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Surface properties of commercially available hydrophobic acrylic intraocular lenses: Comparative study

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Purpose: To analyze and compare the surface properties of commercially available hydrophobic acrylic intraocular lenses (IOLs).

Setting: Eye Clinic, University of Trieste, Italy.

Design: Experimental study.

Methods: The following 6 single-piece hydrophobic acrylic IOL models with the same dioptric power were studied and compared: Clareon SY60WF, Tecnis PCB00, enVista MX60, CT Lucia 601P, Vivinex iSert XY1, and iSert 251. Topography of the IOL surface was analyzed using atomic force microscopy (AFM). Surface contact angle measurements using the sessile drop method were performed to assess IOL wettability.

Results: The AFM analysis showed that the Vivinex iSert XY1 IOL and Clareon SY60WF IOL had the lowest surface roughness ($P < .05$); there was no statistically significant difference in surface roughness between the those 2 IOL models ($P > .05$). Surface contact angle measurements showed that the iSert 251 IOL had the highest hydrophobicity. The CT Lucia 601P IOL had the lowest contact angle of all IOL models.

Conclusions: The AFM analysis and surface contact angle measurements of all IOLs tested showed that the Vivinex iSert XY1 IOL and Clareon SY60WF IOL had the best topographic features. The smoother, more regular surface of these new IOL models might reduce cell adhesion and therefore lower the incidence of posterior capsule opacification.

Phacoemulsification with intraocular lens (IOL) implantation is the main treatment option for symptomatic cataract. Advanced technology in phacoemulsification systems and IOL design and materials has improved surgical and refractive outcomes.[1,2] However, posterior capsule opacification (PCO) remains a concern, and choosing the IOL with the best capsule biocompatibility is essential to preventing it.[3,4]

Posterior capsule opacification is the most frequent complication after cataract surgery, with an incidence of nearly 20% to 40% within 5 years of surgery.[5,6] The physiopathology of PCO has been widely studied, and it is well established that lens epithelial cells (LECs) are the main cellular precursor of the process. The LECs proliferate and migrate onto the IOL surface and capsular bag, leading to secondary opacification and the appearance of Elschnig pearls.[7,8]

Suggested risk factors for PCO include the age of the patient, myotonic dystrophy, myopia, surgical technique, capsulorhexis size, and the presence of retinitis pigmentosa or pseudoexfoliation syndrome.[9–12] In addition to these factors, it is well documented that IOL design and IOL material are predominant factors influencing the incidence of PCO.[13–17] In particular, a sharp-edged optic design is associated with a lower PCO rate; the sharp edge mechanically blocks LEC migration into the space between the IOL and capsular bag.[4,13,14] On the other hand, the IOL's biomaterial plays an important role in the development of PCO.[15–17] Studies[18,19] have found that hydrophobic acrylic has better capsule biocompatibility because of its relatively low propensity to induce cell proliferation in the capsular bag. However, these studies were performed without considering how square the IOL edges were. Werner et al.[20] evaluated the microstructure of the edges of commercially available square-edged hydrophilic acrylic IOLs in terms of their deviation from an ideal square. The authors observed a large variation in the optic edge of hydrophilic acrylic IOLs compared with IOLs of other materials, suggesting that the higher incidence of PCO with hydrophilic

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acrylic IOLs might be the result of the edge difference rather than the IOL biomaterial. Nevertheless, it is not completely clear how a square edge or IOL biomaterial alone influences the behavior of LECs; further studies are needed.

Intraocular lens surface properties, such as surface roughness, might influence the interaction between the material surface and cells. A correlation between IOL surface properties with LEC migration and adhesion on the optic has been recognized, suggesting that IOLs whose surface properties discourage LECs adhesion are more biocompatible.[21–23] Using atomic force microscopy (AFM), Lombardo et al.[21] postulated that higher surface irregularities might account for the higher incidence of PCO. Atomic force microscopy studies[22,23] showed a different surface topography not only between IOLs of different materials but also between those of the same biomaterials with different dioptric power or different manufacturers.

Recently, 2 new hydrophobic acrylic IOL platforms—the Clareon 1-piece (Alcon Laboratories, Inc.) and the Vivinex iSert 1-piece (Hoya Corp.)—were introduced. Both IOLs are hydrophobic acrylic, although the properties of the material differ between the 2 platforms. The biomaterial of the Clareon IOL has a slightly higher water content, resulting in improved clarity and no glistenings.[A] The Vivinex iSert IOL has a modified posterior surface. Specifically, this IOL is treated with ultraviolet–ozone irradiation, which produces active species and introduces oxygen-containing functional groups on the surface material; this enhances protein adsorption and cell adhesion.[24] The surface modification increases the level of adhesion between the IOL and the capsular bag, preventing LEC migration and therefore PCO.

The aim of the present study was to analyze and compare the surface properties of 6 hydrophobic acrylic IOL models with the same dioptric power.

MATERIALS AND METHODS

Six commercially available single-piece hydrophobic acrylic IOLs with the same dioptric power (+20.0 diopters [D]) were evaluated. The IOLs were the Clareon SY60WF (Alcon Laboratories, Inc.), Tecnis PCB00 (Johnson & Johnson Vision Care, Inc.), enVista MX60 (Bausch + Lomb, Inc.), CT Lucia 601P (Carl Zeiss Meditec AG), Vivinex iSert XY1, and iSert 251 (Hoya Corp.).

The surface topography and surface wettability of each model were analyzed and compared. The analyses were performed on the posterior surface of the IOL. This study did not involve human or animal subjects.

Surface Topography Evaluation

The IOL was removed from its sterile pack with an atraumatic forceps and placed on an aluminum sample holder covered with double-sided tape. An atomic force microscope (Perception, Assing S.p.A.) was used to acquire the AFM images. The measurements were performed in air and at room temperature operating in tapping mode. Silicon cantilevers (NSG30, TipsNano OÜ) with a reflective gold-coated side were used. The cantilevers have a nominal spring constant of 40 N/m and a nominal resonant frequency of 320 kHz. The curvature radius of the tetrahedral silicon tip is 10 nm. For each type of IOL, 3 or 4 samples were assessed; 3 areas were recorded for each sample. The dimensions of the areas were 5 $\mu m^2 \times 5\ \mu m^2$ with an image definition of 512 $\text{pixels}^2 \times 512\ \text{pixels}^2$. The image analysis and the extraction of profiles were performed using Gwyddeon software.[25] Before the analysis, the images were processed to correct the background shape and slope. The IOL surface roughness was quantified as the mean surface roughness (Sa) and the root-mean-square surface roughness (RMS).

Surface Wettability Evaluation

Contact angles of the IOL surfaces were measured using the sessile drop method at room temperature with an optical stereomicroscope (MZ16, Leica Microsystems GmbH) equipped with a digital camera (DFC320, Leica Microsystems GmbH).[26] A droplet of distilled water (4 μL) was placed on the surface of the IOL, and the profile of the water drop was recorded after 10 seconds to ensure the stability of the drop. Image-Pro Plus 6.2 software (Media Cybernetics, Inc.) was used to acquire and analyze the images and to measure the contact angle. For statistical analysis, 2 drops were recorded for each IOL and 3 or 4 IOLs were analyzed for each type.

Statistical Analysis

Statistical analyses were performed using Origin software (OriginLab Corp.). The contact angle data satisfied the normality of distribution assumption (Kolmogorov-Smirnov test) but not the equality of variance assumption (Levene test). The surface roughness data did not satisfy either assumption for parametric statistical tests. All data were therefore analyzed using Kruskal-Wallis and Mann-Whitney nonparametric tests and applying a Bonferroni correction. Statistical significance was set at an α level of 0.05.

RESULTS

Surface Topography Analysis

Figure 1 shows the topographic image and topographic profile of each IOL model. Quantitative data (ie, surface roughness [Table 1]) obtained from the topographic analyses showed no statistically significant differences between the Clareon SY60WF IOL (Figure 1, *D*) and Vivinex iSert XY1 IOL (Figure 1, *E*) ($P > .05$, Mann-Whitney *U* test). These 2 IOLs had the lowest mean surface roughness of all IOL models ($P < .05$, Mann-Whitney *U* test). The iSert 251, CT Lucia 601P, and Tecnis PCB00 had the next lowest mean surface roughness. The EnVista MX60 had the highest mean surface roughness; the difference was statistically significant.

The Clareon SY60WF IOL and Vivinex iSert XY1 IOL also had the lowest RMS surface roughness ($P < .05$, Mann-Whitney *U* test). There was no statistically significant difference in the RMS surface roughness between the other IOL models.

Surface Wettability Analysis

Table 2 shows the sessile contact angle measurements of the 6 IOL models. The iSert 251, Vivinex iSert XY1, Clareon SY60WF, enVista MX60, and Tecnis PCB00 IOLs had high hydrophobicity, with mean contact angle values between 72.84 degrees and 84.24 degrees. The 2 iSert models had statistically significantly higher mean contact angle values than the other IOL models ($P < .05$, Mann-Whitney *U* test), although the difference between the 2 was not statistically significant ($P > .05$, Mann-Whitney *U* test). The CT Lucia IOL had the lowest hydrophobicity, and the difference was statistically significant ($P < .05$, Mann-Whitney *U* test).

Figure 2 shows images of the contact angle measurements for the 6 IOLs. The hydrophobicity can be observed.

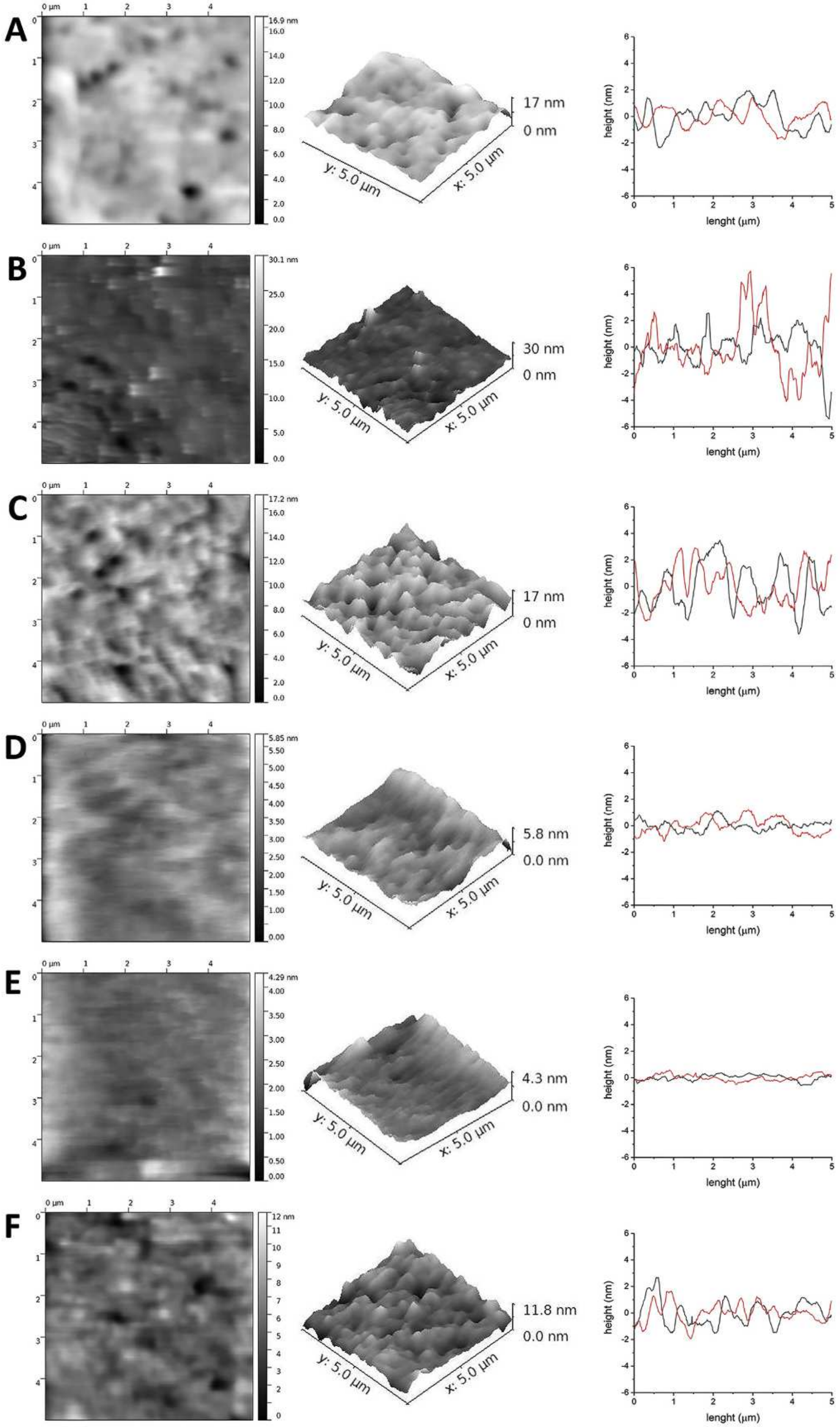

Figure 1. Topographic images and topographic profile of each intraocular lens model. *A*: iSert 251. *B*: CT Lucia 601P. *C*: enVista MX60. *D*: Clareon SY60WF. *E*: Vivinex iSert XY1. *F*: Tecnis PCB00.

DISCUSSION

Intraocular lens implantation is used not only in cataract surgery but also in refractive surgery, such as in cases of high myopia and presbyopia. Thus, using a highly biocompatible IOL is critical to achieving the best postoperative results. Posterior capsule opacification remains the most frequent complication of modern cataract surgery, leading to decreased visual acuity postoperatively.[5,6] This

Table 1. Surface roughness parameters of IOL models.

IOL Model	Mean Surface Roughness ± SD	
	Sa (nm)	Sq (nm)
iSert 251	1.29 ± 0.16	1.78 ± 0.40
CT Lucia 601P	1.51 ± 0.28	2.05 ± 0.36
EnVista MX60	1.69 ± 0.20	2.13 ± 0.26
Clareon SY60WF	0.79 ± 0.33	1.01 ± 0.41
Vivinex iSert XY1	0.49 ± 0.48	0.63 ± 0.57
Tecnis PCB00	1.12 ± 0.24	2.27 ± 2.54

IOL = intraocular lens; Sa = average arithmetic roughness; Sq = root-mean-square roughness

complication is caused by the migration and proliferation of LECs across the posterior surface of the IOL optic and in the space between the IOL and capsular bag[7,8]; thus, choosing an IOL with the highest capsule biocompatibility is essential.[3,4]

Posterior capsule opacification can be successfully treated using a neodymium:YAG laser to create an opening in the posterior lens capsule. However, this procedure can lead to additional complications, including IOL damage, intraocular pressure elevation, glaucoma, cystoid macular edema, retinal tears, and retinal detachment.[27–29]

One way to improve IOL biocompatibility, including uveal and capsule biocompatibility, is to reduce the adhesion of inflammatory cells and LECs to the IOL surface. The importance of optic design in preventing PCO is well documented. Indeed, several studies[4,13,14] found that IOL optics with a square-edged design reduced the incidence of PCO by mechanically blocking LEC migration and proliferation. Moreover, other studies[17,30] showed that varying degrees of cell adhesion and migration also depend on the chemicophysical characteristics of the IOL, such as material hydrophobicity and surface roughness. The topography of IOLs varies, not only between IOL biomaterials but also between IOLs of the same biomaterial but with different dioptric powers or different manufacturers.[22,23]

Table 2. Contact angle values of each IOL model.

IOL Model	Mean Contact Angle (°) ± SD
iSERT 251	84.24 ± 2.15
CT Lucia 601P	48.76 ± 4.91
EnVista MX60	75.22 ± 3.45
Clareon SY60WF	72.84 ± 1.80
Vivinex iSert XY1	78.94 ± 6.66
Tecnis PCB00	74.45 ± 5.11

IOL = intraocular lens

Hydrophobic acrylic IOLs were introduced by Alcon Laboratories, Inc., in the 1990s. These IOLs have favorable properties, including chemical inertia, optical transparency, and a viscoelasticity that allows the IOL to unfold within 3 to 5 seconds and provides safe implantation. These IOLs also have the lowest reported incidence of PCO.[31]

In our study, we tested the surface topography and surface hydrophobicity of different hydrophobic acrylic IOLs with the same dioptric power (20.0 D). The hydrophobicity of all IOLs, except the CT Lucia 601P, was high.

In addition to hydrophobicity, surface topography plays an important role in IOL biocompatibility. Several studies[3,16,23] found that the amount of surface irregularities is strongly correlated with greater adhesion of inflammatory cells and a higher rate of LEC migration onto the optic surface of the IOL.

Lombardo et al.[21] analyzed the surface topography of the posterior optic of different IOLs using AFM. They found that hydrophobic acrylic IOLs had a smoother surface than silicone, hydrophilic acrylic, and poly(methyl methacrylate) (PMMA) IOLs. Tanaka et al.[16] found reduced cell adhesion on hydrophobic acrylic IOLs with a lower surface roughness and higher water contact angle. In a study by Chaudhury et al.,[15] hydrophobic acrylic IOLs had a significantly lower surface roughness than PMMA IOLs, indicating that acrylic IOLs are better at preventing PCO.

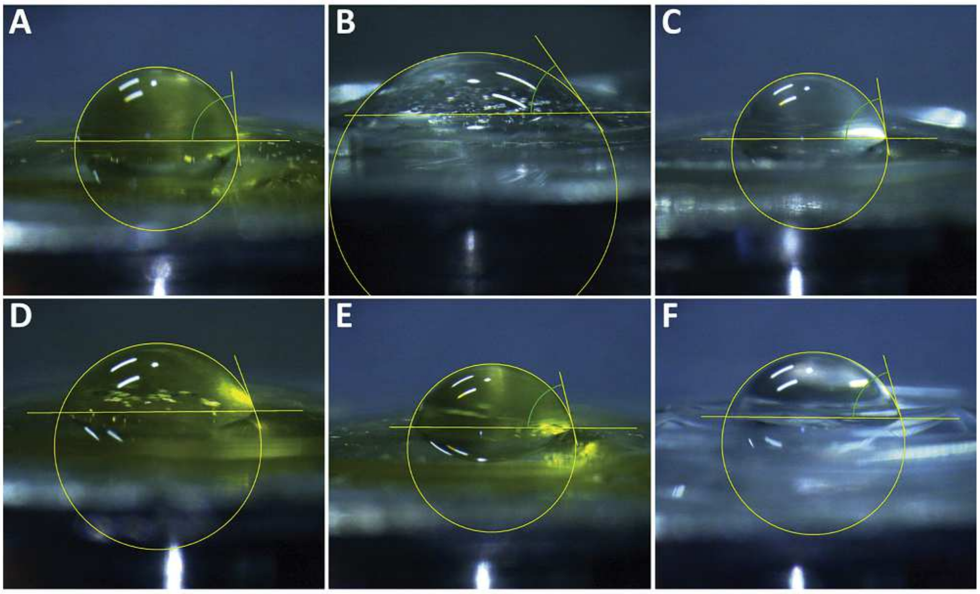

Figure 2. Surface contact angle images obtained through the sessile drop method. *A*: iSert 251. *B*: CT Lucia 601P. *C*: enVista MX60. *D*: Clareon SY60WF. *E*: Vivinex iSert XY1. *F*: Tecnis PCB00.

In our study, the Vivinex iSert XY1 IOL and Clareon SY60WF IOL had the smoothest and most regular surface of the 6 IOL models tested, indicating their ability to effectively prevent PCO. However, in vivo studies are needed to confirm these results.

Although it is well documented that a sharp posterior optic edge is a major factor in the prevention of PCO, the IOL surface topography is also an important parameter influencing capsule and uveal biocompatibility because of the direct interaction between the IOL and intraocular tissue, inflammatory mediators, and proteins. Therefore, choosing the IOL with the best biocompatibility features will make surgery safer and prevent PCO postoperatively.

WHAT WAS KNOWN

- Intraocular lens (IOL) surface properties, such as contact angle and roughness, are the most important factors influencing IOL biocompatibility.
- Atomic force microscopy (AFM) studies show that hydrophobic acrylic IOLs with decreased surface irregularities reduce cell adhesion and, therefore, the incidence of posterior capsule opacification.

WHAT THIS PAPER ADDS

- Two new commercially available hydrophobic acrylic IOLs had the smoothest and most regular surface on AFM analysis.

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