DIFFERENTIAL DIAGNOSTICS OF ASEPTIC AND SEPTIC LOOSENING OF THE CUP OF THE ENDOPROSTHESIS OF THE ARTIFICIAL HIP JOINT BY THE METHODS OF POLARISATION TOMOGRAPHY

Alexander G. Ushenko, Alexander Olar
Chernivtsi National University, Department of Optics and Publishing, Chernivtsi, Ukraine

Abstract. Manuscript contains structural-logical scheme and analytical description of the differential diagnosis of aseptic and septic loosening of the artificial hip joint endoprosthesis using the methods of differential Mueller-matrix mapping of circular birefringence (CB) distributions of polycrystalline synovial films (SF) and results of determining the sensitivity, specificity and accuracy of the wavelet analysis method of differential Mueller-matrix mapping of the distributions of the CB values of polycrystalline films SF patients from the control group and groups with different severity of the hip joint pathology.

Keywords: polarization tomography, Mueller matrix, circular birefringence, synovial films

DIAGNOSTYKA RÓŻNICOWA ASEPTYCZNEGO I SEPTYCZNEGO OBLUZOWANIA PANEWKI ENDOPROTEZY STAWU BIODROWEGO METODAMI TOMOGRAFII POLARYZACYJNEJ

Streszczenie. Manuskrypt zawiera schemat strukturalno-logiczny i opis analityczny diagostyki różnicowej aseptycznego i septycznego obluzowania sztucznego endoprotezy stawu biodrowego z wykorzystaniem metod różnicowego mapowania macierzy Melliera rozkładów dwójłomności kolowej polikrystalicznych filmów błony maziowej i wyników określania czułości, swoistości i dokładności metody analizy falowej różnicowego mapowania macierzy Melliera rozkładów wartości dwójłomności kolowej polikrystalicznych filmów SF pacjentów z grupy kontrolnej i grup o różnym nasileniu patologii stawu biodrowego.

Słowa kluczowe: tomografia polaryzacyjna, macierz Melliera, dwójłomność kolowa, błony maziowe

Introduction

Methods of laser polarimetry are among the most important in the development of the latest introscopy systems of the polycrystalline structure of biological layers. The main pivot of such techniques is the Muller-matrix polarimetry (MMP) [9, 11, 15]. This optical technology provides the most complete information about the optical anisotropic properties of biological tissues.

This manuscript contains structural-logical schemes and analytical descriptions of the differential diagnosis of aseptic and septic loosening of the artificial hip joint endoprosthesis using the methods of differential Mueller-matrix mapping of circular birefringence (CB) distributions of polycrystalline synovial films (SF) films and results of determining the sensitivity, specificity and accuracy of the wavelet analysis method of differential Mueller-matrix mapping of the distributions of the CB values of polycrystalline films SF patients from the control group and groups with different severity of the hip joint pathology [16, 17].

Table 1. structural-logical scheme of differential Mueller-matrix tomography of polycrystalline films of SF in the differential diagnosis of aseptic and septic loosening of the endoprosthesis cup of an artificial hip joint

| Polycrystalline films of synovial fluid (SF) | Differential Mueller-matrix mapping of polycrystalline SF films |
|--------------------------------------------|---------------------------------------------------------------|
| CB maps                                    | LB maps                                                       |

Mean values and fluctuations of the magnitude of the statistical moments of the 1st - 4th orders characterizing the distribution of the value of CB of the samples of SF

Information analysis of the Mueller-matrix polarization tomography method for polycrystalline structure of SF films

| Sensitivity, Se | Specificity, Sp | Accuracy, Ac |
|-----------------|-----------------|--------------|

| Statistical analysis of the amplitude distributions of the wavecoefficients of the CB and LB cards |

Mean values and fluctuations of the magnitude of statistical moments of the 1st - 4th orders, as well as the dispersion and sharpness of the peak of autocorrelation functions within the set of CB maps of the polycrystalline structure of samples of SF

Information analysis of the Mueller-matrix polarization tomography method of polycrystalline structure of SF films

| Sensitivity, Se | Specificity, Sp | Accuracy, Ac |
|-----------------|-----------------|--------------|

Criterias for differential diagnostics method Mueller-matrix polarization tomography polycrystal structures of SF

1. Differential diagnostics of aseptic and septic loosening of the endoprosthesis cup using the Mueller-matrix reconstruction

This part of the research contains materials on the experimental implementation of polarisation reproduction with a comprehensive statistical and correlation analysis of the coordinate distributions of the magnitude of circular birefringence of polycrystalline films of synovial fluid of the hip joint of patients from the control group 1 and research groups 2 and 3 (section 3) [1, 16, 18].

An experimental method for determining the coordinate distributions of the magnitude of the CB of samples of SF polycrystalline films is presented in section 2 (clause 2, paragraph 2).

On a series of fragments of Fig. 1 presents the maps of the CB (left parts), the coordinate distributions of the magnitude of the CB (right parts) and the autocorrelation functions of the maps of the CB (lower parts), which are defined for the polycrystalline films of the SF of the hip joint of patients from group 1 (Fig. 1), group 2 (Fig. 2) and group 3 (Fig. 3) [2, 8, 20].

Comparison of the results of Mueller-matrix tomography (Fig. 2 – 4) of the parameters of the optical anisotropy of polycrystalline films of SF of the hip joint of patients of all groups revealed [14, 19, 23]:

- individual for each group of samples topographic structure of the coordinate distributions of the magnitude of CB (left parts of Fig. 1 – 3);
- significant range of coordinate-non-uniform change in the magnitude of circular birefringence (right parts of Fig. 1 – 3);
- complex and asymmetric structure for each of the groups of distributions of the eigenvalues of the autocorrelation functions (the lower parts of Fig. 1 – 3) [3, 10, 13].

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Fig. 1. Map (left side), coordinate distribution (right side) and autocorrelation function (lower part) of random variables of the CB of the SF polycrystalline film of a patient's syringe of group 1

Fig. 2. Map (left side), coordinate distribution (right side) and autocorrelation function (lower part) of random variables of the CB of the SF polycrystalline film of a patient's syringe of group 2

Fig. 3. Map (left side), coordinate distribution (right side) and autocorrelation function (lower part) of random variables of the CB of the SF polycrystalline film of a patient's syringe of group 3
1.1. Information analysis of the Mueller-matrix data reconstruction

This section contains the results of determining the strength of the Mueller-Marcic method of reproducing the distribution of the magnitude of the CB of SF polycrystalline films by calculating the magnitude of a set of operational characteristics – sensitivity, specificity and accuracy of the polarization tomography technique for all three groups of patients [12, 21, 22].

Table 2. Operational characteristics of the Mueller-matrix tomography method of circular birefringence of SF polycrystalline films

| ST  | $Se$ | $Sp$ | $Ac$ |
|-----|------|------|------|
| 1ST | 21   | 4    | 20   | 5    | 25  |
| 2ST | 20   | 5    | 20   | 5    | 25  |
| 3ST | 22   | 3    | 22   | 3    | 25  |
| 4ST | 23   | 2    | 22   | 3    | 25  |
| 2ST | 21   | 4    | 20   | 5    | 25  |

These $ST1 - ST4$ – statistical moments 1-st – 4-th order, which characterise the distributions of the CB.

From the analysis of the operational characteristics of the method of polarisation reproduction of the distributions of the CB given in Table 2, the following follows:

- the range of variation of the specificity of the polarisation reproduction of the distributions of CB is $80% \leq Sp \leq 88%$;
- the range of variation of the value of the balanced accuracy of the polarisation reproduction of the distributions of the CB is $82% \leq Ac \leq 90%$.

The overall level of the operational characteristics of the metrology of polarisation tomography (sensitivity, specificity and balanced accuracy) reaches 90%.

The overall level of the operational characteristics of the polarisation tomography technique (sensitivity $Se$, specificity $Sp$ and balanced accuracy $Ac$ ) reaches 90% [4, 7].

1.2. Wavelet analysis of CB cards of polycrystalline SF films

On fragments of the series Fig. 4 – 6 shows the wavelet distribution coefficient map CB (upper part) linear section with the MHAT (Mexican hat) scale of function 15 (lower part). Quantitatively, changes in the distributions of the CB value, which is caused by the optical activity of polycrystalline SF films, which illustrate the distributions (mean and variance) of the amplitudes of the wavelet coefficients of maps of circular birefringence of SF samples of the hip joint of patients of all groups, which are presented in table 2 [5, 6].

Fig. 4. The two-dimensional and linear distributions of the wavelet coefficients of the CB map of the polycrystalline SF film of the knee joint of a patient from the control group 1

Fig. 5. The two-dimensional and linear distributions of the wavelet coefficients of the CB map of the polycrystalline film SF of the hip joint of a patient from group 1
Thus, there is an increase in the overall level of the operational characteristics of the polarisation tomography technique (sensitivity $S_e$, specificity $Sp$ and balanced accuracy $Ac$) of the distributions of circular birefringence of polycrystalline SF films to $87 \%- 92\%$.

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