Long-Term Effect of Surface Light Scattering and Glistenings of Intraocular Lenses on Visual Function

KEN HAYASHI, AKIRA HIRATA, MOTOAKI YOSHIDA, KOICHI YOSHIMURA, AND HIDEYUKI HAYASHI

• PURPOSE: To investigate the long-term effect of surface light scattering and glistenings of various intraocular lenses (IOLs) on visual function and optical aberrations after cataract surgery.
• DESIGN: Case-control study.
• METHODS: Thirty-five eyes that underwent implantation of a hydrophobic acrylic, silicone, or polymethyl methacrylate (PMMA) IOL more than 10 years ago were recruited. The scattering light intensity of the surface and internal matrix of the optic was measured using Scheimpflug photography. Visual acuity (VA) was measured using VA charts, and contrast VA and that with glare (glare VA) were examined using a contrast sensitivity tester. Ocular higher-order aberrations (HOAs) were measured using a Hartmann-Shack aberrometer.
• RESULTS: Mean scattering light intensity of the surface and internal matrix of the optic was significantly higher in the acrylic group than in the silicone and PMMA groups ($P < .0001$). Mean uncorrected VA, photopic and mesopic contrast VA and glare VA, and HOAs did not differ significantly among groups, although mean corrected VA in the acrylic group was significantly better than that in the other groups ($P = .0023$). Scattering light intensity of the surface and internal matrix did not correlate with VA, contrast VA, or glare VA, and did not correlate with ocular and internal optic HOAs in the acrylic group.
• CONCLUSIONS: At more than 10 years postoperatively, visual function, including contrast sensitivity, and ocular HOAs were comparable among eyes that received acrylic, silicone, and PMMA IOLs. Surface scattering and glistenings with the acrylic IOLs were not significantly correlated with visual function and optical aberrations. (Am J Ophthalmol 2012;154:240–251. © 2012 by Elsevier Inc. All rights reserved.)

SINCE THE INTRODUCTION OF THE FIRST MODEL OF AcrySof intraocular lens (IOL) in 1994, hydrophobic acrylic IOL have become the most popular IOL used after cataract extraction. The reason is mainly that the incidence of postoperative complications, including posterior capsule opacification (PCO), is lower with the acrylic IOL than with IOLs made of other materials.[1–4] In the early stage after implantation, however, small bright particle formations called glistenings were found in the optic of the acrylic IOL.[5–9] Although studies showed that glistenings occur with any material and design of the IOL, the hydrophobic acrylic IOL has the greater degree of glistenings.[10–13] More recently, light scattering was also noted on the surface of the acrylic IOL in the late stage after implantation.[14–16] Both phenomena depend on the formation of microvacuoles containing water in the optic, although the sizes of the vacuoles differ.[17–22]

Controversy remains, however, as to whether glistenings and surface light scattering deteriorate visual function. Dhaliwal and associates[23] and Gunenc and associates[24] reported that glistenings significantly impair visual acuity (VA) or contrast sensitivity, whereas other studies reported no glistenings-related decrease in visual function.[8,25] Furthermore, a middle-term study by Miyata and associates[26] did not find a significant visual impairment attributable to surface light scattering. In contrast, Matsusima and associates[22] reported that surface scattering of extracted acrylic IOLs decreased the percentage of light transmission by approximately 4%. Because the degree of surface scattering gradually increases for many years,[16,26] the long-term effect of surface scattering on visual function remains a concern.

The purpose of the present study was to assess the long-term effect of glistenings and surface scattering on visual function in eyes that underwent implantation of a hydrophobic acrylic IOL, and to examine the relationship between glistenings as well as surface scattering and visual function. To strictly evaluate the effects of these phenomena on visual function, eyes that received a silicone or polymethyl methacrylate (PMMA) IOL served as controls.

METHODS

• PATIENTS: Thirty-five eyes that had undergone phacoemulsification with implantation of either a hydrophobic acrylic, silicone, or PMMA IOL more than 10 years ago

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From the Hayashi Eye Hospital, Fukuoka, Japan (K.H., M.Y., K.Y.); Department of Ophthalmology, Saga University Faculty of Medicine, Saga, Japan (A.H.); and Department of Ophthalmology, School of Medicine, Fukuoka University, Fukuoka, Japan (H.H.).

Inquiries to Ken Hayashi, Hayashi Eye Hospital, 4-23-35 Hakataekimae, Hakata-Ku, Fukuoka 812-0011, Japan; e-mail: hayashi-ken@hayashi.or.jp

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were planned to be enrolled in each IOL group. For patient enrollment, a clinical research coordinator screened the medical records of patients who had participated in some randomized clinical trials[4,27] performed at Hayashi Eye Hospital more than 10 years ago. Inclusion criteria were: 1) eyes that had uneventful surgery; 2) eyes that had complete in-the-bag implantation; 3) eyes that showed corrected VA of 20/25 or better several days after cataract surgery; 4) eyes with no comorbidity of the cornea, vitreous, macula, or optic nerve; 5) eyes with no history of inflammation or other surgery; and 6) no anticipated difficulties with analysis or examination. Eligible patients who met the criteria were sequentially called by the clinical research coordinator and asked to undergo examinations. Screening and patient enrollment were continued until 35 eyes were included in each of the 3 IOL groups. All enrolled eyes were scheduled to undergo examinations of visual function, Scheimpflug photography, and wavefront aberrations. All implanted IOLs were 6.0-mm round optic spherical IOLs. In the acrylic group, all 35 eyes received a 3-piece AcrySof IOL with PMMA haptics (MA60BM; Alcon Laboratories, Fort Worth, Texas, USA) through a 4.1-mm straight corneoscleral incision. In the silicone group, 18 eyes received a SI30NB and 17 received a SI40NB (Abbot Medical Optics, Santa Ana, California, USA) through a 3.0- or 3.5-mm corneoscleral or clear corneal incision. The SI30NB and SI40NB have silicone optic and rigid polypropylene loops. In the PMMA group, 16 eyes received a MZ60BD (Alcon Laboratories), 17 received a UV25T or UV22 (Menicon, Nagoya, Japan), and 2 received a UV60SB (Menicon) through a 6.0-mm frown incision. The MA60BD and UV60SB were single-piece PMMA IOLs, and the UV25T and UV22 were 3-piece PMMA IOLs with rigid polyimide loops. Informed consent was obtained from all patients. The Supplemental Figure (available at AJO.com) illustrates the patient enrollment method employed.

• **SURGICAL PROCEDURE:** All surgeries were performed by a single surgeon (K.H.) using almost the same surgical procedure as described previously.[3,4] First, a continuous curvilinear capsulorrhexis measuring approximately 5.5 mm in diameter was accomplished using a 25-gauge bent needle through a side port. After continuous capsulorrhexis, a corneoscleral or clear corneal incision was made horizontally for phacoemulsification. A 3.5-mm straight corneoscleral incision was made for implantation of the acrylic and silicone IOLs using a diamond knife and a diamond crescent knife, while a 2.5-mm clear corneal incision was made for implantation of silicone IOL using a stainless steel keratome. For implantation of the PMMA IOLs, a 5.0-mm frown incision with a chord length of 6.5 mm was made using a diamond knife and crescent knife. After hydrodissection, endocapsular phacoemulsification of the nucleus and aspiration of the residual cortex were carried out. Using a stainless keratome, the wound was enlarged to a 3.0, 3.5, 4.1, or 6.0 mm for implantation of the IOL. The lens capsule was inflated with 1% sodium hyaluronate (Healon; Abbot Medical Optics), after which an IOL was implanted. The acrylic IOL was folded and grasped with the Buratto II acrylic IOL implant forceps (Asico, Westmont, Illinois, USA) at room temperature, and placed into the capsular bag through a 4.1-mm incision. The silicone IOL was folded and grasped with the Universal II silicone IOL forceps (Rhein Medical, Tampa, Florida, USA) at room temperature, and inserted into the capsular bag through a 3.0- or 3.5-mm incision. The PMMA IOL was grasped and inserted using a Shepard IOL forceps through a 6.0-mm incision. After IOL insertion, the viscoelastic material was thoroughly evacuated. No suture was placed in any case.

• **MAIN OUTCOME MEASURES:** All enrolled patients were examined for the intensity of scattering light of the optic surface and inner optic of IOLs measured using Scheimpflug photography, corrected distance VA, examination of slit-lamp biomicroscopy and fundoscopy, contrast VA with and without glare, ocular and corneal wavefront aberrations, refractive status, keratometric cylinder, and pupillary diameter. The refractive spherical power as well as cylindrical power and axis were examined using an autorefractometer (KR-7100; Topcon, Tokyo, Japan); the manifest spherical equivalent value was determined as the spherical power plus half the cylindrical power. Best-corrected distance VA was examined using decimal charts and converted to a logarithm of minimal angle of resolution (logMAR) scale for statistical analysis. Pupillary diameter was measured using a Colvard pupillometer (Oasis Medical, Glendora, California, USA). Two physicians (M.Y., K.Y.) determined the grade of the glistenings according to the method described by Miyata and associates,[9] and evaluated the presence of PCO and other ocular comorbidities. When a clinically significant PCO was found, a neodymium–yttrium-aluminum-garnet (Nd:YAG) laser posterior capsulotomy was performed before examination. Careful attention was paid to damage the optics by the Nd:YAG laser shots.

The scattering light intensity of the anterior optic surface, internal matrix of the optic, and the PCO density value was determined with a previously described method[3,4,15,26,28,29] using the Scheimpflug photography system (EAS-1000; Nidek, Gamagori, Japan). In brief, the examiner first obtained a Scheimpflug slit image of the IOL at the 0-degree, 45-degree, 90-degree, and 135-degree meridians after full mydriasis. The highest-quality image was then transferred to an image analysis computer and the average scattering light intensity of the central 3.00 × 0.25-mm area in the anterior optic surface as well as in the posterior capsule, and in the internal matrix of the optic, was measured using the axial densitometry of the computer. The

TABLE 1. Patient Characteristics of the Acrylic, Silicone, and Polymethyl Methacrylate Intraocular Lens Groups

Characteristic Value	Acrylic Group	Silicone Group	PMMA Group	*P* Value
Age at the time of surgery (years)	62.6 ± 5.8	65.5 ± 5.6	58.5 ± 9.5	.0024[a]
Age at the time of examination (years)	75.2 ± 6.0	79.1 ± 9.5	72.1 ± 9.5	.0012[a]
Sex (male/female)	11/24	5/27	13/22	.1327
Left/right	18/17	15/17	18/17	.9130
SE (D)[b]	−1.80 ± 1.10	−0.98 ± 1.07	−1.50 ± 1.32	.2010
Pupillary diameter (mm)[c]	3.16 ± 0.45	3.03 ± 0.54	3.01 ± 0.77	.5698
Decentration of IOL (mm)	0.17 ± 0.09	0.16 ± 0.09	0.18 ± 0.16	.7437
IOL tilt (degrees)	1.14 ± 0.39	0.98 ± 0.48	1.22 ± 1.14	.3064
Interval between surgery and examination (y)	12.7 ± 1.3	13.5 ± 1.3	13.6 ± 1.8	.0613

D = diopter; IOL = intraocular lens; PMMA = polymethyl methacrylate; SE = spherical equivalent.
[a]Statistically significant difference.
[b]Manifest spherical equivalent value.
[c]Pupillary diameter when looking at distance.

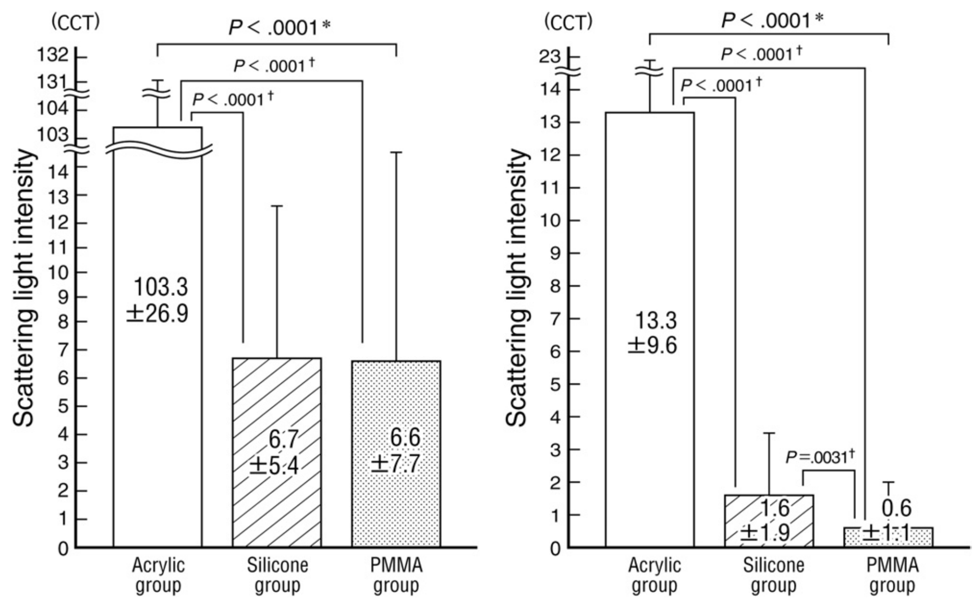

FIGURE 1. Comparison of the mean intensity of scattering light of the optic surface and internal matrix of the optic among the acrylic, silicone, and polymethyl methacrylate intraocular lens groups. The mean intensity of scattering light of both the optic surface (Left) and internal matrix of the optic (Right) in the acrylic intraocular lens group was significantly greater than that in the silicone and polymethyl methacrylate intraocular lens group ($P < .0001$). *Statistically significant difference among the 3 groups. †Statistically significant difference between the 2 groups.

scattering light intensity was expressed in computer-compatible tape steps: the scattering light intensity obtained by densitometry was stratified to range from 0 to 255 (256 steps). The scattering light intensity of the 4 meridians was averaged, and the resultant values of the anterior optic surface and internal matrix of the optic were considered to represent the surface light scattering and glistenings, respectively. In addition, the PCO density value in 1 cross-sectional image was determined by subtracting the scattering light intensity of the anterior optic surface area from that of the posterior capsule area. The PCO values of the 4 meridians were then averaged and considered to represent the PCO value.

Contrast VA and that in the presence of glare (glare VA) under photopic and mesopic conditions were examined after best distance correction using the Contrast Sensitivity Accurate Tester (CAT-2000; Menicon, Nagoya, Japan). This device measures logMAR corrected distance VA, with a range from 1.0 to −0.1, using visual targets with 5 contrast levels (100%, 25%, 10%, 5%, and 2.5%) under photopic and mesopic conditions. Measurement under photopic conditions was performed with chart lighting of 100 cd/m^2, and that under mesopic conditions

TABLE 2. Comparison of Mean Uncorrected and Corrected Distance Visual Acuity Expressed in Snellen Equivalent (logMAR Scale) Between the Acrylic, Silicone, and Polymethylmethacrylate Groups

	Acrylic Group	Silicone Group	PMMA Group	*P* Value
Uncorrected VA	20/42 (0.54 ± 0.50)	20/35 (0.36 ± 0.37)	20/40 (0.39 ± 0.33)	.5804
Corrected VA	20/19 (−0.01 ± 0.05)	20/21 (0.04 ± 0.07)	20/20 (0.00 ± 0.06)	.0023[a]

logMAR = logarithm of minimal angle of resolution; PMMA = polymethyl methacrylate; VA = visual acuity.
[a]Mean corrected distance VA in the acrylic group was significantly better than that in the silicone group (*P* = .0003).

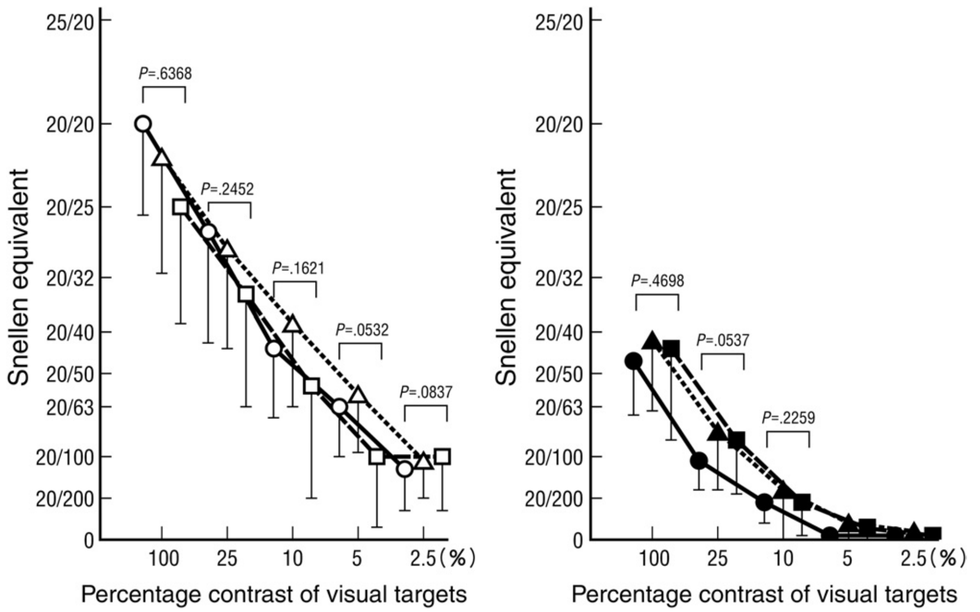

FIGURE 2. Comparison of mean contrast visual acuity under photopic and mesopic conditions among the acrylic, silicone, and polymethyl methacrylate intraocular lens groups. (Left) No significant difference was observed in contrast visual acuity (VA) under photopic conditions between the 3 groups. (Right) Mesopic contrast VA at 100%, 25%, and 10% contrast was not significantly different among groups. Because mesopic contrast VA at 5% and 2.5% was below the limits of detection in most eyes of all groups, a statistical comparison was not performed. Circle = acrylic group; triangle = silicone group; square = polymethyl methacrylate group.

with chart lighting of 2 cd/m^2. For measurement of glare VA, a 200-lux glare source was located in the periphery at 20 degrees around the visual axis.

Ocular wavefront aberrations were determined using the Hartmann-Shack wavefront analyzer, and corneal wavefront aberrations were determined using the videokeratography, both of which are incorporated in the Topcon KR-1W. The details of this apparatus were described previously.[30] After full mydriasis, analysis was conducted by measuring the central 4.0 and 6.0 mm using the aperture. The root mean square (RMS) of the third-order Zernike coefficients was used to represent coma-like aberrations, and that of the fourth-order coefficients was used to represent spherical-like aberrations. Total HOA was defined as the sum of the RMS of the third- to sixth-order coefficients. In addition, assuming a simple eye model, wavefront aberrations of the internal optics were obtained by direct subtraction of the corneal aberrations from the ocular aberrations.[30–32] Examination of slit-lamp biomicroscopy and ocular fundus was performed by the 2 ophthalmologists, and other measurements were performed by 4 experienced ophthalmic technicians unaware of the purpose of the study.

• **STATISTICAL ANALYSIS:** The scattering light intensity of the optic surface and internal matrix of the optic; the PCO value; uncorrected and corrected distance VA; contrast VA and glare VA; ocular and internal optic HOAs; pupillary diameter; and other continuous variables among the acrylic, silicone, and PMMA IOL groups were compared using the Kruskal-Wallis test. Categorical variables were compared among the 3 groups using the χ^2 goodness-of-fit test. When a statistically significant difference was detected among the 3 groups, the difference between each pair of groups was further compared using the

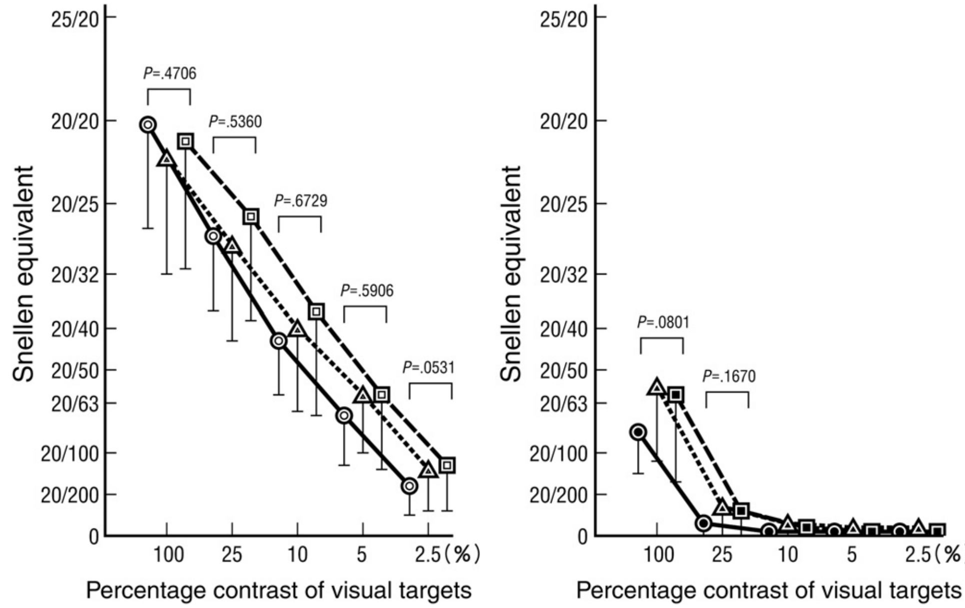

FIGURE 3. Comparison of the mean contrast visual acuity in the presence of glare (glare visual acuity) under photopic and mesopic conditions among the acrylic, silicone, and polymethyl methacrylate intraocular lens groups. (Left) No significant difference was found in glare visual acuity (VA) under photopic conditions among the 3 groups. (Right) Mesopic glare VA at 100% and 25% contrast was not significantly different among groups. Because mesopic contrast VA at 10%, 5%, and 2.5% was below the limits of detection in most eyes of all groups, a statistical comparison was not performed. Double circle = acrylic group; double triangle = silicone group; double square = polymethyl methacrylate group.

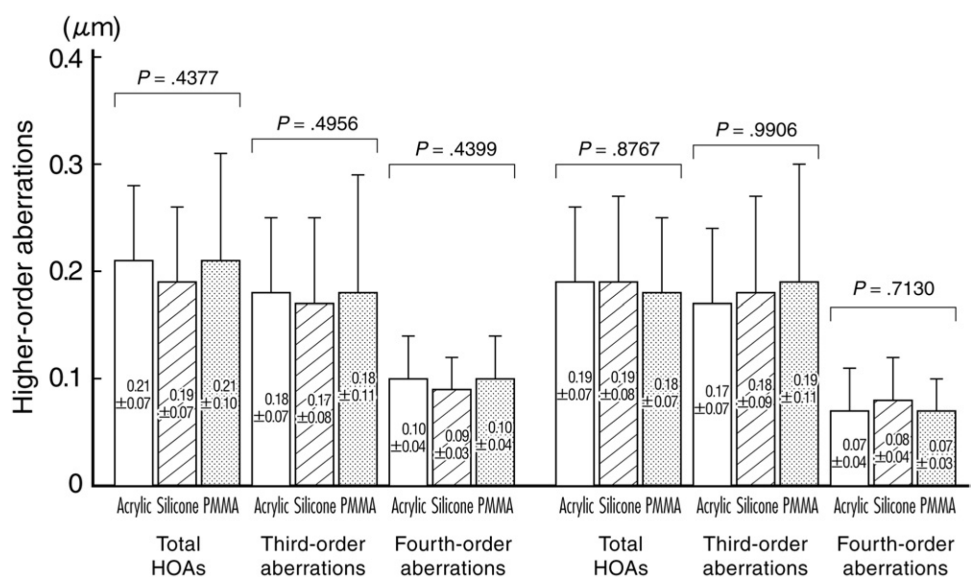

FIGURE 4. Comparison of the mean ocular and internal optic total higher-order aberrations (HOAs), third-order coma-like aberrations, and fourth-order spherical-like aberrations among the 3 groups. Mean ocular (Left) and internal optic (Right) total HOAs, third-order aberrations, and fourth-order aberrations were not significantly different among groups.

Mann-Whitney U test for continuous variables and the χ^2 test for discrete variables with the Bonferroni correction for multiple comparisons. Simple correlation between the scattering light intensity of the optic surface and internal matrix of the optic and corrected VA and contrast VA as well as glare VA, and between the intensity and HOAs, was examined using the Pearson simple correlation analysis. The incidence of eyes that required an Nd:YAG laser capsulotomy was compared between groups using the Kaplan-Meier survival analysis. Any differences with a P value of less than .05 were considered to be statistically significant.

TABLE 3. Simple Correlation Analysis Between the Scattering Light Intensity of Optic Surface or Internal Matrix and Visual Function, and Between the Intensity and Higher-Order Aberrations in the Acrylic Group

	Correlation Coefficient	*P* Value		Correlation Coefficient	*P* Value
Scattering light intensity of optic surface					
CDVA	0.003	.9849		—	—
Photopic contrast VA			Photopic glare VA		
100% contrast	0.019	.9156	100% contrast	0.152	.3820
25% contrast	0.030	.8642	25% contrast	0.147	.3995
10% contrast	0.014	.9346	10% contrast	0.087	.6208
5% contrast	0.051	.7708	5% contrast	0.132	.4491
2.5% contrast	0.001	.9933	2.5% contrast	0.099	.5720
Mesopic contrast VA			Mesopic glare VA		
100% contrast	0.124	.4770	100% contrast	0.105	.5479
25% contrast	0.127	.4656	25% contrast	0.058	.7391
10% contrast	0.090	.6054	10% contrast	—	—
Scattering light intensity of internal matrix of the optic					
CDVA	0.090	.6056		—	—
Photopic contrast VA			Photopic glare VA		
100% contrast	0.164	.3475	100% contrast	0.219	.2056
25% contrast	0.175	.3144	25% contrast	0.219	.2069
10% contrast	0.143	.4122	10% contrast	0.015	.9335
5% contrast	0.065	.7099	5% contrast	0.048	.7848
2.5% contrast	0.016	.9283	2.5% contrast	0.054	.7591
Mesopic contrast VA			Mesopic glare VA		
100% contrast	0.169	.3321	100% contrast	0.011	.9497
25% contrast	0.013	.9422	25% contrast	0.030	.8633
10% contrast	0.106	.5432	10% contrast	—	—

	Correlation Coefficient	*P* Value
Scattering light intensity of optic surface		
Ocular HOAs		
Total ocular HOAs	0.149	.3933
Ocular third-order aberrations	0.174	.3183
Ocular fourth-order aberrations	0.004	.9801
Internal optic HOAs		
Total internal optic HOAs	0.011	.9483
Internal optic third-order aberrations	0.068	.6970
Internal optic fourth-order aberrations	0.132	.4482
Scattering light intensity of internal matrix of the optic		
Ocular HOAs		
Total ocular HOAs	0.277	.1075
Ocular third-order aberrations	0.277	.1066
Ocular fourth-order aberrations	0.180	.3001
Internal optic HOAs		
Total internal optic HOAs	0.134	.4426
Internal optic third-order aberrations	0.143	.4129
Internal optic fourth-order aberrations	0.044	.8011

CDVA = corrected distance visual acuity; HOAs = higher-order aberrations; VA = visual acuity.

RESULTS

OF THE 105 PATIENTS ORIGINALLY ENROLLED, 3 PATIENTS IN the silicone group did not undergo all of the examinations because of scheduling conflicts. Accordingly, 35 eyes in the acrylic group, 32 in the silicone group, and 35 in the PMMA group remained for analysis. Patients and examiners were unaware as to which IOL material was implanted in each eye. Because the investigator that performed the data analysis, who also performed the cataract surgery, did not participate in any examination, patient assignment was kept concealed until all of the data were collected.

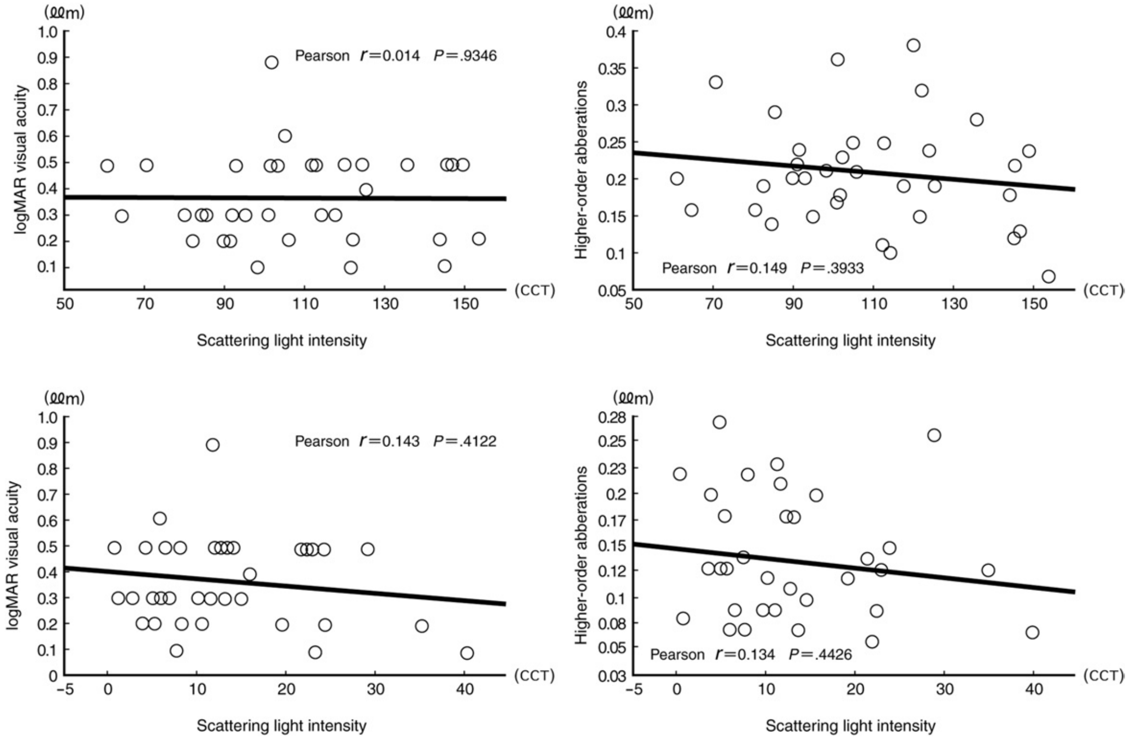

FIGURE 5. Scatterplots showing the association between the scattering light intensity of the optic surface or internal matrix of the optic and the low-contrast visual acuity at 10% and between the scattering light intensity and higher-order aberrations (HOAs) in the acrylic group. The scatterplots shows no significant association between the scattering light intensity of optic surface and the low-contrast visual acuity (VA) at 10% (Top left) or ocular total HOAs (Top right). There was also no significant association between the intensity of the internal matrix of the optic and the low-contrast VA at 10% (Bottom left) or ocular total HOAs (Bottom right).

The mean age of the patients at the time of examination (± standard deviation [SD]) was 75.4 ± 7.7 years; there were 29 men and 73 women. The patient characteristics of the 3 groups are shown in Table 1. The 3 groups were not different in sex, ratio of the left to right eyes, manifest spherical equivalent value, pupillary diameter, or time interval between surgery and examination. The mean age at the time of surgery and examination was significantly different among the 3 groups ($P \leq .0025$); the PMMA group was significantly younger than the acrylic and silicone groups ($P \leq .0080$).

Sixty eyes had already undergone an Nd:YAG laser posterior capsulotomy before enrollment in this study, and extensive pits or cracks were not found in the optic of all eyes. The physicians identified clinically significant PCO in 6 eyes, and these eyes underwent an Nd:YAG laser capsulotomy before examination. Accordingly, the mean PCO value after capsulotomy measured using the Scheimpflug photography was 4.6 ± 11.6 computer compatible tape steps (CCT) in the acrylic group, 3.0 ± 5.2 CCT in the silicone group, and 4.2 ± 7.4 CCT in the PMMA group; there was no significant difference in the PCO value between the 3 groups ($P = .9048$). Furthermore, extensive pits or cracks attributable to the Nd:YAG laser shots were not observed in the optic of these eyes, which may account for the fact that mean corrected distance VA, contrast VA and glare VA, and ocular or internal optic HOAs after capsulotomy were comparable to or better than those before capsulotomy.

The mean intensity of scattering light of both the optic surface and internal matrix of the optic in the acrylic group was significantly greater than that in the silicone and PMMA group ($P < .0001$; Figure 1). The mean grade of glistenings determined by the physician was 0.89 ± 0.83 in the acrylic group, 0.78 ± 0.55 in the silicone group, and 0.40 ± 0.55 in the PMMA group; the mean grade in the acrylic and silicone groups was significantly greater than in the PMMA group ($P \leq .0054$). The mean decentration length and tilt angle was not significantly different between the 3 groups ($P \geq .3065$). Extensive pits or cracks attributable to the Nd:YAG laser shots were not observed in the optics of any eyes.

Mean uncorrected distance VA was not significantly different ($P = .5804$; Table 2), while corrected distance VA was significantly different among the 3 groups ($P = .0023$); mean corrected VA in the acrylic group was significantly better than that in the silicone group ($P = .0003$). Contrast VA (Figure 2) and glare VA (Figure 3) under photopic conditions were not significantly different among the 3 groups. Mesopic contrast VA at 100%, 25%, and 10% contrast and mesopic glare VA at 100% and 25%

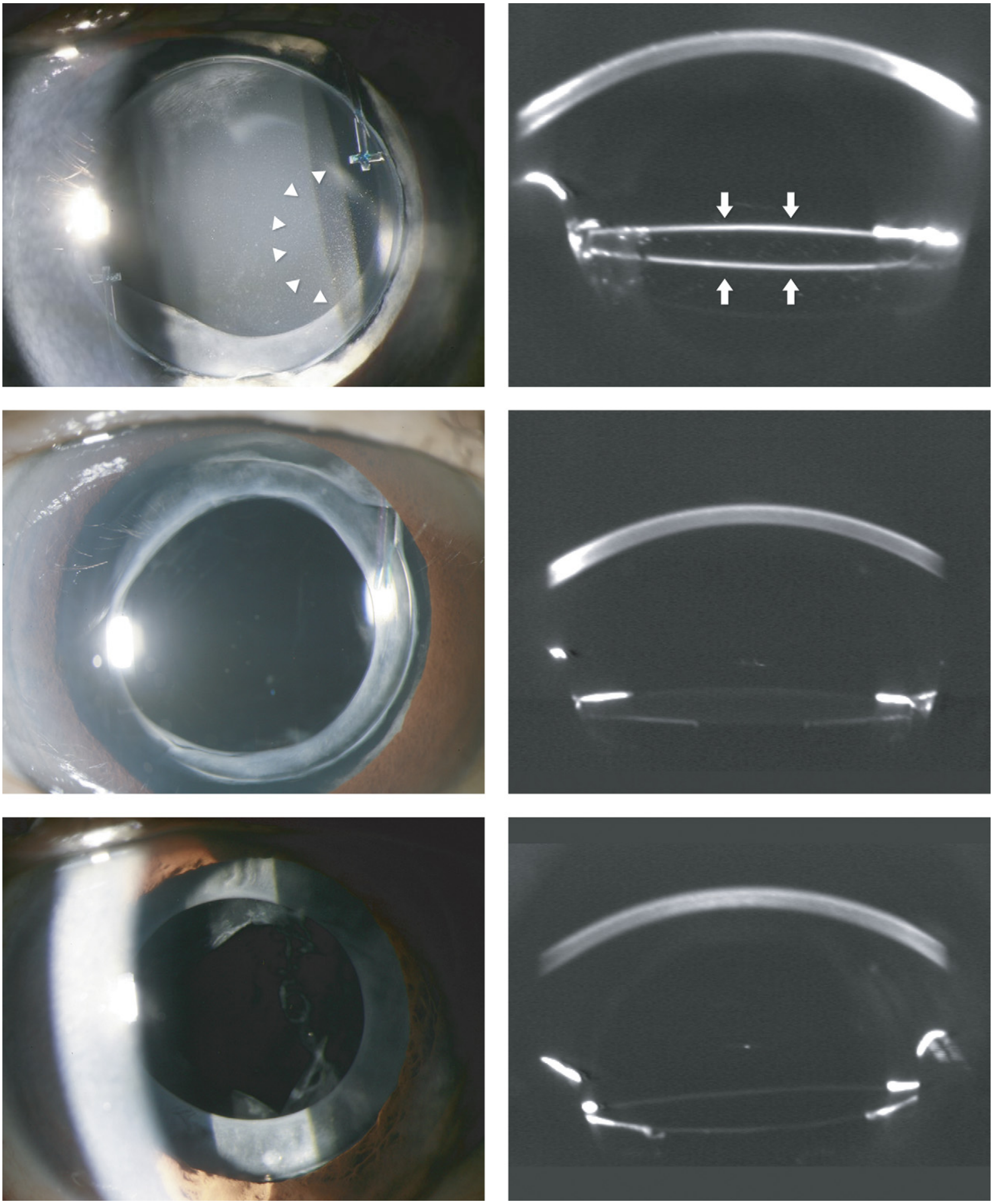

FIGURE 6. Slit-lamp biomicroscopic photographs (Left row) and Scheimpflug slit images (Right row) of representative eyes of the acrylic, silicone, and polymethylmethacrylate intraocular lens groups. In an eye with an acrylic intraocular lens, whitish surface light scattering and small bright glistening particles (arrowheads) are seen in the slit-lamp photograph (Top left), while extensive scattering light (arrows) is noted on the optic surface in the Scheimpflug slit image (Top right). In an eye with silicone intraocular lens, the optic is virtually clear in the slit-lamp microscopic photographs (Middle left), and scattering light is not marked in the optic surface in the Scheimpflug images (Middle right). In an eye with polymethyl methacrylate intraocular lens, the optic is virtually clear in the slit-lamp microscopic photographs (Bottom left), and scattering light is not remarkable in the optic surface in the Scheimpflug images (Bottom right).

contrast were not significantly different. In this series, because mesopic contrast VA at 5% and 2.5% and mesopic glare VA at 10%, 5%, and 2.5% were below the detectable limit in most eyes of all groups, a statistical comparison was not performed for these contrasts. When we assumed a decimal contrast VA and glare VA of 0.2 under photopic conditions at 100%, 25%, and 10% contrast visual targets to be a clinically meaningful difference between the 3 groups using the Kruskal-Wallis test, the statistical powers were calculated to be more than 84%. Additionally, when we assumed a decimal contrast VA and glare VA of 0.1 at the other visual targets to be a clinically meaningful of difference, the statistical powers were calculated to be more than 80%.

For a 4-mm pupil, the mean ocular, corneal, and internal optic total HOAs; third-order coma-like aberrations; and fourth-order spherical-like aberrations were not significantly different among the 3 groups ($P \geq .2307$; Figure 4). Six of 6 eyes that underwent Nd:YAG laser posterior capsulotomy showed improved ocular HOAs in all eyes. When we assumed total HOAs, third-order aberrations, and fourth-order aberrations of 0.05 μm to be a clinically meaningful magnitude of difference between the 3 groups, the statistical powers were calculated to be more than 88%.

The data for simple correlation analyses between the scattering light intensity of optic surface or internal matrix of the optic and visual function and between the scattering light intensity and HOAs in the acrylic group are shown in Table 3. Scattering light intensity of optic surface and internal matrix of the optic was not significantly correlated with corrected VA, nor with contrast VA as well as glare VA, under photopic and mesopic conditions ($P \geq .3820$; Table 3). The scattering light intensity did not significantly correlate with total HOAs, coma-like aberrations, and spherical-like aberrations of the eye, cornea, and internal optics ($P \geq .2040$; Table 3). The scatterplots of the correlation between the scattering light intensity of the optic surface or internal matrix of the optic and the low-contrast VA at 10% contrast and between the scattering light intensity and ocular HOAs showed no significant correlation (Figure 5).

The percentage of eyes that underwent an Nd:YAG laser capsulotomy was 65.7% in the acrylic group, 50% in the silicone group, and 77.1% in the PMMA group. Using the Kaplan-Meier survival analysis, the survival curve was significantly different among the 3 groups ($P = .0077$, Mantel-Cox log-rank test). The survival curve in the silicone and acrylic groups was better than that in the PMMA group; the difference between the silicone and PMMA groups was significant ($P = .0090$) and that between the acrylic and PMMA groups was marginally significant ($P = .0222$).

Figure 6 shows slit-lamp biomicroscopic photographs and Scheimpflug slit images of representative eyes in the acrylic, silicone, and PMMA IOL group. In an eye with the acrylic IOL, whitish surface light scattering and small glistening particles are seen in the slit-lamp photograph, while extensive scattering light is noted on the optic surface in the Scheimpflug slit image. In eyes with silicone and PMMA IOLs, the optics are almost clear in the slit-lamp photographs, and scattering light is not remarkable in the optic surface in the Scheimpflug images.

DISCUSSION

OUR STUDY DEMONSTRATED THAT THE INTENSITY OF scattering light measured using the Scheimpflug photography of the optic surface as well as inner optic in eyes with the hydrophobic acrylic IOL was significantly stronger than that in eyes with the silicone and PMMA IOL, at more than 10 years after implantation. The scattering light intensity of the optic surface and internal matrix of the optic are considered to represent the surface scattering and glistenings, respectively.[15,16,26,28] Accordingly, it was evident that these phenomena were more remarkable in eyes with the acrylic IOL than in eyes with the silicone and PMMA IOLs after long-term intervals.

However, uncorrected VA and contrast sensitivity with and without glare under both photopic and mesopic conditions were comparable among the eyes with the acrylic IOL and those with the silicone and PMMA IOLs, although the statistical powers were high enough to detect a clinically meaningful difference between the groups. In addition, corrected VA with the acrylic IOL was rather better than that with silicone IOL, although the reason for worse corrected VA with the silicone IOL cannot be explained from the results of this study. Furthermore, the intensity of scattering light of both optic surface and internal matrix of the optic were not significantly correlated with VA and contrast sensitivity with and without glare. These results suggest that surface scattering and glistenings of the acrylic IOL may not substantially affect visual function, even at more than 10 years after implantation.

In this study, all of the IOLs examined were spherical IOLs with a similar biconvex design. In addition, the posterior capsule was virtually clear at the slit-lamp microscopic examination, and the degree of PCO measured using the Scheimpflug photography was low and similar among the 3 groups because an Nd:YAG laser capsulotomy was performed. Accordingly, the surface light scattering and glistenings were assumed to be factors possibly relevant to the ocular and internal optic aberrations. Ocular and internal optic HOAs with the acrylic IOLs were similar to those with the silicone and PMMA IOLs. The statistical power was high enough to detect a clinically meaningful difference. These results indicate that surface scattering and glistenings do not markedly affect the optical performance of the eye.

The formation of glistening was noted within the optic soon after the introduction of the hydrophobic acrylic IOL.[5–9] More recently, investigators detected increase in light scattering on the optic surface of the acrylic IOLs.[14–16] Many studies showed that the glistening particles are microvacuoles containing water that are formed within the optic in the early postoperative period,[17–20] while surface scattering is reported to be attributable to trace water molecules that form in the subsurface region in the later period.[21,22] Thus, both phenomena depend upon water phase separation, although their mechanisms may be different.[17–22] More important, it is still controversial whether these phenomena worsen visual function or disturb ocular fundus visualization. Several studies showed that glistenings impair VA or contrast sensitivity,[23,24] and Werner and associates[33] reported 3 cases of acrylic IOL extraction because of glistenings that impaired fundus visualization. Other short-term or experimental studies, however, showed that glistenings do not impair visual function.[8,25] Furthermore, a 3-year study by Miyata and associates[26] showed that surface scattering does not decrease visual function, while Matsusima and associates[22] reported that surface scattering of extracted acrylic IOLs reduces the light transmission by approximately 4%. To date, however, there are no long-term studies regarding the relationship between these phenomena and visual function. Our study is the first to show that glistenings and surface scattering do not markedly affect visual function or optical quality of the acrylic IOL, even at 10 years after implantation.

In this long-term study, the Nd:YAG capsulotomy rates with silicone and hydrophobic acrylic IOLs were better than those with the PMMA IOLs, and the rates with the acrylic and silicone IOLs were not significantly different. Previous middle-term studies showed that the occurrence of PCO was lower with acrylic IOLs than with silicone and PMMA IOLs within several years after surgery.[1–4] Recent long-term studies and a meta-analysis, however, revealed that the PCO and YAG capsulotomy rates with the silicone IOL are comparable to or better than those with acrylic IOLs.[34–37] The results of the present study are in agreement with those of the long-term studies and meta-analysis.

The current study has several limitations. First, because the patients were recruited from among those who participated in our previous clinical studies, the age of the patients in the 3 groups was not matched. The mean age in patients who received an acrylic or silicone IOL was older than that in patients who received a PMMA IOL. It is reasonable to assume, however, that older patients who received the acrylic IOL with marked glistenings and surface scattering have worse visual function than do younger patients who received the PMMA IOL. Therefore, comparable visual results among the 3 groups suggest that the difference in age was not related to the results of the current study. Second, there was inconsistency between the corrected VA and photopic contrast VA at 100% contrast. The corrected VA, however, was measured using decimal charts, while the contrast VA was measured using the CAT-2000. Because the CAT-2000 is a simulator used to measure logMAR corrected VA, the 100% contrast VA is generally a little worse than the VA measured using decimal charts. We believe that the difference between the corrected VA and contrast VA at 100% contrast was attributable to a measurement error, and that such an error between the 2 methods is unavoidable.

In conclusion, at more than 10 years after implantation, eyes that received a hydrophobic acrylic IOL had comparable visual function and optical aberrations to eyes that received silicone and PMMA IOLs, although surface scattering and glistenings were significantly more remarkable with the acrylic IOL. Furthermore, the degree of surface scattering and glistenings seen in the acrylic optic was not correlated with visual function and HOAs. Thus, the findings of our long-term study indicate that surface scattering and glistenings of the acrylic IOL do not remarkably impair visual function and optical quality. Surface scattering, however, continues to increase for many years.[16,26] Longer-term studies are required to continue to assess the effect of these phenomena on visual function in the future.

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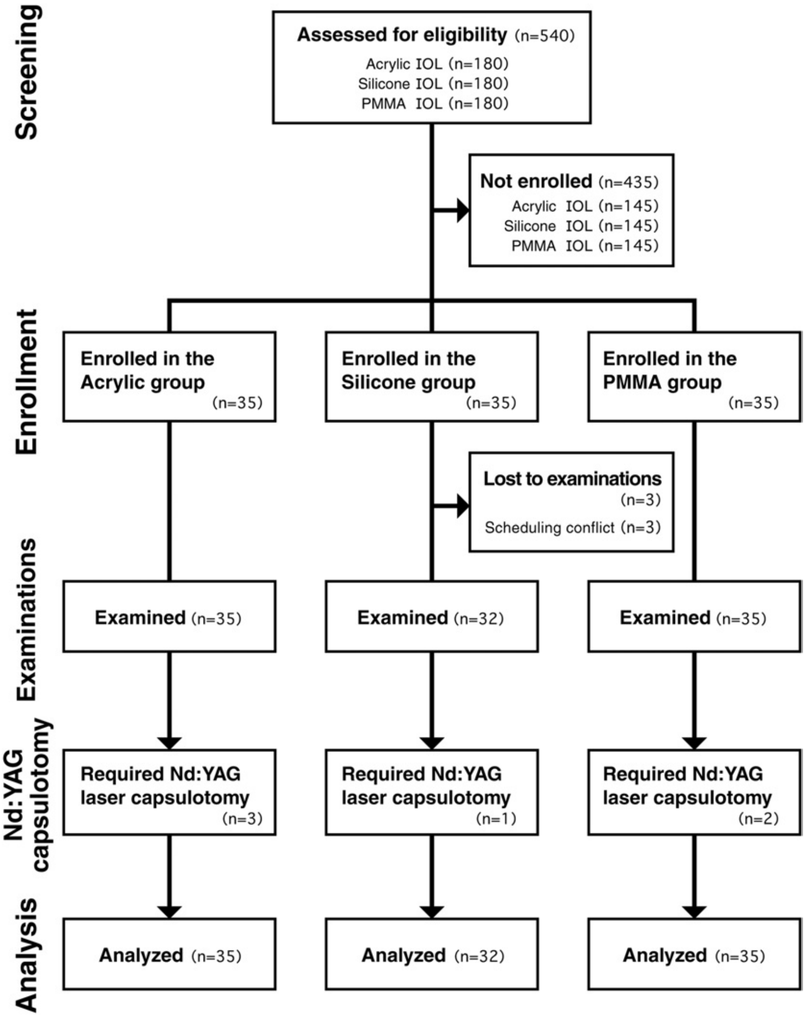
Biosketch

Ken Hayashi is the director of the Hayashi Eye Hospital in Fukuoka, Japan. He graduated in medicine from Kyusyu University in 1982 and completed postgratuate traning in 1989. His main research interests are anterior segment diseases, particularly as they relate to cataract surgery, keratoplasty, and glaucoma surgery. He has published more than 80 peer-reviewed articles in internationally acclaimed journals. He currently serves as an editor-in-chief of the Japanese Journal of Ophthalmic Surgery and editorial board of Journal of Cataract and Refractive Surgery.



SUPPLEMENTAL FIGURE. Flow chart of patients in the acrylic, silicone, and polymethyl methacrylate groups who were screened, enrolled, examined, required an Nd:YAG laser posterior capsulotomy, and were analyzed. IOL = intraocular lens; PMMA = polymethyl methacrylate.