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

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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 diagnostyki różnicowej aseptycznego i septycznego obluzowania sztucznej endoprotezy stawu biodrowego z wykorzystaniem metod różnicowego mapowania macierzy Muellera rozkładów dwójłomności kołowej polikrystalicznych filmów błony maziowej i wyników określania czułości, swoistości i dokładności metody analizy falkowej różnicowego mapowania macierzy Muellera rozkładów wartości dwójłomności kołowej polikrystalicznych filmów SF pacjentów z grupy kontrolnej i grup o różnym nasileniu patologii stawu biodrowego.

Słowa kluczowe: tomografia polaryzacyjna, macierz Muellera, dwójłomność kołowa, 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	
Statistical and correlation analysis		
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 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 wavelet coefficients 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*
Criteria 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].
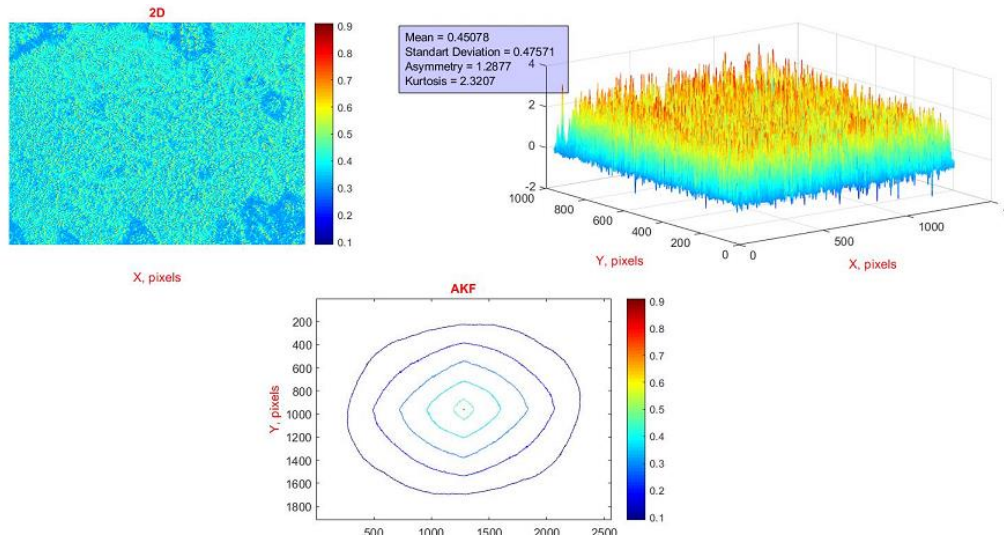
Fig. 1. Map (left side), coordinate distribution (right side) and autocorrelation function (lower part) of random variables of the CB of the SF polycrystalline film of a patient's syringe of group 1
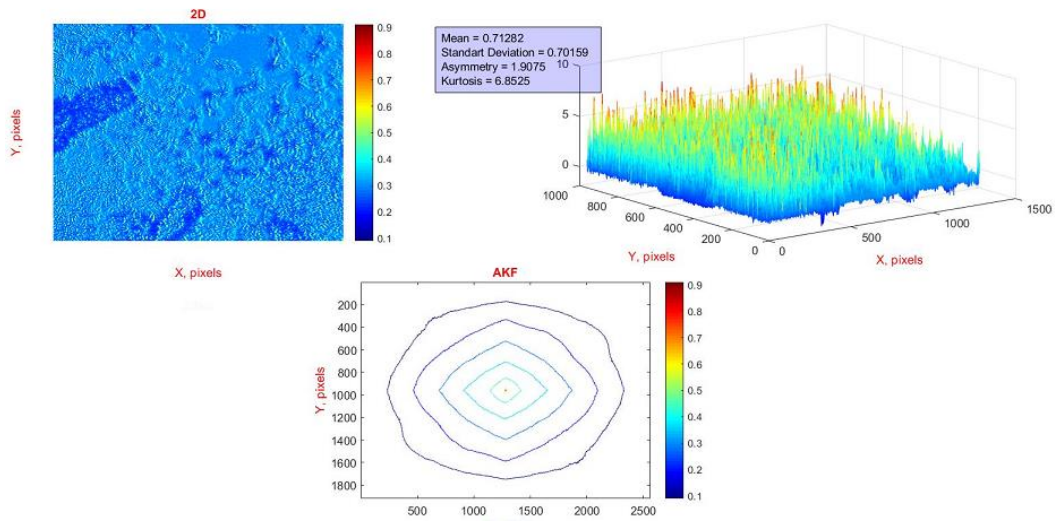

Fig. 2. Map (left side), coordinate distribution (right side) and autocorrelation function (lower part) of random variables of the CB of the SF polycrystalline film of a patient's syringe of group 2
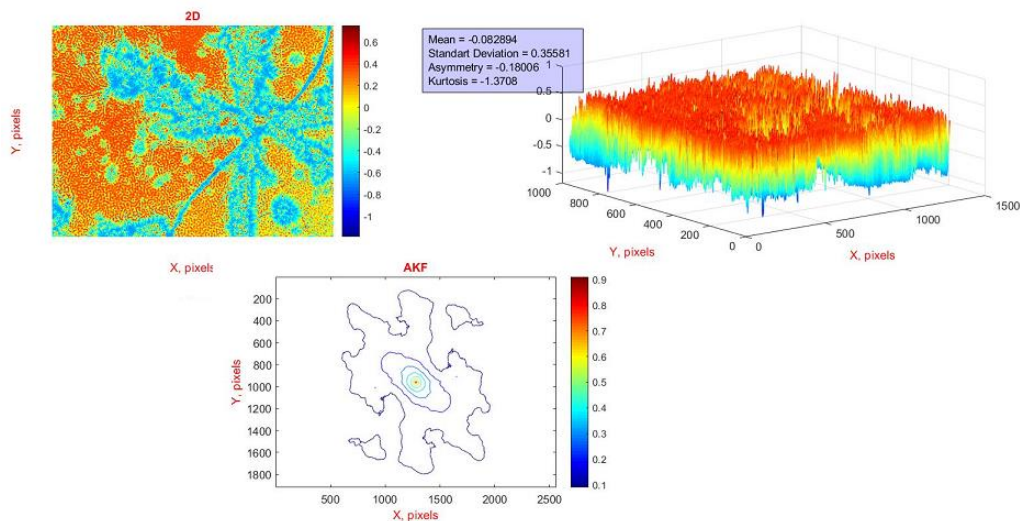

Fig. 3. Map (left side), coordinate distribution (right side) and autocorrelation function (lower part) of random variables of the CB of the SF polycrystalline film of a patient's syringe of group 3

1.1. Information analysis of the Mueller-matrix data reconstruction

This section contains the results of determining the strength of the Mueller-Maric 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

	Se		*Sp*		*Ac*
*ST*1	21	4	20	5	25
	84		**80**		**82**
*ST*2	20	5	20	5	25
	80		**80**		**80**
*ST*3	22	3	22	3	25
	88		**88**		**88**
*ST*4	23	2	22	3	25
	92		**88**		**90**
*ST*4	21	4	20	5	25
	84		**80**		**82**

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

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 (Maxican 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].
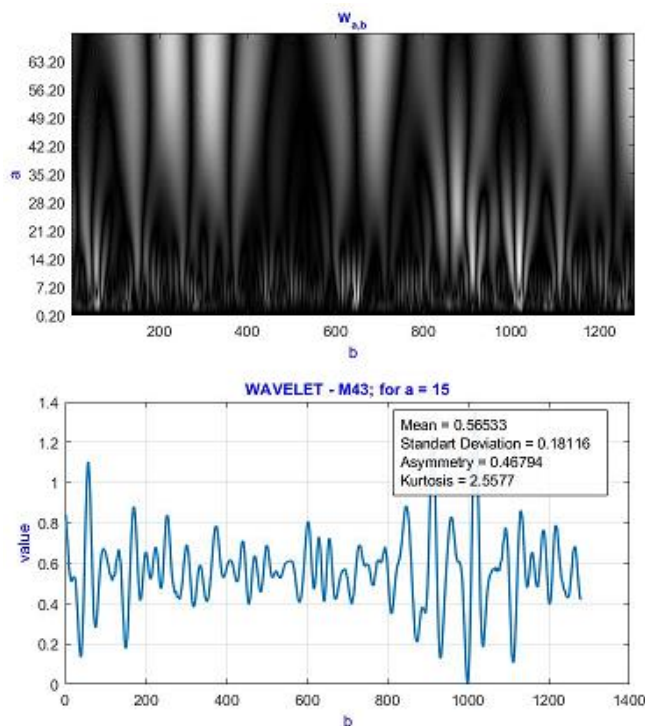

Fig. 4. The two-dimensional and linear distributions of the wavelet coefficients of the CB map of the polycrystalline SF film of the knee joint of a patient from the control group 1
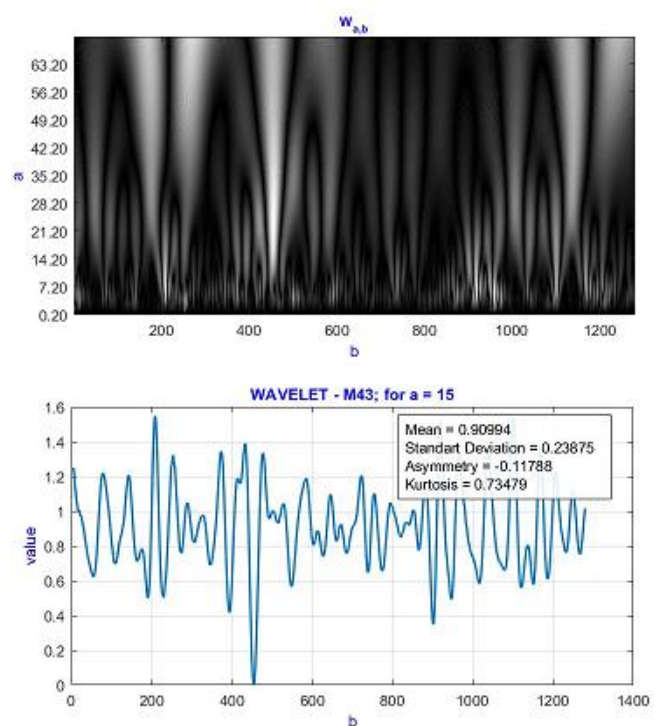

Fig. 5. The two-dimensional and linear distributions of the wavelet coefficients of the CB map of the polycrystalline film SF of the hip joint of a patient from group 1
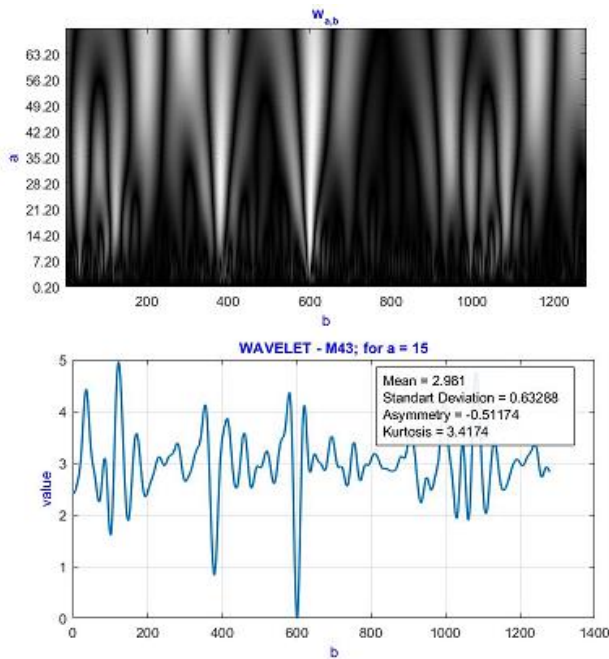
Fig. 6. The two-dimensional and linear distributions of the wavelet coefficients of the CB map of the polycrystalline film SF of the hip joint of a patient from group 3

1.3. Information method of wavelet analysis of the distribution of CB values

The data of the information analysis of the strength of the wavelet analysis method of the Muller-matrix tomography of the distribution of values of CB are presented in table 3.

Table 3. Operational characteristics of the wavelet analysis method Muller-matrix reproduction distributions of the magnitude of CB polycrystalline films SF

	Se		Sp		Ac
	Scale MHAT 55				
$ST1$	21	4	21	4	25
	84		**84**		**84**
$ST2$	22	3	21	4	25
	88		**84**		**86**
	Scale MHAT 15				
$ST1$	23	2	22	3	25
	92		**88**		**90**
n	a	b	c	d	n
$ST2$	22	3	22	3	25
	88		**88**		**88**

2. Conclusions

It can thus be inferred that:
- the range of variation of the sensitivity value of the Muller matrix playback of CB cards is $84\% \leq Se \leq 92\%$;
- the range of variation of the magnitude of specificity of the Muller matrix playback of CB cards is $84\% \leq Sp \leq 88\%$;
- the range of variation of the value of balanced accuracy. The Muller matrix playback of CB maps is $84\% \leq Ac \leq 88\%$.

Thus, there is an increase in the overall level of the operational characteristics of the polarisation tomography technique (sensitivity Se, specificity Sp and balanced accuracy Ac) of the distributions of circular birefringence of polycrystalline SF films to $87\% - 92\%$.

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