The technique of measurement of intraocular lens surface roughness using Atomic Force Microscopy

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Abstract: *Roughness of surface of Intraocular Lens plays an important role, which can provide important information on the interaction between the surface of the implanted lens and lens capsule, among others. Although surfaces appear smooth to the naked eye, they are quite rough at the microscopic levels. The paper presents a technique for measuring surface roughness using AFM. It was found that the size of the scan area does not significantly affect the two standards parameters describing the surface roughness profile (Sa and Sq), however, significantly affect the parameters describing the shape irregularities (Ssk and Ska).*

Keywords: *surface roughness, IOL, AFM, lens*

1. Introduction

Cataract is a social problem in a global perspective, causing about half of the cases of blindness in the world and to this day there is no effective pharmacological treatment of this disease. The only effective therapy is surgery. The procedure involves removing the natural lens and replacing it with an artificial implant – intraocular lens (IOL). This lens provides acceptable vision for limited time, usually a few years, thus the improvement of the quality of implants is still a scientific and technological challenge.

Atomic Force Microscope (AFM) allows to obtain important information about surface profile and other properties, inaccessible in a different way. AFM can map the atomic structure of a surface and observe physical properties with a resolution of a few nanometers. The sensitivity and resolving power of this measuring method enables the study of the behavior of micro- and nanostructures at the level of quantum effects.

The beginning of atomic force microscopy is the moment of constructing the first microscope in 1986 [1]. Since that moment the number of applications have greatly increased. Current applications include testing surfaces of artificial materials and biological structures under physiological conditions etc. Atomic Force Microscope is an efficient and accurate tool for research and analysis of properties of biomaterials.

AFM allows to measure surface topography, micromechanical properties, such as elasticity and viscosity of a transparent intraocular lens (IOL) [2], used in studies on inflammatory effects in the eye, especially in the lenticular capsule when IOL is implanted. The biomaterial of the lens affects the epithelial cells in a way that is not yet understood fully. One of the ways to understand this mechanism is the analysis of the topography and physical (e.g. mechanical) properties of the surface of intraocular lenses [3], which in turn allow to deal with issues such as friction, lubrication, and wear. It also has a major impact on fluid dynamics, thermal resistance, vibration control.

2. Materials and methods

Multiple AFM measurements using an Ntegra NT-MDT AFM microscope of a bispherical PMMA intraocular lens surface were carried out under tapping mode in air. The investigated lens had a radius of curvature equal to 13.20 mm. To prevent the physical degradation IOL was stored in Ringer's solution, except for the time of measurement,. Before the scanning procedure the lens was washed with ultraclean water and then dried with argon. Then, the lens was fixed to AFM stage using a gel, which covered only the bottom part of the lens and did not have contact with the examined surface. The measurement was performed for the following scan areas:

- 3μm x 3μm,
- 5μm x 5μm,
- 10μm x 10μm,
- 15μm x 15μm.

The analysis of results consists of the following steps (Fig. 1):

1. Generating a 3D profile of the measured surface,
2. Subtracting the slope,

3. Cropping the area of measurement in order to eliminate noise and edge artifacts (false large amplitudes of height resulting from scanning direction change).

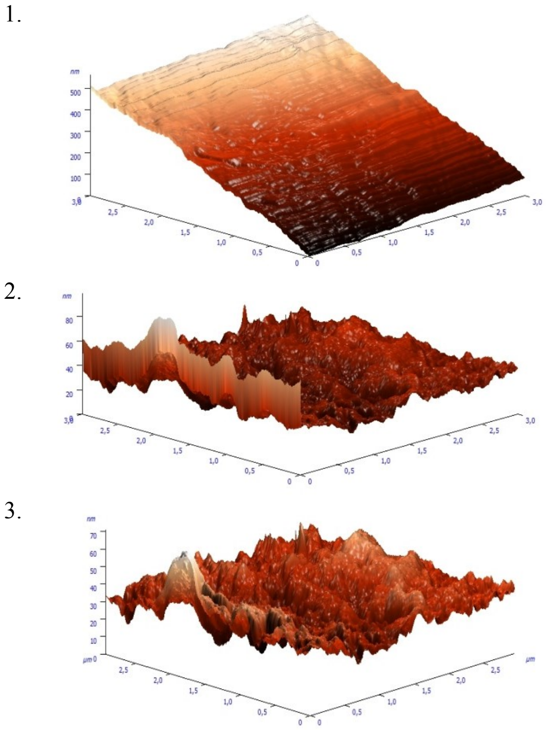


Fig. 1. Scheme of the analysis of results.

3. Surface parameters

Several surface roughness parameters were calculated on the basis of the measurements, that is roughness average S_a, root mean square S_q, cubic mean S_{sk}, biquadratic mean S_{ka}, and 10-point mean S_z. These parameters provide 3D equivalents to the standard 2D R parameters (R_a; R_q, R_z etc.), as well as additional information relevant to 3D surfaces only. Detailed description of the parameters follows.

The roughness average S_a is the arithmetic mean of the absolute values of the surface differences with respect to the mean plane

$$S_a = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\left| z(x_i, y_j) - \bar{z} \right|, \tag{1}$$

where $\bar{z}$ means average height

$$\bar{z} = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} z(x_i, y_j). \tag{2}$$

S_a is typically used to describe the roughness of surfaces. It is useful for detecting general variations in overall profile height characteristics.

The root mean square of $z(x)$, that is S_q, represents the standard deviation of the profile height

$$S_q = \sqrt{\frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\left| z(x_i, y_j) - \bar{z} \right|^2}. \tag{3}$$

The dimensionless cubic mean of $z(x)$, that is S_{sk}, is the cube of the root mean squared height S_q. Skewness describes the asymmetry of the profile relative to the mean plane

$$S_{sk} = \frac{1}{MN{S_q}^3}\sum_{j=1}^{N}\sum_{i=1}^{M}\left| z(x_i, y_j) - \bar{z} \right|^3. \tag{4}$$

If $S_{sk} = 0$ then the profile is symmetric relative to the mean plane,

If $S_{sk} > 0$ then the profile is skewed downwards relative to the mean plane (predominance of peaks),

If $S_{sk} < 0$ then the profile is skewed upwards relative to the mean plane (predominance of valleys).

The dimensionless biquadratic mean of $z(x)$, that is S_{ku}, is the biquadratic of the root mean squared height S_q

$$S_{ku} = \frac{1}{MN{S_q}^4}\sum_{j=1}^{N}\sum_{i=1}^{M}\left| z(x_i, y_j) - \bar{z} \right|^4. \tag{5}$$

The kurtosis describes the sharpness of a surface and is a measure of the "spikiness" of the surface, or the distribution of spikes above and below the mean plane.

$S_{ku} = 3$ for perfectly random surfaces,

$S_{ku} > 3$ for spiky surfaces,

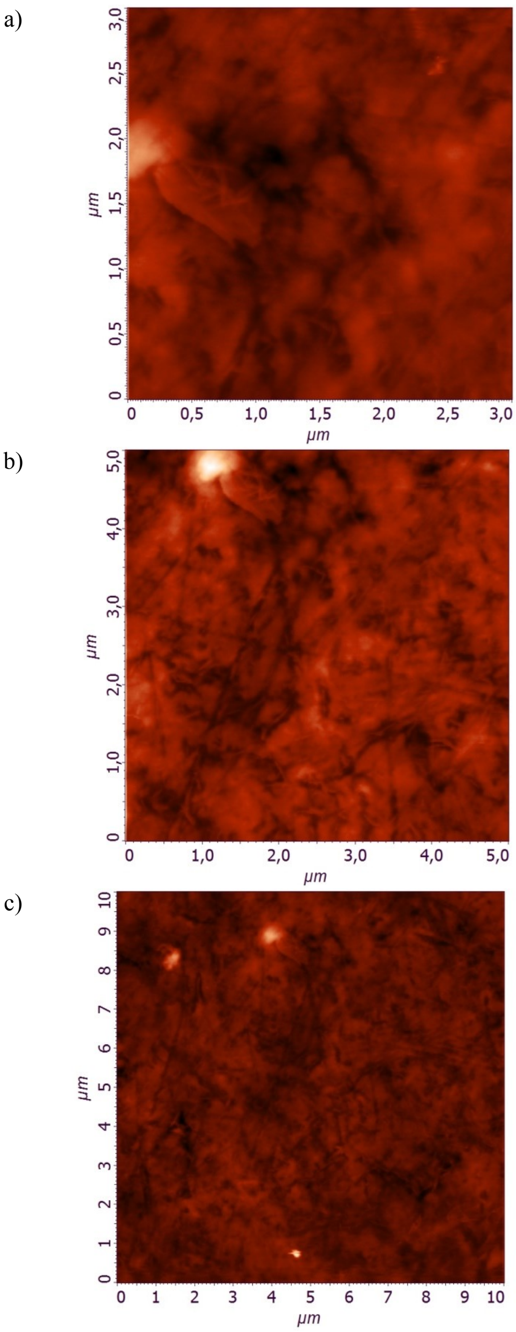
$S_{ku} < 3$ for bumpy surfaces.

The S_z is a 10-point mean of the absolute heights of the five highest peaks z_{pi} and five deepest valleys z_{vi}

$$S_z = \frac{1}{5}\left[\sum_{i=1}^{5}\left| z_{pi} - \bar{z} \right| + \sum_{i=1}^{5}\left| z_{vi} - \bar{z} \right|\right]. \tag{6}$$

4. Results

The results for 4 different scan area sizes are shown in Fig. 2.



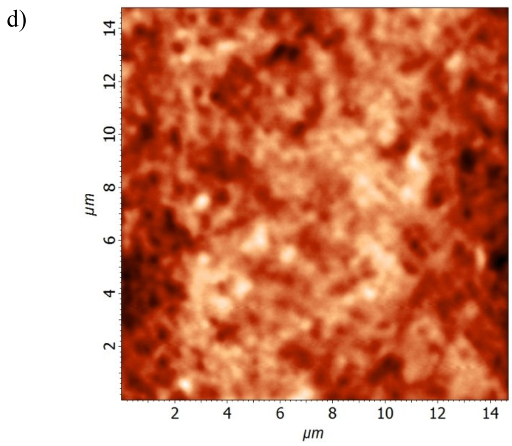


Fig. 2. Topography of the lens surface for different sizes of the scan areas: a) 3µm x 3µm, b) 5µm x 5µm, c) 10µm x 10µm, d) 15µm x 15µm.

The larger area is measured the more reliable the determined statistical parameters are, but at the same time the accuracy of measurement decreases.

Comparison of the defined parameters specifying the surface roughness for all cases is shown in the Figs. 3-7. Average arithmetic roughness S_a and S_q obtained for different scan areas were similar.

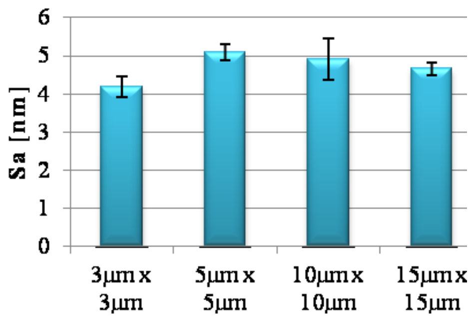


Fig. 3. The average roughness S_a.

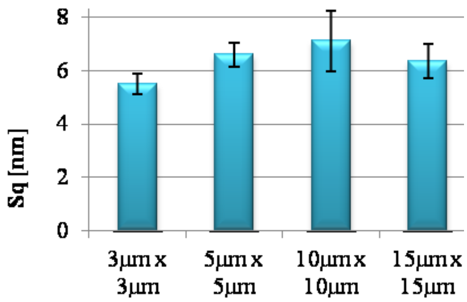


Fig. 4. The root mean squared deviation S_q.

Another two parameters, S_{sk} and S_{ku}, describe the character of valleys and peaks. Both of them have similar values for smaller scan areas 3 µm x 3 µm and 5 µm x 5 µm and in the case of larger areas of 10 µm x

10 μm and 15 μm x 15 μm but there are big differences between larger and smaller areas. These differences result from lower resolution of the larger scan areas in which valleys are no longer easily detected. On this basis one can conclude that the analysis is sufficient if one small area and one large area is measured.

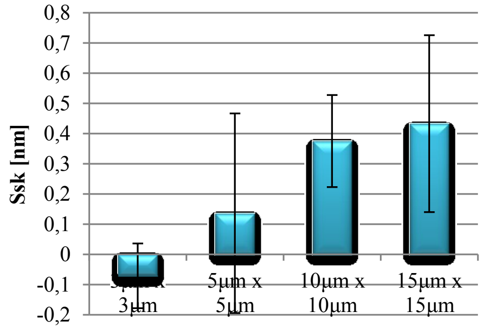


Fig. 5. The surface skewness S_{sk}.

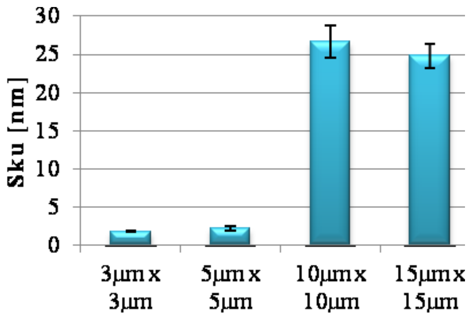


Fig. 6. The surface kurtosis S_{ku}.

The values of parameter S_z characterizes the surface roughness by five highest peaks and five lowest valleys is similar in all cases.

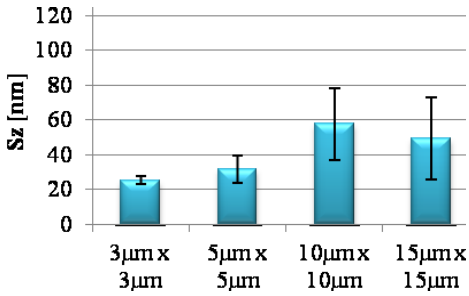


Fig. 7. The 10-point mean of the absolute heights.

It was demonstrated that the usually used parameters (S_a, S_q) cannot discriminate between surfaces expected to give a high interface shear strength from surfaces expected to give a low interface shear strength [4, 5]. The skewness parameter S_{sk} can achieve discrimination in this situation [4]. Roughness parameters S_a and S_q are not sufficient to determine the tribological properties of contact surfaces. Roughness parameters S_{ku} and S_{sk} were found to show good correlation with tribological properties. The most dominant parameter is S_{sk}. The more negative it is the lower friction we expect, even at high average surface roughness. Friction also tends to get lower when parameter S_{ku} is getting higher [5].

The kurtosis parameter S_{ku} is important in the characterization of implant surface roughness because if the modulus of elasticity of an implant material is substantially higher than that of surrounding material then stress peaks will arise in the area adjacent to the roughness peaks [6]. The sharper the asperities of the surface roughness, the higher the stress peaks in the neighborhood [7].

The size of the scan area does not significantly affect the two most important parameters describing the surface roughness profile (S_a and S_q), however, significantly affect the parameters describing the nature of inequality S_{sk} and S_{ku}.

5. Conclusions

The presented measurement technique will be very useful in further work on the measurement of surface topography of intraocular lenses.

Acknowledgments

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