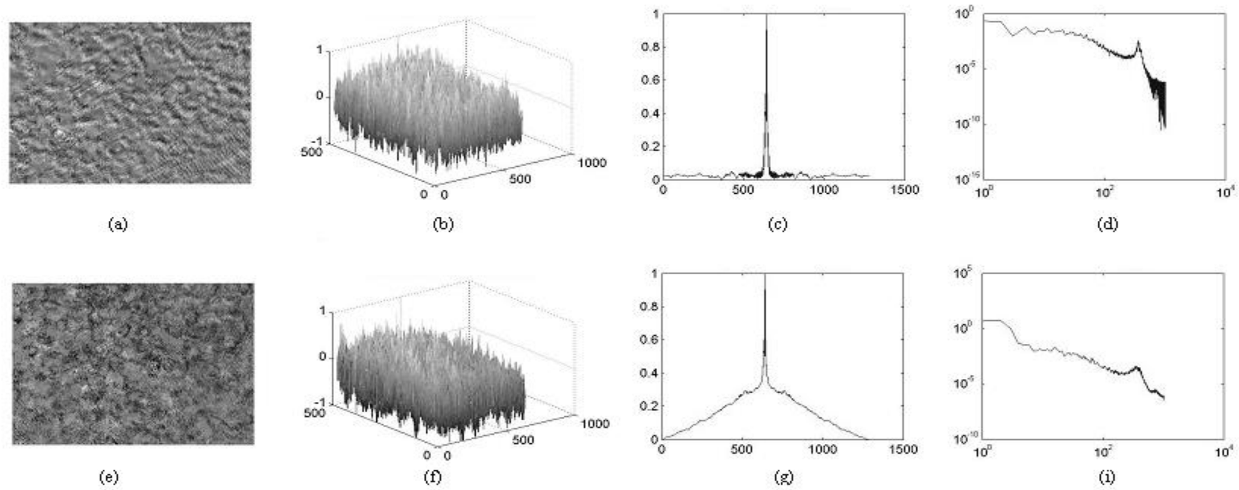

Fig. 2. Statistical, correlation and fractal structure of extreme values dependencies of myometrium phase matrix element $Z_{44} = 0$.

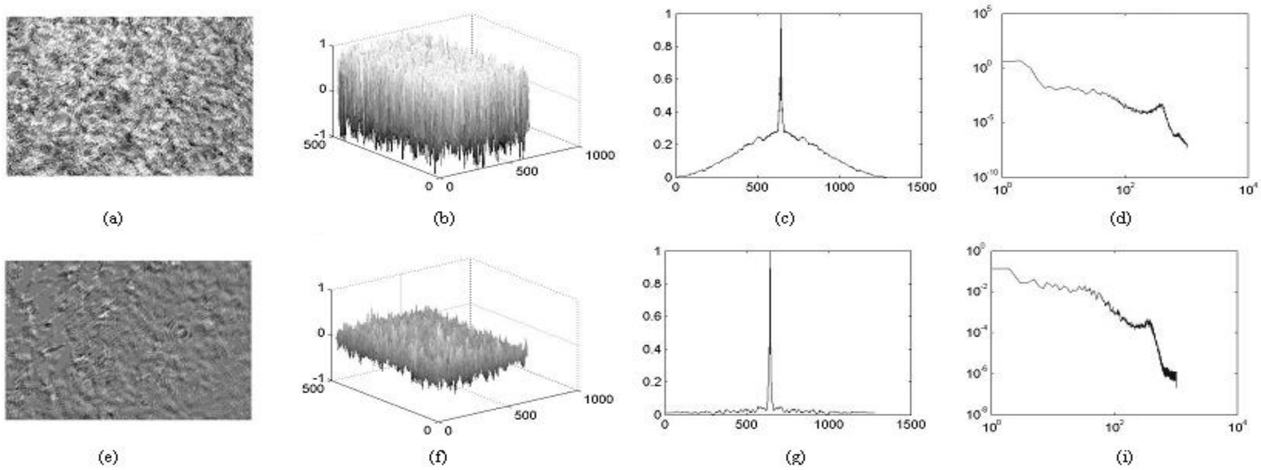

Fig. 3. Statistical, correlation and fractal structure of extreme values dependencies of myometrium phase matrix element $Z_{44} = 0$.

TABLE 1. STATISTICAL MOMENTS $M_{j=1;2;3;4}(Z_{44})$ OF COORDINATE DISTRIBUTIONS $Z_{44}(m \times n)$ OF MYOMETRIUM TISSUE FOR GROUP 1 AND GROUP 2 CASES

Parameters	Group 1	Group 2
$S(Z_{44})$	$0{,}21 \pm 0{,}026$	$0{,}26 \pm 0{,}037$
$Q_2(Z_{44})$	$0{,}35 \pm 0{,}044$	$0{,}31 \pm 0{,}039$
$Q_4(Z_{44})$	$0{,}43 \pm 0{,}051$	$0{,}53 \pm 0{,}062$
$M_1(Z_{44})$	$0{,}21 \pm 0{,}026$	$0{,}26 \pm 0{,}037$
$M_2(Z_{44})$	$0{,}35 \pm 0{,}044$	$0{,}31 \pm 0{,}039$
$M_3(Z_{44})$	$0{,}43 \pm 0{,}051$	$0{,}53 \pm 0{,}062$
$M_4(Z_{44})$	$1{,}16 \pm 0{,}14$	$1{,}37 \pm 0{,}16$

This approach enables to study the statistical manifestations of myometrium myosin fibrils birefringence at its two extreme levels – the minimal, optically isotropic ($N(Z_{44} = 1) \equiv N_1$) level and maximal, optically anisotropic ($N(Z_{44} = 0) \equiv N_0$) one.

As a result of investigating the dependencies of extreme values amount $N(Z_{44} = 1) \equiv N_1$ and $N(Z_{44} = 0) \equiv N_0$ a sufficient diagnostic sensitivity differentiation of group 1 and group 2 was revealed.

Thus, for group 2 the increase (by one order of a value) of the amount of extreme values $Z_{44} = 0$ of myometrium tissue Mueller matrix phase element (Fig. 2, fragments (c) and (d) respectively) occurs. This fact testifies to sufficiently higher level of optical anisotropy of myosin fibrils at group 2 if compared with that of group 1.

Besides, at group 2 it is accompanied by transformation of fractal dimensions $N(Z_{44} = 0) \equiv N_0$ into statistical ones – for the corresponding logarithmic dependencies of power spectra no stable slope of approximating curve is observed (Fig. 2, fragments (g) and (h)).

On the contrary, birefringence degradation of group 1 myometrium is vividly manifested in the increase (by one order of a value) of the amount of another extreme level $Z_{44} = 1$ of myometrium tissue Mueller matrix phase element (Fig. 3, fragments (c) and (d) respectively). At that the value of correlation area $S(Z_{44} = 1)$ of distribution $N(Z_{44} = 1) \equiv N_1$ sufficiently decreases (Fig. 3, fragments (e) and (f)).

The results of the comparative investigation of the value and change ranges of correlation area $S(N_0)$, $S(N_1)$; dispersion $Q_2(N_0)$, $Q_2(N_1)$; excess $Q_4(N_0)$, $Q_4(N_1)$ and statistical moments of the 1st-4th order $M_{j=1;2;3;4}(N_0)$, $M_{j=1;2;3;4}(N_1)$ of power spectra $J(N_0)$, $J(N_1)$ logarithmic dependencies $\log J(N_0) - \log d^{-1}$ and $\log J(N_1) - \log d^{-1}$ of the extreme values $Z_{44} = 0$ and $Z_{44} = 1$ amount of Mueller matrix phase element $Z_{44}(m \times n)$ of group 1 and group 2 myometrium are presented in Table 2 ($N(Z_{44} = 0) \equiv N_0$) and Table 3 ($N(Z_{44} = 1) \equiv N_1$).

TABLE 2. CORRELATION AND FRACTAL PARAMETERS OF THE DEPENDENCIES OF EXTREME VALUES $N_0(Z_{44} = 0)$ AMOUNT OF COORDINATE DISTRIBUTIONS $Z_{44}(m \times n)$ OF MYOCARDIUM TISSUE FOR GROUP 1 AND GROUP 2

Parameters	Group 1	Group 2
$S(Z_{44})$	$0{,}29 \pm 0{,}016$	$0{,}31 \pm 0{,}014$
$Q_2(Z_{44})$	$0{,}21 \pm 0{,}024$	$0{,}23 \pm 0{,}029$
$Q_4(Z_{44})$	$0{,}13 \pm 0{,}015$	$0{,}11 \pm 0{,}012$
$M_1(Z_{44})$	$0{,}62 \pm 0{,}066$	$0{,}51 \pm 0{,}057$
$M_2(Z_{44})$	$0{,}23 \pm 0{,}034$	$0{,}48 \pm 0{,}054$
$M_3(Z_{44})$	$0{,}14 \pm 0{,}015$	$1{,}05 \pm 0{,}16$
$M_4(Z_{44})$	$0{,}31 \pm 0{,}042$	$2{,}97 \pm 0{,}36$

TABLE 3. CORRELATION AND FRACTAL PARAMETERS OF THE DEPENDENCIES OF EXTREME VALUES $N_1(Z_{44}=1)$ AMOUNT OF COORDINATE DISTRIBUTIONS $Z_{44}(m \times n)$ OF MYOCARDIUM TISSUE FOR GROUP 1 AND GROUP 2

Parameters	Group 1	Group 2
$S(Z_{44})$	$0{,}21 \pm 0{,}023$	$0{,}04 \pm 0{,}0037$
$Q_2(Z_{44})$	$0{,}32 \pm 0{,}041$	$0{,}01 \pm 0{,}003$
$Q_4(Z_{44})$	$0{,}54 \pm 0{,}061$	$18{,}11 \pm 2{,}04$
$M_1(Z_{44})$	$0{,}56 \pm 0{,}062$	$0{,}29 \pm 0{,}035$
$M_2(Z_{44})$	$0{,}19 \pm 0{,}023$	$0{,}81 \pm 0{,}093$
$M_3(Z_{44})$	$0{,}31 \pm 0{,}045$	$4{,}75 \pm 0{,}76$
$M_4(Z_{44})$	$0{,}43 \pm 0{,}054$	$9{,}83 \pm 1{,}41$

III. CONCLUSION

The obtained data of experimental investigation of statistical structure of extreme values amount distributions of Mueller matrix phase elements of both types of myometrium indicate the objective possibility of differentiation of oncological changes.

Statistical moments of the 2nd-4th order $M_{j=2;3;4}(N_0)$, $M_{j=2;3;4}(N_1)$ of power spectra $J(N_0)$, $J(N_1)$ logarithmic dependencies $\log J(N_0) - \log d^{-1}$ and $\log J(N_1) - \log d^{-1}$ of $N(Z_{44}=0) \equiv N_0$, $N(Z_{44}=1) \equiv N_1$ distributions of extreme values $Z_{44}=0$ and $Z_{44}=1$ amount of Mueller matrix phase element $Z_{44}(m \times n)$ of group 1 and group 2 myometrium tissue proved to be the most informative.

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