ATOMIC FORCE MICROSCOPY ANALYSIS OF SURFACE PROPERTIES OF INTRAOCULAR LENSES

Vision Engineering
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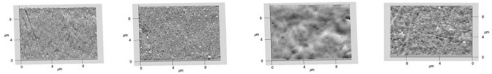
BACKGROUND

The **posterior capsular opacification (PCO)** still represents a significant cause of visual impairment after surgery, with a mean incidence of approximately 5% at a mean of 3 years after surgery. Various surgical strategies have been proposed to minimize the risk of PCO; nevertheless, the **prevention of PCO** is mainly attributed to the development of **new lens materials and optic designs**.

Lens epithelial cells (LECs) are known to be main precursors of this process: since the chemico-physical properties of the lens optic surface represent the main factors that can influence interfacial interactions between the intraocular lens (IOL) and the lens capsule environment, LECs behaviour may be greatly influenced by the **surface properties of the IOL** implanted, such as **morphology or adhesiveness**.

In a previous study*, we investigated the **surface topography** of various types of IOLs using **Atomic Force Microscopy (AFM)**, demonstrating different features with respect to the lens biomaterial and further measuring a smoother optic surface for acrylic and silicone lenses in comparison with PMMA IOLs.

Various types of IOL materials observed with AFM (image scale 10x10 μm)



PMMA IOL | Hydrophilic Acrylic IOL | Hydrophobic Acrylic IOL | Silicone IOL

PURPOSE

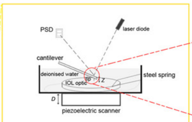
The purpose of the present study was to widen our knowledge on the submicron surface properties of IOLs, analyzing the **adhesiveness** of four different optic lens materials (see **table 1**) using AFM.

MATERIALS & METHODS

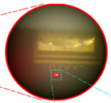
The **adhesion properties** of IOLs were measured using a commercially available AFM (NanoScope III, Veeco, Sunnyvale, CA, USA) in the **Force-vs-Distance (*f-d*) mode**.

To avoid capillarity and double layer forces, adhesion measurements were performed, at room temperature (21°C), in **deionised water**, using rectangular silicon cantilevers of nominal elastic constant of 10 N/m. The nominal value of the tip's radius of curvature was 1 μm and the scanning speed during the acquisitions was in the range 10-400 nm/s.

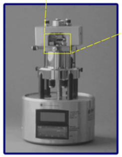
Enviromental cell



The deflection of the cantilever is usually measured using the **optical lever technique**.

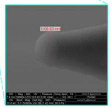


A beam from a laser diode is focused onto the end of the cantilever and the position of the reflected beam is monitored by a position sensitive detector (PSD).



Nanoscope III

***F-d* curves** measure nanonewton-range vertical forces applied to the sample's surface and are generated by performing controlled vertical tip-sample interactions.
The position of the sample is adjusted by the piezoelectric translator.

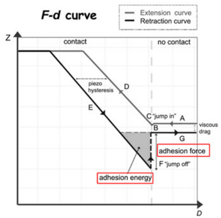


1 μm tip

Advantages of micrometer sized tip:
1) a large radius of curvature allows for a better precision in determining the adhesive forces;
2) it helps preventing damaging the sample.

Table 1 Intraocular lens optic specifications	
IOL Material	**IOL Type and model**
PMMA	Model 102 C, 6.50 mm biconvex rigid, unfoldable, disc optic UV absorbing posterior chamber IOL (Soleko, Pontecorvo, Italy)
Silicone	Model 911A CeeOn Edge, 6.00 mm biconvex soft, foldable, UV absorbing optic posterior chamber IOL (Pharmacia Groningen BV, 9728 NX Groningen, The Netherlands)
Hydrophilic Acrylic	Model Akreos Fit, 5.75 mm biconvex soft, foldable, posterior chamber IOL disc optic (Bausch & Lomb, Rochester, NY, USA)
Hydrophobic Acrylic	Model MA60AC 6.00 mm biconvex soft, foldable, disc UV absorbing optic posterior chamber IOL (Alcon Labs, Forth Worth, TX, USA)

***F-d* curve**



Different parts may be distinguished in the graphical representation of a ***f-d* curve**:
A) at large separation, the interaction between the sample and probe is zero (**no contact region**);
B) as the sample's surface **approaches** the probe, the cantilever may bend upwards due to the repulsive forces (double-layer forces); C) until the probe jumps into contact when the gradient of forces (attractive) exceeds the spring constant of the cantilever, k_c ("**jump-in**"). D) when the force is increased in the **contact region**, the shape of the approach curve may provide direct information on the material properties of the sample (e.g., stiffness).
E) **Upon retraction** of the sample's surface from the probe, the approach and retraction curves may not overlap, due to the difference in the piezo displacement versus applied voltage (**piezo hysteresis**). F) Tip and sample separate when the gradient of the adhesion forces becomes smaller than k_c ("**jump-off**") and the tip returns to its resting position (G). The adhesion between the probe and the IOL surface was measured from the minimum of the run-out: the difference between the minimum of this curve and the tip's resting position is proportional to the maximum **adhesion force**.
The **adhesion energy** was further measured (that is equal to the grey area in the figure).
In a *f-d* plot, **Z** and **D** are the cantilever deflection and the piezo displacement respectively.

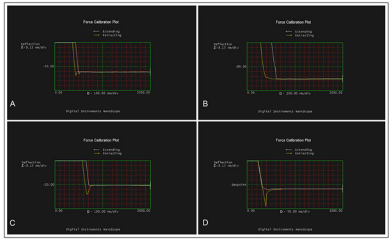
RESULTS

The results on the surface adhesion properties of each IOL are summarized in table 2. Values were significantly different among the lens of various materials (ANOVA, P<0.001). The **adhesion force** was measured to be higher on the **hydrophobic acrylic lens** in comparison with the other lens materials, whereas the force curves acquired on silicone demonstrated the smallest attraction between the tip and the sample's surface. Statistically significant differences (Tukey, P<0.001) were measured when directly comparing each pair of lenses. The highest **adhesion energy** value was measured for the hydrophobic acrylic lens, while the lowest for the silicone lens.

Table 2
Mean (± SD) adhesion force and adhesion energy measurements calculated in the central region of the posterior optic surface for each type of IOL

IOL sample	Adhesion force (NanoNetwon, nN)*	Adhesion energy (FemtoJoule, fJ)*
PMMA	45.77 ± 0.47	1.64 ± 0.01
Silicone	2.10 ± 0.01	0.60 ± 0.01
Hydrophilic Acrylic	84.76 ± 0.94	3.49 ± 0.04
Hydrophobic Acrylic	283.75 ± 0.14	9.70 ± 0.06

* Statistical significance among IOL materials: P0.001 (ANOVA)



The study of *f-d* curves provided a deeper knowledge of the **bio-adhesive properties of IOL materials**. A stronger adhesiveness has been measured at the surface optic of acrylic lenses (C and D) in comparison with **PMMA (A)** and **silicone (B)** IOLs. Statistically significant differences were further determined in our study between **hydrophilic (C) and hydrophobic (D) acrylic materials**. This result could be explained in terms of the hydrophobic effect. In aqueous environment, hydrophobic interactions usually give the highest adhesion force.

CONCLUSION

A **sharp posterior optic edge** is currently considered to be the major factor in preventing PCO development, regardless of the IOL material. On the other hand, the **adhesiveness of the optic material** to the lens capsule has been theorized to be one of the most **desirable** IOL properties for minimizing PCO. Since the capsular bend requires weeks to be completely formed, **a quick and firm contact between the lens material and the capsule** likely represents the first factor that may inhibit the migration of LECs into the space between the lens and capsule, hastening the capsular bend formation process and thus enhancing PCO prevention.

REFERENCE

* Lombardo M et al. Analysis of intraocular lens surface properties with atomic force microscopy. J Cataract Refract Surg 2006; 32: 1378-1384.

FINANCIAL OR COMMERCIAL DISCLOSURES: NONE

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