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Original

Moisture Generation Mechanism of Intraocular Lenses during Fluid/Gas Exchange

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Summary

PURPOSE: To evaluate the characteristics and formation mechanism of condensation on the posterior surface of various types of intraocular lenses (IOLs) during vitreous surgery.

METHODS: A model eye was immersed in a constant-temperature bath, and the temperature and humidity inside the vitreous cavity were maintained at 35 ℃ and 97%, respectively, to cause condensation (moisture formation) on the IOL. The condensation was video recorded under a microscope, and the size of the condensation droplets and the number per unit area (500 μm^2) were determined. The contact angle of the water droplets on each IOL was evaluated by using the sessile-drop method.

RESULTS: The condensation droplet diameter for the polymethyl methacrylate (PMMA), acrylic, and silicone IOLs was 115 ± 32 μm, 74 ± 23 μm, and 50 ± 13 μm, respectively. The number of droplets per unit area was 18.4 ± 1.8, 48.2 ± 16.8, and 86.8 ± 6.7, respectively. Statistical analysis showed significantly smaller sizes but a greater number of droplets per unit area for the silicone IOL. The contact angle for the PMMA, acrylic, and silicone IOLs was 76.4 °, 85.7 °, and 112.8 °, respectively. Thus, for silicone, the contact angle was lowest and the water droplets were spherical.

CONCLUSIONS: Condensation occurs regardless of the IOL material. Compared to other IOLs, the silicone IOL had smaller-sized but a larger number of spherical condensation droplets. This can cause a large amount of refraction of intraocular light, thus leading to decreased visibility.

Key Words: condensation, contact angle, fluid/gas exchange, intraocular lens, intraocular lens material

Introduction

Fluid/gas exchange is an important procedure in vitreoretinal surgery for closing macular holes and repairing retinal detachments. However, during surgery in a pseudophakic eye, condensation occurs on the intraocular lens (IOL), thus leading to decreased visibility and in some cases, difficulty continuing surgery[1-3]. Various studies have shown that condensation formation and decreased visibility occur for silicone IOLs[4]. However, this is not unique to silicone IOLs only. Such condensation also occurs for IOLs made from different materials. In this study, we created a condensation-formation model using a model eye to compare condensation formation on different types of IOL materials.

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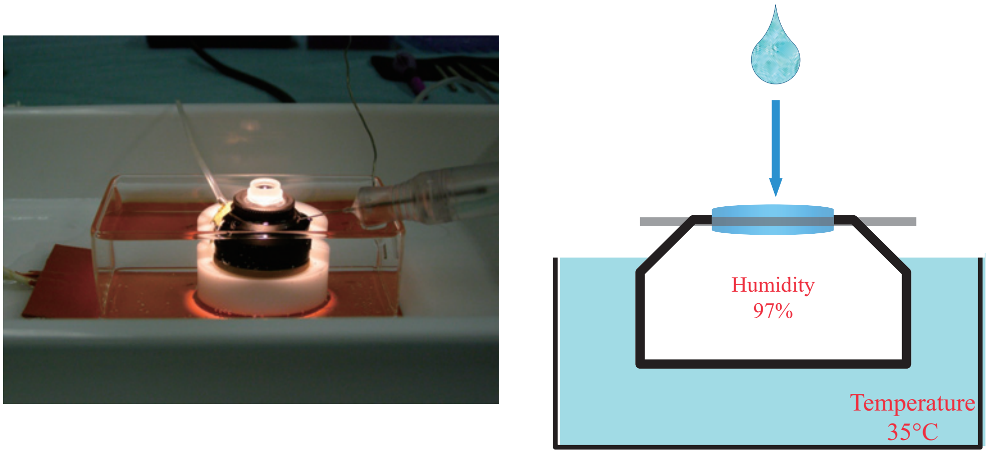

Figure 1 Condensation formation experiment using a model eye
A model eye with an artificial vitreous cavity was placed in a constant-temperature bath to maintain a temperature of 35°C in the vitreous cavity. Intraocular lenses (IOLs) made from different materials were fixed on a disc with a donut-like hole in the center, and this was placed on the artificial vitreous cavity. After placement, the temperature in the vitreous cavity was allowed to stabilize, then a 25°C water drop was dripped onto the IOL optic surface that was open to the air, and condensation was allowed to form by decreasing the IOL surface temperature.

Materials and Methods

Comparison of condensation formation on different IOL materials using a model eye

To compare condensation formation on different IOL materials under the same conditions, we created a condensation-formation model using a model eye. The model eye was placed in a constant-temperature bath at 35 °C to maintain a temperature of 35 °C in the vitreous cavity. The humidity in the artificial vitreous cavity was 97% throughout the experiment.

Five IOLs each of polymethyl methacrylate (PMMA) (UY-65SBT: HOYA, Tokyo, Japan), acrylic (VA-70AD: HOYA, Tokyo, Japan), and silicone (Z9002: Abbott Medical Optics, CA, USA), all with a diopter power of 20, were used as samples. Each IOL was fixed on a disc with a donut-like hole in the center, which was placed on the artificial vitreous cavity (Fig. 1). After placement, the temperature in the vitreous cavity was allowed to stabilize, then a 25 °C water drop was dripped onto the IOL optic surface that was open to the air, and condensation was allowed to form on the bottom of the IOL by decreasing the IOL surface temperature. This process was video recorded under a microscope.

The condensation droplet size was calculated from the number of image pixels based on the IOL diameter (6 mm) using video imaging software (Paint: Microsoft WA, USA). Ten condensation droplets on the IOL were randomly selected, and the mean diameter was also measured. The number of condensation droplets was counted per unit area (500 μm^2) at five randomly selected sites on the IOL optic, average and standard deviation were calculated. The Tukey-Kramer test was used for statistical analysis. The level of statistical significance was 5%.

Measurement of contact angles for different IOLs

To compare the water condensation characteristics of the IOL surfaces, a Drop Master DM500 (Kyowa Interface Science Co, Ltd. Saitama, Japan) was used to measure the contact angles for each IOL. Measurements were performed using the sessile-drop method. One microliter of liquid was dripped on the solid surface, and the shape of the liquid on the IOL was recorded using a CCD camera. The measurement start time was 10,000 ms after dripping. True circle fitting was used for the analysis.

Results

Comparison of condensation formation of different IOL materials using the model eye

When the water was dripped, condensation immediately started to form on all the IOLs, without any dif-

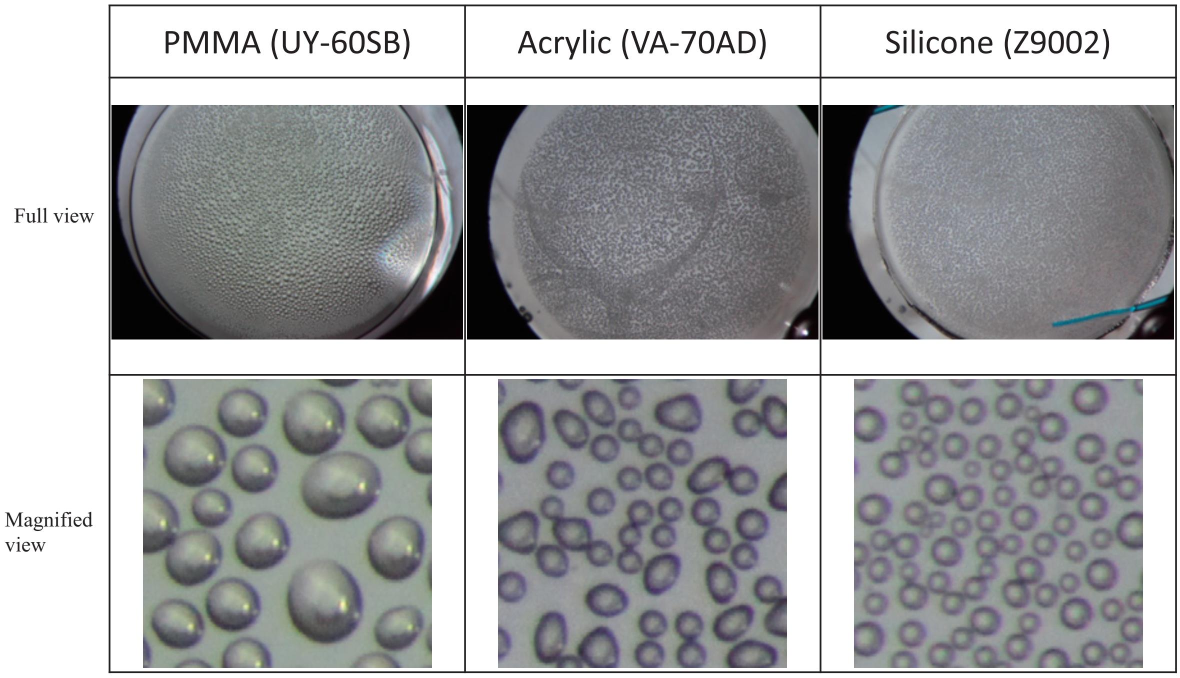

Figure 2 Condensation characteristics of different intraocular lens (IOL) materials
When water was dripped, condensation immediately started to form on all the IOLs, with no difference in formation time. However, compared to the PMMA and acrylic IOLs, the condensation droplets were smaller for the silicone IOL.

Table 1 Condensation droplet size and number of droplets per unit area for different intraocular lens (IOL) materials. The data shows the mean ± standard deviation.

	PMMA	Acrylic	Silicone	P value		
				P vs. A	P vs. S	A vs. S
Size (μm)	115 ± 32	74 ± 23	50 ± 13	< 0.01	< 0.01	< 0.01
Number (drops/500 μm^2)	18.4 ± 1.8	48.2 ± 16.8	86.8 ± 6.7	< 0.01	< 0.01	< 0.01

ference in formation time. However, the condensation characteristics differed for each IOL (Fig. 2). Compared to the PMMA and acrylic IOLs, the condensation droplets were smaller in size for the silicone IOL. The condensation droplet diameter for the PMMA, acrylic, and silicone IOLs was 115 ± 32 μm, 74 ± 23 μm, 50 ± 13 μm, respectively (Table 1). The Tukey-Kramer test showed statistically significant differences among all IOLs ($p < 0.01$), with the smallest droplets being formed on the silicone IOL. The number of droplets per unit area (500 μm^2) was counted and compared among IOLs, and for the PMMA, acrylic, and silicone IOLs was 18.4 ± 1.8, 48.2 ± 16.8, and 86.8 ± 6.7, respectively. The number of droplets was significantly greater for the silicone IOL.

Measurement of contact angle for different IOLs

The contact angle for the PMMA, acrylic, and silicone IOLs was 76.4°, 85.7°, and 112.8°, respectively. The contact angle was largest for the silicone IOL (Fig. 3).

Discussion

In recent times, vitreous surgery outcomes have improved with advances in surgical instruments, and vitreous surgery is now performed in many cases[5]. Vitreous surgery on pseudophakic eyes has also become more common, but it is known that during fluid/gas exchange, condensation forms on the posterior surface of the IOL optic facing the vitreous cavity (without posterior lens capsule), thus decreasing intraocular visibility[1-4]. When the temperature in the anterior cham-

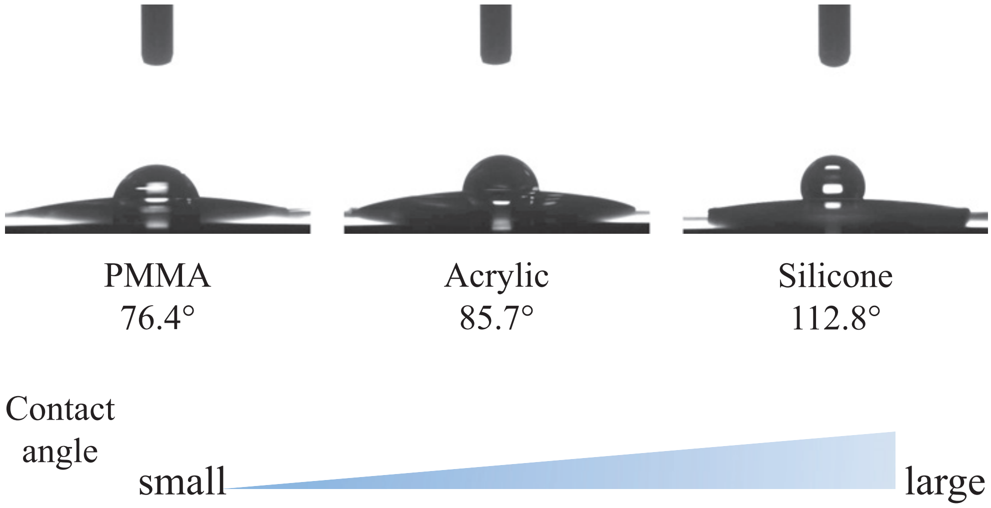

Figure 3 Droplet contact angle for different intraocular lens (IOL) materials
The contact angle for the polymethyl methacrylate (PMMA), acrylic, and silicone IOLs was 76.4°, 85.7°, and 112.8°, respectively.

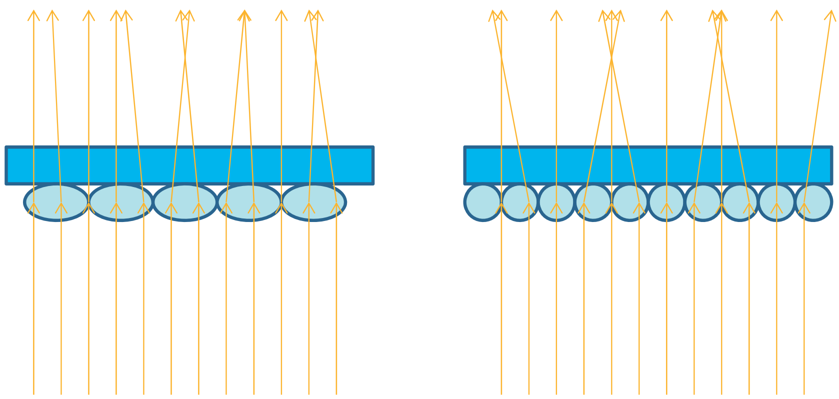

Figure 4 Hypothesis: Condensation characteristics and visibility changes
On an intraocular lens (IOL) with a small contact angle, there are larger-sized but fewer condensation droplets, whereas on an IOL with a large contact angle, there are a large number of smaller droplets. Since light is diffracted at each droplet, the latter case leads to more overall refraction and thus poorer visibility.

ber is lower than that in the vitreous cavity, water vapor molecules present in the vitreous cavity become cooled, and moisture forms on the posterior surface of the IOL optic. Condensation on IOLs is more likely to occur when a posterior capsulotomy is performed[3,6]. It has also been suggested that condensation is more likely to occur with silicone IOLs[4]. In addition, if condensation on a silicone IOL is wiped with a soft-tipped cannula, only a slight improvement in visibility is achieved, and even if visibility is improved by coating with a viscoelastic material, condensation again occur in a short time[7]. However, the shape of condensation droplets has not been investigated previously for IOLs made of different materials.

Therefore, in this study, we compared the condensation characteristics of IOLs made from different materials by artificially producing condensation in a model eye. We found no differences in the time for condensation to occur on different IOLs. However, when we examined the condensation droplet size for the different IOLs, the droplets formed on the silicone IOL were found to be significantly smaller, and the number of droplets per unit area was highest.

To determine the reason for the different condensation characteristics, we measured droplet contact angles for each IOL, and the results showed that PMMA had the smallest contact angle and silicone had the largest. When the contact angle is small, liquid spreads more flatly on a solid substrate, whereas when the contact angle is large, liquid droplets become spherical. Therefore, as the contact angle becomes larger, small spherical condensation droplets tend to form. It is thought that as the droplet diameter decreases, the number of droplets per unit area increases. This is the case for silicone IOLs and is a problem because, as shown in Fig. 4, a large number of small almost-spherical droplets leads to more refraction effects than a small number of large flatter droplets.

With advances in cataract and vitreoretinal surgery, better postoperative outcomes are being expected. Therefore, ensuring good visibility during vitreoretinal surgery is essential. Our study has elucidated the condensation characteristics of different types of IOL materials. A future goal is to develop an IOL material that is less susceptible to condensation for use in vitreoretinal surgery.

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