TOPOGRAPHY AND PHASE IMAGES INVESTIGATION OF THE USED RGP CONTACT LENS INNER SURFACE

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ABSTRACT
Growing interest in biomaterials manufacturing and surface technology has prompted in an investigation of contact lens (CL) surface based on fractal approach, using JSPM 5200 instrument for measurement and MatLab software for image processing. Topography and phase images were recorded in order to investigate surface roughness and properties after an extended period of CL wearing. Since there is no strong recommendation for RGP CL wear period, wearer's reports on the end-stages when they notice that vision is deteriorated, vary considerably. The authors` aim is to point out that time is merely a commercial category for RGP CL replacement and that only significant changes in surface properties render such replacement necessary.

KEYWORDS: Fractals, Topography, Surface, Image

1. INTRODUCTION

The paper describes usefulness of topography and phase images analysis application in the rigid gas permeable contact lens (RGP CL) replacement schedule. There is no strong recommendation for RGP CL wear period and wearer's determine the end-stage, e.g. when they notice either vision deterioration or unpleasant sense during the wearing. The loose of RGP CL functionality has to be investigated and related to measurable parameters in order to recommend replacement based on “hard evidence” instead of time. The use period cannot be a commercial category for RGP CL replacement but should be associated with significant changes in surface properties.

Authors have no attention to deal with RGP CL bulk polymer technology, but, in reality, biomaterial has to have an expiry date. RGP CL materials are commonly composed of monomers containing silicone, fluorine and methylmethacrylate and the guaranteed number of years for retention of polymer performance is one-digit one. Moreover, CL can loose functionality even during this period, due to accumulated proteins, lipids, and other tear components on CL surface, despite routine cleaning activities. Additionally, every single RGP CL wearer provides unique ambient conditions in which these CL biosurfaces have to function, which results in an individual CL end-stage period. Since CL surfaces become significantly rougher after prolonged wear, they became more prone to bacterial adhesion and protein and lipid deposit. The recommended schedule has to take into account the moment when surface roughness exceeds a critical limit.

There is no clear answer to the question as to what surface standard parameter should be used for critical limit determination. The result of the study, reported in /1/, also, confirm the need for replacement schedule for RGP CL. The water contact angle, percentage elemental surface composition and deposit rate of bacteria was related to standard average roughness parameter Ra. It was stated in /2/ that surface roughness was the most influential lens surface property after 10 days of wear. Is Ra good enough for surface roughness representation?

2. FRACTAL SURFACE ROUGHNESS CHARACTERIZATION

Authors belong to the group of researches who prefer fractal parameter characterization as opposed the standard ones, because the latter are simply not good enough. While average roughness (Ra) remains useful as a general guideline of surface textures, it fails to describe the surface's functional nature. Ra makes no distinction between peaks and pits, nor does it provide information about spatial structure. One is supposed to use a number of standard surface parameters to distinguish surfaces, compare them and predict functional behaviour in use.

This paper focuses on the quantification of the textures of CL inner surface, applying a method differing from the standard parameters characterizations. Fractal analysis was used for quantitative characterizations of surface textures. Fractal geometry provides a useful tool for the analysis of complex and irregular structures such as surface topography. These fractal analyses are based on image analysis methods that consider an image as a 3D surface. The image pixels are identified by their x, y position and the grey tone function is the z dimension. The "skyscrapers" method was applied for calculating fractal dimension of surface. This method presupposes surface recording as an image, mainly by using scanning electron microscopy (SEM) or scanning probe microscopy (SPM).

3. AFM RECORDING

Experimental work has been conducted on commercial JOEL scanning probe microscopy - JSPM 5200 (figure 1), which can be configured as either an AFM or a STM by merely changing the tip. In general, JSPM 5200 has three different AFM modes used for topography imaging; these are the non-contact, the contact and the tapping mode.

Figure 1: JOEL scanning probe microscopy - JSPM 5200, taken from /3/.

The tapping mode was used on account of its ability of non-destructive high-resolution imaging of soft and fragile samples in ambient environment. The tip is alternately placed in contact with the surface, so as to provide high resolution, and then lifted off the surface in order to avoid dragging across the sample. In tapping mode AFM, the cantilever is excited into resonance oscillation with a piezoelectric driver in ambient air at or near its fundamental flexural resonance and with free air amplitudes. The interaction with the surface (tapping) leads to energy loss and a reduced oscillation amplitude, as shown in figure 2. The oscillation amplitude is used as a feedback signal to measure topographic variations of the sample. Both the tapping mode topography and phase imaging are viewed side-by-side in real time.

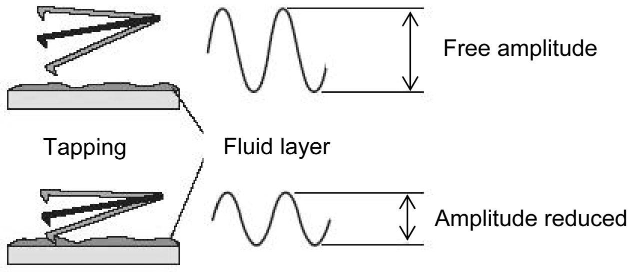


Figure 2: Tapping mode cantilever oscillation amplitude in free air and during the scanning, taken from /4/.

In phase imaging, the phase lag of the cantilever oscillation, relative to the drive signal, is simultaneously monitored with topography data, shown in figure 3. As the phase lag is influenced by energy dissipation experienced during the oscillation cycle, it is very sensitive to material properties and local variations in mechanical properties. Since phase imaging highlights edges and is not affected by large-scale height differences, it provides clearer observation of fine features, which can be obscured by rough topography.

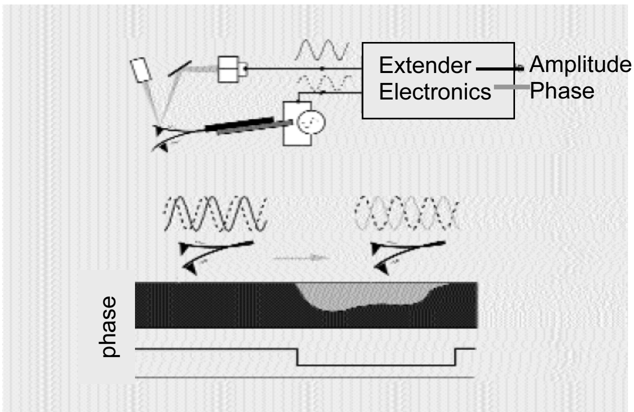


Figure 3: Phase imaging principles.

4. THE PROBLEM OF WORN - OUT CONTACT LENS

The sample was a RGP CL made of ML 92 Siflufocon A, and shown in figure 4, placed on cornea. This lens was worn by 37 years-old female over an extended period (in fact more then 5 years) of regular use and storage. The wearer reports unpleasant sense during the wearing, namely lens sliding across cornea. Ophthalmologist point out that there is no vision deterioration but there is an obvious fast sliding process accompanied by occurrence of air bubble, which can be observed in figure 4.

This RGP CL was "worn out" and was replaced due to change of some surface properties, which caused low adhesion between inner surface and tears film. The adhesion force holds the RGP lens in the eye. Appropriate adhesion force amount obtained by manufacturing process, which consists of turning with polishing as the finishing process. The duration of polishing determines surface quality, meaning surface roughness, and consequently the adhesion.

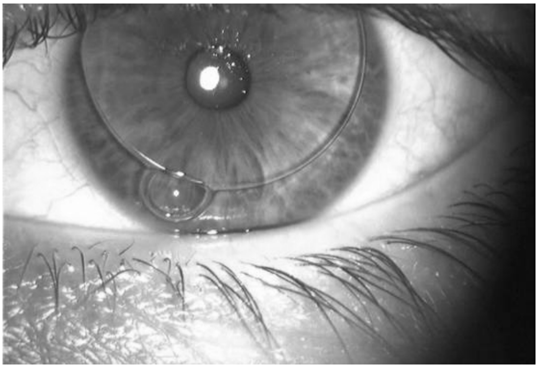
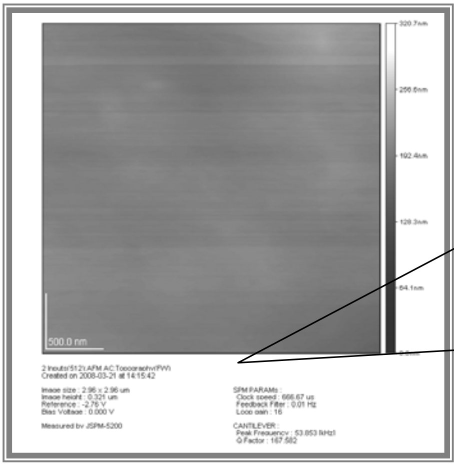


Figure 4: RGP CL placed on cornea with bubble on its edge.

Authors assume that the change of surface topography caused by extended wearing, which includes protein and lipid deposits, is interesting to investigate.

4.1 Experimental work

Fractal dimension of RGP CL inner surface is chosen for observing, as an appropriate surface roughness parameter. Topography image is recorded in tapping mode AFM SJEOL5200 in order to determine fractal dimension by "skyscrapers" method. Figure 5 shows the measurement report. RGP CL was not clean before measurement, in order to take relevant information about disturbing factors on surface layers. In addition, recorded area was near to CL diameter edge, because the bubble appears in that region.



2 Inputs(512):AFM AC: Topography(FW)
Image size: 2.960 x 2.960 μm
Image height: 0.321 μm
Reference: -2.76 V
Bias Voltage: 0.000 V
No of pixels (512,512)
Created on 2008-03-21 at 14:15:42
Measured by JSPM-5200
SPM PARAMs:
Clock speed: 666.67 us
Feedback Filter: 0.01 Hz
Loop gain: 16
CANTILEVER:
Peak Frequency: 53.853 [kHz]
Q Factor : 167.582

Figure 5: Measurement report.

By mapping out the phase of the oscillating cantilever, phase imaging goes beyond simple topographical mapping. The reason for additional phase image recording is the need for additional information about surface condition after an extended time of RGP CL wearing. The phase image has a different appearance compared to topography image in figure 6. It is obvious that phase image provides complementary information, which can be observed as hay-like structures on surface. Such differences between topography and phase images are due to material property differences on the lens surface. The appearance of fine structure in phase images complements the sensitivity to material properties, including contaminants, viscoelasticity, and regions of high and low surface adhesion or hardness. In this case, phase imaging complements lateral force microscopy, providing additional information more rapidly.

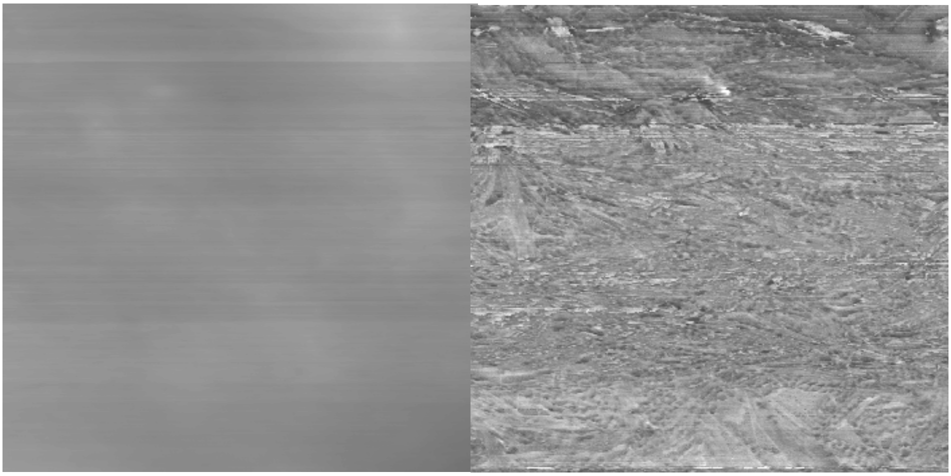


Figure 6: Topography image on the left hand side and phase image on the right side.

The phase image shows the presence of unexpected structures, which are clearly different in their material properties from the area surrounding them. These features are not present in the topography image of the lens. A likely source of the contrast in the phase image is protein and lipid deposit formed from the tears on which the lens was floating before being imaged by the JSPM5200.

4.2 Fractal analysis by "skyscrapers" method

The skyscrapers analysis was originally suggested by Caldwell for fractal dimension calculation of digitized mammography. Pixels that constitute an image can be considered as skyscrapers, the height z(x,y), of which is represented by the intensity of the grey. The surface area of the image A is obtained by measuring the sum of the top squares, representing skyscrapers roofs and the sum of the exposed lateral sides of the skyscrapers, according to /6/ and shown in eq.1. The roof of skyscrapers increases subsequently by adjacent pixel grouping and the intensity of grey is averaged. The square size ε is 2^n.

$$A(\varepsilon) = \sum \varepsilon^2 + \sum \varepsilon \left[\left| z(x,y) - z(x+1,y) \right| + \left| z(x,y) - z(x,y+1) \right| \right] \quad (1)$$

Custom-made procedure for fractal dimension calculation based on "skyscrapers" method was generated using image processing toolbox, as well as custom-developed algorithm. Topographic image recorded in tapping mode AFM was imported in tiff format. The image is of 512x512 pixels in, accompanied by ASCII file, which contains 262144 five-digit numbers. That image is considered as an intensity image type, and represents 512-by-512 array of 8-bit integers that are linearly scaled to produce colormap indices in range [0,255]. ASCII data was modified into matrices size 512-by-512, converting the numbers in 16-bit integer. Such matrix represents an intensity image type with grey scale colormap. The range of values is [0, 65 535].

The image generated from ASCII file is more sensitive compared to tiff image. For that reason gray scale 16-bit image was modified for skyscrapers area calculation. The roof of skyscrapers was increased subsequently by adjacent pixel grouping, causing averaging of the grey levels. Surface area for images was determined using eq.1. These pairs of points (P,A) in double log graph are arranged along the straight line (shown in figure 7). The linear regression is used for fitting the plot and the fractal dimension is obtained from slope using eq. 2, using custom-made procedure for calculation. Fractal dimension generated for image shown in figure 4, by sky-scrapers method is *Ds*=2.7356.

$$\log A = (2 - Ds)\log \varepsilon + c \quad (2)$$

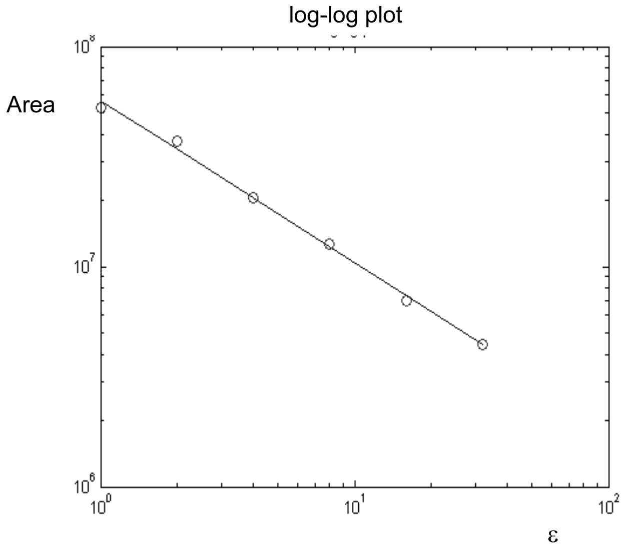


Figure 7: Loglog graph of surface area of the images A vs. each square size ε.

5. CONCLUSION

The rapidly growing list of phase imaging applications includes /5/ characterization of composite materials, mapping of surface friction and adhesion, and identification of surface contaminations. Phase imaging promises to play an important role in the ongoing study of material properties at the nanometre scale. Although there is currently no simple correlation between phase contrast and a single material property, the example shown in this paper demonstrates that phase imaging provides valuable information regarding surface properties. In the given RGP CL case, phase image confirms protein and lipid deposits, which generally cause surface roughness in function. Original surface roughness is changed during the cleaning and wearing processes and examination of real surface roughness could ensure insight into functional behaviour. According to /7/ a surface with fractal dimension if 2.5 would be the optimum as an engineering surface for certain applications. Mandelbrot claimed that nature has a fractal face and scholars proved that engineering surfaces have fractal geometry. The compilation of man-made surface with tears component on it also show fractal behaviour, proven by exponential law of area vs. scale. RGP CL surface topography with deposits has a calculated fractal dimension *Ds=2.7356,* and can be considered as inappropriate, meaning too rough for adequate adhesion property.

6. REFERENCES

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