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Limits in measurements of contact lens surface profile using atomic force microscopy

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ABSTRACT

In the paper the results of AFM surface profile measurements of seven new long-wear contact lenses (CL) available in Poland are presented. Calculated statistical roughness parameters are shown, namely standard deviation (RMS), mean roughness, maximum difference between peak and valley, skewness, and kurtosis. It is demonstrated that CLs manufactured using recent methods, such as two-stage polimerisation or extending silicon chains exhibit small RMS, less than 10 nm, in comparison with older generation CLs which maintains RMS on the level of tens of nanometers. Then, a comparison of results obtained using a typical silicon tip and a silicon tip covered with alkylsilane is also demonstrated. As a result, roughness parameters, such as RMS, are higher for the case of alkylsilane-coated tip than for a typical silicon tip, 8.39 ± 0.16 nm vs. 6.22 ± 0.9 nm, which leads to the conclusion that the proper choice of the tip material significantly influences the outcome of the experiment. Finally, the reliability and limits of such measurements are discussed.

1. Introduction

An ideal contact lens (CL) material should maintain moisture, resist deposits and deliver breathability for a good long-lasting comfort. Low comfort is still the main reason of discontinuation of contact lens wear [1–3].

Since the invention of soft contact lenses made of pHEMA or poly(2-hydroxyethyl methacrylate) hydrogel in 1961 [4] a number of new materials have been proposed that exhibit better biocompatibility and offer better comfort for the wearers [5,6]. The main drawback of the pHEMA was low oxygen permeability that caused corneal edema and neovascularization [5,7–9]. To suppress complications connected with corneal hypoxia silicon hydrogels were introduced in 1998, e.g. balafilcon A and lotrafilcon A (generation I), which have high oxygen permeability, but required an additional surface treatment, such as plasma coating (Ciba Vision/Alcon) or plasma oxidation (Bausch&Lomb) to reduce hydrophobicity of silicon. The high hydrophobicity of silicon was responsible for discomfort in case of refit from hydrogel to silicon hydrogel CLs [5,6,9–11]. These materials are also prone to deposits [5,9–11]. In the next generation (II) an additional moisturizing agent, polyvinylpyrrolidone (PVP) was implemented in the CLs (Johnson&Johnson). Then, III generation of CLs were developed, based on comfilcon A (CooperVision), where long silicon chains with OH-groups were applied [12].

Another method to increase the wear comfort was also proposed, that rely on adding a moisturizing component to the saline solution in the blister, for example HydraGlyde Moisture Matrix (EOBO-41) in Lotrafilcon B (Air Optix, Alcon) and poloxamine in balafilcon A (Pure Vision 2 HD, Bausch&Lomb).

Recently, a new CL was invented, made of samfilcon A (Ultra, Bausch&Lomb), where the surface of CLs is not modified, but hydrophilic properties are achieved by a two-stage polymerization. In the first step, the silicon is polymerized that constitutes the core of a CL, and, in the second step, the PVP polymer chains are supplemented on the surface.

The microstructure of a surface profile of a CL determines its macroscopic properties, and finally, the wearing comfort. A number of papers were published, where the surface was examined using different measuring techniques, such as scanning electron microscopy (SEM) [13], optical profilometry [14], and atomic force microscopy [15–31]. Recently, multifractal analysis of the CL surface profile was proposed to assess the micromorphology of CLs [32].

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Table 1
The list of contact lenses measured experimentally.

No.	Manufacturer/Commercial Name	Material	Surface modification	Water content	Modality	Base radius [mm]
1	Air Optix Night&Day Aqua	lotrafilcon A	plasma coating	24%	monthly continuous wear	8.6
2	Alcon/Air Optix Aqua	lotrafilcon B	plasma coating	33%	monthly extended wear	8.6
3	Alcon/Air Optix plus HydraGlyde	lotrafilcon B	plasma coating	33%	monthly extended wear	8.6
4	Acuvue Oasys with Hydraclear Plus	senofilcon A	internal wetting agent (PVP)	38%	two weeks daily wear	8.4
5	Coopervision/Biofinity	comfilcon A	none	48%	monthly extended wear	8.6
6	Bausch&Lomb/Pure Vision 2HD	balafilcon A	plasma oxidation	36%	monthly continuous wear	8.6
7	Bausch&Lomb/Ultra	samfilcon A	MoistureSeal	46%	monthly daily wear	8.5

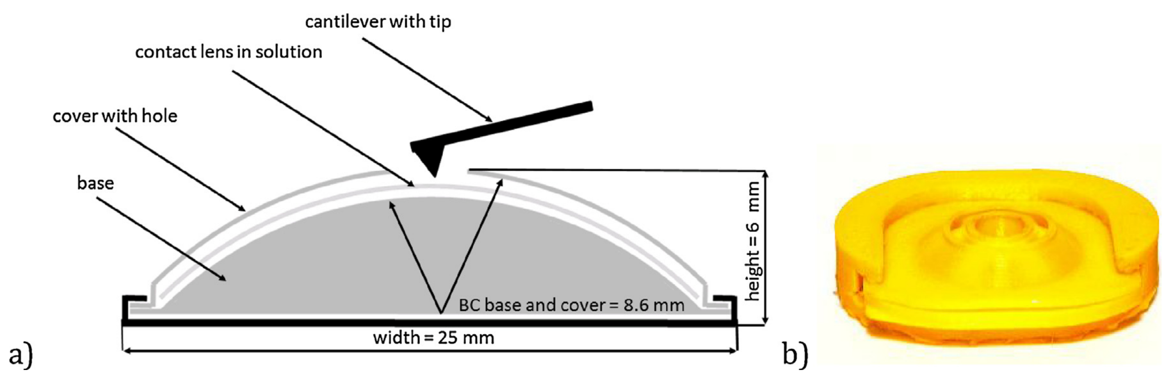

Fig. 1. a) Schematic and b) photo of the CL holder.

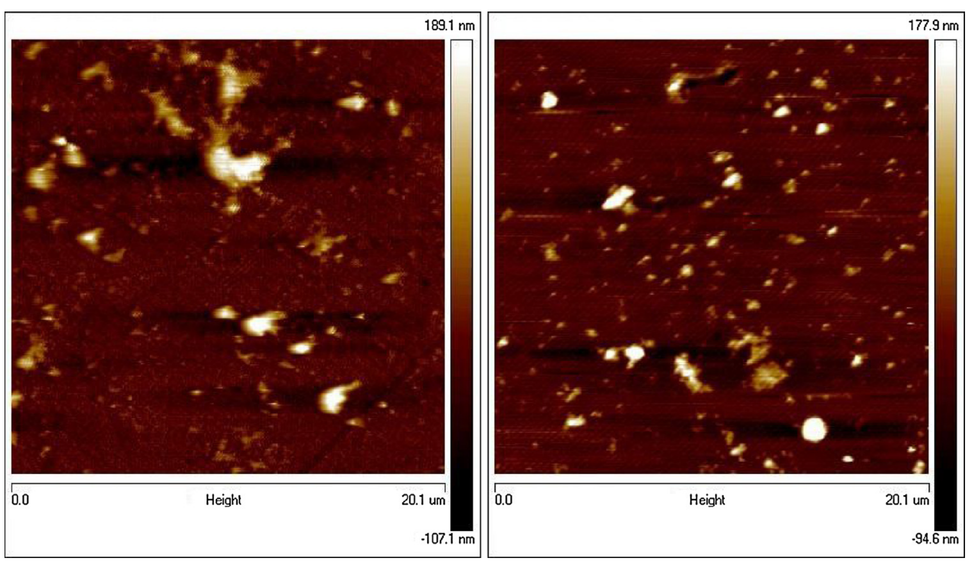

Fig. 2. Surface maps for Air Optix Night&Day Aqua (left) and Air Optix Aqua (right).

The main problem in AFM measurements of CLs is the gentle structure of the material. The samples are usually measured in contact mode and cut into pieces before measurements. In most of the publications small areas, of diameters on the level of single-digit microns, are measured [17,23,26,28].

In this paper the results of the AFM surface profile measurements of seven CLs are presented. Then, a comparison of results obtained using a typical silicon tip and a silicon tip covered with alkylsilane is demonstrated. The reliability and limits of such measurements are also discussed.

2. Experimental setup

The list of contact lenses and their basic properties is shown in Table 1. We measured CLs planned to operate in two-weeks and monthly regime, because in such case the surface of CLs interacts with the tear film for a long time and its profile or roughness should have an impact on the wearing comfort and safety. CLs no. 1–6 are commonly applied and no. 7 is recently introduced to the market in Poland.

2.1. Sample preparation

All measured CLs were new ones. They were taken out from the original blister packaging using sterile tweezers directly before the measurement and then fixed in a holder. No additional cleaning procedure was applied to lenses to simulate the normal wear by a user. The refractive power of all lenses was −3,00 dpt. For the experiment a special holder was prepared to avoid the need of cutting the CLs. The schematic of the holder is shown in Fig. 1. Is was made of ABS plastic and mounted inside a glass Petri plate immersed completely in the 0.9% saline solution. The CL is positioned on a support