Original Article

Long-Term Anterior Segment Biometric Changes after Posterior Chamber Phakic Intraocular Lens Implantation: Conventional Versus Aquaport Implantable Collamer Lens

Farid Karimian *[1], MD; Vahid Ownagh [1], MD; Sepehr Feizi [1], MD; Kiana Hassanpour [1], MD

1- Department of Ophthalmology, Labbafinezhad Medical Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

***Corresponding Author:** Farid Karimian
E-mail: karimianf@yahoo.com

Abstract

Purpose: To compare biometric changes after implantation of posterior chamber phakic collamer lenses (PCLs) between conventional and Aquaport ICL models.
Patients and Methods: Records of myopic patients who underwent ICL implantation between March 2012 and April 2015 were reviewed. Demographics, manifest and cycloplegic refraction, BCVA, and preoperative IOP were documented. All patients underwent ultrasonic biomicroscopy to determine sulcus-to-sulcus distance and angle parameters, along with topography and keratometric measurements. Patients were recalled postoperatively for repeat ultrasonic biomicroscopy. Keratometric values were also obtained using the Galilei Dual Scheimpflug Tomography Analyzer.
Results: Fifty-eight eyes of 30 myopic patients were included; Twenty-eight eyes of 15 patients were assigned to the conventional (V4b) group and 30 eyes of 15 patients to the central-hole (V4c) group. No significant differences in postoperative refraction or intraocular pressure were observed between groups at 1 and 3 months. All preoperative biometric parameters changed after surgery in both groups. Nasal angle parameters (TIA-nasal and AOD500-N) differed significantly between V4b and V4c lenses, while other biometric indices and lens densitometry showed no significant differences.
Conclusion: The central-hole design of the V4c ICL appears as effective as peripheral iridotomy in V4b lenses in preventing deterioration of anterior-segment biometric parameters and may promote a more uniform aqueous humor outflow at the anterior chamber angle. These findings support the clinical use of the V4c design as a safe alternative to conventional ICLs in routine practice, particularly when surgeons prefer to avoid peripheral iridotomy

Keywords: Phakic Intraocular Lenses; Myopia; Anterior Chamber; Biometry; Intraocular Pressure; Tomography; Optical Coherence.

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Introduction

Phakic intraocular lens (PIOL) implantation for moderate to high myopia offers an alternative to corneal refractive surgery for the correction of myopia, hyperopia, and astigmatism. PIOL implantation is a reversible refractive procedure that preserves accommodation and induces fewer higher-order aberrations compared with corneal keratorefractive techniques [1].

Two principal PIOL types are currently available and approved by the U.S. Food and Drug Administration (FDA): iris-fixated anterior chamber PIOLs and posterior chamber implantable collamer lenses (ICLs) [2]. ICLs are considered safe, effective, and predictable for the correction of moderate to high myopia and hyperopia; however, rare postoperative complications such as cataract formation, pupillary block glaucoma, pigment dispersion, and pigmentary glaucoma have been reported [3]. Preventing these complications remains essential. Conventional ICL implantation typically requires two preoperative laser iridotomies to avoid pupillary block. In addition, cataract formation may result from direct contact between the ICL and crystalline lens or from impaired aqueous humor circulation leading to localized metabolic stress [4].

To address these limitations, Fujisawa et al., [5] introduced a modified ICL design incorporating a central artificial hole (Aquaport, V4c model). The 0.36-mm central port does not degrade retinal image quality in vivo or in vitro, owing to its small size, and has been shown to enhance aqueous humor flow around the crystalline lens. Improved aqueous dynamics may reduce the incidence of cataract formation following ICL implantation [5].

Anterior segment biometric alterations following peripheral iridotomies are well-documented, particularly in eyes with narrow angles [6]. Similarly, changes in iridocorneal angle configuration after conventional ICL surgery are known[7]. Peripheral iridotomies may modify postoperative biomechanical changes, but the ability of the Aquaport central hole to replicate this effect has not been fully established.

The aim of this study was to compare anterior segment biometric changes and refractive outcomes after implantation of V4b (conventional) and V4c (central-hole) ICL models.

Patients and Methods

This historical cohort study was conducted at a private cornea clinic in Tehran, Iran. Records of myopic patients who underwent ICL implantation between March 2012 and April 2015 were reviewed. The study adhered to the Declaration of Helsinki and was approved by the institutional review board. Written informed consent was obtained from all patients. All surgeries were performed by a single surgeon (Karimian, F). Demographic data, manifest and cycloplegic refraction, best corrected visual acuity (BCVA), and preoperative intra ocular pressure (IOP) were documented. All patients received comprehensive slit-lamp and funduscopic examinations before surgery. Early refractive and IOP outcomes were analyzed at 1 and 3 months, while biometric changes were evaluated at the final long-term visit.

Patients with corneal or chorioretinal pathology or a diagnosis of keratoconus were excluded. Ultrasonic biomicroscopy (Quantel Biomedical, France) was performed to determine sulcus-to-sulcus diameter and anterior chamber angle parameters under dim illumination. Topography and keratometric

measurements were obtained preoperatively, and ICL size selection was based on sulcus to sulcus (STS) measurements. All patients were examined on the first postoperative day, and at 1 and 3 months after surgery. At each visit, slit-lamp evaluation, refraction, BCVA, IOP, and postoperative complications were recorded.

From September 2015 to February 2016, eligible patients were recalled for re-examination. Postoperative ultrasonic biomicroscopy was repeated using the same settings as preoperatively. Keratometric data were obtained with the Galilei Dual Scheimpflug Analyzer (Ziemer, Switzerland). Trabecular–iris angle (TIA) in temporal and nasal quadrants (TIA-T and TIA-N), angle-opening distance at 500 µm (AOD500-T and AOD500-N), and STS distance were measured. TIA was defined by tracing a 500-µm line from the angle recess toward the Schwalbe line, and a second line along the iris surface to the point perpendicular to the first. AOD500 was defined as the perpendicular distance from the trabecular meshwork, 500 µm anterior to the scleral spur, to the anterior iris surface.

Because the UBM system could not automatically quantify all parameters, pre- and postoperative UBM images were exported to Photoshop software for additional measurements. Preoperative biometric indices included anterior chamber depth (ACD: distance from endothelium to anterior surface of the crystalline lens), STS diameter, and lens-to-STS plain distance (L-STS: distance from the anterior crystalline lens surface to the STS plane). After surgery, the same parameters were re-measured, and three additional variables were defined: vault (distance between posterior ICL surface and anterior crystalline lens surface), Endo-ICL (distance from endothelium to the anterior ICL surface), and ICL-STS (distance between posterior ICL surface and STS plane).

Surgical Technique

Sixty minutes before surgery, topical mydriatic drops containing tropicamide 1 % and phenylephrine 2.5 % were instilled. The conjunctival sac and eyelid margins were prepared with 5 % povidone–iodine. Standard sterile draping was applied. All procedures were performed under topical anesthesia with tetracaine 0.5 %. A temporal clear corneal incision was created with a microkeratome, and the anterior chamber was filled with viscoelastic material (OcuCoat, B&L, Rochester, USA). The ICL (STAAR, USA) was loaded into the injector cartridge and delivered into the ciliary sulcus. Viscoelastic material was meticulously aspirated and replaced with balanced salt solution. The incision was hydrated for wound closure. In the V4 group, a peripheral iridotomy at the 6-o'clock position was performed using a vitrectomy probe. Postoperatively, all patients received topical ciprofloxacin and prednisolone four times daily, along with acetazolamide 250 mg every six hours.

Statistical Analysis

Normality of data distribution was assessed using the Kolmogorov-Smirnov test and Quantile-Quantile (Q-Q) plots. Data were summarized using frequency (percentage), mean ± SD, median, and range. Baseline differences between groups were evaluated with the t-test, Mann–Whitney U test, and chi-square test. Group comparisons adjusted for baseline values were performed using Analysis of Covariance (ANCOVA). Within-group changes over time were analyzed with repeated-measures analysis, with adjustment for follow-up intervals. Correlations between

variables were examined using Pearson or Spearman correlation coefficients. A P value < 0.05 was considered statistically significant. All analyses were conducted using SPSS software, Version 22 (IBM Corp., Armonk, NY).

Results

Fifty-eight eyes of 30 myopic patients met the inclusion criteria and were enrolled. Twenty-eight eyes of 15 patients were categorized into the V4b group, and 30 eyes of 15 patients into the V4c (Aquaport) group. Mean follow-up was 27.7 ± 9.3 months in the conventional group and 26.6 ± 8.8 months in the Aquaport group (P = 0.269). Demographic characteristics are presented in table 1; no significant differences in age, sex, or laterality were observed between groups.

Refraction data (sphere, cylinder, and spherical equivalent) before surgery and at 1 and 3 months postoperatively are summarized in table 2. The overall mean spherical equivalent before surgery was − 9.17 ± 3.98 D: − 10.38 ± 3.78 D in the conventional group and −7.88 ± 3.83 D in the Aquaport group, representing a significant difference (P = 0.016). The mean spherical equivalent at 1 month postoperatively was − 0.38 ± 0.70 D overall, − 0.37 ± 0.86 D in the V4b group, and −0.39 ± 0.50 D in the V4c group, with no significant difference on ANCOVA (P = 0.621). Refraction outcomes at 3 months are also shown in table 2.

Intraocular pressure results are provided in table 3. Baseline mean IOP was 13.17 ± 1.8 mmHg in the V4b group and 13.57 ± 0.88 mmHg in the V4c group (P = 0.337). IOP did not differ significantly from preoperative values in either group at 1- and 3-month follow-up.

Pre- and postoperative biometric measurements are summarized in table 4. No significant baseline differences were observed between

Table1: Demographic findings of patients entering the study

Variable		Group V4	Group V4c	P
Age	Mean ± SD	31.2 ± 4	30.1 ± 3.5	0.269†
	Median (range)	31 (25 to 40)	31 (21 to 36)	
Follow-up time (months)	Mean ± SD	27.7 ± 9.3	26.6 ± 8.8	0.779‡
	Median (range)	24 (16 to 48)	27.5 (14 to 44)	
Eye	OD	15 (50.0 %)	15 (53.6 %)	0.786*
	OS	15 (50.0 %)	13 (46.4 %)	
Gender	F	22 (73.3 %)	23 (82.1 %)	0.421*
	M	8 (26.7 %)	5 (17.9 %)	

† Based on t-test.
‡ Based on Mann-Whitney test.
* Based on Chi-Square test.
OD: Right eye; OS: Left eye; M: Male; F: Female

Table 2: Refractive data pre-operative and then one and three months post surgery

Variable	Time	V4 Mean ± SD	V4c Mean ± SD	P
Sphere	Pre	- 9.33 ± 3.81	- 7.13 ± 3.53	0.027†
	First	- 0.12 ± 0.74	- 0.01 ± 0.57	0.631§
	Third	- 0.12 ± 0.63	- 0.12 ± 0.38	0.841§
Cylinder	Pre	- 2.06 ± 1.46	- 2.09 ± 1.47	0.936†
	First	- 0.49 ± 0.64	- 0.77 ± 0.57	0.093§
	Third	- 0.38 ± 0.62	- 0.35 ± 0.44	0.773§
Spherical Equivalent	Pre	- 10.38 ± 3.78	- 8.24 ± 3.52	0.031†
	First	- 0.37 ± 0.86	- 0.39 ± 0.5	0.571§
	Third	- 0.29 ± 0.65	- 0.29 ± 0.38	0.594§

† Based on t-test.
§ Based on Analysis of Covariance (ANCOVA).

Table3: Comparison of preoperative IOP with first and third month post-operative IOP

Variable	V4 Mean ± SD	V4c Mean ± SD	P
Pre	13.17 ± 1.8	13.57 ± 0.88	0.337 ‡
First	14.73 ± 1.23	15.25 ± 1.08	0.184 §
P for change*	< 0.001	< 0.001	
Third	14.23 ± 1.98	14.57 ± 1.07	0.698 §
P for change*	0.012	< 0.001	
P for change between first and third month*	0.105	< 0.001	

*Based On Wicoxon Test
‡ Based on Mann-Whitney test.
§ Adjusted for the baseline value and follow up, based on analysis of covariance
¥ Adjusted for the follow up, based on repeated measure analysis of variance

Table 4: Comparison of anterior segment biometric data pre and post-operative

Variable	Time	V4 Mean ± SD	V4c Mean ± SD	P	P adj
TIA-T	Pre	45.57 ± 5.05	46.75 ± 5.41	0.256‡	0.338
	Post	28.57 ± 4.56	30.25 ± 4.33		
	Change (%)	- 37 ± 8	- 35 ± 10		
	P-within¥	< 0.001	< 0.001		
AOD-T	Pre	0.75 ± 0.12	0.8 ± 0.14	0.636‡	0.493
	Post	0.45 ± 0.11	0.47 ± 0.09		
	Change (%)	- 40 ± 12	- 39 ± 14		
	P-within¥	< 0.001	< 0.001		
TIA-N	Pre	44.54 ± 5.39	46.57 ± 4.37	0.022‡	0.018
	Post	27.5 ± 3.92	30.18 ± 3.79		
	Change (%)	- 38 ± 9	- 35 ± 9		
	P-within¥	< 0.001	< 0.001		
AOD-N	Pre	0.76 ± 0.13	0.79 ± 0.11	0.040‡	0.03
	Post	0.43 ± 0.07	0.48 ± 0.08		
	Change (%)	- 42 ± 12	- 39 ± 11		
	P-within¥	< 0.001	< 0.001		
ACD	Pre	3.33 ± 0.21	3.36 ± 0.36	0.293‡	0.615
	Post	3.24 ± 0.21	3.3 ± 0.34		
	Change (%)	- 3 ± 5	- 2 ± 3		
	P-within¥	0.008	0.004		
STS	Pre	12.14 ± 0.24	12.14 ± 0.62	0.128‡	0.155
	Post	12.91 ± 0.43	12.76 ± 0.47		
	Change (%)	6 ± 3	5 ± 4		
	P-within¥	< 0.001	< 0.001		
L-STS	Pre	0.58 ± 0.13	0.56 ± 0.14	0.116‡	0.275
	Post	0.67 ± 0.16	0.6 ± 0.17		
	Change (%)	17 ± 27	10 ± 34		
	P-within¥	0.001	0.332		

‡ Based on Mann-Whitney test.
§ Adjusted for the baseline value and follow up, based on Analysis of Covariance (ANCOVA)
¥ Adjusted for the follow up, based on Repeated measure analysis of Variance (Repeated measure ANOVA).
P adj: P value adjusted for preoperative spherical equivalent.
TIA-T: Trabecular–Iris Angle (Temporal); AOD-T: Angle-Opening Distance (Temporal); TIA-N: Trabecular–Iris Angle (Nasal); AOD-N: Angle-Opening Distance (Nasal); ACD: Anterior Chamber Depth; STS: Sulcus–to–Sulcus distance; L-STS: Lens to STS plane distance

groups. All biometric parameters, TIA-T, AOD500-T, TIA-N, AOD500-N, ACD, L-STS, and STSm changed significantly after ICL implantation in both groups, with the exception of L-STS in the V4c eyes. Postoperative reduction in nasal angle parameters (TIA-N and AOD500-N) was significantly smaller in the V4c group compared with V4b (P = 0.022 and P = 0.04, respectively). The magnitude of postoperative change in other biometric indices was not significantly different between groups.

TIA-T decreased from 45.57 ± 5.05° to 28.57 ± 4.56° in the V4b group, and from 46.75 ± 5.41° to 30.25 ± 4.33° in the V4c group. ACD changed from 3.33 ± 0.21 mm to 3.24 ± 0.21 mm in V4b eyes, and from 3.36 ± 0.36 mm to 3.30 ± 0.34 mm in V4c eyes. STS increased from 12.14 ± 0.24 mm to 12.91 ± 0.43 mm in V4b eyes, and from 12.14 ± 0.62 mm to 12.76 ± 0.47 mm in V4c eyes.

Post-ICL parameters (vault, Endo-ICL, and ICL-STS) showed no significant differences between groups.

Postoperative vaulting was significantly correlated with preoperative STS (P = 0.024), ACD (P = 0.001), pupil diameter, ICL size, refractive cylinder magnitude, and L-STS (Table 5).

TIA-T change correlated significantly with preoperative TIA-T, TIA-N, AOD500-T, and L-STS (Table 6).

TIA-N change showed significant correlation with preoperative TIA-N and L-STS (Table 7).

All recalled patients completed UBM and topography examinations; no long-term imaging data were missing.

Table 5: Correlation of vaulting with preoperative parameters

Variable	Vaulting	
	R	P value*
ACD	0.438	0.001
STS	0.301	0.024
Pupil Dia.	0.322	0.019
Pre. Cylinder	- 0.474	0.002
ICL size	0.401	0.002
LSTS	- 0.37	0.005
ICL-STS	0.143	0.295

*Two tail Pearson correlations with Sig in P<0.05 level
ACD: Anterior Chamber Depth; STS: Sulcus-to-Sulcus distance; Pupil Dia.: Pupil Diameter; Pre. Cylinder: Preoperative Cylinder; ICL size: Implantable Collamer Lens Size; L-STS: Lens to STS plane distance ; ICL-STS: Posterior ICL surface to STS plane distance

Table 6: Correlation of TIA-T

Variable	TIA-T change (%)	
	R	P value*
TIA-T	- 0.3	0.025
TIA-N	- 0.287	0.035
AOD-T	- 0.386	0.003
L-STS	0.317	0.017

*Two tail Pearson correlations with Sig in P < 0.05 level
TIA-T: Trabecular–Iris Angle (Temporal); TIA-N: Trabecular–Iris Angle (Nasal); AOD-T: Angle-Opening Distance (Temporal); L-STS: Lens to STS plane distance

Discussion

The Aquaport ICL was developed to facilitate a more physiologic route for aqueous humor

Table7: Correlation of TIA-N

Variable	TIA-N change (%)	
	R	P value*
TIA-N	0.239	0.035
L-STS	0.332	0.012

*Two tail Pearson correlations with Sig in P < 0.05 level
TIA-T: Trabecular–Iris Angle (Temporal); L-STS: Lens to STS plane distance

circulation in the anterior chamber and to eliminate the need for peripheral iridotomy. This raises the question of whether a central hole can adequately replace the function of a peripheral iridotomy. The present study compared anterior segment biometric changes after implantation of V4 (conventional) versus V4c (central-hole) ICLs.

Our findings confirm that ICL implantation causes substantial biometric alterations in the anterior segment. Overall, the magnitude of these changes did not differ significantly between the two lens models.

Fernandez-Vigo et al., [8] evaluated iridocorneal angle changes after V4c implantation using anterior segment OCT at 1 and 3 months and found temporal TIA decreased from 48.2 ± 8.7° to 30.1 ± 11.9° and nasal TIA from 48.7 ± 8.7° to 30.6 ± 12.3° at 3 months [8]. These values are comparable to those observed in our cohort. They also reported significant changes in ACD, WTW, and axial length following ICL placement.

Chung et al., [6] assessed angle configuration with UBM and gonioscopy up to 2 years postoperatively, reporting mean decreases in TIA and AOD of 41.5 % and 31.8 % at 1 month, with no further progressive narrowing thereafter (mean follow-up 33.2 ± 7.3 months).

A key finding of our study is that nasal angle narrowing (TIA-N and AOD500-N) was significantly less pronounced in V4c eyes. Previous reports have shown that peripheral iridotomy has a localized effect on angle anatomy in addition to global biometric changes [9,10], and postoperative angle widening varies according to iridotomy location [9,10]. The smaller degree of nasal angle change in V4c lenses may indicate more balanced aqueous flow facilitated by the central hole, compared to the asymmetric flow pattern produced by peripheral iridotomy in V4 lenses.

ICL–iris touch was observed in almost all eyes, consistent with prior studies. This supports the concept that most angle narrowing results from mechanical displacement of the iris rather than altered aqueous dynamics [6]. The similarity in angle changes between V4b and V4c groups, with the latter providing more physiologic aqueous flow, further reinforces this mechanical explanation.

Although vault tended to be higher in V4b eyes, the difference was not statistically significant. Lee et al., [11, 12] reported that vaulting in V4 lenses is greater under photopic conditions, while V4c vault increases under mesopic conditions. They observed a wider range of vault change in V4c eyes and proposed that aqueous trapped behind the V4 lens resists backward displacement, unlike the free flow permitted by the central hole in V4c.

Vault measurements in our series were lower overall compared with several published studies. Mean vault was 470 ± 300 µm for V4 lenses and 370 ± 230 µm for V4c. Lee et al., [13] reported mean V4 vaulting of 518.6 ± 258 µm in 129 eyes at ≥ 6 months using UBM, and Alfonso et al.,[14] reported 414 ± 228 µm using AS-OCT in 452 eyes. They also demonstrated that vault declines over time, particularly during the first 6 months, with a

mean decrease of 71 ± 58 µm [14]. Variability in vaulting likely reflects differences in patient ethnicity, refractive error range, and ICL sizing strategy.

In our study, vault correlated with preoperative ACD, STS, ICL size, pupil diameter, refractive cylinder magnitude, and L-STS. Traditionally, the discrepancy between ICL size and STS has been regarded as the primary determinant of vault. However, our analysis did not show a significant association between vault and either ICL size – STS or ICL size/STS ratio. Lee et al., [13] reported a significant correlation between vault and ICL size – STS, ICL size – WTW, ICL size, ACD, and age.

Both groups demonstrated an increase in STS following surgery. Whether this represents true sulcus expansion from mechanical stretching of the ciliary sulcus or a measurement artifact caused by the presence of the ICL on UBM remains uncertain. Confirmation of real sulcus expansion would have important implications for ICL sizing and postoperative vault prediction.

IOP elevation is a known concern in ICL surgery, particularly when vaulting is high or angle narrowing occurs. An additional concern with the V4c model is the absence of peripheral iridotomy, raising theoretical risk of pupillary block. In our cohort, IOP remained stable in both groups, with no significant changes from baseline at 1 and 3 months. These findings support the effectiveness of the V4c central-port design in maintaining physiologic aqueous outflow. Higueras-Esteban et al., [15] likewise found no significant IOP differences between V4 and V4c lenses over 3 months. Almaki et al., [16] reported a 10 % transient postoperative IOP rise, most often due to retained viscoelastic or steroid response.

Refractive outcomes at 1 and 3 months were comparable between groups and consistent with previously published results. Because preoperative myopia was significantly higher in the V4 group, ANCOVA was applied for statistical adjustment. At 3 months, mean spherical equivalent was − 0.29 ± 0.65 D in V4 eyes and − 0.29 ± 0.38 D in V4c eyes. Huseynova et al., [17] found similar refractive accuracy, reporting spherical equivalents of 1.50 ± 0.20 D with V4 and 0.19 ± 0.40 D with V4c lenses at 3 months.

This study has several limitations. Its historical cohort design and non-random allocation introduce the possibility of selection bias and baseline imbalance, particularly in preoperative refractive error. The inclusion of both eyes from most patients without accounting for inter-eye correlation may also influence statistical precision. UBM measurements were obtained under dim light and partly quantified using exported images, which may introduce measurement variability despite identical settings before and after surgery. In addition, endothelial cell density and detailed lens densitometry results were not available for all subjects, limiting comprehensive safety assessment. Finally, as a single-center study with a relatively small sample size, the findings should be interpreted cautiously and validated in larger prospective cohorts. Future prospective studies with larger sample sizes and standardized imaging protocols are warranted to confirm these findings.

Conclusion

The central-hole design of the V4c ICL appears as effective as peripheral iridotomy in V4b lenses in preventing deterioration of anterior-segment biometric parameters and may promote a more uniform aqueous humor outflow at the anterior chamber angle. These

findings support the clinical use of the V4c design as a safe alternative to conventional ICLs in routine practice, particularly when surgeons prefer to avoid peripheral iridotomy

Authors ORCIDs

Farid Karimian:
https://orcid.org/0000-0001-6758-7457

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Footnotes and Financial Disclosures

Conflict of interest:

The authors have no conflict of interest with the subject matter of the present manuscript.