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Scheimpflug analysis of corneal power changes after hyperopic small incision lenticule extraction

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Abstract

Purpose: To assess the ability of the Pentacam in predicting the corneal power after hyperopic small-incision lenticule extraction (SMILE).

Methods: Twenty-five eyes of 22 patients underwent hyperopic SMILE were prospectively followed. All patients finished at least 6 months visit. Cornea power was obtained by Pentacam HR, in the format of mean keratometry (Km), equivalent keratometry (EKR) and total cornea refractive power (TCRP). Calculation of TCRP were centered on either the corneal apex or the pupil center within a ring or zone, giving a total of four different subtypes naming AR、AZ、PR、PZ. Clinical history method (CHM) was regarded as a gold standard and was compared with other cornea power parameters.

Results: Center difference had no impact on the TCR*P* values (PR vs AR and PZ vs AZ, $P > 0.05$). Compared with CHM, no difference was found in Km, EKR 4.0 mm, EKR 4.5 mm, PR 3.0 mm, PR 4.0 mm, AR 3.0 mm and AR 4.0 mm. PR 4.0 mm showed the least difference with CHM (-0.14 ± 1.03D, $P > 0.05$). The 95% limit of agreement (LOA) of the TCRPs and CHM was not close. The top two were PR 3.0 mm and PR 4.0 mm, LOA of which were -2.20 to 1.84 D and -2.18 to 1.68 D respectively. Central cornea thickness was correlated with error (TCRP $-$ CHM) of PR 4.0 mm ($r = 0.58$, $P = 0.003$).

Conclusions: The Pentacam topographer is an alternative method of measuring corneal power in eyes after hyperopic SMILE. The optimal options seem to be the TCRP (PR 4.0 mm). The agreement needs more verifications.

Keywords: Cornea power, Hyperopia, SMILE, TCRP, CHM

Introduction

Cornea refractive surgery is getting wide acceptance by surgeons and patients around the world. Surgical methods are constantly updated, from mechanical knife to femtosecond laser [1–3]. A common problem among the cornea refractive surgery recipients is accurate prediction of the corneal power for future use in intraocular lens (IOL) calculation. Several methods have been proposed to solve this problem [4]. In case the preoperative information is missing, one reliable postoperative cornea power would be helpful in IOL calculation. Traditional methods such as keratometer and Placido disc assume the anterior to posterior curvature is a fixed value. Cornea refractive surgery alters the cornea shape, thus traditional methods may cause an error of keratometric refraction index [5, 6]. In contrast, Scheimpflug topography considers both anterior and posterior cornea layer

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Fu *et al. BMC Ophthalmology*   (2021) 21:282

Page 2 of 6

and can be used to calculate overall refractive power [7, 8]. Promising results of the ray tracing have been reported in eyes after myopic photorefractive keratectomy (PRK), laser in situ keratomileusis (LASIK), and small incision lenticule extraction (SMILE) [9–13].

Different from myopia, hyperopia is corrected by increasing the central refractive power and reducing the peripheral refractive power. There are a few studies about cornea power change after hyperopic surgery, and most of them focused on hyperopic LASIK [11, 14–17]. Hyperopic LASIK used excimer laser to ablate mid-periphery cornea area. Compared with LASIK, hyperopic SMILE is a relative young cornea surgery, by creating a convex lens using femtosecond laser. Reinstein et al. have reported the promising refractive results of hyperopic SMILE [18]. In terms of cornea power prediction, it seems no published study exists.

This study aims to assess the ability of the Pentacam in predicting the corneal power in eyes after hyperopic SMILE.

Methods

Ethics

This prospective study was performed at Eye, Ear, Nose and Throat Hospital (EENT) of Fudan University, Shanghai, China. All enrolled patients were informed and signed a consent form. All procedures in the study get approval of ethic committee of EENT and adhered to the tenets of Helsinki.

Subjects

Patients satisfying following conditions were enrolled:

Inclusion criteria: age ≥ 18 years old; + 0.5 D ≤ spherical equivalent (SE) ≤ + 6.0 D; stable refraction for more than 2 years; finish at least 6 months follow-up, corrected distance visual acuity (CDVA) ≥ 20/40.

Exclusion criteria: Patients with significant abnormal corneal morphology or confirmed keratoconus; history of intraocular surgery; other eye diseases except ametropia such as significant dry eye, cataract, corneal degeneration, et.al; mental disorders or systemic diseases.

Examinations

Regular preoperative examinations were performed, including uncorrected distance visual acuity (UDVA), CDVA, subjective refraction, corneal topography, axial length, and fundus topography. When compared with cornea power, refraction was adjusted for the corneal plane by using a vertex distance of 12 mm [19].

Corneal topography was collected by professional technicians using Pentacam HR (oculus, Wetzlar, Germany). Corneal powers were recorded in following formats:

total cornea refractive power (TCRP): TCRP can be measured in four ways according to the center location (pupil center or cornea apex) and ways of measuring (ring or zone):

PR: Taking the center of pupil as the center, the average value was calculated by ring.

PZ: Taking the center of pupil as the center, the average value was calculated by zone.

AR: Taking the corneal apex as the center, the average value was calculated by ring.

AZ: Taking the corneal apex as the center, the average value was calculated by zone.

equivalent keratometry reading (EKR): EKR is displayed in the "Holladay EKR Detail Report" in Pentacam. The calculation formula is "$EKR = 0.376/r_1 - 0.03165/r_2$", where r_1 and r_2 represent anterior and posterior corneal curvature respectively [20].

mean keratometry (Km): This is the mean value of maximum and minimum axial power within the central 3.0 mm area. Km is calculated by "$Km = (n-n_0)/r_1$", where n is the traditional keratometric index of refraction (1.3375), n_0 is the refraction index of air and r_1 is the radius of the anterior cornea surface [12].

clinical history method (CHM): CHM is regarded as the gold standard of predicting postoperative corneal power [21]. It is obtained by subtracting the refractive change from the preoperative keratometry (Km in the current study).

Surgical procedure

All the operations were performed by the same surgeon (XTZ). The patients were asked to lie flat on the operating table after disinfection, and their eyes were fixed on the green dot of the central stroboscopic ring. The laser scanning time was about 35 s. The corneal cap diameter was set to be 8.8 mm with thickness being 120 μm. The optical zone was 6.2–6.3 mm, adding a transition area of 2 mm. The lenticule thickness is calculated by the software, and the thinnest thickness was 15 μm. After scanning, the lens was removed from a small incision with a diameter of 2.3 mm at 12 o'clock.

Statistics

The statistical software was SPSS (version 22, IBM Corp, USA). Before data analysis, *Kolmogorov Smirnov* was used to test whether the data obeyed normal distribution. For continuous variables, *ANOVA* was used to analyze the differences between different groups. The least significant difference (LSD) test was used for multiple comparisons. Paired t test was used to compare preoperative and postoperative results. The *Bland-*

Fu *et al. BMC Ophthalmology*   (2021) 21:282

Page 3 of 6

Altman was used to test agreement between cornea powers and CHM. *Pearson* correlation analysis was used to detect correlated factors. $P < 0.05$ was considered to be statistically significant.

Results

Refractive outcomes

The average follow up time was 8.4 ± 3.4 months (6–12 months). The average age of enrolled patients was 33.6 ± 10.6 years (18–55 years). No serious adverse events occurred during and after operation. The basic information of the enrolled patients is shown in Table 1. The average change of spherical equivalent (SE) was 3.15 ± 1.26D till the last visit.

Corneal power

The postoperative TCRP values were shown in Table 2. Four methods showed no difference within 5 mm area. Since diameter of 6 mm, TCRP calculated in zone was greater than values calculated in ring. From the center to the surrounding area, TCRP showed a trend of first increasing and then decreasing. The highest TCRP value mainly located at 3-5 mm area. Center difference had no impact on the TCRP values (PR vs AR and PZ vs AZ, $P > 0.05$).

After translation to cornea plane, the mean CHM was 45.88 ± 1.83 D. Taking the CHM as the gold standard, no difference was found in Km, EKR 4.0 mm, EKR 4.5 mm, PR 3.0 mm, PR 4.0 mm, AR 3.0 mm and AR 4.0 mm. PR 4.0 mm showed the least difference with CHM

Table 1 Preoperative and postoperative refractive information of enrolled patients

SMILE for Hyperopia	
No. of people (eyes)	22 (25)
Preoperative SE (D)	3.47 ± 1.46
Preoperative AL (mm)	22.18 ± 0.70
Preoperative UDVA (logMAR)	0.37 ± 0.27
Preoperative CDVA (logMAR)	0.09 ± 0.09
Preoperative central corneal thickness (μm)	558.8 ± 35.2
Preoperative IOP (mmHg)	15.8 ± 2.6
Lenticule thickness (μm)	107.0 ± 27.2
Postoperative SE (D)	0.32 ± 0.93
Postoperative UDVA (logMAR)	0.15 ± 0.09
Postoperative CDVA (logMAR)	0.10 ± 0.10
Preoperative ACD (mm)	2.78 ± 0.37
Postoperative ACD (mm)	2.72 ± 0.35
ΔSE (D)	3.15 ± 1.26

SE spherical equivalent, *AL* axial length, *UDVA* uncorrected distance visual acuity, *CDVA* best corrected distance visual acuity, *IOP* intraocular pressure, *Km* mean corneal curvature, *ACD* anterior chamber depth, ΔSE = preoperative SE – postoperative SE

Table 2 The mean TCRP within a diameter of 1.0 to 8.0 mm in eyes after hyperopic SMILE

	PR (D)	PZ (D)	AR (D)	AZ (D)	F	P
Diameter (mm)						
1	44.60 ± 1.89	44.46 ± 1.89	44.75 ± 1.92	44.67 ± 1.95	0.10	0.96
2	45.12 ± 1.83	44.75 ± 1.87	45.18 ± 1.91	44.93 ± 1.92	0.26	0.85
3	45.63 ± 1.90	45.11 ± 1.84	45.57 ± 1.95	45.19 ± 1.91	0.45	0.72
4	45.70 ± 1.94	45.38 ± 1.86	45.48 ± 1.97	45.36 ± 1.91	0.16	0.92
5	45.04 ± 1.87	45.37 ± 1.85	44.72 ± 1.90	45.26 ± 1.89	0.56	0.65
6	43.45 ± 1.84	44.98 ± 1.82	43.15 ± 1.88	44.84 ± 1.83	6.26	0.00
7	41.32 ± 2.16	44.25 ± 1.77	41.20 ± 2.19	44.10 ± 1.78	17.22	0.00
8	40.16 ± 2.39	43.41 ± 1.83	39.90 ± 2.40	43.3 ± 1.77	18.00	0.00

PR: Taking the center of pupil as the center, the average value was calculated by ring
PZ: Taking the center of pupil as the center, the average value was calculated by zone
AR: Taking the corneal apex as the center, the average value was calculated by ring
AZ: Taking the corneal apex as the center, the average value was calculated by zone

(-0.14 ± 1.03D, $P = 0.39$). Km was the most correlated parameter with CHM ($r = 0.9$, $P < 0.01$), followed by AZ 5.0 mm ($r = 0.885$, $P < 0.01$) and AZ 4.0 mm ($r = 0.883$, $P < 0.01$). (Table 3).

Figure 1 showed the agreement between CHM and part of cornea power parameters. The 95% limits of agreement (LOA) of the Km and CHM was relatively high (-1.92 to 1.28 D). The LOA of PR 3.0 mm and CHM, PR 4.0 mm and CHM were -2.20 to 1.84 D and -2.18 to 1.68 D respectively.

Since PR 4.0 mm showed the minimum error to CHM. Correlation analysis was performed between error PR 4.0 mm (PR 4.0 mm - CHM) and preoperative parameters (central cornea thickness [CCT], preoperative sphere, cylinder and intraocular pressure, maximum lenticule thickness). Results showed only CCT was correlated with error of PR 4.0 mm ($r = 0.58$, $P = 0.003$).

Discussion

The current study demonstrated that the TCRP and EKR could potentially reflect the cornea power change after hyperopic SMILE.

The study found that all cornea power underestimated the CHM. The good predictor with minimum error was PR 4.0 mm (-0.14 ± 1.03 D), followed by PR 3.0 mm (-0.21 ± 0.99 D), EKR 4.5 mm (-0.21 ± 1.02 D) and Km (-0.28 ± 0.81D). It was reasonable that Km showed the highest correlation and narrowest LOA. Because in current study CHM was calculated based on Km. Km was one traditional keratometry calculating by thin-lens formula. It is equivalent to the simulated K of traditional corneal topographers, which was proved to be an accurate method to predict cornea power [22]. Our results

Fu *et al. BMC Ophthalmology*   (2021) 21:282

Page 4 of 6

Table 3 Comparisons and correlation between CHM and other cornea power parameters

Cornea power	Mean ± SD (D)	Difference vs CHM (D)	*P* value	Correlation Coefficient	*P* value
CHM	45.88 ± 1.83	/			
Km	45.56 ± 1.73	−0.32 ± 0.80	0.06	0.900	0.00
EKR4.0 mm	45.41 ± 1.74	−0.34 ± 1.04	0.13	0.823	0.00
EKR4.5 mm	45.50 ± 1.71	−0.25 ± 1.01	0.24	0.831	0.00
PR2.0 mm	45.12 ± 1.83	−0.76 ± 0.97	0.00	0.858	0.00
PR3.0 mm	45.63 ± 1.90	−0.25 ± 0.97	0.22	0.866	0.00
PR4.0 mm	45.70 ± 1.94	−0.14 ± 1.03	0.39	0.858	0.00
PR5.0 mm	45.04 ± 1.87	−0.84 ± 1.00	0.00	0.852	0.00
PZ2.0 mm	44.75 ± 1.87	−1.13 ± 1.10	0.00	0.824	0.00
PZ3.0 mm	45.11 ± 1.84	−0.76 ± 0.98	0.00	0.857	0.00
PZ4.0 mm	45.38 ± 1.86	−0.50 ± 0.93	0.01	0.873	0.00
PZ5.0 mm	45.36 ± 1.85	−0.51 ± 0.90	0.01	0.881	0.00
AR2.0 mm	45.18 ± 1.91	−0.69 ± 0.96	0.00	0.870	0.00
AR3.0 mm	45.57 ± 1.95	−0.31 ± 0.94	0.12	0.879	0.00
AR4.0 mm	45.48 ± 1.97	−0.39 ± 0.96	0.06	0.874	0.00
AR5.0 mm	44.72 ± 1.90	−1.16 ± 1.00	0.00	0.856	0.00
AZ2.0 mm	44.93 ± 1.92	−0.95 ± 1.05	0.00	0.850	0.00
AZ3.0 mm	45.19 ± 1.91	−0.68 ± 0.94	0.00	0.876	0.00
AZ4.0 mm	45.36 ± 1.91	−0.52 ± 0.91	0.01	0.883	0.00
AZ5.0 mm	45.26 ± 1.89	−0.61 ± 0.89	0.00	0.885	0.00

PR: Taking the center of pupil as the center, the average value was calculated by ring
PZ: Taking the center of pupil as the center, the average value was calculated by zone
AR: Taking the corneal apex as the center, the average value was calculated by ring
AZ: Taking the corneal apex as the center, the average value was calculated by zone
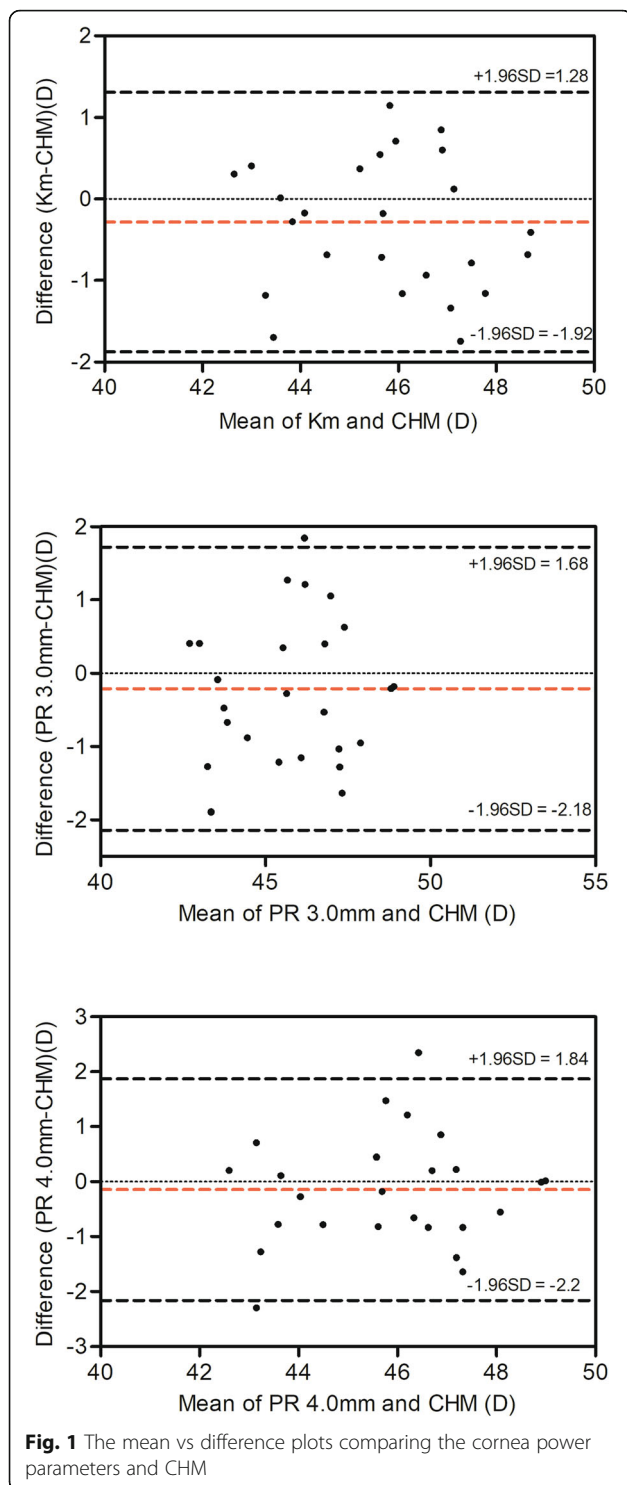*CHM* Clinical history method

demonstrated Km can be alternative of CHM after hyperopic SMILE.

Both EKR 4.0 mm and EKR 4.5 mm showed no difference with CHM, though the LOAs were relatively wide. The EKR was the same value measured by standard keratometry on the front surface, but considering the effect of the back surface power difference from normal. Holladay et al. found the optimal zone was EKR 4.5 mm in determining the IOL power. Compared with CHM, the average error was − 0.06 ± 0.56 D with range being − 1.63 to ±1.34 D [20]. In myopic LASIK, Alex et al. [10] demonstrated EKR 4.0 mm was the closest agreement with CHM. In myopic SMILE, Pan et al. [9] found EKR 4.0 mm and 4.5 mm showed no difference with CHM. The present study added the evidence of EKR after hyperopic SMILE.

In TCRP calculation, center location had no effect on TCRP values. Though hyperopia usually owes a higher kappa angle, our results were in agreement with previous studies [7, 9]. One reason was probably small sample size which lacks representation. Another interfering factor is pupil center may change with pupil size. Further studies in a larger population are warranted to explore this topic.

Among four methods, we found values at diameter 3.0 to 4.0 mm showed relative higher agreement. Previous studies have compared different curvature calculation methods, such as sim K, true net power and TCRP. All of them have come to the conclusion that TCRP is more suitable for actual refractive changes than only analyzing the axial refractive power of corneal surface [12, 14]. In hyperopic LASIK [14, 15], the TCRP 4.0 mm/5.0 mm zone calculation was proved to best predicted the surgically induced change in manifest refraction. Though their comparison standard is sphere equivalent change, not CHM in present study. Besides, the ablation method of LASIK is different from SMILE. The LASIK uses excimer laser ablates the peripheral cornea while retaining the central cornea (3 mm generally) unchanged, while the SMILE uses femtosecond laser to create complete stromal lens inside the corneal stroma, so the changes of corneal curvature should be different. This study takes the lead in analyzing the curvature changes of hyperopic SMILE, which may be of guiding significance for its clinical application and exploration.

Fu *et al. BMC Ophthalmology*   (2021) 21:282

Page 5 of 6

Fig. 1 The mean vs difference plots comparing the cornea power parameters and CHM

Correlation analysis showed that preoperative corneal thickness affected the accuracy of TCRP in evaluating cornea power. The thinner the corneal thickness, the more likely TCRP underestimated the cornea power. The relationship between corneal thickness and corneal curvature is controversial. Some scholars believe that there is no correlation between corneal thickness and refraction and corneal curvature [23], while others hold the opposite opinion [24]. In addition, the accuracy of calculation may also be related to corrected refraction level, cornea aberration and other factors [25, 26]. Therefore, the inclusion of larger samples and more reference factors in the future is of great value to the accuracy of prediction.

One of the limitations is that the sample size is small and the influencing factors are not comprehensive enough, so the application of the results is limited, including the correlation with CHM may altered several years later. It should not be ignored that hyperopia SMILE has a relatively long recovery period, so longer-term postoperative corneal topography and curvature changes are still very valuable, and more factors should be considered, such as epithelial thickness, corneal aberration, etc. The above points can be continuations of present study in the future.

Conclusions

The Pentacam topographer is an alternative method of measuring corneal power in eyes after hyperopic SMILE. The optimal options seem to be the TCRP (PR 4.0 mm). The agreement needs more verification.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of the Eye and ENT Hospital of Fudan University and was carried out following the tenets of the Declaration of Helsinki. Written informed consent was obtained from all the participants.

Consent for publication
Not applicable.

Competing interests
There are no conflicts of interest to declare for all authors.

Fu *et al. BMC Ophthalmology*   (2021) 21:282

Page 6 of 6

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