# Posterior Chamber Phakic Intraocular Lens Implantation for the Correction of Myopia and Myopic Astigmatism: A Retrospective 10-Year Follow-up Study

TOMOAKI NAKAMURA, NAOKI ISOGAI, TAKASHI KOJIMA, YOKO YOSHIDA, AND YASUO SUGIYAMA

• PURPOSE: To assess the 10-year clinical outcomes of implantable collamer lens (ICL) implantation for myopia and astigmatism.
• DESIGN: Retrospective observational case series.
• METHODS: This study included 114 eyes of 61 patients who underwent ICL implantation for correction of myopia and myopic astigmatism. We assessed the safety, efficacy, predictability, stability, and adverse events preoperatively, at 6 months (106 eyes) and 1 (94 eyes), 3 (58 eyes), 5 (65 eyes), 8 (89 eyes), and 10 (70 eyes) years postoperatively. Only the eyes with clinical data available at each follow-up time were analyzed.
• RESULTS: The mean logMAR uncorrected and corrected distance visual acuities were –0.01 ± 0.24 and –0.18 ± 0.07 at 10 years postsurgery. The mean indices for safety and efficacy were 0.88 ± 0.15 and 0.66 ± 0.26, respectively. At 10 years postsurgery, 71.4% and 87.1% of the eyes were within 0.5 and 1.0 diopters (D), respectively, of the attempted spherical equivalent correction. The mean intraocular pressure was 13.1 ± 2.4 mmHg preoperatively and 13.1 ± 2.9 mmHg at 10 years postoperatively. The mean endothelial cell loss was 5.3% at 10 years postsurgery. Twelve of 114 eyes (10.5%) developed anterior subcapsular cataract during 5-10 years' follow-up; among these, 4 eyes (3.5%) were symptomatic and ICL explantation and phacoemulsification surgery were performed. No vision-threatening complications occurred during the observation period.
• CONCLUSION: ICL implantation offered good overall outcomes in all measures of safety, efficacy, predictability, and stability for the correction of myopia and myopic astigmatism throughout a long-term follow-up period of 10 years. (Am J Ophthalmol 2019;206:1–10. © 2019 Elsevier Inc. All rights reserved.)

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VISIAN IMPLANTABLE COLLAMER LENSES (ICLS), which are posterior chamber phakic intraocular lenses (IOLs) (STAAR Surgical, Nidau, Switzerland), have been reported to be effective for correcting refractive errors such as myopia,[1,2] hyperopia,[3,4] and astigmatism.[5,6] These ICLs are made from a soft material called collamer, which is a hydroxyethyl methacrylate/collagen copolymer. Collamer is negatively charged owing to a constituent collagen and is known to be a highly biocompatible material onto which particles such as proteins are not deposited. Therefore, it remains stable in the eye for a long time. Once ICLs are implanted, they rarely need to be replaced; however, the implantation process is reversible and the lens can be easily taken out when necessary. In addition to these benefits, various risks have been described, including glaucoma, angle closure, cataract formation, corneal decompensation, pupil ovalization, uveitis, and endophthalmitis.[7,8]

Because ICL implantation is mostly performed on relatively young patients, it is vital to monitor the long-term safety and stability using continuous postoperative observation. Several previous studies of the long-term (up to 5 years) outcomes of ICL implantation have been published[2,9–13]; however, there are only a few long-term studies (spanning more than 10 years) on the visual and refractive outcomes of ICL implantation.[14–17] In this study, we investigated the long-term (10-year) clinical outcomes of ICL implantation for the correction of myopia and myopic astigmatism. In addition, we examined the general tendency of visual acuity reduction and myopic regression after surgery over a long term.

## METHODS

• STUDY DESIGN: In this study, we retrospectively analyzed patients who visited our clinic for postoperative examinations at least once during the 5- to 10-year period after ICL implantation. Records of 114 eyes of 61 consecutive patients who underwent implantation of a posterior phakic lens for the correction of moderate to high myopia with and without astigmatism between 2005 and 2007 at

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the Nagoya Eye Clinic were reviewed. This study was approved by the Institutional Review Board at Nagoya Eye Clinic and followed the tenets of the Declaration of Helsinki. Informed written consent for the surgery was obtained from all patients.

The inclusion criteria for this surgical technique were as follows: (1) unsatisfactory correction with spectacles or contact lenses; (2) age 20 years or older; (3) age 50 years or younger; (4) stable refraction for at least 1 year; (5) –0.5 to –18.0 diopters (D) of myopia; (6) anterior chamber depth (ACD) greater than 2.7 mm measured from the corneal endothelium to the anterior lens capsule; (7) endothelial cell density (ECD) greater than 1800 cells/mm$^2$; (8) pupillary dilation greater than 7.5 mm with mydriatic eye drops; (9) no history of ocular surgery, active inflammation in the outer ocular area, cataracts (nuclear myopia), glaucoma, active ocular inflammation accompanying uveitis, or scleritis; and (10) no systemic or immunodeficiency disease that could affect wound healing, such as severe diabetes and severe atopic disease. Eyes with progressive keratoconus were also excluded from this study.

Preoperative examination included logarithm of the minimal angle of resolution (logMAR) of uncorrected distance visual acuity (UDVA), logMAR of corrected distance visual acuity (CDVA), manifest spherical equivalent (SE) refraction, intraocular pressure (IOP), and ECD. Before surgery, the horizontal white-to-white distance (WTW) and ACD were measured using a scanning-slit topograph (Orbscan IIz; Bausch & Lomb, Rochester, New York, USA), and the mean keratometric readings and central corneal thicknesses were measured using an autorefractometer (ARK-700A; Nidek, Gamagori, Japan) and a pachymeter, respectively. The intraocular pressure (IOP) was assessed by a noncontact tonometer (KT-500; Kowa, Tokyo, Japan). The ECD was determined by a noncontact specular microscope (SP-8800; Konan, Nishinomiya, Japan).

Examination data of patients who visited the clinic at 1 day, 1 week, 1 month, 6 months, and 1, 3, 5, 8, and 10 years postoperatively were collected. Postoperative examinations included UDVA, CDVA, manifest spherical power and refractive cylinder, safety index (postoperative CDVA/preoperative CDVA), efficacy index (postoperative UDVA/preoperative CDVA), IOP, ECD, and complications.

The vault between the anterior surface of the crystalline lens and the posterior surface of the ICL was initially assessed with slit lamp. From 2010, the vault was measured by anterior segment optical coherence tomography (AS-OCT) (Visante; Carl Zeiss Meditec, Jena, Germany).

• **ICL CALCULATION FOR LENS SELECTION:** The appropriate power and size of the ICL was selected. The ICL power calculation was performed by STAAR Surgical based on subjective refraction, keratometry, and ACD. In all eyes, emmetropia was targeted in an attempt to correct the refraction error. The ICL size was also selected by the manufacturer. Specifically, we sent the ACD and WTW measured with Orbscan IIz to STAAR Surgical, who then informed us regarding the ICL size. The lens models used were the ICL V4 model and the Toric ICL V4 model.

• **SURGICAL PROCEDURE:** Two weeks before ICL implantation, 2 peripheral laser iridotomies, using Nd:YAG and an argon laser, were performed at 10:30 and 1:30 clock-hour positions. After topical anesthesia, paracentesis was performed, with the aqueous humor replaced with a viscoelastic material (sodium hyaluronate 1% [Opegan; Santen, Osaka, Japan]). The ICL was inserted through a 2.9-mm temporal clear corneal incision using an injector cartridge (STAAR Surgical) after placement of the viscoelastic material (sodium hyaluronate 1% [Opegan; Santen]) into the anterior chamber. Regarding the toric ICL, 4 markings were made on the cornea preoperatively, and the alignment mark attached to the ICL was adjusted to the instructed angle during the operation. After initially placing the ICL on the iris, a specially designed manipulator was used to place the 4 haptics behind the iris. Once the ICL was positioned correctly in the center of the pupillary zone, the remaining viscoelastic material was completely washed out of the anterior chamber with balanced salt solution, and a miotic agent (acetylcholine chloride [Ovisot; Daiichi-Sankyo, Tokyo, Japan]) was instilled. Postoperatively, 250 mg of acetazolamide was administered orally to decrease the IOP. Steroidal (betamethasone 0.1%, Sanbetasone; Santen) and antibiotic (levofloxacin 0.5%; Teika, Toyama, Japan) medications were topically administered, 4 times daily for 1 week, at a dose that was steadily reduced.

• **STATISTICAL ANALYSIS:** The means, standard deviations, and coefficients of variation were calculated using Microsoft Excel 2013 (Microsoft, Redmond, WA, USA). Data are presented as the mean ± standard deviation (SD), and the 95% limits of agreement (LoA) are defined as the mean ± 1.96 SD.

All statistical analyses were performed using EZR 1.35.[18] Normality of data was examined by Kolmogorov-Smirnov test. Comparison of the mean values of the 2 groups was analyzed using *t* test, and the time course after the surgery was analyzed using 1-way analysis of variance (ANOVA) with multiple comparisons by Tukey test. Comparison of the male-to-female ratios of the 2 groups was carried out by Fisher exact test. All tests were 2-tailed, and values of $P < .05$ were considered statistically significant.

## RESULTS

IN THIS STUDY, A TORIC ICL WAS IMPLANTED INTO 72 EYES and a spheric (nontoric) ICL into 42 eyes. Table 1 shows

**TABLE 1.** Preoperative Descriptive Statistics of 114 Eyes From 61 Patients Who Underwent Implantable Collamer Lens Implantation

| Parameter | Toric ICL, Mean ± SD (n = 72 Eyes) | Spherical ICL, Mean ± SD (n = 42 Eyes) | *P* Value[a] | Whole, Mean ± SD (Range) (n = 114 Eyes)[b] |
|---|---|---|---|---|
| Age, y | 36.8 ± 7.33 | 36.5 ± 8.04 | .885 | 36.2 ± 7.7 (21 to 49) |
| Sex, male/female, n (%) | 16 (36)/28 (64)[c] | 19 (63)/11 (37)[c] | .033 | 28 (46)/33 (54) |
| UDVA logMAR | 1.53 ± 0.22 | 1.47 ± 0.17 | .154 | 1.51 ± 0.20 (1.1 to 2) |
| CDVA logMAR | −0.23 ± 0.07 | −0.24 ± 0.08 | .485 | −0.23 ± 0.08 (–0.30 to 0.05) |
| SE, D | −10.29 ± 2.21 | −9.41 ± 2.33 | .755 | −9.97 ± 2.29 (–17.0 to –4.1) |
| Sphere, D | −9.43 ± 2.22 | −9.30 ± 2.29 | .755 | −9.38 ± 2.24 (–16.5 to –3.3) |
| Cylinder, D | −1.72 ± 1.10 | −0.23 ± 0.39 | <.001 | −1.17 ± 1.15 (−7 to 0) |
| ACD, mm | 3.15 ± 0.25 | 3.26 ± 0.23 | .017 | 3.19 ± 0.25 (2.73 to 3.77) |
| IOP, mm Hg | 13.24 ± 2.20 | 12.98 ± 2.76 | .582 | 13.1 ± 2.4 (9 to 19) |
| ECD, cells/mm$^2$ | 2789 ± 364 | 2655 ± 345 | .57 | 2740 ± 362 (1884 to 3795) |

ICL = implantable collamer lens; SD = standard deviation; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; logMAR = logarithm of the minimal angle of resolution; SE = spherical equivalent; D = diopters; ACD = anterior chamber depth; IOP = intraocular pressure; ECD = endothelial cell density.

[a]The relationship between the toric ICL and spherical ICL groups was evaluated by *t* test or Fisher exact test (sex).

[b]"Whole" refers to the total group (toric group and spheric group).

[c]Because 13 patients were implanted with a toric ICL or spheric ICL into either of the left or right eyes, the sum of the toric ICL and spheric ICL is different from the "whole."

the preoperative demographic data for the toric ICL group, spheric ICL group, and the entire cohort (114 eyes from 61 patients). There was no significant difference in the preoperative data for the toric ICL group and the spheric ICL group (*t* test, $P > .05$) except for sex, refractive cylinder, and ACD. In addition, there was no significant difference in UDVA, CDVA, manifest spherical power and refractive cylinder, safety index, efficacy index, IOP, and ECD (*t* test, $P > .05$) between the toric ICL group and the spheric ICL group at 1 day, 1 month, 6 months, and 1, 3, 5, 8, and 10 years postoperatively (Supplemental Table).

After surgery, the number of eyes examined at each visit was 106 (93.0%) at 6 months and 94 (82.5%), 58 (50.9%), 65 (57.0%), 89 (78.1%), and 70 (61.4%) at 1, 3, 5, 8, and 10 years, respectively. At the last visit at 10 years postsurgery, 70 eyes of 38 patients were examined, and the remaining 44 eyes were excluded from the last analysis because the patient had undergone bilensectomy surgery (4 eyes) or did not visit the clinic for the examination (40 eyes).

• **SAFETY OUTCOMES:** Favorable CDVA was maintained postoperatively. CDVA logMAR at 10 years was –0.18 ± 0.07 (corresponding to Snellen equivalents of 20/13.2). Ten years after surgery, 5 eyes had lost 2 or more lines, 26 eyes had lost 1 line, 38 eyes were the same as the preoperative measurement, and 1 eye had gained 1 line (Figure 1). Figure 1 summarizes the CDVA logMAR line changes at all postoperative times. The mean safety index was 0.88 ± 0.15 at 10 years of follow-up (Table 2).

• **EFFICACY OUTCOMES:** Although UDVA tended to decrease slightly with time after surgery, a favorable outcome was obtained throughout the follow-up period. The UDVA logMAR at 10 years was –0.01 ± 0.24 (corresponding to Snellen equivalents of 20/19.6) (Table 2 and Figure 2). Sixty-five eyes (92.9%) had Snellen visual acuity of 20/40 or more after 10 years (Figure 2). The mean efficacy index was 0.66 ± 0.26 at 10 years of follow-up (Table 2).

• **PREDICTABILITY:** At 6 months and 1, 3, 5, 8, and 10 years, 99 (93.4%) of 106, 84 (89.4%) of 94, 48 (82.8%) of 58, 53 (81.5%) of 65, 63 (67.7%) of 93, and 50 (71.4%) of 70 eyes, respectively, were within ±0.5 D of the attempted SE correction, and 104 (98.1%) of 106, 93 (98.9%) of 94, 54 (93.1%) of 58, 65 (100%) of 65, 81 (87.1) of 93, and 61 (87.1%) of 70 eyes, respectively, were within ±1.0 D of the attempted SE correction (Figure 3). A scatter plot of the attempted vs the achieved SE correction is shown in the Supplemental Figure.

Figure 4 presents the manifest refractive cylinder before toric ICL implantation compared with the follow-up outcomes up to 10 years postsurgery. The mean refractive cylinder of the toric ICL group was –1.72 ± 1.10 (Table 1), and 2 (2.8%) and 24 (33.3%) of 72 eyes had a preoperative refractive cylinder within –0.5 D and –1.0 D, respectively. At 6 months and 1, 3, 5, 8, and 10 years postoperatively, 60 (90.0%) of 67, 48 (85.7%) of 56, 29 (82.9%) of 35, 26 (70.3%) of 37, 38 (67.9%) of 56, and 24 (57.1%) of 42 eyes, respectively, were within –0.5 D of the attempted cylinder correction, and 64 (95.5%) of 67, 55 (98.2%) of 56, 34 (97.1%) of 35, 36 (97.3%) of 37, 54 (96.4) of 56, and 42 (100%) of 42 eyes, respectively, were within –1.0 D of the attempted cylinder correction. This result shows that the toric ICL was properly selected, and the corrected astigmatism was stable and did not deteriorate after 10 years.

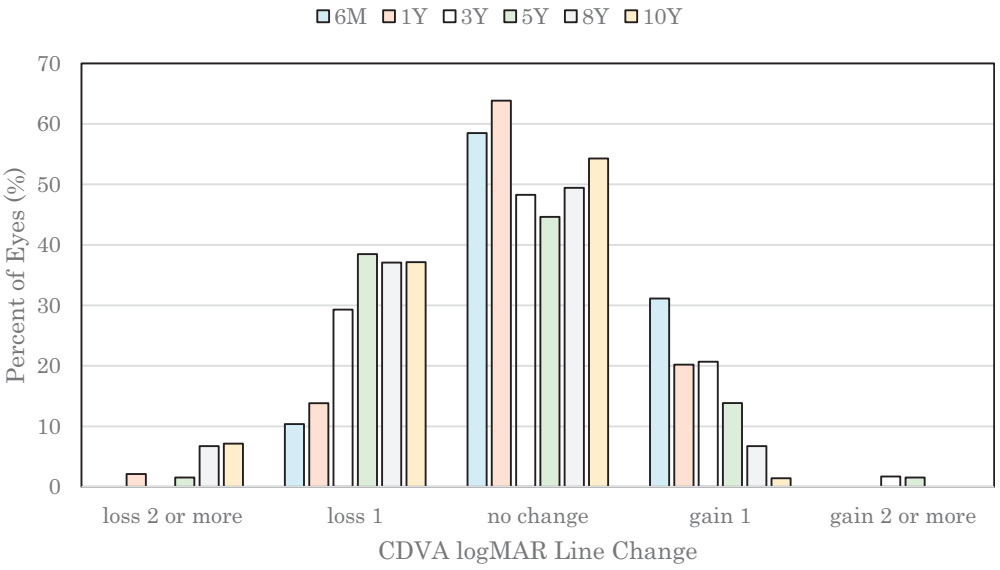


**FIGURE 1. Changes in corrected distance visual acuity (CDVA) at 6 months (6M), 1 year (1Y), 3 years (3Y), 5 years (5Y), 8 years (8Y), and 10 years (10Y) after implantable collamer lens implantation.**

There was 1 eye that rotated, but no problem unique to toric ICL was confirmed.

• **STABILITY:** Figure 5 shows the achieved SE of refraction as a function of time. The mean refraction is shown at each time point. The postoperative manifest SE nearly reached emmetropia on day 1 and remained stable with a slight myopic shift throughout follow-up (ANOVA, $P < .001$). Multiple comparison (Tukey test) revealed significant differences between measurements made at 1 day and at 10 years postsurgery ($P < .001$), at 1 month and at 10 years postsurgery ($P = .004$), at 6 months and at 10 years postsurgery ($P = .014$), and at 1 day and at 8 years postsurgery ($P = .002$).

In this study, we conducted an analysis of stability when the SE refraction was not within 1.0 D of the attempted correction in the 10-year follow-up period, that is, the post-surgery SE value became less than –1.0 D, and presumed myopic regression occurred; hence, the following stability analysis was conducted. We have designated a myopic regression group that had myopic change by 1 D or more. The mean SE changed from presurgery –9.97 D to postsurgery 0.13 D at 1 month and then became –0.43 D at 10 years with gradual change. At 1 month after the surgery, SE within 1.0 D of the attempted correction was 99% (100/101) of eyes, with 1 eye showing –1.125 D, so the selection of ICL power was appropriate. Then, eyes within ±1.0 D were 87.1% (81/93) at 8 years, with 12 eyes of less than –1.0 D. At 10 years, eyes within ±1.0 D were 87.1% (61/70), with 9 eyes of less than –1.0 D. These 9 eyes were the same eyes from the 12 eyes at 8 years. The details of the 12 eyes included 2 eyes showing <–2.0 D, 4 eyes showing –2.0 to –1.51 D, and 6 eyes showing –1.5 to –1.01 D. Therefore, these 12 eyes were analyzed as a group that generated postsurgery myopic regression (myopic regression group). The presurgery SE of the myopic regression group (12 eyes) and nonmyopic regression group (102 eyes) were –9.84 ± 1.74 D and –9.98 ± 2.35 D, respectively; there was no significant difference between the 2 groups (*t* test, $P = .84$). In addition, there was no significant difference in age between the myopic regression group (37.7 years) and the nonmyopic regression group (35.6 years) (*t* test, $P = .366$). Figure 5 also shows the comparison of the postsurgery process between the myopic regression group and the nonmyopic regression group. In the myopic regression group, a significant difference was shown in SE at 1 month and 6 months after the surgery (0.04 D vs –0.23 D; $P = .016$), but there was no difference in the non-myopic group (0.14 D vs 0.13 D; $P = .77$). Moreover, the myopic regression group advanced the myopic shift of SE at 1 year and onward and reached the decline of uncorrected eyesight (Snellen decimal of 0.5 or less) after 5 years and became near-sighted.

• **IOP:** The IOP was 13.1 ± 2.4, 13.6 ± 2.7, 13.5 ± 2.9, 13.4 ± 3.1, 13.8 ± 2.8, 13.4 ± 3.1, and 13.1 ± 2.9 mmHg at presurgery and at 6 months and 1, 3, 5, 8, and 10 years postsurgery, respectively (ANOVA, $P = .715$). No significant increase in IOP occurred in any case during the observation period.

• **ENDOTHELIAL CELL DENSITY:** The endothelial cell density changed from 2739 ± 362 cells/mm$^2$ preoperatively to 2775 ± 318, 2766 ± 339, 2752 ± 302, 2725 ± 298, 2668 ± 293, and 2581 ± 345 cells/mm$^2$ at 6 months and 1, 3, 5, 8, and 10 years postoperatively,

**TABLE 2.** Visual and Refractive Outcomes During Follow-up

| | 6 mo | 1 y | 3 y | 5 y | 8 y | 10 y |
|---|---|---|---|---|---|---|
| Number of eyes | 106 | 94 | 58 | 65 | 89 | 70 |
| UDVA logMAR | −0.21±0.11 (−0.30 to 0.52) | −0.18±0.13 (−0.30 to 0.40) | −0.10±0.19 (−0.30 to 0.52) | −0.10±0.18 (−0.30 to 0.52) | −0.01±0.22 (−0.30 to 0.70) | −0.01±0.24 (−0.30 to 0.82) |
| CDVA logMAR | −0.25±0.07 (−0.30 to −0.08) | −0.24±0.08 (−0.30 to 0) | −0.22±0.08 (−0.30 to 0.16) | −0.21±0.07 (−0.30 to 0) | −0.18±0.09 (−0.30 to 0.30) | −0.18±0.07 (−0.30 to 0) |
| Efficacy index | 0.98±0.22 (0.33 to 1.33) | 0.90±0.22 (0.2 to 1.33) | 0.79±0.27 (0.15 to 1.67) | 0.77±0.27 (0.2 to 1.67) | 0.66±0.26 (0.1 to 1.0) | 0.66±0.26 (0.08 to 1.0) |
| Safety index | 1.08±0.18 (0.75 to 1.33) | 1.02±0.18 (0.6 to 1.33) | 1.00±0.22 (0.75 to 1.67) | 0.94±0.21 (0.67 to 1.67) | 0.90±0.18 (0.25 to 1.33) | 0.88±0.15 (0.25 to 1.25) |

Values expressed as mean ± standard deviation (range).
UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; logMAR = logarithm of the minimal angle of resolution.

respectively (ANOVA, $P = .008$). Multiple comparison (Tukey test) revealed significant differences between measurements made preoperatively and at 10 years ($P = .046$), at 6 months and at 10 years ($P = .008$), and at 1 year and at 10 years ($P = .014$). The mean percentage of endothelial cell loss was 5.3% ± 12.3% (range, –21.0% to 38.5%) at 10 years postoperatively.

• **COMPLICATIONS:** There were no intraoperative complications. Of 114 eyes, 12 (10.5%) developed an anterior subcapsular cataract (ASC) during the 5- to 10-year follow-up period. The presurgery SE of the eyes that generated ASC (–12.3 D) was significantly different ($P < .001$) from the presurgery SE of the eyes that did not generate ASC (–9.7 D), but there was no significant difference in the age at the time of surgery (38.8 vs 35.4 years) ($P = .14$). Of these 12 eyes, 4 eyes were symptomatic and underwent ICL explantation and phacoemulsification surgery (93.8 ± 12.1 months). Of these 4 eyes, the preoperative SEs (D) were –9.50, –13.13, –16.50, and –13.00 D; the ages at ICL implantation (years) were 28, 45, 41, and 40 years; the cataract onset times (months) were 65, 59, 86, and 99 months; the lens extraction times (months) were 103, 75, 98, and 104 months; and the CDVA line changes at lens extraction time were –6, –1, +1, and –2. One eye had an asymptomatic nuclear cataract after 9 years (102 months).

Pigment dispersion glaucoma, pupillary block, or any other vision-threatening complications were not observed during the 10-year follow-up period.

The vault measured with AS-OCT was 0.433 ± 0.196 (51 eyes), 0.418 ± 0.200 (57 eyes), and 0.381 ± 0.190 mm (37 eyes) at 5, 8, and 10 years postoperatively (ANOVA, $P = .463$). At 10 years after surgery, the vault of the eyes that generated ASC (0.276 ± 0.197 mm) was not significantly different ($t$ test, $P = .188$) from the vault of the eyes that did not generate ASC (0.397 ± 0.187 mm).

## DISCUSSION

THE RESULTS OF OUR 10-YEAR FOLLOW-UP STUDY WERE compared with those of the long-term follow-up studies (Table 3). In this study, regarding the safety of ICL, the safety index showed 0.88 after 10 years, which reflected numerical results slightly inferior to the already reported value (1.1 or higher up to the last visit). This was likely due to the presurgery CDVA of the target eyes, having an average logMAR of –0.23, compared with the other long-term follow-up of logMAR 0.31 to –0.13, resulting in a group having eyes with superior visual potential. In other words, at 6 months after the ICL surgery, 1 line gain was observed in the CDVA logMAR within 31% (33/106) of the eyes, and the safety index became 1.08. Afterward, the decline in the ratio of the eyes with a

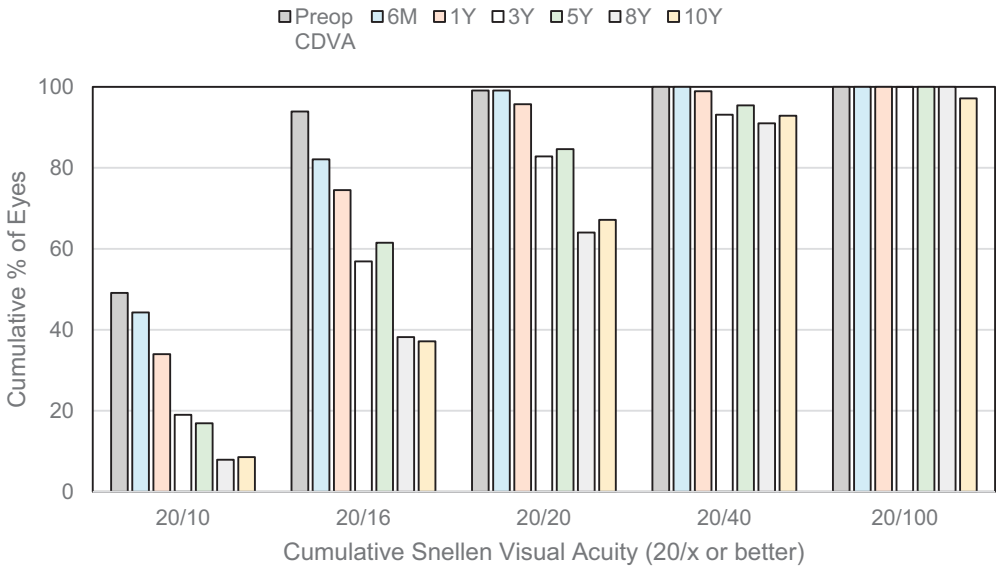


**FIGURE 2. Cumulative distribution of preoperative corrected distance visual acuity (CDVA) and uncorrected distance visual acuity at 6 months (6M), 1 year (1Y), 3 years (3Y), 5 years (5Y), 8 years (8Y), and 10 years (10Y) postoperatively.**

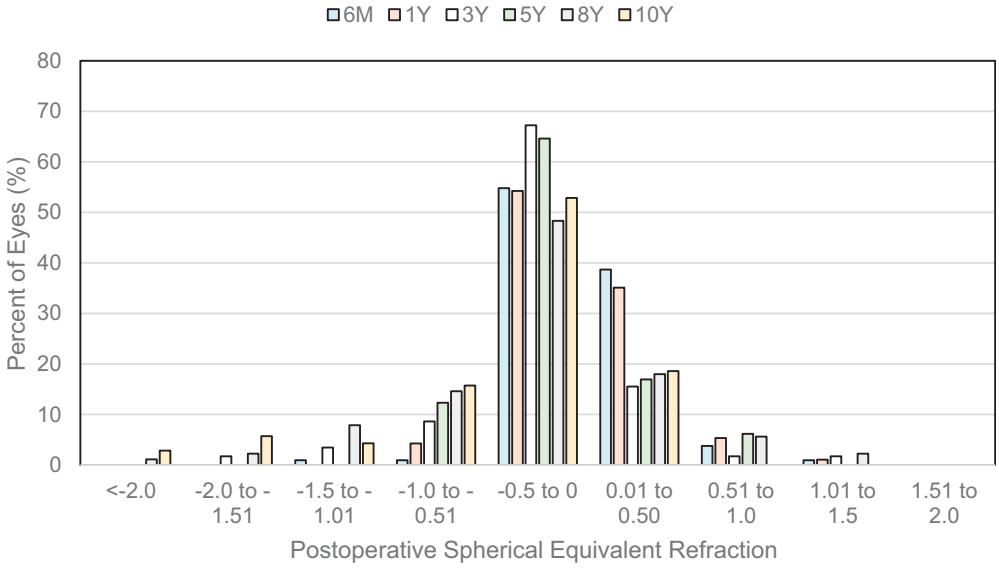


**FIGURE 3. Percentages of eyes within different diopter ranges of the attempted correction at 6 months (6M), 1 year (1Y), 3 years (3Y), 5 years (5Y), 8 years (8Y), and 10 years (10Y) after implantable collamer lens implantation.**

line gain and the increase of the ratio of eyes with a line loss occurred with time, as did the decrease of the safety index. At 10 years, 2 lines or more were lost in 7.1% (5/70) of the eyes. Other researchers reported a nearly equivalent line loss rate. That is, a line loss of 2 lines or more including 2% (1/50) of eyes[13] at 5 years, 7% (3/41) of eyes[14] at 8 years, 8.9% (10/112) of eyes at 12 years,[15] 5.3% (4/75) of eyes[16] at 10 years, and 1.8% (5/281) of eyes[17] in the last visit (5-9 years). In our ICL implantation surgery this time, the CDVA after loss was 20/20 Snellen visual acuity or better, even with a loss of 2 lines or more. A standard of the FDA's "key safety variables" requires "no eyes with CDVA worse than 20/40 at 1-3 years postoperatively."[2] According to this standard, it can be said that surgery sufficiently met safety standards, as the ICL implantation this time showed 20/20 Snellen visual acuity or better for CDVA in all eyes at 10 years.

Regarding the effectiveness of the ICL implantation, one of the standards of FDA's key efficacy variables states, "UDVA Snellen visual acuity of 20/40 or more at 3 years

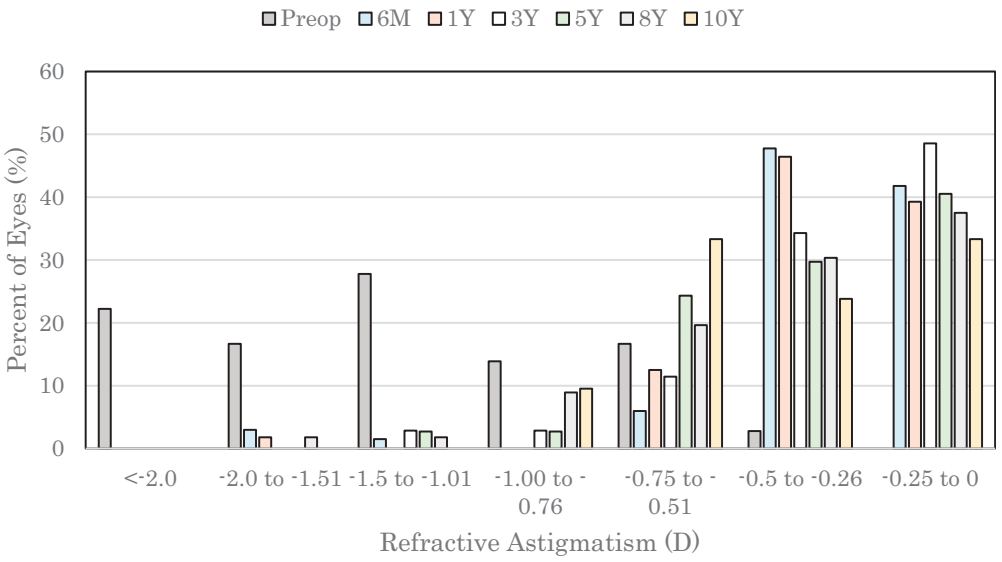


**FIGURE 4. Preoperative and postoperative astigmatism (cylinder refraction) of eyes implanted with toric implantable collamer lenses.**

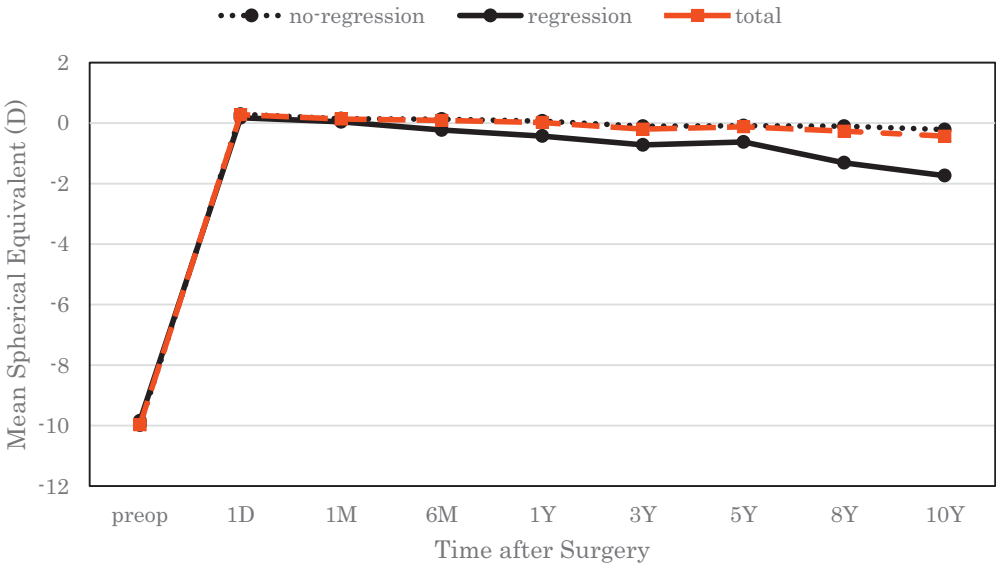


**FIGURE 5. Time course of manifest spherical equivalent refraction at 1 day (1D), 1 month (1M), 6 months (6M), 1 year (1Y), 3 years (3Y), 5 years (5Y), 8 years (8Y), and 10 years (10Y) after implantable collamer lens implantation. *No-regression*, *regression*, and *total* indicate the nonmyopic regression group (102 eyes), myopic regression group (12 eyes), and total (114 eyes), respectively. The number of eyes in the myopic regression group was 12, 12, 9, 9, 4, 12, and 10 at 1 month, 6 months, and 1, 3, 5, 8, and 10 years, respectively. The number of eyes in the nonmyopic regression group was 101, 94, 85, 49, 61, 77, and 60 eyes at 1 month, 6 months, and 1, 3, 5, 8, and 10 years, respectively.**

should be 81.3%, and for patients with preoperative CDVA of more than 20/20 at 3 years, it should be 94.7%."[2] Although long-term follow-up studies conducted by other researchers resulted in 68%[13] at 5 years, 87.8%[14] at 8 years, 57.1%[15] at 12 years, and 90.4%[17] in the last visit (5-9 years) for UDVA Snellen visual acuity of 20/40 or more, our target eyes this time showed 92.9% at 10 years, which were good results similar to the FDA's standard. On the contrary, the efficacy index was 0.66 at 10 years and was lower compared to the reported value of other researchers. The efficacy index is the value of the postoperative UDVA divided by the preoperative CDVA; thus, it is difficult to maintain favorable indices, as in the case of the safety index, when the group of eyes has a presurgery CDVA

**TABLE 3.** Long-term Clinical Outcomes of Implantable Collamer Lens Implantation

| | ICL | Eyes | Follow-up, y | Age, y | SE (D) | Safety Index | Efficacy Index | Predictability (±1.0 D) | EC Loss (%) | Cataract (%) (Removal) |
|---|---|---|---|---|---|---|---|---|---|---|
| Alfonso | V4 | 188 | 5 | 33.5 | −11.17 | 1.27 | 0.89 | 62 | 7.5 | 1.6 (0.5) |
| Igarashi | V4 | 41 | 8 | 37.3 | −10.19 | 1.13 | 0.83 | 85.4 | 6.2 | 24.5 (4.9) |
| Moya | V3 and V4 | 144 | 12 | 30.7 | −16.9 | 1.22 | 0.65 | 34.3 | 9.17 | 13.88 (7.63) |
| Guber | V4 | 133 | 10 | 38.8 | −11.4 | 1.25 | 0.76 | 65.7 | No change | 54.8 (18.3) |
| Lee | V4 | 281 | 7.3 | 30.3 | −8.74 | 1.20 | 1.01 | 87.2 | 7.8 | 2.1 (0) |
| Current | V4 | 114 | 10 | 36.2 | −9.97 | 0.88 | 0.66 | 87.1 | 5.3 | 11.4 (3.51) |

ICL = implantable collamer lens; SE = spherical equivalent; D = diopter; EC = endothelial cell.

average of logMAR –0.23 (Snellen decimal 1.7). This is because visual acuity tends to decline over time, after the refractive surgical procedure, because of aging changes of the eyes.

Concerning the predictability of the ICL implantation, the FDA's standard is determined to be "88.8% within 1.0 D of the attempted correction at 3 years."[2] In the long-term follow-up studies of other researchers, although the results showing within 1.0 D of the attempted correction were 62% (31/50) of eyes at 3 years,[13] 85.4% of eyes at 8 years,[14] 34% of eyes at 12 years,[15] 65.7% (23/35, emmetropic group) of eyes at 10 years,[16] and 87.2% of eyes in the last visit (5-9 years),[17] the target eyes this time were 87.1% at 10 years, which were good results similar to the FDA's standard. In the studies by Alfonso and associates[13] and Moya and associates,[15] a substantial number of eyes showed –20 D or more of the presurgery SE value, and the ratio of intentionally undercorrected eyes was high because of ICL power, resulting in a lower predictability value. The low predictability value in the intended emmetropic group was due to bias in the restriction of available ICL.[16] In this way, the reason why predictability is outside the scope of ±1.0 D of the attempted correction is not only caused by the low power of ICL, which is proved by the postsurgery SE value, but also known to be caused by the generation of myopic regression and lens opacification as time progresses after the surgery and the decline of optical characteristics of crystal lenses such as the increase in distortion.

Concerning the stability of the ICL implantation, the myopic shift (regression) after ICL implantation is reported in theses of long-term observation. Alfonso and associates[13] and Lee and associates[17] reported that SE is inclined to have myopic shift. Igarashi and associates explained that efficacy and predictability slightly decreased chronologically because eyes showed mild myopic regression and suggested that the change in axial length is related to myopic regression based on the correlation of the change in refraction and axial length.[14] Guber and associates stated that SE was stable in the emmetropic group, but efficacy slightly decreased in the myopic shift.[16] However, no report has stipulated the timing and ratio when myopic regression occurred, but this study proved that myopic regression started to occur a few months or later after ICL implantation.

On the contrary, Kamiya and associates reported that myopic regression could be explained using age and axial length before the surgery, as a result of the multiple regression analysis of the myopic regression level from 1 month to 6 years after the ICL implantation.[19] The present study showed that SE and age were not related to myopic regression. Unfortunately, because the axial length was not measured for the target eyes, we were unable to examine the possibility of increase in axial length in the myopic regression group. This is a future issue to be examined.

Regarding IOP, Alfonso and associates reported that 3 eyes (1.6%) showed a mild transient increase in IOP, but no treatment was required.[13] In the report of Igarashi and associates, there was no case of increase in IOP.[14] Moya and associates reported that 15.71% (22/140) was beyond 21 mmHg 1 day after the surgery, but returned to the presurgery IOP level because of the drop of the hypotensive agent.[15] Guber and associates reported 10 cases of transient hypertension in the immediate postoperative phase, but no acute glaucoma was observed owing to the angle block.[16] However, a significant proportion of the study eyes had pigmentation in the iridocorneal angle and ocular hypertension requiring IOP-lowering medication.[16] Lee and associates found that ICL was exchanged because 2 eyes had very large ICL and increased IOP.[17] The other eyes had stable IOP after the surgery.[17] In the present study, IOP was stable up to 10 years after the ICL surgery. Moreover, there was no high IOP case that could become a risk of glaucoma.

Regarding ECD, in the FDA ICL trial report, the number of endothelial cells decreased (2%-3%/year) and became stable afterward. These 3 years are the period of prolonged corneal endothelial remodeling, and it was explained that they are reflected in the change in ECD following trauma after the ICL surgery (hypothesis).[20] Additionally, ECD is generally lost at a rate of 0.5%-0.6% annually because of natural aging. In long-term follow-up studies, Alfonso

and associates showed a 7.7% loss in the 5-year follow-up period (5.5% loss in the first year) and a 1.5% loss in the annual average.[13] Igarashi and associates reported a 6.2% loss in the 8-year follow-up period and 0.8% loss in the annual average.[14] This level is considerably low compared with those in previous reports. Moya and associates showed 19.75% in the 12-year follow-up period.[15] It was estimated that 4.64% decreased in the first year and then an annual ratio of 1.2% decreased.[15] This level is rather high compared with those in previous reports. There is almost no change in the 5-year follow-up period in the report of Guber and associates.[16] Lee and associates showed 7.8% loss in the 5-9-year follow-up period and approximately 0.9% loss annually.[17] The study this time showed a 5.3% loss in the 10-year follow-up period. This level is the same as the decrease rate of ECD attributable to aging in the normal 10 years. Unlike the FDA report, no rapid decrease was observed in the 1-3-year period. In this way, the variation in the pattern of the ECD loss and the degree of loss in ICL among research groups may be attributable to a measurement error and a difference in measurement position caused by a difference in the testing device. This will be an issue in the future. Furthermore, presurgery laser iridotomies could influence ECD, but it appears to have no influence based on the result of this study.

The most concerning complication of ICL surgery is cataract formation. In the projection of the incidence and risk factor, there was inconsistency in long-term follow-up reports. In the ICL FDA trial of 2008, Sanders reported that the ASC incidence was 5.9% (31/526 eyes) in the 5-year follow-up period, of which 1.3% (7) of the eyes had clinically significant cataract. Sanders discussed that presurgery myopia (>12.00 D) and age (>40 years) were the risk factors of ASC incidence and stated no relation with vault.[21] In addition, the incidence of nuclear cataract was 0.9% (5/526) of the eyes. In the same 5-year follow-up period, Alfonso and associates also reported an ASC incidence of 1.6% (3/188 eyes), of which 1 eye had a clinically significant cataract,[13] which was approximately the same as the incidence reported by the FDA. On the contrary, in the report of Schmidinger and associates, the ASC incidence was 28% (20/84 eyes) in the 10-year follow-up period, and 17% of the eyes were extracted. Unlike the report of Sanders, insufficient central vaulting is attributed to ASC incidence.[22] The report of Igarashi and associates showed ASC incidence of 14.6% (6/41 eyes) in the 8-year follow-up period, of which 2 eyes had clinically significant cataract. In addition, the incidence of nuclear cataract was 9.8% (4/41 eyes). Igarashi and associates stated that the incidence is high because of the long survey period.[14] Moya and associates reported that clinically relevant cataract was 13.88% (20/144) of the eyes in the 12-year follow-up period.[15] Eleven eyes were extracted, and the diagnosis of clinically relevant cataract (20 eyes) was correlated only with the selection of V3 ICL model, and there was no relation with lower vaulting.[15] However, these were the comprehensive results of ICL V3 (15 eyes) and ICL V4 (129 eyes), and no incidence of V4 model was referenced, so it cannot be compared for the V4 model. Guber and associates reported an ASC incidence of 54.8% in the 10-year follow-up period, and 18 eyes (18.3%) were extracted. In addition, the small vault was related to the development of lens opacity and phacoemulsification.[16] The points that the extraction ratio is high and vaulting becomes a factor are similar to that reported by Schmidinger and associates.[22] Guber and associates considered that the high incidence depends on the observation method of surface opacity.[16] Lee and associates showed ASC incidence of 2.1% (6/281 eyes) in the 5-9-year follow-up period, with no clinically significant cataract. Lee and associates stated that this low incidence was due to the young age of the patients and the low presurgery SE (moderate myopia) unlike other reports.[17] In the present study, presurgery SE was related to ASC development, suggesting that high myopia was a risk factor. This retrospective study unfortunately did not follow the vault with AS-OCT from early postsurgery; however, at 10 years postsurgery, we did not find a significant correlation between low vault and the incidence of ASC generation, consistent with other studies.[15,21]

As described above, low vault, older age, and high myopia have been discussed as the causes or risk factors of the incidence of cataract after ICL, but the opinions differ by researchers, and no factor has been discovered that obtained the consensus. As a generation mechanism of ASC, it is easily imagined that the crystal lenses was damaged because ICL physically touched the front surface of the crystal lens. Besides, the obstacles placed in the flowing route of the aqueous fluid and the change of the flow route due to laser iridotomies generated metabolism abnormality, in which the influenced crystal lens could not maintain homeostasis and transparency, either; hence, the lens became cloudy. In fact, when hole ICL implantation was started in our clinic, the aqueous fluid penetrates the hole, and metabolism is maintained. Even when there is no vault and nearly contacted, no opacification occurred. Moreover, ICL is slightly moved by pupil reaction, and the aqueous fluid appears to be flowing with the operation of a pump. Therefore, the crystal lenses can easily become cloudy, because the pupil reaction weakens with age, and metabolism tends to become abnormal. This will be an issue in the future.

In addition, in this long-term follow-up study, the 12 eyes that generated myopic regression and 13 eyes (12 ASC and 1 NC) that generated cataract were different. The risk factor may be different. This will be an issue in the future.

Finally, in the long-term follow-up studies of toric ICL, which occupies 63% of the eyes targeted for the observation for this study, safety and effectiveness were equivalent to nontoric ICL. Stable effects were observed in the long term especially with correction of astigmatism.

There are limitations related to the retrospective nature of the study, the lack of quantitative data for vault

analysis by AS-OCT measurements in the early stages of the study, and less or poor data for vector analysis with respect to astigmatism. As these data have been stored over the previous 5 years, it will possibly provide valuable information for future long-term follow-up studies.

In conclusion, this study showed that ICL implantation offered generally good outcomes in all measures of safety, efficacy, predictability, and stability for the correction of moderate to high myopia and myopic astigmatism throughout the long-term follow-up period of 10 years. No vision-threatening complication was seen at any time during the 10-year follow-up period. In our long-term follow-up, a slight return to myopia was observed in some eyes, and there was preoperative high myopia as a risk factor for the occurrence of ASC.

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