

Surface Quality Characteristics of Intraocular Lenses Assessed By Atomic Force Microscopy

Dr Partha Biswas¹

Dr Subhrangshu Sengupta¹, Dr Koel Choudhury², Dr Ajoy Paul¹, Dr Arnab Biswas

1. B B Eye Foundation; 2/5, Sarat Bose Road, Kolkata - 700020.
2. School of Medical Science and Technology; Indian Institute Of Technology, Kharagpur.

Introduction

"20/10 in the year 2010".... is what the refractive ophthalmology community is talking about today. Posterior Capsular Opacification (PCO) is perhaps one of the most common long term complications of cataract surgery and one of the biggest obstacles towards reaching a 20/10 and sustaining it years post operatively. Clinically significant PCO occurs in around 10% of cataract patients 2 – 3 years after the operation and is chiefly of two types, regeneratory and fibrotic. It is needless to say that PCO has immense impact on the long term visual outcome after cataract surgery. This issue has assumed all the more importance with the advent of Accommodative IOLs.

In the words of Dr David Apple, MD : "Even a small amount of epithelial cell growth, fibrosis or calcification may irreparably damage the delicate optics and mechanisms of modern presbyopia correcting lenses. Until recently, surgeons didn't care about PCO, you just did a YAG and no problem. But now PCO can obviate the function of these various refractive lenses. You need a clear media and a non stiff lens to get the movement from these accommodative lenses."

Eminent ophthalmologists across the world are ruing the fact that the effect of the Accommodative IOLs are often disappearing after even one year possibly due to capsular fibrosis. Unfortunately, not much progress has been made in the prevention or treatment of PCO by drugs. It is mainly treated by YAG laser capsulotomy.

Address for correspondence :

Dr. Partha Biswas

Email : drpartha_biswas07@yahoo.co.in

Cell : 00919830531457

The main surgical strategies to minimize the incidence of PCO include a central, well-positioned curvilinear capsulorhexis that overlaps the anterior edge of the IOL optic and the removal of as many equatorial lens epithelial cells (LECs) as possible through rigorous cortical cleanup. Also, the IOL's vertical edge configuration can substantially decrease PCO occurrence, 5% to 15% at 5 years postoperative. The surface quality of Intraocular Lenses, which is mainly dependant on the constituent of the IOL, and their edge properties are important determinants in the development of PCO after cataract surgery.

Studies also suggest that the constituent and the surface characteristics of IOLs have a role in determining the risk of post operative endophthalmitis. Materials used in intraocular lens manufacture and their surface characteristics also determine long-term uveal and capsular biocompatibility, as well as ultimate transparency after implantation⁷.

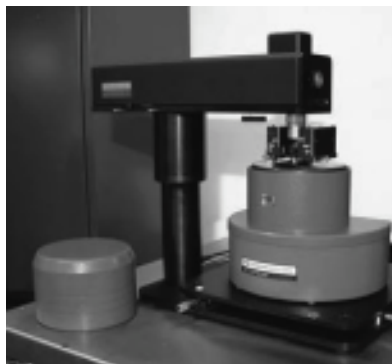
Biomaterials used for IOLs :

All IOLs materials are polymers; either "Copolymers" or "Homopolymers". The constituent monomers determine the physical and chemical properties. The different materials commonly used for the manufacture of IOLs are:

1. Acrylic
2. Poly-methyl methacrylate (PMMA)
3. Poly-2-hydroxyethyl methacrylate (HEMA)
4. Silicone

Role of IOL Biomaterial :

The different physical properties of the surface of the lens biomaterial influence the adherence and migration of the Lens Epithelial Cells (LECs) on the optic of the IOL and hence influence its long term



biocompatibility and visual results. The mechanism by which the IOL's biomaterial influences the behavior of LECs is not well understood and requires further investigation by analyzing the surface or the mechanical properties of the IOLs. Several reports suggest that acrylic and silicone IOLs are associated with less PCO than PMMA and HEMA lenses.

It seems that bacterial adhesion also is strongly influenced by IOL material and its surface characteristics. Epidemiological studies suggest that the implantation of silicone IOLs might be associated with increased rates of endophthalmitis. Experimental studies have shown that hydrophobic IOLs such as silicone or acrylic hydrophobic IOLs are more permissive to bacterial adhesion and growth than hydrophilic IOLs such as acrylic hydrophilic IOLs⁸. Among the interactions that govern bacterial attachment to the IOLs, it seems that hydrophilic-hydrophobic interactions have the greatest influence.

Study Design

This double blinded study was carried out at B. B. Eye Foundation, Kolkata and School of Medical Science & Technology, Indian Institute of Technology, Kharagpur from November 2007 to April 2008. Eighteen different IOL models (two different temporally separated batches of each model) which are commonly available commercially were included in the study.

Surface roughness parameters of these IOLs were analyzed using Atomic Force Microscopy (AFM), Model-CPII (Veeco).

Materials and Methods

Atomic Force microscope (AFM) is ideal for exploring biomaterials since it extends the atomic resolution of the scanning tunneling microscope (STM) to non-conducting materials. It explores IOL surfaces in conditions similar to the ocular environment. The AFM avoids artifacts due to dehydration and coating which can occur even with low voltage SEM. The problems of sample preparation are also greatly reduced. Tapping mode images were obtained by the AFM using V shaped silicon nitride cantilever (catalog no. MMP-11123, Veeco, USA).

Cantilever Specifications were as follows:

1. spring constant 20-80 N/m,
2. length 115-135 μm
3. radii of curvature <10 nm

The tapping mode settings were as follows:

1. scan rate 1 Hz
2. scan size of 10 \times 10 μm
3. data points per scan 256 \times 256.

Eighteen different IOL models commonly available commercially were included in the study and their posterior surfaces analyzed using AFM.

Results

Atomic force microscopy & data analysis

Topological data were analyzed using Image Processing and Data Analysis software (version 2.1.15; copyright TM Microscopes USA).

Roughness parameter compared are :

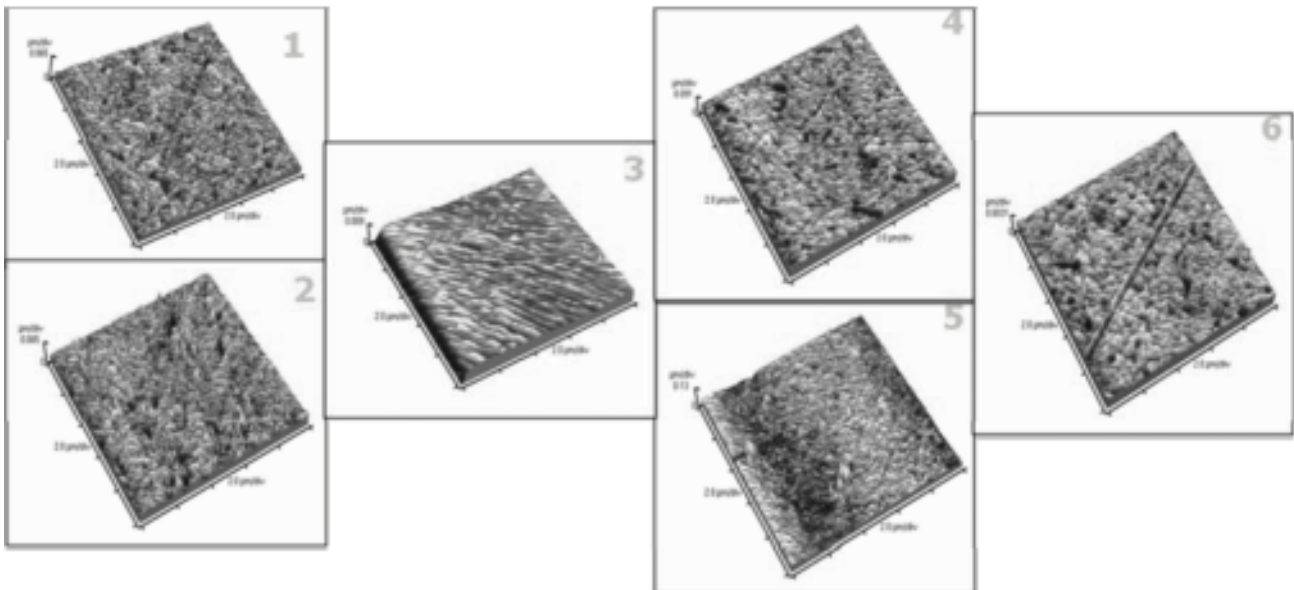
- Peak to valley ratio (Rp-v)
- Average roughness (Ra) nm
- Root mean square roughness (Rq) nm
- Mean height (nm)
- Median height (nm)

Roughness Parameters of PMMA IOLs

| IOLs | Rp-v | Rq | Ra | Mean Ht | Median Ht |
|---|-------|-------|-------|---------|-----------|
| Surgi eye | 65.29 | 3.539 | 2.680 | 20.03 | 20.14 |
| CILCO MZ60BD, Alcon | 46.25 | 6.311 | 4.811 | 20.69 | 20.33 |
| Oii | 64.88 | 4.719 | 3.479 | 27.80 | 27.80 |
| Duralens II,AMO | 89.06 | 9.261 | 6.385 | 52.96 | 53.09 |
| SCB60E2S, Universal medical products | 90.67 | 6.031 | 4.384 | 60.51 | 60.19 |
| Ocularvision | 127.9 | 9.451 | 7.259 | 39.26 | 29.24 |
| Preziol | 86.2 | 5.23 | 4.89 | 52.3 | 48.9 |

$P < 0.05$

2D and 3D AFM images of HEMA IOLs



1. Surgi eye; 2. oii; 3. AMO; 4. Universal eye lens; 5. Ocularvision; 6. Preziol

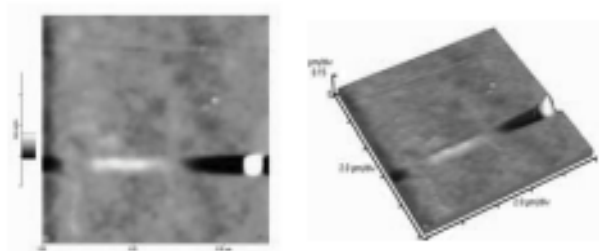
Roughness Parameters of Hydroxy ethyl methyl acrylate (HEMA) IOLs

| IOLs | Rp-v | Rq | Ra | Mn Ht | Md Ht |
|---------|-------|-------|-------|-------|-------|
| Aurolab | 150.1 | 5.974 | 2.342 | 52.16 | 52.27 |

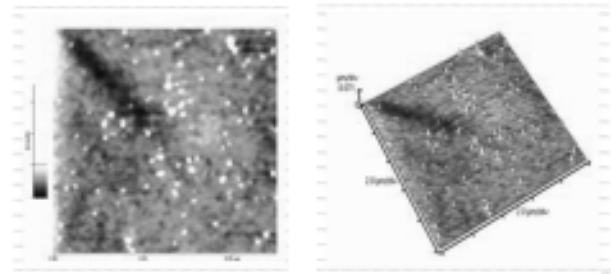
Roughness Parameters of Silicone IOLs

| IOLs | Rp-v | Rq | Ra | Mn Ht | MdHt |
|-----------|-------|-------|-------|-------|-------|
| AMO | | | | | |
| Clariflex | 70.73 | 3.582 | 2.312 | 10.40 | 10.01 |

2D and 3D AFM images of HEMA IOLs



2D and 3D AFM images of SILICONE IOLs

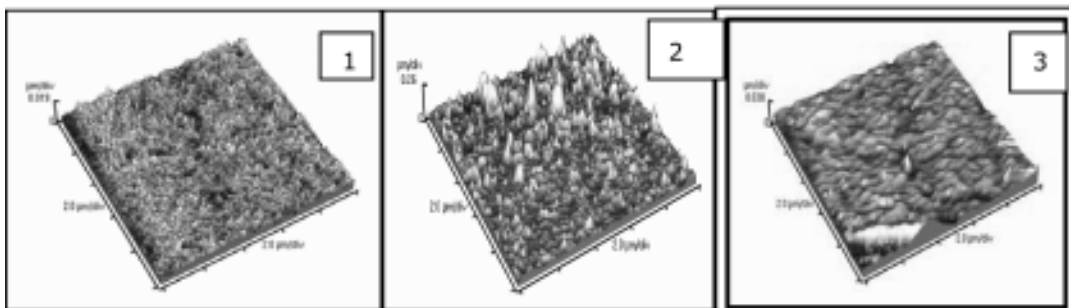
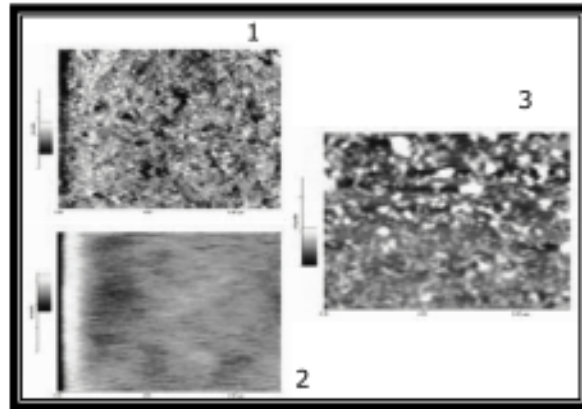


Roughness Parameters of Acrylic Hydrophilic IOLs

| IOLs | Rp-v | Rq | Ra | Mean Ht | Median Ht |
|--|-------|-------|-------|---------|-----------|
| Imax (1) | 18.84 | 1.477 | 1.115 | 7.463 | 7.483 |
| SQRYCF Acrylic(2) | 33.56 | 2.545 | 1.495 | 24.80 | 24.81 |
| Akreos | 283.3 | 15.20 | 10.17 | 91.04 | 92.53 |
| XL STABI ZO, Carl Zeiss Meditec (3) | 37.87 | 3.149 | 2.230 | 19.16 | 19.15 |
| C-flex, Rayner | 210.5 | 17.27 | 13.03 | 110.9 | 114.4 |
| XL STABI SKY,IOLTech | 153.1 | 13.48 | 8.463 | 56.10 | 54.89 |
| BIOCRYL-600-ROH | 49.97 | 3.423 | 2.120 | 32.04 | 32.41 |

$p < 0.05$

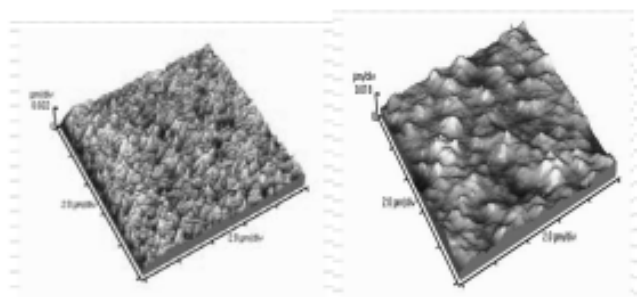
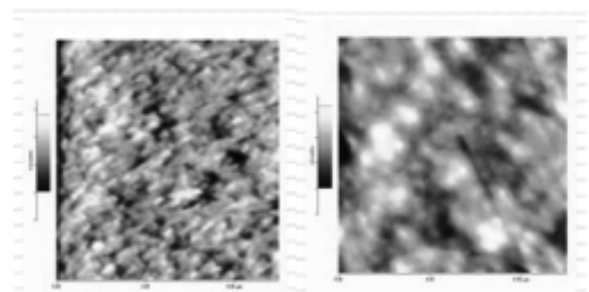
2D and 3D AFM images of Acrylic Hydrophobic IOLs



Roughness Parameters of Hydrophobic Acrylic IOLs

| IOLs | Rp-v | Rq | Ra | Mn Ht | Md Ht |
|------------|-------|-------|-------|-------|-------|
| Acrysof IQ | 18.44 | 2.126 | 1.662 | 10.53 | 10.44 |
| AMO Tecnis | 21.73 | 2.274 | 1.757 | 12.15 | 12.21 |

2D and 3D AFM images of Acrylic Hydrophobic IOLs



Comparison Chart

(Average value of all models of a particular material)

| Serial Number | Material Roughness | Rp – V Roughness | RMS Ht (Rq) nm | Av. Ht (Ra) nm | Mean nm | Median nm |
|---------------|---------------------|------------------|----------------|----------------|---------|-----------|
| 1 | PMMA | 81.46 | 6.36 | 4.84 | 39.08 | 37.10 |
| 2 | HEMA | 150.1 | 5.974 | 2.342 | 52.16 | 52.27 |
| 3 | Acrylic Hydrophilic | 112.45 | 8.08 | 5.52 | 48.79 | 49.38 |
| 4 | Acrylic Hydrophobic | 20.09 | 2.2 | 1.71 | 11.34 | 11.33 |
| 5 | Silicone | 70.73 | 3.582 | 2.312 | 10.40 | 10.01 |

Here all the models of a specific material were taken collectively and the level of significance was compared with the other remaining five materials. The Rq and Ra values of Acrylic Hydrophilic IOLs appear high due to the very high values of three acrylic hydrophilic IOL models.

P value was found to be < 0.001 in all cases, so results are highly significant.

Discussion and Conclusions

It is well known that to prevent PCO, roughness of intraocular lenses is an important factor. Studies have shown that fewer anterior chamber cells adhere to the optics of IOLs with lower roughness values, and fewer cells adhere to the IOL surface with increased contact angles. Hydrophobic optics with small roughness values of acrylic IOLs may reduce the number of adherent cells and escape the unexpected inflammatory cell reaction associated with intraocular inflammation in the eye⁹. It has also been shown that inflammatory cell adhesion to the IOL optical surface is directly proportional to the Ra value of the IOLs¹⁰. Experimental results have also shown that the deteriorative effect of surface roughness on the optical quality of retina image is minimal unless the average roughness is over 50 nm, which extremely exceeds the range of roughness of IOLs used in clinic¹¹. Hence, a knowledge of the surface properties of the biomaterials used to manufacture IOLs is extremely important.

From our study, we see that the atomic force microscopy permits high-resolution imaging of IOL optic surface characteristics. It is very effective and accurate in analyzing IOL optics. Our study takes into consideration 18 different IOLs. Previous studies have considered only four IOLs (Lombardo et al)¹. Our study shows that the surface topography of IOLs vary with different manufacturing processes and biomaterials. The root mean square roughness of the IOL surface is significantly different between lenses of various materials. The roughness of the same class of IOLs, but from different manufacturers, varies, possibly due to the different manufacturing processes involved. HEMA IOLs have similar roughness parameters when compared with PMMA IOLs. Silicone IOLs have roughness parameters lower than PMMA and HEMA IOLs but somewhat higher than most Acrylic IOLs. Overall most (except three) acrylic IOLs have lower roughness parameters than the other group of IOLs. Certain indigenous IOLs have better surface qualities compared to their Western counterparts.

Hence we see that the Atomic Force Microscope can accurately measure various roughness parameters of the commercially available IOLs. It will be an essential tool for the roughness parameter assessment and quality control of current IOLs as well as the ones which are being newly developed. AFM is thus almost indispensable in the march towards 20/10. It is time we asked for AFM images of the IOLs we implant in our patients' eyes.

References

1. Lombardo M, De Santo MP, Lombardo G, Barberi R, Serrao S. Analysis of intraocular lens surface properties with atomic force microscopy. *J Cataract Refract Surg* 2006; 32:1378–1384
2. Bhatia S, Goldberg EP, Enns JB. Examination of contact lens surfaces by Atomic Force Microscope (AFM). *The CLAO Journal* 1997; 23(4):264–269
3. Hollick EJ, Spalton DJ, Ursell PG, Pande MV. Lens epithelial cell regression on the posterior capsule with different intraocular lens materials. *Br J Ophthalmol* 1998; 82:1182–1188
4. Davison JA. Neodymium:YAG laser capsulotomy after implantation of AcrySof intraocular lenses. *J Cataract Refract Surg* 2004; 30:1492–1500
5. Serry FM. Applications of Atomic Force Microscopy for Contact Lens Manufacturing. www.veeco.com
6. Kurosaka D, Obasawa M, Kurosaka H, Nakamura K. Inhibition of lens epithelial cell migration by an acrylic intraocular lens in vitro. *Ophthalmic Res* 2002; 34:29–37
7. Werner L, et al. Biocompatibility of intraocular lens materials. *Curr Opin Ophthalmol*. 2008 Jan; 19(1):41–9.
8. Baillif S, et al. Intraocular lens and cataract surgery: comparison between bacterial adhesion and risk of postoperative endophthalmitis according to intraocular lens biomaterial. *J Fr Ophtalmol*. 2009 Sep; 32(7):515–28. Epub 2009 Jun 17.
9. Tanaka T, et al. Cell adhesion to acrylic intraocular lens associated with lens surface properties. *Journal of Cataract & Refractive Surgery*, Volume 31, Issue 8, Pages 1648–1651.
10. Surface roughness of intraocular lenses and inflammatory cell adhesion to lens surfaces. *Journal of Cataract & Refractive Surgery*, Volume 29, Issue 2, Pages 367–370.

Kato Noriyuki. Effect of Surface Roughness of Intraocular Lens on the Optical Image Quality of Pseudophakic eye. *Japanese Journal of Visual Science*. Vol.21; No.3/4; Page.81–86 (2000)