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Evaluation of impact of posterior phakic IOL implantation on biometry and effectiveness of concomitant use of anterior segment OCT on IOL power calculation for cataract surgery

Masayuki Ouchi, MD, PhD

Purpose: To evaluate the effects of phakic intraocular lens (pIOL) implantation on the intraocular lens (IOL) power calculation and subsequently to evaluate the effectiveness of concomitant use of anterior segment optical coherence tomography (AS-OCT) against biometric changes.

Setting: Masayuki Ouchi Eye Clinic, Kyoto, Japan.

Design: Prospective consecutive case series.

Methods: 100 patients (100 eyes) who underwent pIOL implantation were enrolled. In each eye, biometry was performed using partial coherence interferometry (PCI) and AS-OCT. Pre-pIOL and post-pIOL implantation IOL power calculation using SRK/T (S), Haigis (H), and Barret Universal II (B) formulas was compared.

Results: 100 patients (100 eyes) were included. Anterior chamber depth (ACD) was significantly shorter at post-pIOL implantation for both PCI ($P < .001$) and AS-OCT ($P = .05$). When using PCI, the crystalline lens surface was misidentified in 75% of eyes, and in these eyes, the ACD difference between pre-pIOL and post-pIOL implantation exceeded that with both PCI and AS-OCT. The estimated IOL power was significantly lower at post-pIOL implantation according to the H and B formulas (both $P < .001$) but remained unchanged by the S formula. However, no difference was observed when AS-OCT–derived ACD and lens thickness (LT) values were introduced in the H ($P = .16$) and B ($P = .55$) formulas.

Conclusions: Misidentification of the lens surface occurs in many pIOL-implanted eyes with PCI measurements and could influence the power calculation with H and B formulas while leaving the S formula unaffected. AS-OCT–derived ACD and LT value substitution is recommended for H and B formulas.

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In addition to laser in situ keratomileusis, another type of corrective surgery for severe myopia involves the implantation of a posterior phakic intraocular lens (pIOL). With the advent of models with perfusion ports in the center of the IOL that improve aqueous humor flow, this procedure has become increasingly common in these years.[1] Furthermore, recently, the number of individuals with a history of refractive surgery who require cataract surgery has increased. Alterations in corneal morphology caused by laser in situ keratomileusis surgery change the calculations used to determine corneal curvature and postoperative effective lens position, thereby markedly affecting the calculations of intraocular lens (IOL) power.

Furthermore, the number of patients who have undergone pIOL refractive surgery and subsequently require cataract surgery is expected to increase in the near future.[2,3] Although pIOL implantation surgery does not alter corneal morphology, it can potentially change the anterior chamber depth (ACD), and the presence of the pIOL itself may further affect the measurements of light and other properties of the anterior chamber.[4,5]

A previous report describing IOL power calculation after pIOL implantation considered only changes based on previous generation partial coherence interferometry (PCI), and the impact of change in ACD on IOL power calculation was unclear, which also needed to be addressed.[6] Thus, in this study, we examined the effects of pIOL implantation on the calculation of IOL power for cataract surgery using PCI and subsequently evaluated the effectiveness of concomitant use of anterior segment optical coherence tomography (AS-OCT).

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Masayuki Ouchi Eye Clinic, Minami-ku, Kyoto, Japan.

Corresponding author: Masayuki Ouchi, MD, PhD, Masayuki Ouchi Eye Clinic, 9-1 Nishikujo Ohkuni-cho, Minami-ku, Kyoto 601-8449, Japan. Email: mouchi@skyblue.ocn.ne.jp.

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METHODS

Subjects

This study was performed in accordance with tenets of the Declaration of Helsinki. After being approved by the Masayuki Ouchi Eye Clinic Ethics Committee, it was registered in the UMIN clinical trial registry system (UMIN000038359). Informed consent was obtained from all included cases.

The subjects were 100 right eyes from 100 individuals who underwent pIOL (EVO + Visian ICL, Staar Surgical Corp.) implantation for myopia or myopic astigmatism and who completed all the scheduled follow-up visits at the Masayuki Ouchi Eye Clinic between January 2020 and April 2021, with all procedures performed by the same surgeon. Cases in which the ACD was < 2.8 mm or in which ophthalmological illnesses other than refractive abnormalities were present were excluded. Subjects consisted of 36 men and 64 women, with a mean age of 31.1 ± 8.6 years (21 to 57 years). These subjects were included in a prospective trial.

Measurements

The following parameters were compared before and 1 month after insertion of the pIOL: estimated power of the inserted IOLs (aimed at emmetropia); the ACD and lens thickness (LT), measured using PCI (IOL Master 700, Zeiss Corp.) and AS-OCT (CASIA2, TOMEY Corp.). The misidentification rate, that is, the percentage of cases in which the anterior surface of the pIOL was misidentified during PCI as the anterior surface of the IOL, was also noted, and the ACD and LT was measured in such cases.

ACD measurements using PCI have been reported to increase significantly when the pupil is dilated; thus, all measurements were performed with the pupil undilated.[7] When PCI measurements taken after pIOL implantation were captured such that the segmentation line on the postoperative anterior segment image (which indicates the anterior surface of the crystalline lens) was properly drawn on the anterior surface of the IOL, the measurement was labeled "no misidentification present" (Figure 1, A). However, when the segmentation line was drawn on the anterior surface of the pIOL (or anywhere other than on the anterior surface of the IOL), the measurement was considered as "misidentified" (Figure 1, B).

Furthermore, postoperative ACD and LT measurements using AS-OCT were manually corrected for misidentification of the anterior surface of the crystalline lens using the semiautomatic trace function preloaded onto the machine so that all the ACD values measured using AS-OCT coincide with the distance between corneal epithelium and crystalline lens surface. Visual acuity, subjective and objective refraction, axial length, and corneal radius of curvature were measured as well.

Visual acuity was measured using a space-saving chart (SSC-370, Nidec Corp.). Objective refraction was measured using an autorefractometer (ARK1, Nidec Corp.). After obtaining objective refractions using the autorefractometer, the results were referenced as a starting point for a full manifest refraction. PCI was used to measure axial length and corneal radius of curvature.

To calculate IOL power, the target IOL was set as the SN60WF model (Alcon Corp.) and three formulas were used to calculate the IOL power necessary to set estimated postoperative refraction to emmetropia, using the same machine. The formulas were the SRK/T formula (S formula), the Haigis formula (H formula), and the Barret Universal II TK formula (B formula). PCI measurements were performed at least 6 times automatically, and the measurement values were produced after reproducibility was confirmed. The constants used in the various calculation formulas were taken from values published by the User Group for Laser Interference Biometry. These values were as follows: 119.1 (S formula); a0: −1.268, a1: 0.342, a2: 0.233 (H formula); and LF: 1.94, DF 5.0 (B formula).

Size of the pIOL was determined using the K-S and N-K formulas given in the pIOL sizing mode of the AS-OCT machine. Data from subjective visual acuity tests were used as input data for determining spherical/cylindrical power and the targeted insertion axis for the toric model.

Statistical Analysis

All measurements are expressed as mean ± standard deviation. The R statistical software package (R Development Core Team) was used for all statistical analyses (https://www.r-project.org/). After creating Bland-Altman plots, preoperative and postoperative ACD and LT measurements were tested for fixed error using the one-sample *t* test. Repeated measures analysis of variance was used to compare the preoperative and postoperative IOL powers obtained using each of the calculation formulas, following verification of normal data distribution with the Shapiro-Wilk test. The threshold of statistical significance was set at 5%.

RESULTS

Refraction, Visual Acuity, and Complications

As an intraoperative complication, in 1 eye, the haptic of the pIOL was broken during insertion; the IOL was extracted, and the operation was performed once again at a later date. Adjustment of the toric axis (with 15 degrees) after surgery was required for 1 eye. The intraocular pressure did not exceed 21 mm Hg in any of the cases at 1 month postoperatively.

Table 1 shows preoperative and postoperative visual acuity and refraction data. In all cases, postoperative visual acuity was improved, and postoperative spherical/cylindrical power was smaller than the preoperative values both subjectively and objectively. There was no difference in corrected visual acuity.

Biometry

In 75 of 100 eyes (75%), postoperative PCI measurements misidentified the anterior surface of the pIOL as the anterior surface of the crystalline lens, placing the segmentation line there.

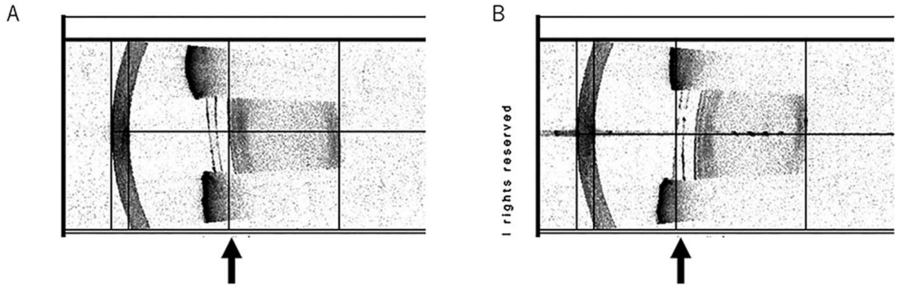

Figure 1. Identification of the anterior surface of the crystalline lens using partial coherence interferometry following posterior pIOL implantation. (*A*) No misidentification: The third segmentation line from the left (*arrow*) correctly identifies the anterior surface of the lens. (*B*) Misidentification: The segmentation line has misidentified the anterior surface of the pIOL as the anterior surface of the crystalline lens. pIOL = phakic IOL

Table 1. Preoperative and Postoperative Acuity and Refraction.

pIOL implantation	UDVA (logMAR)	CDVA (logMAR)	Subjective spherical (D)	Subjective cylindrical (D)	Subjective SE (D)	Objective spherical (D)	Objective cylindrical (D)	Objective SE (D)	IOP (mm Hg)
Pre	1.36 ± 0.35	−0.10 ± 0.11	−6.98 ± 2.96	−0.88 ± 1.03	−7.41 ± 3.06	−6.85 ± 3.27	−1.16 ± 1.15	−7.65 ± 3.14	14.5 ± 2.6
Post	−0.11 ± 0.16	−0.11 ± 0.05	−0.04 ± 0.19	−0.15 ± 0.30	−0.11 ± 0.23	−0.10 ± 0.44	−0.58 ± 0.35	−0.36 ± 0.42	13.6 ± 2.6

Post = postoperative; Pre = preoperative; SE = spherical equivalent refraction

Figure 2 depicts Bland-Altman plots for preoperative and postoperative ACD and LT measurements collected using PCI and AS-OCT. ACD measurements collected using PCI exhibited a positively skewed distribution (Figure 2, A), and a fixed error was observed (P < .001). LT values were skewed negatively (Figure 2, C), and a fixed error was also observed (P < .001). However, in comparison, AS-OCT measurements exhibited only a small amount of variance in both ACD and LT (Figure 2, B and D).

Table 2 lists preoperative and postoperative biometry values. Axial length and the mean of the steepest/flattest meridian power remained unchanged between preoperative and postoperative measurements. However, significant differences were seen between ACD and LT values measured preoperatively and postoperatively by means of PCI (both P < .001). When categorized by the presence or absence of misidentification, a preoperative to postoperative difference of 0.07 mm was observed for cases with no misidentification; however, in cases where misidentification occurred, the mean preoperative to postoperative difference was 0.5 mm or more in ACD. Thus, a large difference was observed. By contrast, LT was measured as longer in cases with misidentification than in those without misidentification. Finally, in AS-OCT measurements, measured ACD was significantly shorter postoperatively (P = .05), but this difference was smaller than that seen with PCI. Moreover, no difference was observed in LT.

Calculation of IOL Power

Table 3 lists preoperative and postoperative results for IOL power calculations. No difference was observed in preoperative and postoperative values calculated using the S formula (P = .29), but when using the H formula and B formula, postoperative values were significantly smaller than preoperative values (both P < .001), although no difference was seen in comparison with non-misidentified cases between preoperatively and postoperatively, both in the H formula (10.40 ± 3.43 and 10.38 ± 3.25; P = .80) and in the B formula (10.20 ± 3.20 and 10.13 ± 3.05; P = .53). However, after recalculating postoperative values by substituting AS-OCT–measured ACD and LT values in misidentified cases, no significant difference with preoperative values was observed (P = .16, P = .55, respectively).

DISCUSSION

Using three main IOL power calculation formulas, we demonstrated the effects of previous pIOL surgery on the calculation of IOL power for cataract surgery. Although values calculated using the S formula did not change from preoperatively to postoperatively, significantly lower IOL power was calculated postoperatively when the H and B formulas were used after pIOL implantation. However, when PCI was used for biometry, in 75% of cases, measurements taken after pIOL implantation were unable to identify the anterior surface of the crystalline lens correctly. In these cases, when ACD and LT values measured with AS-OCT were substituted and recalculations performed, no difference was observed in preoperative and postoperative IOL powers when using either the H or B formula.

When calculating IOL power, biometry, including measurement of axial length, is exceedingly important.

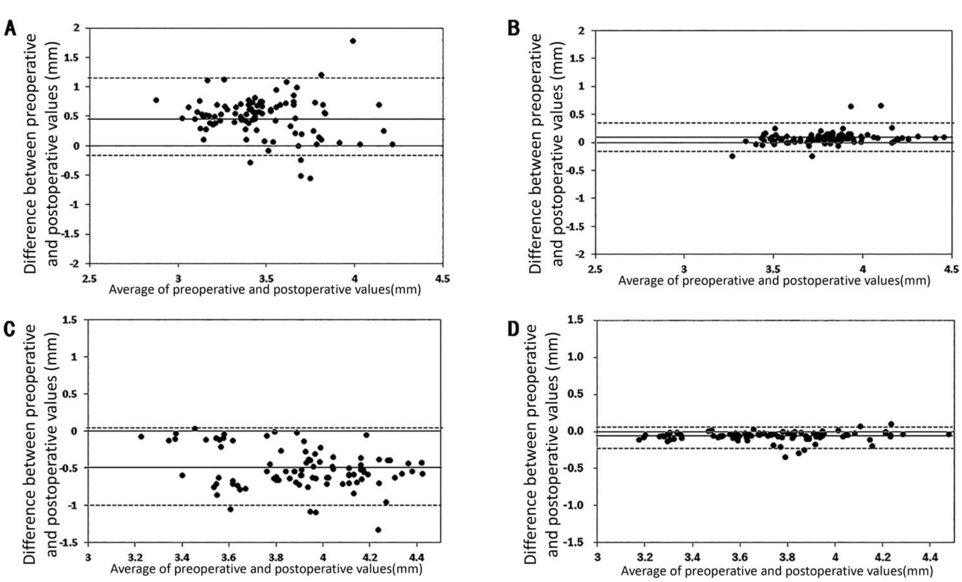

Figure 2. Bland-Altman plots for ACD and LT before and after pIOL insertion. (*A*) ACD values measured using PCI, (*B*) ACD values measured using AS-OCT, (*C*) LT values measured using PCI, and (*D*) LT values measured using AS-OCT. Solid line: mean value of the difference between the measured values. Dashed line: upper and lower bounds of the 95% CI. ACD = anterior chamber depth; LT = lens thickness; PCI = partial coherence interferometry; pIOL = phakic IOL

Table 2. Results of Biometry Before and After Implantation of Posterior Phakic IOL.

Biometry	Preoperative	Postoperative	*P* value[a]
Axial length (mm)	26.57 ± 1.27	26.58 ± 1.24	.79
Corneal power (D)	43.61 ± 2.13	43.52 ± 3.88	.43
ACD (mm)			
PCI (all cases, n = 100)	3.72 ± 0.30	3.23 ± 0.34	<.001
PCI (no misidentification, n = 25)	3.79 ± 0.30	3.72 ± 0.35	.06
PCI (misidentification, n = 75)	3.71 ± 0.30	3.20 ± 0.34	
AS-OCT	3.84 ± 0.28	3.79 ± 0.25	.05
LT (mm)			
PCI (all cases, n = 100)	3.70 ± 0.33	4.19 ± 0.38	<.001
PCI (no misidentification, n = 25)	3.88 ± 0.30	3.83 ± 0.27	
PCI (misidentification, n = 75)	3.84 ± 0.28	3.87 ± 0.23	
AS-OCT	3.71 ± 0.30	3.77 ± 0.31	.08

ACD = anterior chamber depth; LT = lens thickness; misidentification = cases in which the segmentation line indicating the anterior surface of the lens was mistakenly placed on the anterior surface of the posterior phakic IOL during postoperative measurement; PCI = partial coherence interferometry
[a]One-sample *t* test

Previous comparisons of axial length measurements taken before and after pIOL implantation did not report any significant changes.[8,9] Similarly, in our study, the difference between pre-pIOL and post-pIOL implantation axial length was only 0.01 mm, and was not statistically significant. The mean axial length of the cases targeted in this study was 26.57 mm, a rather large value; this may have further minimized the effects of changes in this value on calculations of IOL power. However, vitreous liquefaction and posterior vitreous detachment are believed to occur early in eyes with severe myopia, and particularly, in eyes with long axial length. These factors are believed to lead to changes in refraction in large volume areas of the eye and thereby potentially affect the measurements of optical path length.[10] However, here, we compared preoperative and early postoperative data (1 month postoperatively) and considered that it was not necessary to take these other factors into account. Furthermore, corneal power, another important factor when calculating IOL power, is affected by variables such as tearing during measurement, but in this study population, the preoperative and postoperative difference in corneal power was less than 0.1 diopters (D).[11]

On the one hand, there were issues with ACD measurement, and significant differences were observed in the values measured preoperatively and postoperatively. Although there have been several reports that used anterior segment analysis devices to explore changes in ACD before and after pIOL implantation, all these defined postoperative ACD as the distance from the corneal endothelium to the anterior surface of the pIOL, which is different from the definition used in this report.[4,5,12] On the other hand, in an existing report that used an older PCI model (IOL Master 500), postoperative measurements were reported to have decreased by 0.27 mm.[6] However, the IOL Master 500 takes measurements using the lateral slit illumination method. Not only does this method result in intersubject reproducibility issues, but it is also quite likely that this approach frequently misidentified the anterior pIOL surface as the anterior lens surface. By contrast, in the PCI used in this study (IOL Master 700), anterior depth measurements were also based on optical coherence tomography images, and the ACD on the visual axis was measured with good reproducibility. It seemed that, in 75% of cases, the anterior surface of the pIOL was mistaken for the anterior surface of the IOL. ACDs measured using PCI differed by approximately 0.5 mm, which was larger than that previously reported. LT measurements were also greatly affected. Under these circumstances, it is clear that IOL powers calculated using the H formula (which is based on axial length and ACD) and the B formula (whose specific equation has not been publicized, but which also incorporates axial length and ACD) would be different. In the aforementioned report in which the IOL Master 500 was used, although ACD measurements reduced by

Table 3. Estimated Lens Powers Before and After Implantation of Posterior Phakic IOL (Estimated Values Aiming for Emmetropia With SN60WF as the Target Lens).

Formula	Preoperative	Postoperative	*P* value[a]	Postoperative substitution	*P* value[a]
SRK/T formula (D)	11.70 ± 3.53	11.61 ± 3.51	.29	11.61 ± 3.51	.29
Haigis formula (D)	12.05 ± 3.60	11.75 ± 3.53	<.001	12.02 ± 3.60	.16
Barret formula (D)	11.78 ± 3.43	11.57 ± 3.37	<.001	11.80 ± 3.43	.55

Barret formula: Barret universal II TK formula. Postoperative substitution: In cases where partial coherence interferometry could not place the segmentation line correctly on the anterior surface of the lens, the anterior chamber depth and lens thickness, measured using AS-OCT, were substituted, and the values were recalculated.
[a]Repeated measures analysis of variance (Bonferroni adjustment)

0.27 mm after pIOL insertion, no difference was observed in powers calculated using any of the formulas, including the H or B formulas, for reasons that are not immediately clear.[6]

Thus, in this study, after using AS-OCT to trace the location of the measured value onto the surface of the crystalline lens, we remeasured ACD and LT values. However, despite this correction, postinsertion ACD and LT values were 0.05 mm shorter and 0.06 mm longer, respectively; we believe these discrepancies to have been caused by manual error introduced during the tracing process. Nevertheless, these differences were significantly smaller than those engendered by PCI measurement. We found that this process could be used to assist in the calculation of IOL power. Ultimately, on substituting these corrected values into the H and B formulas in cases where misidentification had occurred, differences in powers calculated before and after pIOL insertion disappeared.

The excellent accuracy of the B formula, which is generally classified as a fourth generation IOL power calculation formula, has been reported previously.[13] The H formula has also been reported to be as highly accurate as the B formula, in eyes with axial length > 26.0 mm.[14] However, as seen in this study, when used in individuals with implanted pIOLs, there are certain conditions in which both the H and B formulas are affected. On the other hand, the S formula uses only axial length and corneal power for calculations; neither of these parameters changed with pIOL insertion. Furthermore, even if the H and B formulas are used, if values are substituted by those measured using AS-OCT, the estimated IOL powers no longer differ from those calculated preoperatively.

This study had certain limitations. This was a single-center preintervention/postintervention trial and included a geographically limited population. Moreover, age-related changes of corneal aberration, LT, or vitreous should be considered further in actual clinical practice. Meier et al. reported that 57.9% and 82% cases registered less than 0.5 D and 1.0 D postoperative refractive error using the S formula in cataract surgery concurrent with pIOL extraction.[15]

A main unresolved issue with these study results is that because a small difference was observed even with measurements taken using AS-OCT, it remains unclear whether pIOL insertion truly shortens ACD or whether it simply affects the fidelity of measurement techniques. In addition to having low refractive power, all pIOLs are concave lenses. Thus, they have, at most, a small impact on light measured at the optical center. Nevertheless, cases with pIOL correction for hyperopia, which involve a large center thickness, need to be considered. Further studies should be conducted once ACD measurement in pIOL-implanted eyes has been fully automated.

In conclusion, if a patient with a pIOL requires cataract surgery, it is possible to calculate IOL power without pre-pIOL data. However, although the biometric measurement can be used directly if applying the S formula, when the H or B formulas are used, there is a need to verify whether the PCI has correctly identified the anterior surface of the crystalline lens. If a misidentification has occurred, AS-OCT or another form of measurement must be used to make correct ACD and LT measurements, and these values can then be substituted back into the formula to obtain a result approximating that which would have been calculated with measurements taken in the absence of the pIOL. In the future, the aforementioned explorations of measured values for ACD in pIOL-implanted eyes are necessary to gain further insight into the factors at play in this situation.

WHAT WAS KNOWN

- Phakic IOL (pIOL) implantation surgery does not alter the axial length but could potentially change the measured value of the anterior chamber depth (ACD).
- IOL power calculation using the third or fourth generation formula has shown excellent accuracy even in pIOL-implanted eyes.
- The impact of change of ACD on IOL power calculation following pIOL implantation, using partial coherence interferometry (PCI), has not been assessed.

WHAT THIS PAPER ADDS

- PCI measurement misidentifies the lens surface in 75% of pIOL-implanted eyes.
- The estimated IOL power was significantly lower at post-pIOL implantation according to the H and B formulas (both $P < .001$), whereas the S formula was not affected.

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Disclosures: *None reported.*

First author:
Masayuki Ouchi, MD, PhD

Masayuki Ouchi Eye Clinic, Minami-ku, Kyoto, Japan