

Simulation of 20-year Deterioration of Acrylic IOLs Using Severe Accelerated Deterioration Tests

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Purpose: To investigate IOL deterioration by conducting severe accelerated deterioration testing of acrylic IOLs.

Setting: Department of Ophthalmology, Tokai University School of Medicine

Methods: Severe accelerated deterioration tests performed on 7 types of acrylic IOLs simulated 20 years of deterioration. IOLs were placed in a screw tube bottle containing ultra-pure water and kept in an oven (100°C) for 115 days. Deterioration was determined based the outer appearance of the IOL in water and under air-dried conditions using an optical microscope. For accelerated deterioration of polymeric material, the elapse of 115 days was considered to be equivalent to 20years based on the Arrhenius equation.

Results: All of the IOLs in the hydrophobic acrylic group except for AU6 showed glistening-like opacity. The entire optical sections of MA60BM and SA60AT became yellowish white in color. Hydrophilic acrylic IOL HP60M showed no opacity at any of the time points examined.

Conclusion: Our data based on accelerated testing showed differences in water content to play a major role in transparency. There were differences in opacity among manufacturers.

The method we have used for determining the relative time of IOL deterioration might not represent the exact clinical setting, but the appearance of the materials would presumably be very similar to that seen in patients.

Key words: acrylic IOL, accelerated deterioration test, glistening, hydrophobic, hydrophilic

INTRODUCTION

Approximately one million patients receive intraocular lens (IOL) implants annually in Japan alone. Implanted IOLs may remain stable in vivo as an artificial organ without deterioration for 5, or even 10, years. However, we do not know whether the implanted IOL will remain stable in vivo as an artificial organ without deterioration for more than 20 years. In order to assess the possible appearance of implanted IOLs after 20 years, IOLs were subjected to severe accelerated deterioration tests. As IOLs are artificial organs, we investigated whether the results obtained correlate with results in clinical settings.

MATERIALS AND METHODS

Study IOLs

Three of each type of lens (20 diopter), provided by the manufacturers, were used.

There were two different lenses from each of six different companies.

Clear hydrophobic acrylic IOLs: MA60BM (Acrysof: Alcon), SA60AT (Acrysof: Alcon), AR40e (Sensor: AMO), VA-60BB (Acryfold: HOYA), N4-18B (Nex-Acri: NiDEK), AU6 (Avansee: KOWA)

Clear hydrophilic acrylic IOL: HP60M (Hydroview: Bausch & Lomb)

Methods

IOLs were placed in 50mL screw tube bottles containing ultra-pure water and kept in an oven (100°C)

for 115 days (Fig. 1).

Deterioration of the IOLs was observed on the 115th day. Photographs were taken in water at room temperature at each time point employing an optical microscope (NIKON SMZ1500). Since ISO11979-6 aims to confirm stability within expiration date, the experiment will take too much time when it follows the condition of ISO11979-6. The experiment used the accelerated deterioration method in order to confirm durability of IOLs (stability for a few decades) in a short term. The speed of deterioration on severe acceleration testing was determined by the deterioration of the polymeric material based on the Arrhenius equation.

The Arrhenius equation is an empirical equation that expresses the following principle: "the lower the temperature, the slower a given chemical reaction will proceed, and conversely, the higher the temperature, the faster a reaction will proceed."

Arrhenius equation: $k = A \exp(-E_a/RT)$

[k: the rate at which the reaction proceeds A: the constant for the material (frequency factor), E_a : apparent activation energy (eV), R: Boltzmann's constant ($0.86171 \times 10^{-4} \text{ eV/K}$), T: absolute temperature]

A simplified version of the Arrhenius equation is the acceleration formula:

$Q_{10} ((T_a - T_0)/10) < 10^\circ\text{C rule} >$

(T_a = oven aging temperature, T_0 = room temperature (ambient/use/storage))

Based on the hypothesis that "23 days in a 100°C

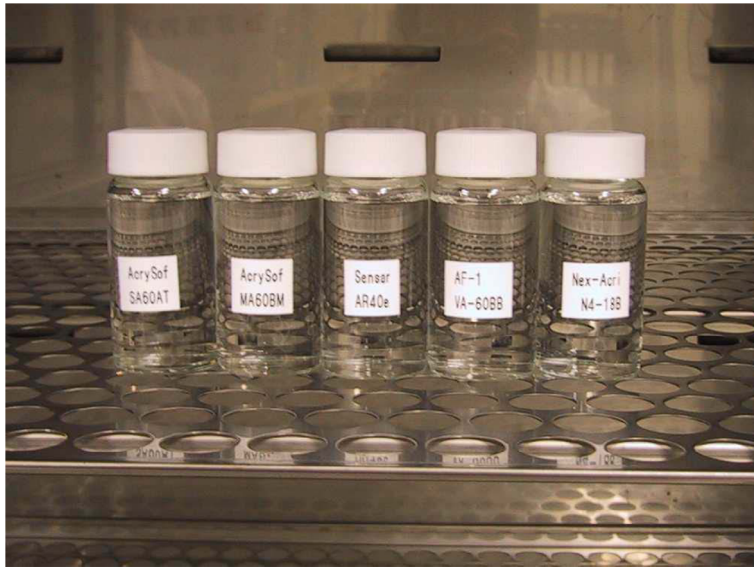


Fig. 1 IOLs were placed in a screw tube bottle containing ultra-pure water and kept in an oven (100°C) for 115 days.

Based on the hypothesis that “23 days in a 100°C oven is equivalent to four years at 37°C,” 115 days were chosen to simulate 20 years.

oven is equivalent to four years at 37°C,” 115 days were chosen to simulate 20 years. Since the recommended heating temperature according to the Arrhenius equation is 50°C–60°C, the accelerated testing in the present study was more severe than accelerated testing based on the Arrhenius equation. The typical relationship selected for commonly used medical polymers is $Q_{10} = 2$ [1].

RESULTS

Observed deterioration

All of the IOLs in the hydrophobic acrylic group except for AU6, i.e., MA60BM SA60AT, AR40e, VA-60BB and N4-18B, showed glistening-like opacity. The entire optical sections of MA60BM and SA60AT became light yellowish white. AR40e showed granular change. VA-60BB and N4-18B showed white opacity throughout the lenses, and the granulation disappeared. No opacity was observed on AU6 or the hydrophilic acrylic IOL, HP60M (Fig. 2).

Discussion

Since acrylic soft lenses have a molecular structure that maintains their soft shape, reactions such as oxidation, hydrolysis, depolymerization and cross-linking of polymers occur after contact with heat, light, oxygen and water, etc. These reactions cause staining, increased brittleness, cloudiness, surface cracks and major reductions in strength [2–7]. In addition, our studies revealed deterioration and opacity of each acrylic IOL to differ among manufacturers.

As to the hydrophobic acrylic lenses, the alteration in the opacity of the AcrySof (Alcon) lens was a glistening-like change that appeared in the early stage of testing [4, 7]. However, other factors need to be considered to explain this yellowish white change occurring on the 115th day (after 20 years).

Yaguchi reported that AcrySof lenses did not show increased changes under conditions simulating 20 years of aging. The lenses were placed in a laboratory oven at 90°C [8]. Our method was to place IOLs in a

50mL screw tube bottle containing ultra-pure water and then maintain them in an oven (100°C) for 115 days [9]. There are various possible reasons for the differences in the opacity of acrylic IOLs. The materials used in acrylic lenses and manufacturing processes need to be investigated as factors affecting opacity [5, 6, 9, 10].

Possible material-related factors affecting the opacity of the lens are the type of copolymer used in manufacturing the IOL, the refractive index, the Abbe number, the glass transition temperature, water content (temperature close to body temperature: 30–40°C), ultraviolet absorber, coloring agent and whether the IOL is hydrophobic or hydrophilic [10–13].

The hydrophobic acrylic lenses used in the present experiment were AcrySof (Alcon), Sensor (AMO), Acryfold (HOYA), Nex-Acri (NIDEK) and Avanse (KOWA). The AcrySof (Alcon) lens uses a copolymer of phenylethyl acrylate and phenylethyl methacrylate. The refractive index is 1.55, the Abbe number is 37, Tg is 18.5°C, and the water content is not more than 0.3%. The Sensor (AMO) lens uses a copolymer of ethyl acrylate and ethyl methacrylate. The refractive index is 1.47, the Abbe number is 59, Tg is 12°C, and the water content is 0.7%. The Acryfold (HOYA) lens uses a copolymer of butyl acrylate and phenylethyl methacrylate. The refractive index is 1.52, the Abbe number is 43, Tg is 12°C, and the water content is not more than 0.35%. The Nex-Acri (NIDEK) lens uses a copolymer of butyl acrylate and phenoxy ethyl acrylate. The refractive index is 1.52, the Abbe number is 42.0, Tg is 3.6°C, and the water content is not more than 0.1%. The Avanse (KOWA) lens uses a copolymer of phenoxyethyl acrylate and ethyl acrylate. The refractive index is 1.52, the Abbe number is 43.0, Tg is 15°C, and the water content is not more than 2.0%. The material used in the hydrophilic acrylic lens, Hydroview (Bausch & Lomb), is a copolymer of hydroxyethyl methacrylate and hydroxyhexyl methacrylate. The refractive index is 1.47, Tg is 2°C, and the water content is 18% (Table 1).

A comparison of the differences in opacity among

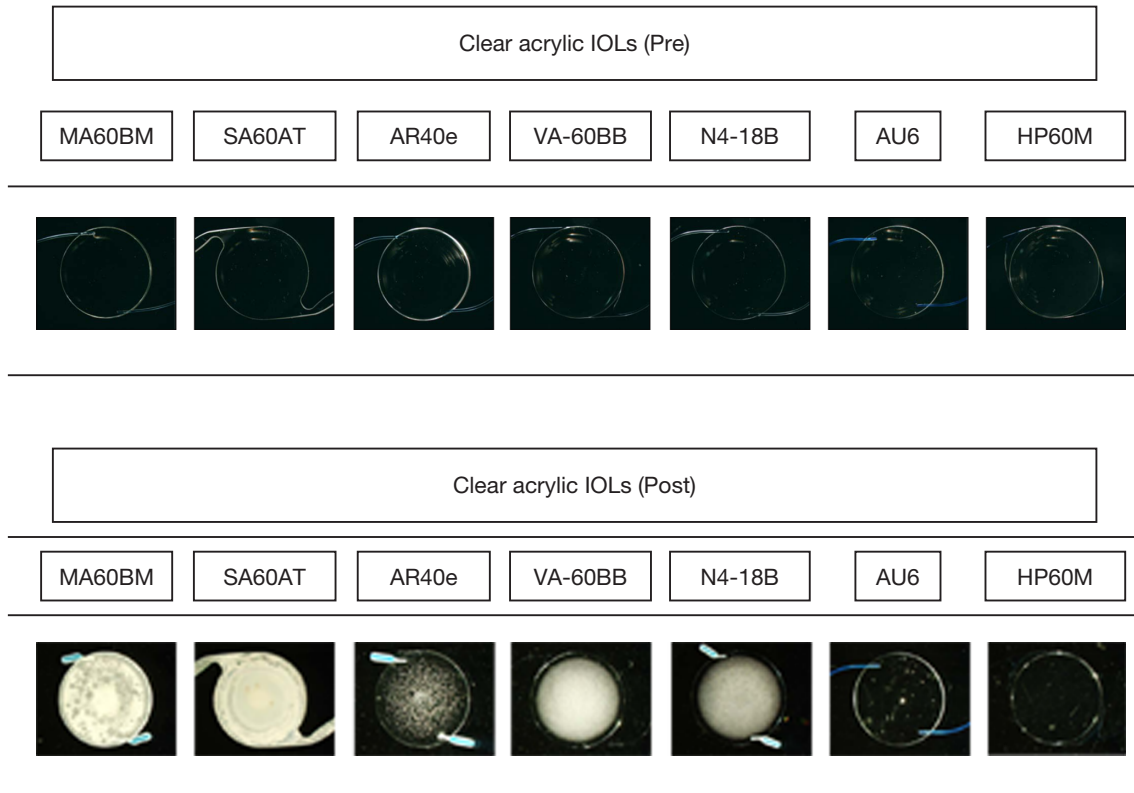


Fig. 2 Study IOLs: The clear acrylic IOLs (MA60BM, SA60AT, AR40e, VA-60BB, N4-18B, AU6 and HP60M) were selected for measurement. After 115 days (20 years), the entire optical sections of MA60BM and SA60AT had become a light yellowish white in color. AR40e showed an increase in granular change. VA-60BB and N4-18B showed white opacity throughout, and the granulation disappeared. There was no opacity in the case of AU6. Hydrophilic acrylic IOL HP60M showed no opacity.

IOLs yielded by our experiment and the above factors showed that the higher the water content, the better transparency was maintained. Therefore, we speculate that this factor may have been responsible for the differences in opacity among IOLs.

Miyata reported that glistening occurs in acrylic IOLs due to infiltration of water molecules associated with a change in the molecular structure caused by heat [10].

The method of manufacturing acrylic IOLs differs among manufacturers. Some are manufactured by the cast-molding method, while others are manufactured by the lathe-cut method [7, 14].

Thus, we investigated differences among the manufacturing processes, i.e., whether the cast molding method or the lathe-cut method was used.

Of the IOLs studied herein, SA60AT (Alcon), MA60BM (Alcon) and AU6 (KOWA) were manufactured by the cast-molding method, while AR40e (AMO), VA-60BB (HOYA), N4-18B (NIDEK) and HP60M (Bausch & Lomb) were manufactured by the lathe-cut method.

Looking at the IOLs that were manufactured by the cast-molding method, MA60BM and SA60AT showed pronounced opacity, while AU6 exhibited almost no opacity. In the case of IOLs manufactured by the lathe-cut method, AR40e, VA-60BB and N4-18B showed granular opacity and white opacity, but HP60M, a hydrophilic IOL, exhibited almost no opacity. It was

concluded that differences in manufacturing methods did not account for the differences in opacity among the IOLs studied.

We believe that the results of this study provide a good reference when considering which IOL to choose for children and other young cataract patients who will undergo long-term IOL implantation.

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Table 1 Material and Quality of IOL's

Manufacture	Alcon		AMO	HOYA	NIDEK	KOWA	Bausch & Lomb
Product name	AcrySof		Sensar	AF-1	Nex-Acri	Avansee	Hydroview
Model name	MA60BM	SA60AT	AR40e	VA-60BB	N4-18B	AU6	HP60M
Hydrophobicity/ Hydrophilicity	hydrophobic acrylic lens		hydrophobic acrylic lens	hydrophobic acrylic lens	hydrophobic acrylic lens	hydrophobic acrylic lens	Hydrophilic acrylic lens
Material	copolymer of phenylethylacrylate and phenylethylmethacrylate		copolymer of ethylacrylate and ethylmetacrylate	copolymer of buthylacrylate and phenylethyl-methacrylate	copolymer of buthylacrylate and phenoxy-ethyl-acrylate	copolymer of phenoxy-ethyl-acrylate and ethyl-acrylate	copolymer of Hydroxyethyl-methacrylate and hydroxyhexyl-methacrylate
Refractive index	1.55		1.47	1.52	1.52	1.52	1.47
Abbe number	37.0		55.0	43.0	42.0	43.4	—
Tg. (°C)	18.5		13.0	12.0	3.6	15.0	2.0
Water Content at 35°C	≤ 0.3%		≤ 0.7%	0.16%	≤ 0.1%	≤ 2%	18%
Cast-molding / Lathe-cut method	cast-molding method		lathe-cut method	lathe-cut method	lathe-cut method	cast-molding method	lathe-cut method

Tg: glass transition temperature,.

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