

Intraocular lens power calculation after two different successive corneal refractive surgeries

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ABSTRACT

Purpose: To report two challenging intraocular lens power calculation cases with patients each underwent different successive corneal refractive surgeries, respectively.

Observations: Biometry data, including the Back to Front corneal radii ratio (B/F ratio), were collected by Lenstar, IOL Master, and Pentacam AXL for Case 1 (received radial keratotomy (RK) and photorefractive keratectomy (PRK)) and Case 2 (received RK and laser-assisted in situ keratomileusis (LASIK)). The IOL power calculation was determined by several methods, including Shammas, Haigis-L, and Barrett True-K, which are available in the American Society of Cataract and Refractive Surgery online calculator and Pentacam AXL. The Barrett True-K (no history, post-RK) was more accurate in Case 1 (increased B/F ratio), whereas the Shammas, Haigis-L, and Barrett True-K (no history, post-LASIK/PRK) were more accurate in Case 2 (decreased B/F ratio).

Conclusion and importance: The B/F ratio may be a factor to be considered when selecting the IOL power calculation formula for patients who undergo two different corneal refractive surgeries. The further study focusing on this issue should be performed to clarify the results in the future.

1. Introduction

Radial keratotomy (RK) was frequently performed in the 1980s and 1990s to correct myopic refractive errors in China. However, the risk of refractive errors still exists after RK. As refractive errors after RK are often undercorrected or overcorrected, photorefractive keratectomy (PRK) or laser-assisted in situ keratomileusis (LASIK) are usually used to correct the residual refractive errors.^{1–3} This creates a challenge to calculate the intraocular lens (IOL) power in patients receiving both RK and LASIK/PRK.

The ratio between the anterior and posterior corneal surface is always altered.⁴ The Back to Front corneal radii ratio (B/F ratio) is decreased after myopic LASIK/PRK, while it is increased after hyperopic LASIK/PRK, which makes keratometric index invalid.⁵ In contrast, the B/F ratio increases after RK in most cases.⁶ The changes of the relationship between the anterior and posterior cornea are less changes in RK than in LASIK/PRK.⁷ The average value of B/F ratio is reported to be around 84% in normal eyes.⁸ However, this value is quite variable. M. Kim et al.⁹ used the posterior/anterior corneal curvature radii ratio to improve the accuracy of IOL power calculation, called Eom's

Adjustment Method. Therefore, the B/F ratio maybe an important factor to affect the selection of IOL power calculation formulas.

The American Society of Cataract and Refractive Surgery (ASCRS) online calculator (<https://ascrs.org/tools/iol-calculator>) is recommended for the calculation of IOL power after refractive surgery in patients with prior myopic LASIK/PRK or RK,^{7,10} including seven LASIK/PRK calculators: Double-K Holladay 1, Shammas-PL, Haigis-L, Barrett True K (post LASIK/PRK, "history" and "no history" options), Masket, Modified-Masket and OCT-based; three RK calculators: the Barrett True K (post RK, "history" and "no history" options), Double-K Holladay 1 and OCT-based. These calculators require entry of the optical biometric data measured by the IOL Master/Lenstar or other devices. Recently, some formulas have been provided for the Pentacam AXL to calculate the IOL power after refractive surgery,⁵ including Double-K Holladay 1, Potvin-Hill Shammas PM, Hill Potiv Post RK, Barrett True K (post LASIK/PRK or post RK).

Although many formulas have been used to calculate the IOL power after refractive surgeries,⁵ Barrett True-K (post-LASIK/PRK) is considered to be either equal to or better than alternative methods available on the ASCRS online calculator for predicting IOL power in eyes with

Abbreviations: IOL, Intraocular lens; RK, Radial keratotomy; LASIK, Laser-assisted in situ keratomileusis; PRK, Photorefractive keratectomy.

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myopic LASIK/PRK previously.¹¹ When no refractive history is available in eyes with RK, Barrett True-K (post-RK) also performs well.⁷ However, few reports have discussed the suitable formula to predict IOL power for the patients who have undergone RK combined with LASIK/PRK corneal refractive surgeries.¹² Here, we report the IOL power calculations of two cases with different B/F ratios who underwent RK combined with LASIK/PRK.

2. Case report

2.1. Case 1

A 45-year-old man came to our hospital with complain of poor near vision and far vision. In 1991, he underwent bilateral RK for myopia at another hospital at the age of 22. His uncorrected distance visual acuity (UDVA) was improved in both eyes after surgery. However, his vision gradually decreased due to myopia regression. He therefore underwent PRK in 2002. Unfortunately, his vision was overcorrected after PRK, and he had to wear a pair of hyperopia glasses.

An ocular examination revealed a UDVA of 20/63 in the right eye and 20/50 in the left eye. The corrected distance visual acuity (CDVA) was 20/25 in both eyes, and the objective refraction was +3.50DS/+1.75DC \times 160° (subjective refraction: +3.00DS/+1.75DC \times 160°) in the right eye and +3.75DS/+1.25DC \times 160° (subjective refraction: 3.50DS/+1.00DC \times 170°) in the left eye. Both corneas had eight cut RK wounds and PRK wounds, and the patient had mild cataract in both eyes (Figs. 1 and 2). The optical zone of each cornea was 3.0 mm horizontally and 2.5 mm vertically approximately. No obvious abnormality was found in the vitreous and fundus. Refractive cataract surgery was suggested for both eyes after thorough discussion with the patient to explain the risks and complications, including refractive errors. We used the Lenstar LS900 (Haag-Streit, Switzerland), IOL Master 500 (Carl Zeiss Meditec AG, Jena, Germany), and Pentacam AXL (Oculus, Wetzlar, Germany) to collect his keratometry and biometry data (Table 1). The data collected by the Lenstar LS900 and IOL Master 500 were input into the ASCRS online calculator, and five formulas (post-RK or post-LASIK/PRK) were used for the IOL power calculation (Table 2). The B/F ratio measured by the Pentacam AXL was 104.9% in the right eye (Fig. 3), and 100.8% in the left eye (Fig. 4).

Phacoemulsification and IOL implantation were first performed in the left eye. A 2.4 mm upper scleral tunnel incision and a 5.0 mm continuous circular capsulorhexis were made. Cataract extraction was performed with the phaco chop technique. A SA60AT 30.0D IOL (Alcon, USA) was implanted into his left eye. The A-constant 118.8, SF 1.67, a_0

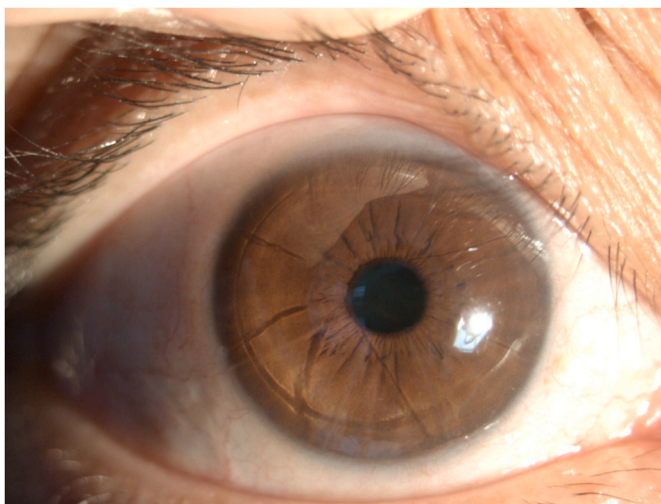


Fig. 1. Anterior segment photographs of the right eye.

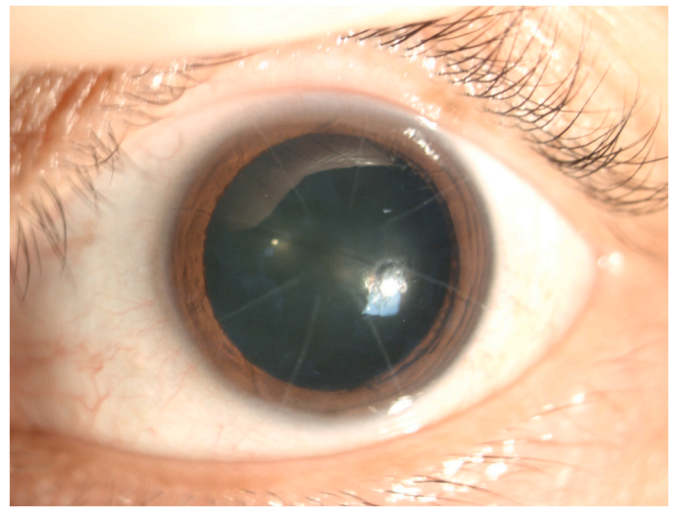


Fig. 2. Anterior segment photographs of the left eye (dilated pupil).

-0.111, a_1 0.249, and a_2 0.179 were used. A proper IOL power was chosen according to the Barrett True-K (no history) formula with the target refraction power set at 0D. At one month after the surgery for the left eye, the UDVA was 20/32, the CDVA was 20/20, and the objective refraction was +1.25 DC \times 160° (subjective refraction: +1.00DC \times 160°). On the same day, cataract surgery was performed in his right eye, together with implantation of a SA60AT 30.0D IOL (Alcon, USA). At one month after the surgery for the right eye, the UDVA of the right eye was 20/40, the CDVA was 20/25, and the objective refraction was +1.75DS/-3.00DC \times 75° (subjective refraction: +1.75DS/-3.00DC \times 75°).

At about one year after the surgery, the UDVA and CDVA for both eyes remained the same as the data obtained one month after the surgery. However, the objective refraction of the right eye was +0.75DS/-3.00DC \times 75° (subjective refraction: +0.50DS/-2.75DC \times 75°) and the spherical equivalent (SE) was -0.75D, while the objective refraction of the left eye was +0.50DS/-1.50DC \times 75° (subjective refraction: +0.50DS/-1.50DC \times 75°) and the SE was -0.25D. The IOL power was recalculated using the methods provided by ASCRS website and Pentacam AXL, and the post-operative target refraction was set to -0.75D for right eye and -0.25D for left eye. The differences from the actual IOL power used (30D) were shown in Table 2. In general, Barrett True-K (no history, post-RK) performed better than Barrett True-K (no history, post-PRK) and other formulas to predict IOL power (Table 2). However, one exception was that Barret True-K (no history, post-PRK) was more accurate in IOL power calculation when Pentacam AXL was used (Table 2).

2.2. Case 2

A 51-year-old man underwent bilateral RK to correct myopia 20 years ago. Due to regression, he underwent LASIK in his left eye 10 years ago.

Before the surgery, the UDVA was 20/200 in both eyes. The CDVA was 20/80 in the right eye and the objective refraction was -15.00DS/-3.00DC \times 100° (subjective refraction: -14.50DS/-3.00DC \times 100°). The CDVA was 20/63 in the left eye and the objective refraction was -12.00DS/-2.00DC \times 100° (subjective refraction: -11.75DS/-1.75DC \times 100°). The corneas had twelve RK cuts in the left eye. The optical zone of the cornea in left eye was 3.2mm horizontally and 3mm vertically approximately.

We also used the Lenstar LS900, IOL Master 700, and Pentacam AXL to collect his keratometry and biometry data (Table 3). The data collected by the Lenstar LS900 and IOL Master 700 were input into the ASCRS online calculator, and six formulas (post-RK or post-LASIK/PRK) were used for IOL power calculation (Table 2). The B/F ratio measured

Table 1
Biological parameters measured by different devices (Case 1).

Devices	Right eye							Left eye						
	AL	K1	K2	Km	ACD	WTW	LT	AL	K1	K2	Km	ACD	WTW	LT
Lenstar LS900	24.91	31.91	34.66	33.29	2.97	12.42	4.75	25.02	31.74	33.57	32.66	3.15	12.2	4.71
IOLMaster500	24.88	32.17	35.30	33.5	2.72	12.0	–	25.02	32.08	34.40	33.24	3.24	12.1	–
Pentacam AXL	24.839	32.3	34.8	33.5	2.97	11.8	–	25.01	32.9	33.8	33.4	3.04	11.8	–

Table 2
Intraocular lens power is calculated using formulas from the ASCRS online calculator with Lenstar LS 900 and IOL Master data and the Pentacam AXL (Case 1).

Parameters measured by	Condition	Formula	Right eye		Left eye	
			IOL power (Target refraction)	Difference from the actual IOL power used (30D)	IOL power (Target refraction)	Difference from the actual IOL power used (30D)
Lenstar LS900	Post PRK	Shammas	33.85	3.85	33.79	3.79
		Haigis-L	35.14	5.14	35.52	5.52
		Barrett True-K (no history)	31.43	1.43	31.34	1.34
	Post RK	Double-K Halladay 1	32.45	2.45	32.36	2.36
		Barrett True-K (no history)	30.15	0.15	30.04	0.04
IOL Master 500	Post PRK	Shammas	33.30	3.30	32.95	2.95
		Haigis-L	34.21	4.21	34.42	4.42
		Barrett True-K (no history)	30.90	0.90	30.72	0.72
	Post RK	Double-K Halladay 1	31.92	1.92	31.56	1.56
		Barrett True-K (no history)	29.63	−0.37	29.45	−0.55
Pentacam AXL	Post PRK	Hill Potiv Shammas PM	28.11	−1.89	28.06	−1.94
		Barrett True-K (no history)	31	1	30.25	0.25
	Post RK	Double-K Halladay 1	31.25	1.25	31.09	1.09
		Hill Potiv Post RK	30.96	0.96	30.97	0.97
		Barrett True-K (no history)	29.75	0.25	29	1

Note: 1. Double-K Halladay 1 was also used to post LASIK/PRK.
2. AL, K, and ACD measured by Lenstar and IOL Master were input into ASCRS calculator.
3. The IOL Power given by Barrett True-K in Pentacam AXL was estimated.

by the Pentacam AXL was 77.3% in his left eye (Fig. 5).

Phacoemulsification and IOL implantation were performed in his left eye in our hospital. A 21.5D SN60WF IOL (Alcon, USA) (Target power was set to about -3D) was implanted in his left eye using A-constant 119.0, SF 1.84, a_0 -0.769, a_1 0.234, and a_2 0.217.

At about 6 months after the surgery, the UDVA of the left eye was 20/40, and the CDVA was 20/20. The objective refraction of the left eye was $-3.50DS/-0.75DC \times 90^\circ$ (subjective refraction: $-3.50DS/-0.75DC \times 90^\circ$) and the SE was $-3.875D$. The IOL power was recalculated using the methods provided at ASCRS website and Pentacam AXL with the post-operative target refraction set as $-3.875D$ for OS. The differences of the calculated IOL power from the actual IOL power used (21.5D) were shown in Table 4. Haigis-L formula had the good prediction performance (Difference: $-0.11D$) when data was obtained by Lenstar LS900, and Shammas formula performed well when IOL Master 700 (Difference: $-0.12D$) was used for measurements. The Barrett True-K (no history, post-LASIK/PRK) was the most accurate formula regardless Pentacam AXL (Difference: $0D$) or Lenstar LS900 (Difference: $-0.08D$) used.

3. Discussion

Over the last 15 years, ophthalmic community has developed more than 30 methods to calculate IOL power for the eyes after corneal refractive surgery.⁴ Regardless of whether the patient is post-LASIK/PRK or post-RK, the IOL power calculation formula can be divided into a with-clinical-history methods and a no-clinical-data methods, according

to the availability of clinical data before the corneal surgery.¹³ Recently, researchers began to focus on new methods, those do not rely on pre-operative data, mainly because of the uncertainty of preoperative data and poor accuracy of old measurement equipment. The main aim of the present study was to study the accuracy of IOL power calculation formulas, which do not rely on preoperative data in the patients who have undergone RK and LASIK/PRK. In comparison, preoperative K value is necessary for the Double K method.¹⁴ If the value is unavailable, a corneal power of 43.86 D is used to estimate the effective lens position (ELP).

A growing number of ophthalmologists are using ASCRS online calculator to calculate IOL power and evaluating its accuracy for IOL power calculation after corneal refractive surgery.^{10,15,16} The Barrett True-K formula with or without previous data (post-LASIK/PRK or post-RK) gave better results in comparison with various methods and formulas from the ASCRS online calculator.^{11,12,15-18} In case 1, the Barrett True-K (no history, post-RK) formula from the ASCRS online calculator predicted more accurately with the data (AL, K, ACD) from both IOL Master 500 and Lenstar LS900, with the differences from the actual IOL power less than 1D. For the right eye of case 1, our results showed that Barrett True-K (no history, post-RK) was better than Barrett True-K (no history, post-PRK) when using AL/K/ACD either with or without the lens thickness (LT) measured by the Lenstar LS900. However, the calculation results of the patient's left eye using Pentacam AXL did show that Barrett True-K (no history, post-PRK) was slightly better than the one post-RK. We could not exclude the possibility that our

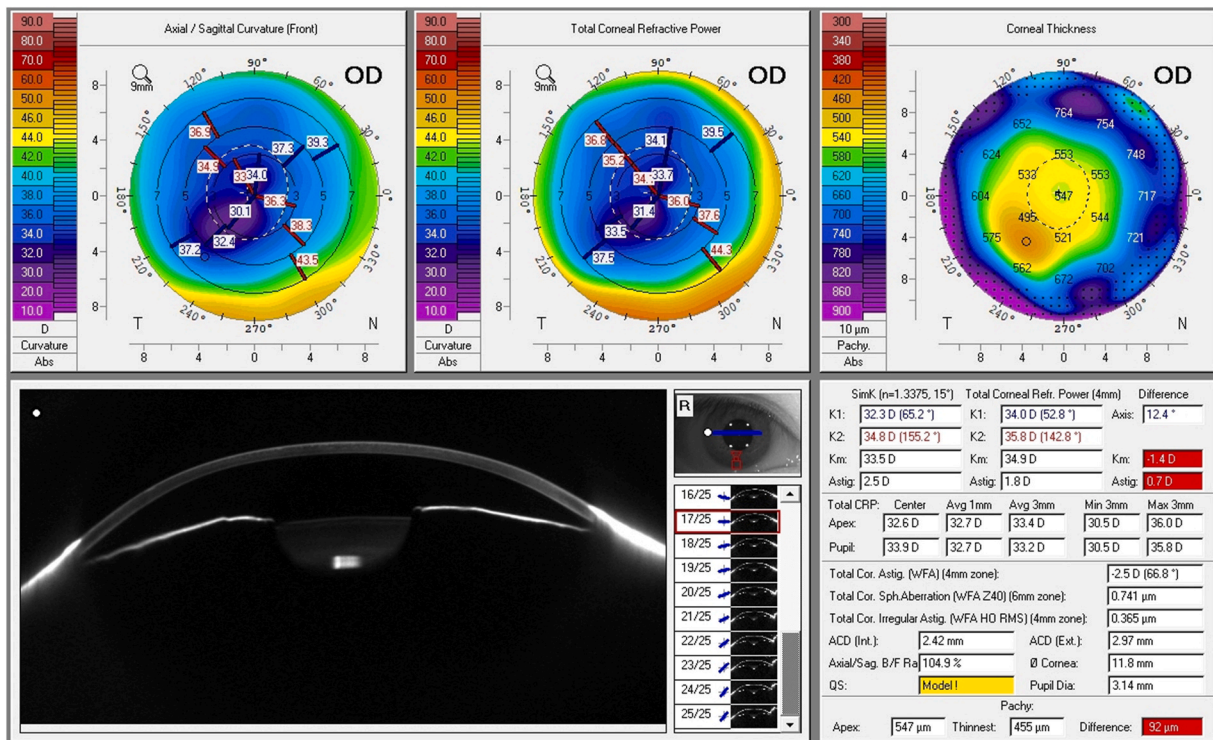


Fig. 3. Pentacam cataract pre-op mode of the right eye (the B/F ratio was 104.9%).

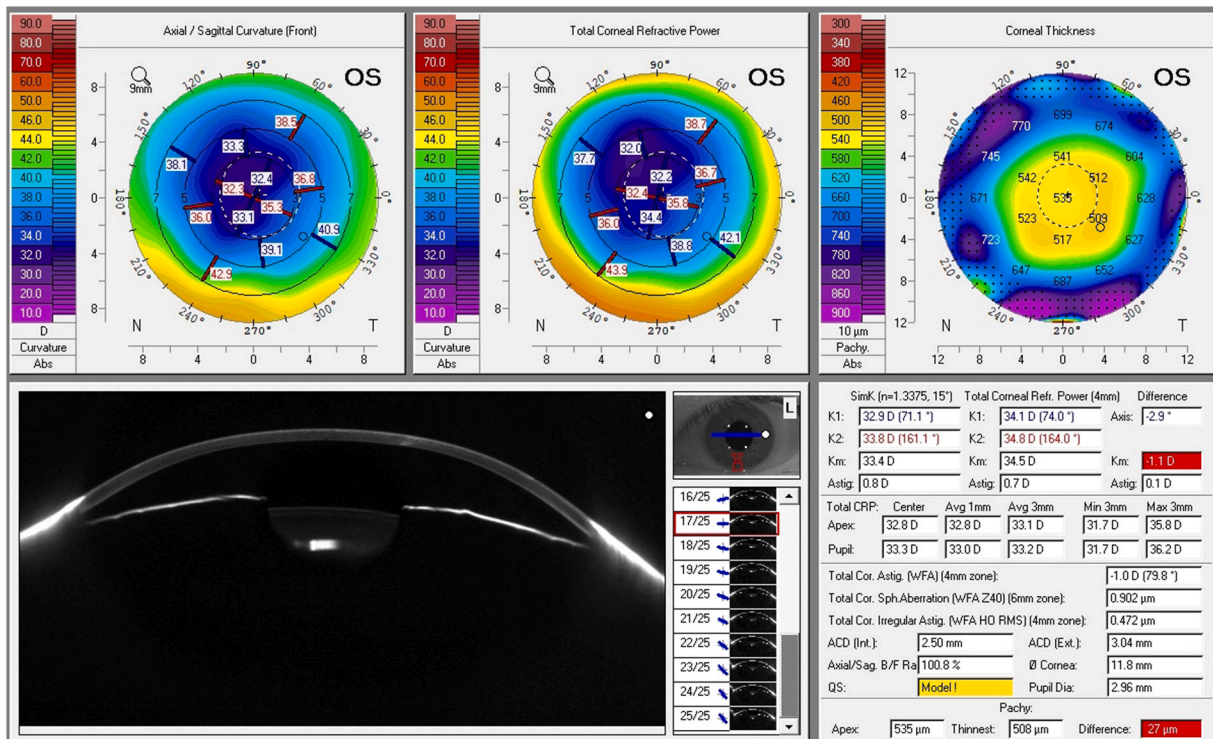


Fig. 4. Pentacam cataract pre-op mode of the left eye (the B/F ratio was 100.8%).

measurements may be restricted by the accuracy of curvature and other parameters collected by the device. For example, the parameters used for calculation, which were obtained by Pentacam AXL, like the diopter of K, were greater than IOL Master 500 and Lenstar LS900. Moreover, Pentacam AXL is unable to measure LT value. The Shammas and Haigis-L were inappropriate for this case, and this observation was

different from a previous report which calculates the IOL power of a patient who received both RK and LASIK.¹² In case 1, the B/F ratio measured by the Pentacam AXL was increased (OD:104.9%, OS: 100.8%). This is because the relationship between the anterior and the posterior surfaces of the cornea was altered in the eyes that had undergone ablative corneal refractive surgeries previously.¹⁹ This is

Table 3
Biological parameters measured by different devices (Case 2).

Devices	Left eye						
	AL	K1	K2	Km	ACD	WTW	LT
Lenstar LS900	30	36.23	36.59	36.41	3.68	12.12	4.38
IOL Master700	29.92	35.66	36.18	35.92	3.71	12.1	4.37
Pentacam AXL	29.943	36.1	36.8	36.5	3.73	11.9	-

consistent with the characteristics of patients who underwent RK only, while it is different from patients who underwent only myopia LASIK/PRK (B/F ratio decreased). Using the Sim K and True Net Power (TNP) (4mm, Apex, zone) provided by Pentacam based on Liu's report,¹² the calculated B/F ratio of that patient was 73.76%, which is less than the normal eyes and the eyes of case1, but close to the right eye of case 2 (OS:77.3%). In case 2, the Haigis-L and Barrett True-K (no history, post-LASIK/PRK) used the data from the Lenstar LS900 performed well, whereas the Barrett True-K (no history, post-LASIK/PRK) had better prediction results when using the Pentacam AXL, which was similar to the findings of Liu's report.¹²

However, the Barrett True-K (no history, post-LASIK/PRK) was not, but the Shammas formula was the most accurate formula with the data from the IOL Master 700. The reason might be the differences of the Km values. The range measured by IOL Master 700 (3.5mm) was larger than the optical zone in the cornea of case 2, which results in the smallest Km value measured by IOL Master 700 (35.92D) among three machines.

The B/F ratio of the patients was decreased after myopic LASIK/PRK, and the conventional formula overestimated the corneal refractive power. The Shammas, Haigis-L, and Barrett True-K all use a regression formula to correct the corneal refractive power. When a patient undergoes both RK and LASIK/PRK, the B/F ratio may decrease or increase. In our two cases both patients underwent RK surgery first. After RK, the B/F ratio (4mm zone measured by Pentacam) may be in the normal range. If myopic LASIK/PRK was performed on such cornea, the anterior surface of the cornea would be cut flat, the radius of curvature of the anterior surface would be increased, and the B/F ratio would be

decreased. Clinically, the B/F ratio increases significantly in most patients with simple RK. For these patients, B/F ratio could not be reduced below the normal range after myopic LASIK/PRK, and the final ratio is still increased. When the B/F ratio is decreased, the calculation results of the Shammas, Haigis-L, and Barrett True-K (no history, post LASIK/PRK) are recommended. However, the formulas in the post RK condition, such as the Barrett True-K (no history, post RK), may be better than the ones in the post LASIK/PRK condition when it is increased. We detected the differences in the preoperative curvature measured by the different devices in the RK patients, which were related to the amount of RK surgical incisions or the area of the cornea that had not been radially cut.

Due to the swelling of the RK incision and temporary flattening of the cornea, the early refractive measurements of these patients after cataract surgery were often unreliable. The patients with a history of RK are well-known to be hyperopia initially, and then followed by partial myopia regression subsequently. These phenomena leveled off after 3 months.⁷ The follow-up time of our two cases were more than half a year, and the process of hyperopia and myopia regression was observed.

In addition, Savini et al.⁴ suggested that surgeons should also consider the diurnal variation of refraction when dealing with post-RK eyes and evaluating the refractive outcome of IOL power calculation. For some RK patients, diurnal fluctuation in visual acuity and refraction restricted them to wear proper glasses, and the refraction shift from hyperopia in the morning to myopia at the night due to steepening of the cornea.²⁰ According to Koppen C's report,²⁰ we suggested that the corneal curvature should be measured in the morning to avoid post-operative hyperopia when calculating the IOL power for these patients. Thus, the preoperative corneal curvature and postoperative refraction of our two cases were collected in the morning. Considering that we didn't focus on the effects of diurnal variation of corneal curvature and the refraction for the IOL calculation, the further study should be performed in the future.

Based on the results of these two cases, we propose that the formulas in post-LASIK/PRK condition, such as Shammas, Haigis-L, and Barrett True-K (no history, post-LASIK/PRK) maybe more accurate when the B/F ratio is decreased. However, when the B/F ratio increases, the

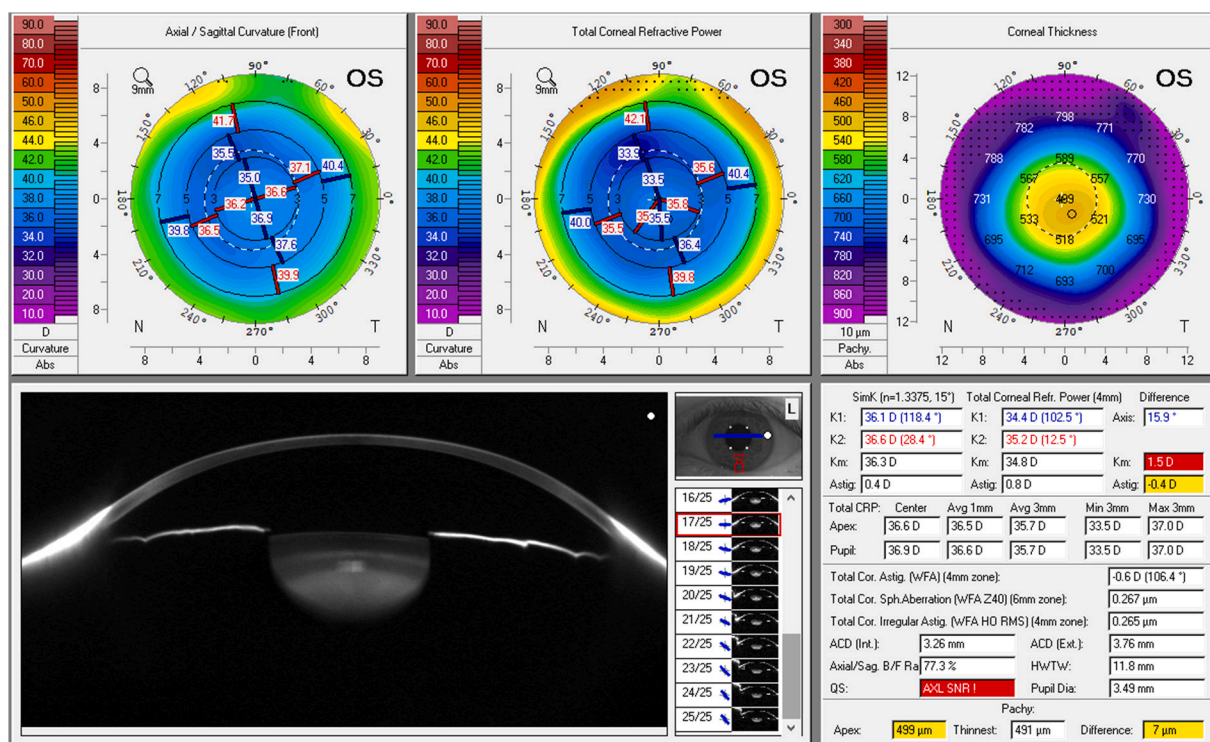


Fig. 5. Pentacam cataract pre-op mode of the left eye (the B/F ratio was 77.3%).

Table 4

Intraocular lens power is calculated using formulas from the ASCRS online calculator with Lenstar LS 900 and IOL Master data and the Pentacam AXL (Case 2).

Parameters measured by	Condition	Formula	Left eye	
			IOL power (Target refraction)	Difference from the actual IOL power used (21.5D)
Lenstar LS900	Post LASIK	Shammas	20.51	-0.99
		Haigis-L	21.39	-0.11
		Barrett True-K (no history)	21.58	-0.08
	Post RK	Double-K	17.98	-3.52
		Halladay 1		
		Barrett True-K (no history)	20.15	-1.35
IOL Master 700	Post LASIK	Shammas	21.38	-0.12
		Haigis-L	22.47	0.97
		Barrett True-K (no history)	22.30	0.8
	Post RK	Double-K	18.85	-2.65
		Halladay 1		
		Barrett True-K (no history)	20.86	-0.64
Pentacam AXL	Post LASIK	Hill Potiv	20.5	-1
		Shammas PM		
		Barrett True-K (no history)	21.5	0
	Post RK	Double-K	18	-3.5
		Halladay 1		
		Hill Potiv Post RK	17.5	-4
		Barrett True-K (no history)	20	-1.5
		Olsen Ray tracing	20.5	-1

Note: 1. Double-K Halladay 1 was also used to post LASIK/PRK.

2. The IOL Power given by Barrett True-K in Pentacam AXL was estimated.

formulas such as the Barrett True-K (no history) in the post RK condition may be better than other conditions. More cases are needed to confirm these findings. In addition, we look forward to reading more reports evaluating the accuracy of IOL power calculation in patients with both RK and LASIK/PRK as well as the development of new relevant formulas.

Patient consent

The written consent was obtained from the patient.

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Authorship

All authors attest that they meet the current ICMJE criteria for

Authorship.

Declaration of competing interest

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