

Research Article

Comparison of Total Corneal Astigmatism between IOLMaster and Pentacam

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Purpose. To compare the total corneal astigmatism (TCA) measured by IOLMaster 700 and Pentacam and to investigate the consistency of corneal keratometry (CK) measured by IOLMaster and Pentacam. **Methods.** Cataract patients were retrospectively enrolled in March and April, 2021. Retrospective analysis was performed on those patients with binocular and monocular CK measured by IOLMaster and Pentacam. **Results.** A total of 102 patients (204 eyes) were included, 64 of whom were female (62.75%). The flat (K1) and steep (K2) CK of anterior corneal surface (ACS) and flat (TK1) and steep (TK2) of total cornea measured with IOLMaster 700 were 44.16 ± 1.60 D, 45.09 ± 1.68 D, 44.12 ± 1.62 D, and 45.14 ± 1.69 D, respectively. Those measured with Pentacam were 44.31 ± 1.57 D, 45.22 ± 1.65 D, 44.15 ± 1.67 D, and 45.19 ± 1.82 D, respectively. The astigmatism of ACS and TCA were -0.94 ± 0.63 D and -1.02 ± 0.69 D ($p < 0.01$) in the IOLMaster group and -0.90 ± 0.59 D and -1.05 ± 0.81 D in the Pentacam group, respectively ($p < 0.01$). TCA measurement results of IOLMaster and Pentacam were consistent (Pearson = 0.710, $p < 0.01$), and there was no significant difference ($p = 0.591$). **Conclusions.** Total corneal astigmatism measured by IOLMaster was consistent with that measured by Pentacam. The difference between the astigmatism of anterior corneal surface and total cornea was detected in the measurement of IOLMaster and Pentacam, respectively.

1. Introduction

With the application of toric and presbyopia-correcting intraocular lens (IOL, toric IOL and PC-IOL), precise assessment of preoperative corneal astigmatism (CA) has played an increasingly important role in the past twenty years [1–4]. The larger the CA, the poorer the postoperative visual acuity at all distances after implantation of either monofocal or multifocal IOLs [5, 6]. Improvements of postoperative astigmatism, such as toric IOL, clear corneal incision location, and peripheral corneal relaxing incisions, were developed. All of these were based on accurate preoperative CA measurement.

The keratometer, as a standard device for corneal keratometry (CK) measurement, has been widely used in

clinic practice for many years. The problem is that the CA measurement results are different with different types of orthokeratology devices. The main limitation of CA measurements currently available is that they are limited to the anterior corneal surface (ACS) [7–11]. Previous studies have shown that CA of posterior corneal surface (A-PCS) cannot be ignored in at least some eyes [12]. In addition, the astigmatism of ACS (A-ACS) scatter axis is quite different from that of the A-PCS axis, resulting in different total CA (TCA).

The Pentacam Scheimpflug imaging system (OCULUS, Wetzlar, Germany) has been introduced into the clinic, mainly using the biometry measurement of corneal morphology [13, 14]. In many hospitals, the SimK of ACS provided by Pentacam is used to calculate the power of IOLs

and the total CK (TCK), named Total Corneal Refractive Power (TCRP), also used for the choice of toric or PC-IOLs. Compared with the models and nomograms based on statistical measurement, Pentacam shows greater advantages in compensating for outliers [13].

IOLMaster 700 (Carl Zeiss Meditec, Germany) is the upgraded version of IOLMaster 500, which is widely used for the measurement of axial length (AL) and CK in cataract patients and others [15, 16]; TCK is also available recently [17–19]. It is now possible to measure the posterior corneal surface directly with SS-OCT and apply the formula on IOLMaster and Z-CALC, without changing the original clinic workflow.

TCA measured by IOLMaster and Pentacam might be different due to different principles and different measurement regions [20–22]. Comparison of TCK values obtained by IOLMaster, Pentacam, and other different devices on the same eye can provide clues to understand the trends of current corneal power measurement systems. Therefore, the primary purpose of this study was to investigate the consistency and correlation between IOLMaster and Pentacam of TCA measurements. The secondary objective was to compare A-ACS and TCA of TCK obtained by IOLMaster and Pentacam.

2. Methods

2.1. Sampling. The study was approved by the Human Research Ethics Committee of Peking University People's Hospital and adhered to the guidelines of the Declaration of Helsinki. Written informed consent was obtained from each subject after explaining the nature of this study. Consecutive patients diagnosed with cataract were retrospectively enrolled in March and April, 2021. The inclusion criteria were as follows: cataract patients with binocular biometry measurement obtained with IOLMaster 700 and Pentacam. Exclusion criteria for this study: corneal operation or corneal opacity (such as corneal leukoplakia, except cornea arcus senilis).

2.2. Data Acquisition. CK was measured using the same program of IOLMaster and Pentacam. In accordance with the user guidelines of each device, effective measurements (measurement quality check list was ok for Pentacam and three K readings difference would be less than a quarter diopter for IOLMaster) were used in the final analysis. The measured diameter of the central cornea is 2.5 mm for anterior and total CK in IOLMaster 700 and 3 mm for anterior and 4 mm for total CK in Pentacam. The software used was version 1.22r01 in Pentacam and version 1.88.1.64861 in IOLMaster 700. All measurements were performed in a semidark room. The subjects were asked to place their chin on the chin rest and press the forehead against the forehead strap. The eye was then aligned to the corneal topographic axis by using a central fixation light or target. The subjects were instructed to perform a complete blink before each measurement. All axis values more than 90° were recalculated by minus 180. For example, one axis value was 101° and recalculated as -79°.

TABLE 1: Demographics of included patients.

Characteristics	No.
Eyes (patients)	204 (102)
Age (years) (mean ± SD)	70.57 ± 8.95
Sex (% female)	64 (62.75%)
Axial length (mm) (mean ± SD)*	23.77 ± 1.75
Anterior chamber depth (mm) (mean ± SD)*	3.14 ± 0.64

SD = standard deviation. *Measured by IOLMaster.

2.3. Vector Analysis of Astigmatism. Vector analysis was used to compare CA values from these two devices. The astigmatism values were decomposed into two perpendicular components as follows: $X = A * \cos(2\alpha)$; $Y = A * \sin(2\alpha)$ [23–25]. And $J0 = -(A/2) * \cos(2\alpha)$; $J45 = -(A/2) * \sin(2\alpha)$. The corrected astigmatism values were calculated as follows: $\alpha_{va} = \arctan([Y1-Y2]/[X1-X2])$, $A_{va} = [Y1-Y2]/\sin\alpha_{va}$, where X , $X1$, and $X2$ are the cardinal component, Y , $Y1$, and $Y2$ are the oblique component, A and A_{va} are the astigmatism magnitude in diopters, and α and α_{va} are the astigmatism axis in degrees; A_{va} is the corrected astigmatism with vector analysis.

2.4. Statistical Analysis. Statistical analyses were performed using commercial software (SPSS for Windows, Version 20.0; SPSS Inc., Illinois, USA). A p value of less than 0.05 was considered to be statistically significant. The Kolmogorov-Smirnov test was used to assess data normality. Based on the data normality test result, paired two-tailed t -test analysis and related sample nonparametric test were utilized to compare CA values among these two devices. The sample size for normality test is 204 and 102 for each eye. And the normality test was run as one sample in non-parametric test with automatic mode.

3. Results

204 eyes of 102 patients were included in the final study. Demographics of the study population are summarized in Table 1.

CK and CA obtained using IOLMaster and Pentacam are listed in Table 2.

The Kolmogorov-Smirnov test result demonstrated that not only the flat keratometry (K1) and the steep keratometry (K2) of anterior corneal surface but also the flat (TK1) and steep (TK2) of total cornea, measured with IOLMaster and Pentacam, passed the test of normality (all $p > 0.05$). However, the values of astigmatism did not pass the normality test. And the related sample nonparametric test was used to compare the difference of astigmatism.

A-ACS and TCA measured with IOLMaster were -0.94 ± 0.63 D@ $2.16 \pm 59.94^\circ$ and -1.02 ± 0.69 D@ $1.21 \pm 64.34^\circ$; those measured with Pentacam were -0.90 ± 0.59 D@ $1.88 \pm 50.13^\circ$ and -1.05 ± 0.81 D@ $2.52 \pm 55.61^\circ$. Those of A-ACS and TCA measured with IOLMaster and Pentacam for the right eyes were -0.94 ± 0.71 D@ $5.21 \pm 58.33^\circ$, -1.02 ± 0.78 D@ $5.18 \pm 63.20^\circ$, -0.88 ± 0.59 D@ $-1.95 \pm 51.13^\circ$,

TABLE 2: Corneal power and astigmatism obtained using IOLMaster and Pentacam.

	IOLMaster at 2.5 mm (mean \pm SD) (range)	Pentacam at 3.0 mm (anterior corneal surface) or 4.0 mm (total cornea) (mean \pm SD) (range)
K flat of anterior corneal surface, K1 (D)	44.16 \pm 1.60 (38.62~49.91)	44.31 \pm 1.57 (38.70~49.50)
K flat of anterior corneal surface axis ($^{\circ}$)	2.16 \pm 59.94 (-89.00~90.00)	1.88 \pm 50.13 (-88.60~89.30)
K steep of anterior corneal surface, K2 (D)	45.09 \pm 1.68 (41.55~53.63)	45.22 \pm 1.65 (40.50~52.00)
Astigmatism of anterior corneal surface (A-ACS) (D)	-0.94 \pm 0.63 (-4.84~0.00)	-0.90 \pm 0.59 (-3.80~0.00)
K flat of total cornea, TK1 (D)	44.12 \pm 1.62 (39.05~50.15)	44.15 \pm 1.67 (40.00~49.00)
K flat of total cornea axis ($^{\circ}$)	1.21 \pm 64.34 (-89.00~90.00)	2.52 \pm 55.61 (-88.90~89.90)
K steep of total cornea, TK2 (D)	45.14 \pm 1.69 (41.63~54.13)	45.19 \pm 1.82 (41.90~55.40)
Astigmatism of total cornea (TCA) (D)	-1.02 \pm 0.69 (-4.76~0.00)	-1.05 \pm 0.81 (-7.20~0.00)

D = diopters; K = keratometry.

and -1.07 ± 0.95 D@ $2.50 \pm 54.45^{\circ}$. And those for the left eyes were -0.94 ± 0.53 D@ $-0.88 \pm 61.64^{\circ}$, -1.03 ± 0.58 D@ $-2.76 \pm 65.54^{\circ}$, -0.93 ± 0.58 D@ $5.71 \pm 49.07^{\circ}$, and -1.02 ± 0.63 D@ $2.53 \pm 57.00^{\circ}$. There were significant differences between A-ACS and TCA, measured with not only IOLMaster ($p < 0.01$) but also Pentacam ($p < 0.01$). And those were similar for the right eyes ($p < 0.01$ and $p < 0.01$) and the left eyes ($p < 0.01$ and $p < 0.05$). The differences between the astigmatism values measured with IOLMaster and Pentacam were not significant, either A-ACS (-0.04 ± 0.45 D, $p = 0.307$) or TCA (0.02 ± 0.58 D, $p = 0.871$). Those of A-ACS and TCA for the right eyes (-0.06 ± 0.45 D, $p = 0.480$; 0.05 ± 0.62 D, $p = 0.652$) and the left eyes (-0.01 ± 0.45 D, $p = 0.467$; -0.01 ± 0.54 D, $p = 0.860$) were similar. Figure 1 shows the Bland-Altman plots to compare keratometric and astigmatic values with the mean difference and the upper and lower 95% LoA graphed between IOLMaster and Pentacam and visualized the consistency between the devices.

Pearson analysis revealed the significant correlation between A-ACS and TCA, measured both in IOLMaster and Pentacam (Pearson = 0.956, $p < 0.01$; Pearson = 0.751, $p < 0.01$, respectively). Comparing the measurement results from the two devices, the correlations were significant in both A-ACS (Pearson = 0.729, $p < 0.01$) and TCA (Pearson = 0.710, $p < 0.01$), shown as Figure 2.

After vector analysis, the correct difference between A-ACS and TCA measured with IOLMaster was 0.20 ± 0.11 D, and that of Pentacam was 0.39 ± 0.47 D ($p < 0.01$). Those for the right eyes were 0.20 ± 0.11 D and 0.42 ± 0.59 D ($p < 0.01$) and for the left eyes were 0.20 ± 0.11 D and 0.37 ± 0.29 D ($p < 0.01$). Moreover, after vector analysis, the correct difference between the values got from IOLMaster and Pentacam was 0.42 ± 0.33 D of A-ACS and 0.56 ± 0.45 D of TCA ($p < 0.01$). Those for the right eyes were 0.40 ± 0.31 D and 0.55 ± 0.46 D ($p < 0.01$) and for the left eyes were 0.45 ± 0.35 D and 0.57 ± 0.44 D ($p < 0.01$). For vector components, Pearson analysis revealed the significant correlation for J_0 and J_{45} of A-ACS between IOLMaster and Pentacam (Pearson = 0.849, $p < 0.01$; Pearson = 0.732, $p < 0.01$, respectively) and also of TCA between the devices (Pearson = 0.762, $p < 0.01$; Pearson = 0.638, $p < 0.01$, respectively).

4. Discussions

With the popularity of toric and PC-IOL in ophthalmology clinic, accurate CA measurement has an increasing influence on the postoperative refractive results. The accurate preoperative biometric measurement, especially CA, is the determination factor for the final toric IOL power and the meridian of IOL alignment required by all toric IOL calculators. Moreover, it is also a very important factor to help us to make the decisions, such as whether to use PC-IOL or not and what exact model to use. Besides the different measurement results due to the different keratometry and corneal topography devices, the curvature of posterior corneal surface, known as TCK, might also be responsible for refractive errors. One of the purposes of this study was to evaluate the TCK measurement accuracy by IOLMaster, a new method introduced recently. It is compared with Pentacam, an earlier method which has been used in clinic for many years to evaluate its consistency. Previous study had reported that Pentacam had large ACD values than IOLMaster [26]. Besides the difference of measuring mode, the measuring diameters also are different [27-29].

This study revealed good consistency of TCK measurement results by IOLMaster and Pentacam, similar with other study [27]. As Pentacam is an earlier device to measure TCK, good consistency between the two devices indicated that IOLMaster could be used as another method to obtain accurate cornea curvature and astigmatism to guide the usage of toric and PC-IOLs. As the two devices use different measurement principles and areas, minor differences were found in this study. The TCK value measured by IOLMaster is slightly less than that measured by Pentacam. After the vector analysis, the correction of total cornea astigmatism was quite similar.

IOLMaster has been regarded as a reliable method for measuring anterior corneal curvature in clinical practice. This study showed that there was no significant difference between A-ACS measured with IOLMaster and Pentacam, although the measurement results by IOLMaster were slightly higher than those by Pentacam. This is consistent with some previous studies [30-32]. This may be due to the relatively smaller corneal diameter measured by IOLMaster (2.5 mm) than that by Pentacam (3.0 mm or 4.0 mm) [33]. The mean difference of

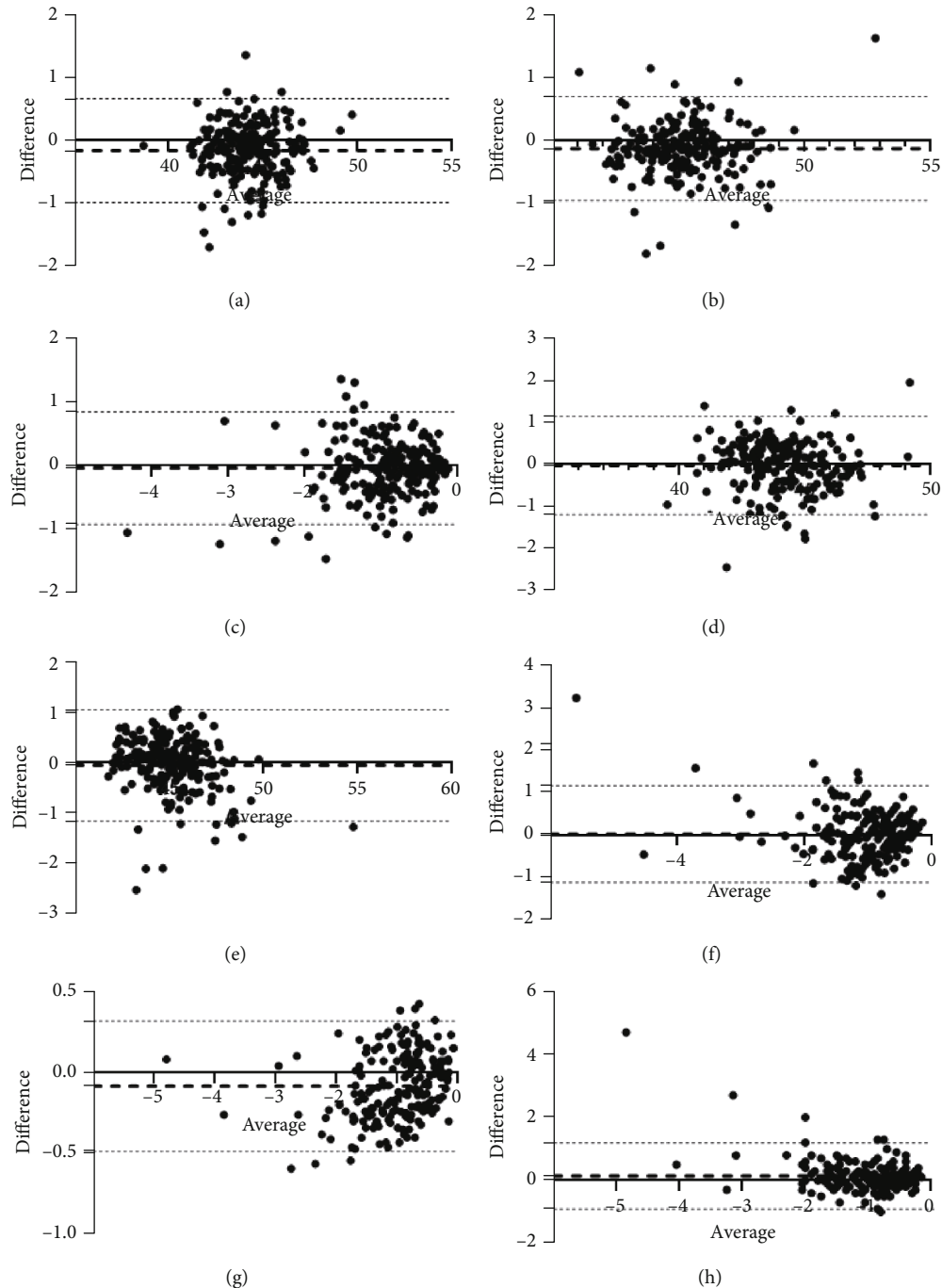


FIGURE 1: Bland–Altman plot shows consistency in the corneal keratometry and astigmatism (unit diopters (D)) for the x -axis. (a) K flat of anterior corneal surface (K1) between IOLMaster and Pentacam. (b) K steep of anterior corneal surface (K2) between IOLMaster and Pentacam. (c) Astigmatism of anterior corneal surface (A-ACS) between IOLMaster and Pentacam. (d) K flat of total cornea (TK1) between IOLMaster and Pentacam. (e) K steep of total cornea (TK2) between IOLMaster and Pentacam. (f) Astigmatism of total cornea (TCA) between IOLMaster and Pentacam. (g) Astigmatism of anterior corneal surface (A-ACS) and total cornea (TCA) measured by IOLMaster. (h) Astigmatism of anterior corneal surface (A-ACS) and total cornea (TCA) measured by Pentacam.

A-ACS between these two devices was only 0.04D, which was far lower than the toric IOL 0.5 D gradation of cylinder power at the cornea plane.

Another interesting finding was the significant difference between A-ACS and TCA, both in IOLMaster and Pentacam. Since it is not easy to measure the total cornea curva-

ture, using and calculation of toric and presbyopia correcting IOLs were based on the data obtained from manual keratometry and other devices. These data are not the total keratometry, sometimes leading to significant postoperative refractive errors [34]. Pentacam is a good method to obtain total corneal astigmatism data, but sometimes

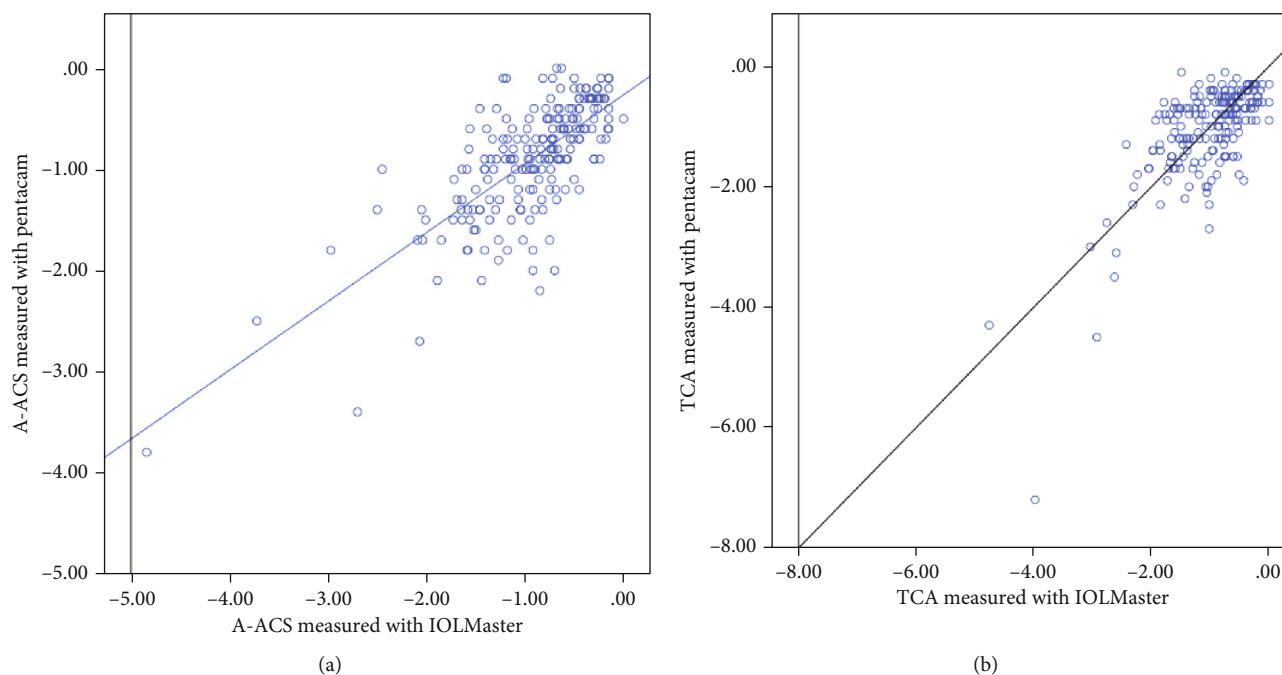


FIGURE 2: Correlation of corneal astigmatism between the corneal keratometry measured with IOLMaster and Pentacam (unit diopters (D)). (a) Correlation of anterior corneal surface astigmatism. A-ACS: corneal astigmatism of anterior corneal astigmatism. (b) Correlation of total corneal astigmatism. TCA: total corneal astigmatism.

ophthalmologists need another device/method to identify the difference of astigmatism between the anterior and posterior cornea. Previous studies have shown that the significant differences of astigmatism are associated with the posterior corneal surface. This study also revealed significant differences between the astigmatism of anterior and total cornea, both by using IOLMaster and Pentacam. Our finding made an evidence to support that the curvature of the posterior cornea could be not ignored in ophthalmology clinic. Furthermore, measured with IOLMaster and Pentacam, the difference of anterior corneal surface (0.04 ± 0.45 D) was relatively larger than that of total keratometry (0.02 ± 0.58 D). What does it mean? We may need to collect more cases for further exploration. Our study showed that after vector analysis, the correct difference between A-ACS and TCA measured with IOLMaster was smaller than that of Pentacam. This difference might be due to the difference of measuring diameters as shown in Table 2. The measuring diameter of IOLMaster 700 is 2.5 mm for both anterior and total cornea. In Pentacam, the measuring diameter for the anterior surface is 3.0 mm, and that for the posterior is 4.0 mm. However, this reason could not explain the difference of IOLMaster 700 and Pentacam comparing A-ACS with TCA. A possible cause might be the effect of tear film on those different measurements [35–37]. But the advance study is still needed.

In conclusion, the present study evaluated the consistency of total corneal astigmatism measurement between IOLMaster and Pentacam. IOLMaster can accurately measure total keratometry. Moreover, the astigmatism difference between anterior corneal surface and total cornea was also identified, both of IOLMaster and Pentacam.

Data Availability

The data used to support the findings of this study are included within the article.

Ethical Approval

The study was in accordance with the tenets of the Declaration of Helsinki and has been approved by the institutional review board of Peking University People's Hospital.

Consent

Written informed consent was obtained from all patients.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

All authors had made substantial contributions for this manuscript. Xiaochun Li and Xiaoguang Cao contribute equally to the writing of this article and are co-first authors.

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References

- [1] G. Savini, L. Taroni, and K. J. Hoffer, "Recent developments in intraocular lens power calculation methods-update 2020," *Ann Transl Med*, vol. 8, no. 22, p. 1553, 2020.
- [2] S. Kang, M. Jeong, J. Ahn et al., "Evaluation of fluid leakage into the canine vitreous humor during phacoemulsification using contrast-enhanced magnetic resonance imaging," *Veterinary Ophthalmology*, vol. 18, no. 1, pp. 13–19, 2015.
- [3] D. D. Koch, S. F. Ali, M. P. Weikert, M. Shirayama, R. Jenkins, and L. Wang, "Contribution of posterior corneal astigmatism to total corneal astigmatism," *Journal of Cataract and Refractive Surgery*, vol. 38, no. 12, pp. 2080–2087, 2012.
- [4] M. Hosny, A. Badawy, L. Khazbak, M. Anis, and S. Azzam, "Contribution of posterior corneal astigmatism to total corneal astigmatism in a sample of Egyptian population," *Clinical Ophthalmology*, vol. Volume 14, pp. 3325–3330, 2020.
- [5] J. P. Berdahl, D. R. Hardten, B. A. Kramer, and R. Potvin, "Effect of astigmatism on visual acuity after multifocal versus monofocal intraocular lens implantation," *Journal of Cataract and Refractive Surgery*, vol. 44, no. 10, pp. 1192–1197, 2018.
- [6] K. Hayashi, S. I. Manabe, M. Yoshida, and H. Hayashi, "Effect of astigmatism on visual acuity in eyes with a diffractive multifocal intraocular lens," *Journal of Cataract and Refractive Surgery*, vol. 36, no. 8, pp. 1323–1329, 2010.
- [7] B. W. Lee, A. Galor, W. J. Feuer et al., "Agreement between Pentacam and IOL master in patients undergoing toric IOL implantation," *Journal of Refractive Surgery*, vol. 29, no. 2, pp. 114–120, 2013.
- [8] M. A. Bullimore, T. Buehren, and W. Bissmann, "Agreement between a partial coherence interferometer and 2 manual keratometers," *Journal of Cataract and Refractive Surgery*, vol. 39, no. 10, pp. 1550–1560, 2013.
- [9] N. Visser, T. T. J. M. Berendschot, F. Verbakel, J. de Brabander, and R. M. M. A. Nuijts, "Comparability and repeatability of corneal astigmatism measurements using different measurement technologies," *Journal of Cataract and Refractive Surgery*, vol. 38, no. 10, pp. 1764–1770, 2012.
- [10] S. Srivannaboon, C. Chirapapaisan, P. Chonpimai, and S. Koodkaew, "Comparison of corneal astigmatism measurements of 2 optical biometer models for toric intraocular lens selection," *Journal of Cataract and Refractive Surgery*, vol. 41, no. 2, pp. 364–371, 2015.
- [11] J. B. Ale Magar, F. Cunningham, and G. Brian, "Comparison of automated and partial coherence keratometry and resulting choice of toric IOL," *Optometry and Vision Science*, vol. 90, no. 4, pp. 385–391, 2013.
- [12] J. D. Ho, C. Y. Tsai, and S. W. Liou, "Accuracy of corneal astigmatism estimation by neglecting the posterior corneal surface measurement," *American Journal of Ophthalmology*, vol. 147, no. 5, pp. 788–795.e2, 2009.
- [13] M. N. Motlagh, M. Moshirfar, M. S. Murri et al., "Pentacam® corneal tomography for screening of refractive surgery candidates: a review of the literature, part I," *Med Hypothesis Discov Innov Ophthalmol*, vol. 8, no. 3, pp. 177–203, 2019.
- [14] K. Doctor, K. P. Vunnavu, R. Shroff et al., "Simplifying and understanding various topographic indices for keratoconus using Scheimpflug based topographers," *Indian Journal of Ophthalmology*, vol. 68, no. 12, pp. 2732–2743, 2020.
- [15] X. Mao, G. Savini, Z. Zhuo et al., "Repeatability, reproducibility, and agreement of corneal power measurements obtained with a new corneal topographer," *Journal of Cataract and Refractive Surgery*, vol. 39, no. 10, pp. 1561–1569, 2013.
- [16] E. Saad, M. C. Shammas, and H. J. Shammas, "Scheimpflug corneal power measurements for intraocular lens power calculation in cataract surgery," *American Journal of Ophthalmology*, vol. 156, no. 3, pp. 460–467.e2, 2013.
- [17] M. Aksoy, L. Asena, S. G. Gungör, A. Küçüködük, and A. Akman, "Comparison of refractive outcomes using Scheimpflug Holladay equivalent keratometry or IOLMaster 700 keratometry for IOL power calculation," *International Ophthalmology*, vol. 41, no. 6, pp. 2205–2212, 2021.
- [18] R. Oh, J. Y. Oh, H. J. Choi, M. K. Kim, and C. H. Yoon, "Comparison of ocular biometric measurements in patients with cataract using three swept-source optical coherence tomography devices," *BMC Ophthalmology*, vol. 21, no. 1, p. 62, 2021.
- [19] A. Levron, H. el Chehab, E. Agard, R. Chudzinski, J. Billant, and C. Dot, "Impact of measured total keratometry versus anterior keratometry on the refractive outcomes of the AT TORBI 709-MP toric intraocular lens," *Graefes archive for clinical and experimental ophthalmology = Albrecht von Graefes Archiv fur klinische und experimentelle Ophthalmologie*, vol. 259, no. 5, pp. 1199–1207, 2021.
- [20] C. Yong Park, J. R. Do, and R. S. Chuck, "Predicting postoperative astigmatism using Scheimpflug keratometry (Pentacam) and automated keratometry (IOLMaster)," *Current Eye Research*, vol. 37, no. 12, pp. 1091–1098, 2012.
- [21] D. H. Chang and G. O. T. Waring, "The subject-fixated coaxially sighted corneal light reflex: a clinical marker for contra-rotation of refractive treatments and devices," *American Journal of Ophthalmology*, vol. 158, no. 5, pp. 863–874.e2, 2014.
- [22] R. J. Symes and P. G. Ursell, "Automated keratometry in routine cataract surgery: comparison of Scheimpflug and conventional values," *Journal of Cataract and Refractive Surgery*, vol. 37, no. 2, pp. 295–301, 2011.
- [23] D. Huang, R. D. Stulting, J. D. Carr, K. P. Thompson, and Waring GO 3rd, "Multiple regression and vector analyses of laser in situ keratomileusis for myopia and astigmatism," *Journal of Refractive Surgery*, vol. 15, no. 5, pp. 538–549, 1999.
- [24] X. Liao, Y. Peng, B. Liu, Q. Q. Tan, and C. J. Lan, "Agreement of ocular biometric measurements in young healthy eyes between IOLMaster 700 and OA-2000," *Scientific Reports*, vol. 10, no. 1, p. 3134, 2020.
- [25] Y. Inoue, H. Takehara, T. Sugita et al., "Impact of small incision sutureless cataract surgery on the natural course of astigmatism in 10 to 20 years," *Journal of Cataract and Refractive Surgery*, vol. Publish Ahead of Print, 2022.
- [26] M. De Bernardo, M. Borrelli, R. Imparato, F. Cione, and N. Rosa, "Anterior chamber depth measurement before and after photorefractive keratectomy. Comparison between IOLMaster and Pentacam," *Photodiagnosis and Photodynamic Therapy*, vol. 32, article 101976, 2020.
- [27] R. Asaworarith, V. Satitpitakul, P. Taweekitkul, and K. Pongpirul, "Agreement of total corneal power between 2 swept-source optical coherence tomography and Scheimpflug tomography in normal and keratoconic patients," *PLoS One*, vol. 17, no. 5, article e0268856, 2022.
- [28] M. M. Hansen, D. Bach-Holm, and L. Kessel, "Biometry and corneal aberrations after cataract surgery in childhood," *Clinical & Experimental Ophthalmology*, pp. 1–8, 2022.
- [29] E. Chalkiadaki, P. S. Gartaganis, T. Ntravalias, I. Giannakis, E. Manousakis, and E. Karmiris, "Agreement in anterior

- segment measurements between swept-source and Scheimpflug-based optical biometries in keratoconic eyes: a pilot study,” *Therapeutic advances in ophthalmology*, vol. 14, 2022.
- [30] M. Shirayama, L. Wang, M. P. Weikert, and D. D. Koch, “Comparison of corneal powers obtained from 4 different devices,” *American Journal of Ophthalmology*, vol. 148, no. 4, pp. 528–535.e1, 2009.
- [31] Y. Zhang, J. Dong, S. Zhang et al., “Corneal astigmatism measurements comparison among ray-tracing aberrometry, partial coherence interferometry, and Scheimpflug imaging system,” *Journal of Ophthalmology*, vol. 2020, Article ID 3012748, 7 pages, 2020.
- [32] Q. Wang, G. Savini, K. J. Hoffer et al., “A comprehensive assessment of the precision and agreement of anterior corneal power measurements obtained using 8 different devices,” *PLoS One*, vol. 7, no. 9, article e45607, 2012.
- [33] H. Lee, J. L. Chung, E. K. Kim, B. Sgrignoli, and T. I. Kim, “Univariate and bivariate polar value analysis of corneal astigmatism measurements obtained with 6 instruments,” *Journal of Cataract and Refractive Surgery*, vol. 38, no. 9, pp. 1608–1615, 2012.
- [34] S. Feizi, S. Delfazayebaher, M. A. Javadi, F. Karimian, V. Ownagh, and F. Sadeghpour, “Mean posterior corneal power and astigmatism in normal versus keratoconic eyes,” *J. Ophthalmic Vis. Res.*, vol. 13, no. 2, pp. 93–100, 2018.
- [35] G. Kundu, R. Shetty, P. Khamar et al., “Impact of tear optics on the repeatability of Pentacam AXL wave and iTrace in measuring anterior segment parameters and aberrations,” *Indian Journal of Ophthalmology*, vol. 70, no. 4, pp. 1150–1157, 2022.
- [36] B. Gjerdrum, K. G. Gundersen, P. O. Lundmark, and B. M. Aakre, “Repeatability of OCT-based versus Scheimpflug- and reflection-based keratometry in patients with hyperosmolar and normal tear film,” *Clinical ophthalmology (Auckland, N.Z.)*, vol. Volume 14, pp. 3991–4003, 2020.
- [37] T. Hiraoka, H. Asano, T. Ogami et al., “Influence of dry eye disease on the measurement repeatability of corneal curvature radius and axial length in patients with cataract,” *Journal of Clinical Medicine*, vol. 11, no. 3, p. 710, 2022.