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ORIGINAL PAPER

Assessment of total corneal power after myopic corneal refractive surgery in Chinese eyes

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Abstract
Purpose To develop a new regression formula based on the Gaussian thick lens formula and to verify the accuracy of the regression formula.
Methods In this prospective study, 207 eyes of 207 myopic subjects and 133 eyes of 67 postoperative subjects were included. For the 133 postoperative eyes, 127 eyes underwent laser-assisted in situ keratomileusis, and 6 eyes underwent photorefractive keratectomy. Subjective refraction and Pentacam HR were performed preoperatively and postoperatively, and IOLMaster was performed in the postoperative group. Sim$K$, keratometry based on the Gaussian optic formula (K_{GOF}), K_{CHM} obtained using the clinical history method, and the regression formulas K_{RF1} and K_{RF2} were calculated.
Results (1) A statistically significant difference (t = 155.164, P = 0.000) between Sim$K$ and K_{GOF} of 1.24 ± 0.12 D was observed, and there was a good correlation between Sim$K$ and K_{GOF} (r = 0.996, P = 0.000). The first regression formula ($K_{RF1} = 0.351 + 1.021 \times K_{GOF}$) was obtained using linear regression. (2) Statistically significant differences (t = 19.114, − 25.184, 4.702, and all P = 0.000) between Sim$K$ and K_{CHM}, K_{GOF} and K_{CHM} and K_{RF1} and K_{CHM} of 0.75 ± 0.45 D, 0.96 ± 0.44 D and 0.18 ± 0.43 D, respectively, were obtained. Good correlations between Sim$K$ and K_{CHM}, K_{GOF} and K_{CHM} and K_{RF1} and K_{CHM} (all $r \geqq 0.977$, all Ps = 0.000) were also observed. The regression formula ($K_{RF2} = -1.204 + 1.027 \times K_{RF1}$) was obtained using linear regression. (3) Six methods were used for the prediction of IOL power in the postoperative group. The highest results were obtained from the Shammas formula (without preoperative data) combining K_m (obtained by IOLMaster) followed by the K_{CHM} and K_{RF2} combining Haigis formula. The third was obtained from the K_{CHM} and K_{RF2} combining Hoffer Q formula; and the smallest was the K_m combining Haigis formula.
Conclusion The IOL power predicted by K_{RF2} in eyes after myopic CRS may be accurate.

Keywords Corneal refractive surgery · Corneal power · Intraocular lens power · Keratometric index · Pentacam HR

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Introduction

The prediction of intraocular lens (IOL) power for eyes after keratorefractive surgery is a puzzle for cataract and refractive surgeons. Conventional methods of IOL power prediction may lead to "hyperopia surprise" postoperatively [1, 2]. The reason for the predicted error is attributed to three factors [3]. First, the total corneal power measurement for eyes after corneal refractive surgery (CRS) is inaccurate [4]. Currently, the corneal power (ordinarily named simulated keratometry, Sim*K*) obtained using conventional keratometry or corneal topography is determined using the combination of anterior corneal curvature within the certain central zone (r), the standard corneal refractive index (1.3375) [5–7] and the refractive index of air (1.000): $\mathrm{Sim}K = (1.3375 - 1.000)/r$. The ratio of anterior to posterior corneal curvature is a hypothesized constant of 1.13 [27]. The ratio is close to this constant for most virgin eyes. However, the actual ratio may be faraway from this constant in eyes after keratorefractive surgery, and the formula may lead to inaccurate results. Second, the prediction of effective lens position (ELP) that is used in the third-generation IOL formula is not accurate for eyes after keratorefractive surgery [8]. ELP in the third-generation IOL formula is calculated based on corneal height, which is calculated according to corneal curvature. Therefore, a steep cornea corresponds to a deep ELP and a flat cornea corresponds to a shallow ELP. This relationship does not exist in eyes after keratorefractive surgery, and the ELP prediction is wrong. Third, the corneal refractive index changes after surgery [9, 10].

Devices that can detect information from the posterior corneal surface have been applied in clinical ophthalmology since the 1990s, including the slit-scan system (e.g., Orbscan, Bausch and Lomb, America) [11–14], the Scheimpflug rotating camera system (e.g., Pentacam, Oculus, Germany) [15–18] and anterior segment optical coherence tomography (AS-OCT) [19, 20]. These devices allow the calculation of total corneal power using the Gaussian thick lens formula based on anterior and posterior corneal curvatures and central corneal thickness (CCT). The present study used the Pentacam HR Scheimpflug camera system (Oculus, Germany) to obtain the anterior and posterior corneal curvatures and CCT, and the total corneal power was calculated pre- and postoperatively. And we developed a regression formula of total corneal power based on the Gaussian thick lens formula in Chinese eyes after myopic CRS and verified it preliminarily.

Subjects and methods

Subjects who underwent keratorefractive surgery at Eye Hospital of Wenzhou Medical University between August 2011 and July 2012 were enrolled. All subjects were divided into two groups, the virgin group and the postoperative group. Subjects in the virgin group received ordinary preoperative examinations. Subjects in the postoperative group received ordinary preoperative examinations and uneventful CRS and were followed up 3 months after laser-assisted in situ keratomileusis (LASIK) or 6 months after photorefractive keratectomy (PRK). Flaps of 110 μm were created and the diameters of the optical zone ranged from 6.0 to 7.0 mm (mean 6.61 ± 0.30 mm) for LASIK. The remaining corneal stromal thicknesses ranged from 319 to 419 μm (mean 354.9 ± 25.3 μm). Inclusion criteria were subjects with good communication and cooperation. All subjects had good fixation with their eyes. Subjects who received ordinary preoperative examinations exhibited a best corrected visual acuity ≥ 1.0, a refractive error < 10 diopter (D) spherical and < 1.5 D cylinder, intraocular pressure between 10 and 21 mmHg, and stable refraction for 2 years (refractive change less than 0.5 D annually). Subjects who received postoperative examinations exhibited a best uncorrected visual acuity ≥ 1.0 without severe dry eyes, corneal opacity or other complications. The study adhered to the tenets of the Declaration of Helsinki, and the Office of Research Ethical Committee of the Eye Hospital of Wenzhou Medical University approved the study. All subjects were informed of the purpose of the study and signed an informed consent.

Subjects in this prospective study received routine examinations preoperatively, including subjective refraction, slit lamp examination, fundus examination, intraocular pressure, Topolyzer corneal tomographer, Pentacam HR Scheimpflug camera system (Oculus, Germany) and A-scan pachymetry. Subjective refraction, Pentacam HR Scheimpflug camera system and IOLMaster (Carl Zeiss) were performed for more than 3 months (for LASIK eyes) or 6 month (for PRK eyes) after the surgery. The same sophisticated operator performed all the examinations. Pentacam HR was performed in a dark room. Subjects placed their chin on the chinrest, fixed their eye to the indicator, and opened their eyes wide after blinking. The Pentacam HR automatically captured pictures in 2 s. The results were considered valid when the quality specification displayed “OK.” Three valid results for the same eye were obtained. The anterior corneal curvature, posterior corneal curvature and corneal thickness in a 3-mm central zone were obtained using the Pentacam HR. IOLMaster obtained the axial length (AL), corneal power (K_m), anterior chamber depth (ACD) defined as the distance from the corneal epithelium to the anterior surface of lens, and corneal diameter (CD) for the IOL power calculation.

Assessment of total corneal power:

The anterior and posterior corneal curvatures in certain central zones were named R_a and R_p, respectively. The refractive index of air (n_0) is 1.000. The real corneal refractive index (n_1) is 1.376. The standard corneal refractive index (n) is 1.3375, and the aqueous refractive index (n_2) is 1.336 [21].

1. Simulated keratometry (Sim$K$): The cornea is regarded as a thin lens, and the ratio of R_a to R_p is a constant. Sim$K$ using R_a, n (1.3375) and n_0 (1.000) is calculated as follows:

   $$\text{Sim}K = (1.3375 - 1.000)/R_a = 0.3375/R_a$$

2. Keratometry based on the Gaussian optics formula (K_{GOF}): The cornea is regarded as a thick lens. The R_a, R_p and CCT in certain central zone were obtained, and the K_{GOF} was calculated as follows [21, 22]:

   $$K_{GOF} = (n_1 - n_0)/R_a + (n_2 - n_1)/R_p - (\text{CCT}/n_1) \times [(n_1 - n_0)/R_a] \times [(n_2 - n_1)/R_p]$$

3. Keratometry based on clinical history methods (K_{CHM}) [23]: The following three parameters are needed for the calculation of K_{CHM}: preoperative spherical equivalent (SEQ_{pre}) at the corneal plane, postoperative spherical equivalent (SEQ_{post}) at the corneal plane and preoperative Sim$K$. First, the amount of refractive change is calculated in diopters using the formula: $\Delta\text{SEQ} = \text{SEQ}_{pre} - \text{SEQ}_{post}$. Second, K_{CHM} is calculated using the following formula: $K_{CHM} = \text{Sim}K - \Delta\text{SEQ}$. Sim$K$ was obtained by Pentacam HR in the present study. In several previous studies, this method was a standard for the assessment of corneal power after keratorefractive surgery [15, 18, 24].

Statistical analysis

All data were entered into SPSS17.0 and MedCalc Software (Vision11.4.2.0, MedCalc, Inc.) for statistical analyses. The results are expressed as the mean ± standard deviation (SD). A P value less than 0.05 was statistically significant. Normality of all data distributions was confirmed using the Kolmogorov–Smirnov test (all $Ps > 0.05$) before parametric statistical tests were used for data analyses.

Paired t test and Pearson correlation coefficient analyze differences and correlations between Sim$K$ and K_{GOF} in virgin group. Linear regression analysis analyzed the linear relationship between Sim$K$ and K_{GOF}, and the regression formula was obtained.

The regression formula from the virgin group was applied to obtain the modified corneal power K_{RF1} in the postoperative group. Paired t test and Pearson correlation coefficient analyzed the difference and correlation between K_{RF1} and K_{GOF}. Linear regression analysis analyzed the linear relationship between K_{RF1} and K_{GOF}, and the other regression formula was obtained.

We assumed that the eyes received the uneventful surgery of phacoemulsification and IOL implantation in postoperative group. The IOL of SN60WF (Alcon, USA) was implanted with the target refraction of − 1 D after the surgery. The results of the K_{RF2} combining Haigis and Hoffer Q were compared to other methods.

Results

A total of 207 eyes (109 right and 98 left) of 207 subjects (121 men, 59%) with a mean age of 24.2 ± 5.3 years were included in virgin group. The mean spherical equivalent refraction was − 3.65 ± 1.74 D. A total of 133 eyes (67 right and 66 left) of 67 subjects (30 men, 45%) with the mean age of 23.1 ± 5.0 years were included in postoperative group. A total of 127 eyes underwent LASIK, and 6 eyes underwent PRK. The mean preoperative spherical equivalent refraction was − 5.01 ± 1.91 D (range − 9.50 D to − 1.50 D). The mean postoperative spherical equivalent refraction was 0.03 ± 0.38 D (range − 1.50 D to 0.88 D). The amount of refractive change was 5.05 ± 1.81 D (range 1.25 D to 8.88 D). Table 1 shows the anterior and posterior corneal curvatures and central corneal thickness in the two groups.

Comparison of total corneal power using different methods

Sim$K$ and K_{GOF} in virgin group were 43.42 ± 1.31 D and 42.17 ± 1.27 D, respectively. Sim$K$ was 1.24 ± 0.12 D larger than K_{GOF} (t = 155.164, P = 0.000). Good correlation was observed between Sim$K$ and K_{GOF} (r = 0.996, P = 0.000) (Fig. 1, Tables 2, 3). The regression equation between Sim$K$ and K_{GOF} was obtained from linear regression analysis: $K_{RF1} = 0.351 + 1.021 \times K_{GOF}$ (Fig. 2).

Sim$K$, K_{GOF} and K_{CHM} in postoperative group were 39.22 ± 1.81 D, 37.51 ± 1.88 D and 38.47 ± 2.01 D, respectively. Sim$K$ was 0.75 ± 0.45 D larger than K_{CHM} (t = 19.114, P = 0.000). K_{GOF} was 0.96 ± 0.44 D smaller than K_{CHM} (t = − 25.184, P = 0.000). Good correlations were observed between Sim$K$ and K_{CHM}, K_{GOF} and K_{CHM}. K_{RF1} was 0.18 ± 0.43 D larger than K_{CHM} (t = 4.702, P = 0.000). Sim$K$ was 1.71 ± 0.17 D larger than K_{GOF} (t = 4.702, P = 0.000), and good correlation was observed between Sim$K$ and K_{GOF} (Fig. 3, Tables 3, 4). The following regression equation between K_{CHM} and K_{RF1} was obtained: $K_{RF2} = -1.204 + 1.027 \times K_{RF1}$ (Fig. 4).

The prediction of IOL power in postoperative group obtained by K_m (from IOLMaster) combining Shammas formula [25], K_m combining Haigis formula, K_{CHM} combining Haigis formula, K_{CHM} combining Hoffer Q formula, K_{RF2} combining Haigis formula and K_{RF2} combining Hoffer Q formula were 23.97 ± 1.77 D, 22.71 ± 1.67 D, 23.68 ± 1.64 D, 23.29 ± 1.66 D, 23.65 ± 1.66 D and 23.29 ± 1.69 D, respectively. The result from the Shammas formula was the highest followed by the K_{CHM} combining Haigis formula and the K_{RF2} combining Haigis formula. The K_{CHM} combining Hoffer Q formula and K_{RF2} combining

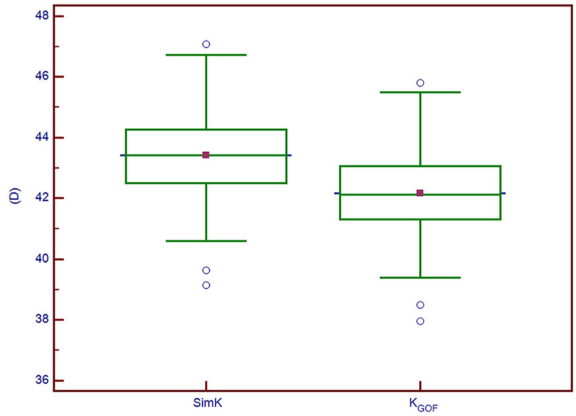

Fig. 1 Comparison graph of Sim$K$ and K_{GOF} in the virgin group

Table 2 Keratometry obtained by different algorithms

Parameters	Mean ± SD	Min	Max
Virgin eyes			
Sim$K$ (D)	43.42 ± 1.31	39.15	47.09
K_{GOF} (D)	42.17 ± 1.27	37.98	45.80
Postoperative eyes			
Sim$K$ (D)	39.22 ± 1.81	33.73	43.43
K_{GOF} (D)	37.51 ± 1.88	31.77	41.58
K_{CHM} (D)	38.47 ± 2.01	31.68	43.18
K_{RF1}	38.64 ± 1.92	32.78	42.81

Sim$K$ simulated Keratometry, K_{GOF} keratometry based on Gaussian optics formula, K_{CHM} keratometry based on clinical history method

Table 1 The $R_{anterior}$, $R_{posterior}$ and CCT in the virgin and postoperative eyes

Parameter	Mean (D) ± SD	Min	Max
Virgin eyes			
$R_{anterior}$ (mm)	7.780 ± 0.235	7.167	8.620
$R_{posterior}$ (mm)	6.341 ± 0.225	5.753	6.963
CCT (μm)	541.67 ± 31.79	472.33	617.33
Postoperative eyes			
$R_{anterior}$ (mm)	8.625 ± 0.412	7.770	10.007
$R_{posterior}$ (mm)	6.379 ± 0.237	5.767	7.043
CCT (μm)	461.89 ± 34.70	379.00	549.00

$R_{anterior}$ anterior corneal curvature, $R_{posterior}$ posterior corneal curvature, *CCT* central corneal thickness

Table 3 Differences and correlations among keratometries obtained by different algorithms

Parameter pairings	Mean differences ± SD (D)	Paired *t* test		Pearson correlation	
		t	*P*	*r*	*P*
Virgin eyes					
Sim*K* versus K_{GOF}	1.24 ± 0.12	155.164	0.000	0.996	0.000
Postoperative eyes					
Sim*K* versus K_{GOF}	1.71 ± 0.17	114.312	0.000	0.996	0.000
Sim*K* versus K_{CHM}	0.75 ± 0.45	19.114	0.000	0.977	0.000
K_{GOF} versus K_{CHM}	− 0.96 ± 0.44	− 25.184	0.000	0.977	0.000
K_{RF1} versus K_{CHM}	0.18 ± 0.43	4.702	0.000	0.977	0.000

Sim*K* simulated keratometry, K_{GOF} keratometry based on Gaussian optics formula, K_{CHM} keratometry based on clinical history methods, K_{RF1} keratometry calculated by the new regression formula based on virgin eyes

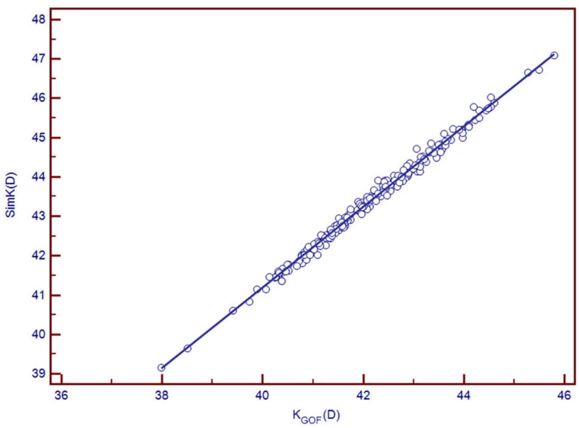

Fig. 2 Comparison graph of K_{GOF}, K_{RF1}, K_{RF2} and K_{CHM} in the postoperative group

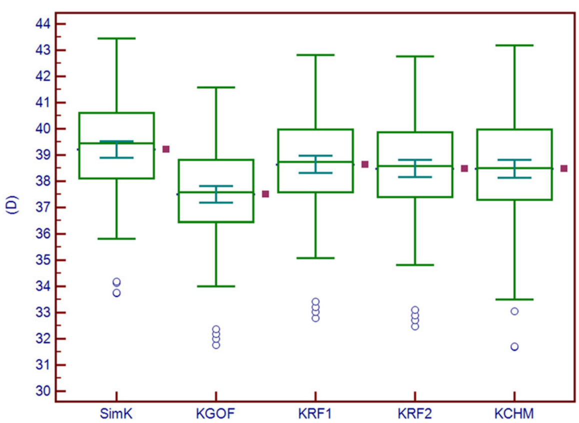

Fig. 3 Scatter diagram and regression line of Sim*K* and K_{GOF} in the virgin group. The regression equation was Sim*K* = 0.3512 + 1.0212 × K_{GOF}

Hoffer Q formula were third, and the K_m combining Haigis formula was the smallest (Fig. 5, Table 4).

Discussion

The difference between Sim*K* and K_{GOF} in our study was 1.24 ± 0.12 D in the virgin group, and it increased to 1.71 ± 0.17 D in postoperative group. These results are similar to previous studies. Jin et al. [26] measured 352 virgin eyes and 102 post-LASIK/PRK eyes using Pentacam HR. The differences between Sim*K* and K_{GOF} in the virgin group and post-LASIK/PRK group were 1.23 D and 1.71 D, respectively, which are almost identical to the present study. Borasio et al. [24] used Topcon corneal tomography and Pentacam to measure 143 virgin eyes of 82 subjects. The difference between Sim*K* and K_{GOF} was 1.30 D. Savini et al.'s study [16] included 71 normal eyes and found that Sim*K* obtained using TMS-2 corneal tomography, Keraton and Pentacam were 1.20 D, 1.29 D and 1.25 D larger than K_{GOF} obtained by Pentacam, respectively. Wang et al's study found differences of 1.30 D in normal eyes and 1.51 D in post-LASIK/PRK eyes [22]. The reason for differences between Sim*K* and K_{GOF} may be attributed to two factors. First, the reference planes of Sim*K* and K_{GOF} are different. The cornea was regarded as thin lens in the calculation of Sim*K*, and Sim*K* was defined as the power of posterior corneal vertex. However, the secondary reference plane of K_{GOF} is the anterior corneal vertex. This difference in references results in a difference of approximately 0.8 D [22]. Second, the

Table 4 Prediction of intraocular lens power using different methods

Formula	Mean ± SD (D)	Range (D)	95% CI (D)
Shammas-K_m	23.97 ± 1.77	19.60–28.90	23.66–24.27
Haigis-K_m	22.71 ± 1.67	18.25–27.00	22.43–23.00
Haigis-K_{CHM}	23.68 ± 1.64	19.50–27.50	23.39–23.96
Hoffer Q-K_{CHM}	23.29 ± 1.66	19.10–27.00	23.01–23.58
Haigis-K_{RF2}	23.65 ± 1.66	19.10–28.00	23.36–23.93
Hoffer Q-K_{RF2}	23.29 ± 1.69	18.60–27.80	23.00–23.58

K_m keratometry obtained by IOLMaster, K_{CHM} keratometry obtained by clinical history method, K_{RF2} keratometry obtained by regression formula 2, Shammas-K_m K_m joint Shammas formula, Haigis-K_m K_m joint Haigis formula, Haigis-K_{CHM} K_{CHM} joint Haigis formula, Hoffer Q-K_{CHM} K_{CHM} joint Hoffer Q formula, Haigis-K_{RF2} K_{RF2} joint Haigis formula, Hoffer *Q*-K_{RF2} K_{RF2} joint Hoffer Q formula

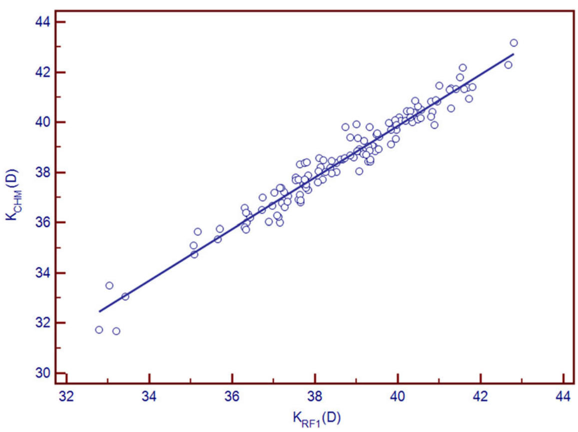

Fig. 4 Scatter diagram and regression line of K_{CHM} and K_{RF1} in the postoperative group. The regression equation was $K_{CHM} = -1.2042 + 1.0266 \times K_{RF1}$

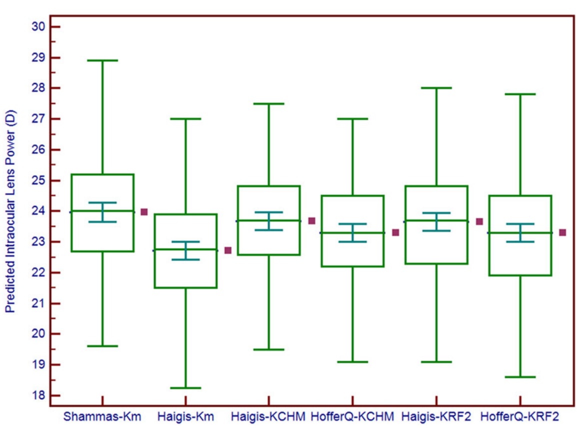

Fig. 5 Comparison graph of IOL power obtained using the Shammas formula, Haigis-K_m, Haigis-K_{CHM}, Hoffer Q-K_{CHM}, Haigis-K_{RF2} and Hoffer Q-K_{RF2} in the postoperative group

standard corneal refractive index of 1.3375 is obtained based on the assumption that the ratio of the anterior and posterior corneal curvatures is a constant of 1.132, but it was not the case in the present study. Therefore, this factor may contribute to the remaining difference of approximately 0.4 D [6]. The reason that why the difference between Sim*K* and K_{GOF} in the postoperative group tended to increase compared with the virgin group is that the ratio of anterior to posterior corneal curvatures was faraway from the constant of 1.132. This difference may also explain the reason why Sim*K* was not accurate for assessments of total corneal power in postoperative eyes.

The above-mentioned results suggest that K_{GOF} should be more accurate than Sim*K* for the assessment of total corneal power. Two reasons to support this hypothesis are as follows. First, K_{GOF} is obtained based on Gaussian optic formula, and the posterior corneal curvature and CCT are considered, and Sim*K* is obtained based on the assumptions of the cornea as a thin lens and a certain ratio of anterior and posterior corneal curvatures. Second, the standard corneal refractive index of 1.3375 is considered inaccurate, and this index was smaller than 1.3375 in several previous studies [9, 10, 24, 26]. Therefore, K_{GOF} is better for the assessment of total corneal power than Sim*K*. However, whether K_{GOF} can be used for the prediction of IOL power in cataract eyes is questionable. We believe that the answer is no, for virgin eyes and postoperative eyes. The current clinical practice and reported studies of virgin eyes demonstrate that optimized Sim*K* combining third-generation theoretical formulas (Haigis, HofferQ, Holladay1 and SRK/T) predict IOL power accurately

[27–29], but the average K_{GOF} is approximately 1.2 D smaller than Sim$K$. The use of K_{GOF} combining third-generation theoretical formula directly would result in the overestimation of IOL power. The prediction of ELP or postoperative anterior chamber depth (post-ACD) for postoperative eyes using third-generation theoretical formulas is inaccurate because ELP or post-ACD (for Holladay 1 and Hoffer Q) are predicted by corneal height, which is calculated using corneal curvature. There are certain relationships between corneal curvature and ELP/post-ACD in virgin eyes, e.g., a steeper corneal curvature corresponds to a deeper ELP or post-ACD. However, this relationship is broken in postoperative eyes, and the prediction is flawed. The current IOL prediction method is Sim$K$ combining IOL formulas after correction and optimization. If K_{GOF} is applied to IOL formulas, it also should be optimized and combined with specific formulas.

There is no widely accepted method for the prediction of IOL power in eyes after CRS. In previous studies, the clinical history method proposed by Holladay was considered as the standard for eyes after keratorefractive surgery [15, 18, 30–32], but some studies indicated that it was not as precise as proposed [33, 34]. The time interval between the two operations (cornea and lens) may be several years or decades, and it is impossible for many patients to provide preoperative data. This study identified a proper method to assess total corneal power in postoperative eyes for IOL power prediction. The present study established a regression equation between Sim$K$ and K_{GOF} in a virgin group and applied the regression equation to obtain K_{RF1} in postoperative group. K_{RF1} was very close to K_{CHM}, with a difference of 0.18 ± 0.43 D. This difference was statistically significant ($P < 0.05$), but it was clinically acceptable for the IOL power prediction. There was also good correlation between K_{RF1} and K_{CHM}. The regression equation between K_{CHM} and K_{RF1} was calculated in the postoperative group to obtain K_{RF2}. We suspect that K_{RF1} is better than Sim$K$ for the assessment of total corneal power, which was used for IOL power predictions in virgin eyes, especially in eyes that have steeper or flatter corneas. These cases tend to substantially deviate from model eyes, and the standard corneal refractive index of 1.3375 is no longer applicable. Therefore, the Sim$K$ obtained will deviate. The calculation of K_{RF1} considers variation in posterior corneal curvature and CCT. Therefore, K_{RF1} may be more accurate. Eyes after CRS may be considered serious deviation from model eyes. The fact that K_{RF1} was very close to K_{CHM} in postoperative group also corroborates this conclusion. However, further research is needed to confirm this hypothesis.

We assumed that all the postoperative eyes underwent phacoemulsification and IOL implantation, and the implanted IOL model was SN60WF (Alcon, USA) with − 1 D reserved to verify the accuracy of K_{RF2} for the prediction of IOL power in postoperative eyes. IOL powers were predicted using 6 methods: Shammas formula (no preoperative data), K_m (obtained by IOLMaster) combining Haigis formula, K_{CHM} combining Haigis formula, K_{CHM} combining Hoffer Q formula, K_{RF2} combining Haigis formula and K_{RF2} combining Hoffer Q formula. McCarthy et al. [33] examined 173 eyes that underwent CRS and cataract surgery, and the IOL power was predicted using 25 methods. They found that 5 of the 25 methods generated predicted outcomes that were near the actual outcome: the Masket method [35] combining Hoffer Q formula, Shammas formula, Haigis-L formula [36, 37], K_{CHM} combining Hoffer Q formula and Latkany's Flat-K [38] combining SRK/T formula. The predicted errors compared to actual outcome were − 0.18 ± 0.87 D, − 0.10 ± 1.02 D, − 0.26 ± 1.13 D, − 0.27 ± 1.04 D and − 0.37 ± 0.91 D, respectively. These results demonstrated that the predicted outcomes using the Shammas formula instead of the K_{CHM} combining Hoffer Q formula were the closest to the actual outcomes. The Shammas formula achieved the highest outcome in the present study followed by the K_{CHM} combining Haigis formula and K_{RF2} combining Haigis formula. The K_{CHM} and K_{RF2} combining Hoffer Q formula ranked third, and the K_m (obtained by IOLMaster) combining Haigis formula achieved the last. However, further studies should be performed to optimize K_{RF2} combining related formulas to improve the accuracy of IOL power prediction in eyes after CRS.

There were several limitations in this study. (1) We only included eyes after myopic LASIK or PRK, and eyes after hyperopic CRS or radial keratotomy were not included. (2) We obtained K_{RF2} based on K_{CHM} as the standard in the postoperative group. However, the repeatability of K_{CHM} was not previously verified. (3) Unfortunately, the present study did not apply K_{RF2} to eyes that underwent two surgeries (cornea and lens) for verification. This comparison will be performed in our subsequent study.

Our results support the followed conclusions. (1) Sim*K* was 1.2 D to 1.3 D larger in virgin eyes than the total corneal power calculated by the Gaussian optic formula, and the difference increased in eyes after myopic CRS. (2) The IOL power predicted by K_{RF2} in eyes after myopic CRS may be accurate.

Author contributions Yanjun Hua wrote the main manuscript text. Chao Pan collected and analyzed data. Qinmei Wang revised the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare no competing financial interests.

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