Abstract

The aim of the study is combining polarimetry and spectropolarimetry techniques for identifying the changes of optical-geometrical structure in different kinds of biotissues with solid tumours. It is researched that a linear dichroism appears in biotissues (human esophagus, muscle tissue of rats, human prostate tissue, cervical smear) with cancer diseases, magnitude of which depends on the type of the tissue and on the time of cancer process development.

Keywords: Polarization, biological tissue, statistical moments, tumor, spectropolatimetry

1. Introduction

The variety of real physical objects including biological tissues and fluids are optically-inhomogeneous. Studying the light scattering phenomenon in biomedical application is an important task in a wide range of problems solved in biomedical optics [1]. There are several groups of techniques which were used to investigate the optically inhomogeneous biotissue’s (BT) structure:

- spectrophotometric techniques based on the analysis of spatial or temporal changes of intensity of optical radiation scattered by BT structure [2];
- polarimetric techniques which use the coherence matrix of light oscillations and are based on the analysis of polarization degree as a correlation function of the orthogonal components of light oscillations in one point of the scattered radiation field [3];
- correlation techniques which are based on the analysis of correlation degree among the parallel components of light oscillations polarization in different points of object field [2-3].

Modern optical techniques in medicine allow early detecting of malignant transformation in biotissues and, that is important, allows the changes preceding of malignant transformation in order to make a correct diagnosis [1].

The aim of this research is combining polarimetry and spectropolarimetry techniques for identifying the changes of optical geometrical structure in different kinds of biotissues with solid tumours.

2. Materials and methods

In this research, the methods of assessment of the cervix connective tissue in terms of specific volume of fibrous component and optical density of staining the connective tissue fibers [2-3] in the stroma of squamous (keratinizing and non-keratinizing) cancer \(n = 25\) and cervix adenocarcinoma \(n = 19\) are used. These results likely to allow one to make precise the histochemical differential diagnosis of squamous and glandular cancers of different differentiation stages (G1, G2, G3), indicating the feasibility of using computer microspectrophotometry in terms of additional sensitive diagnostic test.
The research was conducted on male Wistar rats with average weight of 110 g, clinically healthy, from the animal house of the Institute of Oncology in Bucharest. The tumoral implant was performed with suspension of cells, about $1 \times 10^7$ cells in 1.0 ml saline buffer subcutaneous injection in the right flank. In 7 days after the cells inoculation the clinical manifestations appeared; the tumour was tangible in 14 days.

Also, as objects of study the samples of thin sections of muscle tissue of rats at different stages of cancer are used: 7, 17, 40, 47, 52 days since the cancer cells were implanted. Because the procedure is performed on five rats, the total amount of samples for the study was 25. To demonstrate the research methods and the treatment of the experiment results, we shall consider a certain example for a sample of one rat after 7 days of infection.

As experimental techniques we used laser polarimetry and spectropolarimetry setup [2-3].

3. Polarimetry experimental results and discussion

Polarization parameters (azimuth $\alpha$ and ellipticity $\beta$) in every point of the boundary field of the object field are determined according to the following algorithms:

$$\alpha = 0.5 \arctan \left( \frac{f_{20}S_3^0 + f_{30}S_4^0 + f_{40}S_5^0}{f_{22}S_3^0 + f_{32}S_5^0 + f_{44}S_4^0} \right)$$

$$\beta = 0.5 \arcsin \left( f_{40}S_2^0 + f_{50}S_3^0 + f_{60}S_4^0 \right)$$

where

$$S_{i=2,3,4}^o = \begin{cases} \cos 2\alpha_o \cos 2\beta_o; \\ \sin 2\alpha_o \cos 2\beta_o; \\ \sin 2\beta_o. \end{cases}$$

Here $S_{i=2,3,4}^o$ – the Stokes vector parameters of the beam illuminating the BT; $\alpha_o, \beta_o$ – its azimuth and polarization ellipticity.

The statistical approach in the analysis of polarization images of biological tissues is represented below. Statistic moments of the first ($M$), second ($\sigma$), third ($A$) and fourth ($E$) orders were used as the analytical instrument [2] for estimating the ensemble of random values of $z$.

$$M = \frac{1}{N} \sum_{i=1}^{N} z_i$$

$$\sigma = \frac{1}{N} \left( \sum_{i=1}^{N} z_i^2 \right)^{1/2}$$

$$A = \frac{1}{\sigma^4} \left( \sum_{i=1}^{N} z_i^3 \right)$$

$$E = \frac{1}{\sigma^6} \left( \sum_{i=1}^{N} z_i^4 \right),$$

where $N = m \times n$ – total number of pixels of CCD-camera.

For estimation of diagnostic potentiality of statistical analysis of the prostate tissue images the histological sections of physiologically normal (21 samples) and oncologically changed (22 samples) tissue were investigated.

Polarization images of optically thin (reduction factor $r \leq 0.1$, geometrical thickness 40 $\mu m$) histological sections of post-surgery healthy (a, b) prostate tissue and oncologically changed (c, d) one, obtained for coaxial (0-0) and crossed (0-90) polarizer 4 and analyzer 9 are presented in Fig. 1.
The left part of Fig. 1 corresponds to microscopy of the samples in laser light. The choice of the sample’s thickness is determined by the task of modelling the polarized laser radiation passing in the case of single scattering mechanisms [2]. This enabled to theoretically assess the statistical parameters of intensity distribution of the field for polarized radiation.

The analysis of the obtained results shows high diagnostic sensitivity of statistic moments of the 3\textsuperscript{rd} and 4\textsuperscript{th} orders of coordinate distributions of matrix elements of both types of BT to the changes of optical-geometric structure.

4. Spectropolarimetry results

The technique of differential diagnosis of malignant or benign tumors, which uses no sophisticated biochemical analysis, but a simple optical method [3], is presented in this section. There was no need to measure across the whole spectrum, it would be enough to measure the value of dichroic ratio $D = \frac{1 - r_\lambda}{1 - r_\omega}$ only in two characteristic wavelengths: $\lambda_1$ – in the maximum of the spectral dependence of $\Delta$ and at $\lambda_2 = 700-800$ nm, for which $\Delta = 0$. It is obvious that for malignant tumors the dichroic ratio values for both wavelengths differ by 1.5-2.0 times in the case of prostate cancer and up to 6-10\% for the esophagus, while benign or healthy tissue is virtually indistinguishable (Fig. 2).

It can be explained by the fact that with the growth of the cancer tumor its structure arrangement grows to some range (47-50 days), and then destructive processes begin in 50 days. Two maxima are observed in the beginning of the process (7-17 days) in most cases in the dependence $\Delta = f(\lambda)$: the first one is at $\lambda \approx 430$ nm and the second one is at $\lambda \approx 500$ nm; at the end of the process (47 days) – there is only one maximum in the area of $\lambda \approx 450-500$ nm. It is better observed when we conduct the average of the values $\Delta$ on five rats on five investigated stages of the cancer disease development. The results of these calculations are shown by the graphs in Fig. 2.

As the linear dichroism is lacking for healthy tissues, then the obtained results can have diagnostic value with the purpose of detection and estimation of the stage of the cancer disease development.
5. Conclusion

Thus, it was experimentally established that the 3rd (A) and the 4th (E) statistic moments of coordinate intensity distributions \( I_{00}, I_{090} \) of polarization images of human prostate tissue are the most sensitive to the changes in orientation-phase of architectonic structure. The statistic moments of the 3rd (A) and 4th (E) orders appeared to be the most sensitive to pathological changes of orientation-phase structure of architectonics of prostate tissue. Their value (asymmetry of distribution \( I_{090} \)) changes within the limits of two orders.

It is determined that the linear dichroism appears in biotissues (human esophagus, muscle tissue of rats) in all cases with the cancer disease; its value depends on the type of the tissue and on the time of the cancer process development. Spectral manifestation of cancer changes in biological tissues is determined. The attempt to establish substances in the tumor, which acts as optical indicators of cancer changes in biological tissues, has been made.

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References