SURFACE ROUGHNESS OF CONTACT LENSES INVESTIGATED WITH ATOMIC FORCE MICROSCOPY

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Abstract. *The objective of this study is to make a comparison of surface roughness for various types of contact lenses (CLs), generated by the manufacturing process and to determine the roughness parameters of 3D surface using atomic force microscopy (AFM). Contact lenses commercially available from two manufacturers: Johnson & Johnson Vision Care (Jacksonville, USA) and CIBA Vision Corp. (Grosswallstadt, Germany) were investigated. Two lenses from each of the four contact lenses groups, manufactured by cast-moulding, were used in experiments. For imaging surface roughness of contact lenses on nanometer scale, we employed atomic force microscopy in tapping mode in an aqueous environment. Three parameters obtained by atomic force microscopy (Sa, Sq and St) were used in evaluation of contact lenses surface roughness. A comparison of surface roughness for the probed contact lenses was made. The surface roughness have a considerable influence on biocompatibility and generates important information about the material surface quality. The results obtained in this study may assist researchers in developing and prescribing contact lenses with optimal performance characteristics.*

Keywords: *engineering design, contact lenses, surface roughness, biocompatibility, atomic force microscopy*

1. INTRODUCTION

A contact lens (CL), also known as a contact, is a corrective, cosmetic, or therapeutic lens usually placed on the cornea of the eye [1, 2].

The biocompatibility assessment of contact lenses involves multidisciplinary work teams that use an agreed range of methodologies, the accreditation of participating testing laboratories, and the adoption of different rigorous protocols based by quality certified reference materials.

During the past decades, several different microscopy and spectroscopy techniques (these include X-rays photoemission spectroscopy, scanning electron microscopy and atomic force microscopy) have been applied to the evaluation the materials surface roughness of contact lenses [3].

The ability of a contact lens to be biocompatible with the ocular surface is limited by different factors such as hypoxia, dryness, or mechanical trauma [4].

The main features of a CL material are those related to the surface wettability (hydrophilicity, hydrophobicity), surface topography, electrostatic charge, bulk matrix, hydration, and oxygen permeability; properties related to the mechanical behavior, elastic modulus, flexure and hardness, and hydraulic and ionic permeability; the degradation profile and toxicity of degradation products [5 – 8].

The surface characteristics of CLs is a key factor in understanding of its clinical performance in the ocular environment, but are difficult to measure, evaluate and quantify [9 - 12].

The CLs surface characteristics are referred to the physicochemical surface properties and surface topography.

A CL surface has a 3D particular topography, generated by the manufacturing process.

3D surface characterization of CLs is an integral part of quality control process and permits a better understanding of the functional performance of CLs surfaces and innovative new designs [13]. Also, it permits to understand the interaction of contact lens biomaterials with the ocular surface [14 - 17].

To help understand the complexity of phenomena such as contacting surfaces [18], friction [19 - 22] and lubrication surface [23 - 31], how and where protein molecules and contaminants adhere to the CLs [32 - 39], the topography of CLs surfaces can be mapped in great detail with AFM at nanometer spatial resolution [40].

2. THE SURFACE AMPLITUDE PARAMETERS

Surface topography is the 3D representation of the finer irregularities of the surface texture, usually including those irregularities that result from the inherent action of the manufacturing process.

Considering a surface topography $z(x_i, y_j)$ defined in a rectangular coordinating system *OXYZ*, with *M* and *N* being the measurement points on *OX* and *OY* axes respectively ($i = 1,\ldots, M$ and $j = 1, \ldots, N$). If l_x and l_y are the lengths on *OX* axis and *OY* axis of the measured surface *A*, than it could be expressed as:

$$A = l_x \cdot l_y;\ l_x = (M-1)\cdot\Delta x,\quad l_y = (N-1)\cdot\Delta y \qquad (1)$$

The S amplitude parameters are defined as [41]:

a) The arithmetic mean deviation of the surface (*Sa*) is the arithmetic mean of the absolute values of the surface departures from the mean plane and is given by:

$$Sa = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\left|z(x_i, y_j) - \bar{z}\right| \qquad (2)$$

with $\bar{z}$ representing the mean height:

$$\bar{z} = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} z(x_i, y_j) \qquad (3)$$

b) The root mean square deviation of the surface (*Sq* or *RMS*) is defined as:

$$Sq = \sqrt{\frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\left|z(x_i, y_j) - \bar{z}\right|^2} \qquad (4)$$

c) The vertical distance between the highest peak and the lowest surface point (*St*) is defined as:

$$St = |Sp - Sv| \qquad (5)$$

where *Sp* and *Sv* are the highest peak and the lowest valley of the surface respectively,

$$Sp = \max\{z(x_i, y_j) : 1 \le i \le M, 1 \le j \le N\};$$
$$Sv = \min\{z(x_i, y_j) : 1 \le i \le M, 1 \le j \le N\}; \qquad (6)$$

3. EXPERIMENTAL PROCEDURE

Contact lenses commercially available from two manufacturers: Johnson & Johnson Vision Care (Jacksonville, USA) and CIBA Vision Corp. (Grosswallstadt, Germany) were investigated.

Specifications of the contact lenses used in this study are listed in Table 1.

Table 1. Specifications of the contact lenses

Contact lenses	Manufacturer	Material
Acuvue Advance	Johnson & Johnson Vision Care	Galyfilcon A
Acuvue 2	Johnson & Johnson Vision Care	Etafilcon A
Focus Dailies	CIBA Vision	Nefilcon A
Focus Night & Day	CIBA Vision	Lotrafilcon A

Two lenses from each of the four contact lenses groups, manufactured by cast-moulding, were used in experiments. Only the anterior surface of each sample was evaluated.

Before AFM imaging, every CL was received in original container filled with a physiological saline solution from the manufacturer and was removed with a sterile silicone protected tweezers.

A small piece of the contact lens was obtained and fixed with an adhesive onto a sample holder without inducing material bending. During AFM imaging, to maintain its hydration, the same saline solution used to store the contact lens was used.

Topographic analysis of the CLs surfaces was performed with an atomic force microscope (Nanoscope III, Digital Instruments, Santa Barbara, CA) which was operated in tapping mode in an aqueous environment using the liquid cell of the AFM.

Cantilevers with a nominal force constants of k = 0.58 [N/m] and oxide sharpened Si3N4 tips (Olympus, Tokyo, Japan) were used for measurements.

The measurements of each sample were made over on 4 different reference areas of 4 µm x 4 µm, to verify the reproducibility of the observed features. After AFM imaging in the tapping mode the sample can be used again. The experiments were made at room temperature (21 - 24 °C) and approximately 50 % relative humidity.

For analyze of AFM images and evaluation of surface roughness parameters Nanoscope III software was used.

Three quantitative parameters were used to characterize the morphology and roughness of the CL surface: the arithmetic mean deviation of the surface (*Sa*), the root mean square deviation of the surface (*Sq*) and vertical distance between the highest peak and the lowest surface point (*St*). A comparison of surface roughness for the tested contact lenses was made.

The Kruskal-Wallis test was used to statistically compare the differences among CLs values for each type of CL model. When statistical significance was found, the difference between two groups was further compared using the Mann-Whitney U test. The Kruskal-Wallis and Mann-Whitney U tests were also used to compare data between the two CL models of same dioptric power. Differences with a P value of 0.05 or less were considered statistically significant.

4. RESULTS

AFM images revealed at the contact lenses surfaces a particular surface structure which are evident at all magnification range.

The surface roughness parameters of CLs are shown as mean ± standard deviation (SD) in Table 2.

Table 2. The values of surface roughness of contact lenses obtained by AFM measurements

Contact lenses	The values of surface roughness		
	Sa [nm]	*Sq* [nm]	*St* [nm]
Acuvue Advance	2.75 ± 0.74	3.98 ± 0.61	31.12
Acuvue 2	2.94 ± 0.79	4.17 ± 0.68	35.72
Focus Dailies	3.25 ± 0.82	4.45 ± 0.73	37.18
Focus Night & Day	3.58 ± 0.89	4.63 ± 0.72	41.12

The four contact lenses groups showed significantly different surface topography with very fine nano-irregularities due to the particularity of CLs fabrication processes.

5. DISCUSSION

The surface roughness of each investigated contact lens is according required clinically levels of stability, optical performance and biocompatibility.

The obtained results suggest that the differences between the tested contact lenses have implications on their clinical behavior concerning deposit formation and bacterial colonization that could result in subsequent eye infection and eye inflammation.

6. CONCLUSIONS

The atomic force microscope (AFM) is an accurate tool for measuring surface roughness on the nanometre scale [42, 43].

CLs surface topography investigated with AFM permits to choose CLs more appropriate for individual patient characteristics and to minimize the potential for eye infection and eye inflammation.

This investigation of the AFM measurement system is in good agreement with experimental observations from the literature [9, 40] and thus leads to the belief that the results obtained with this measuring instrument are reliable in the case of CLs surfaces [44 - 50].

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