Ophthalmol Ther (2023) 12:3263–3279
https://doi.org/10.1007/s40123-023-00815-9

ORIGINAL RESEARCH

Repeatability and Interobserver Reproducibility of a Swept-Source Optical Coherence Tomography for Measurements of Anterior, Posterior, and Total Corneal Power

Chak Seng Lei · Xuanqiao Lin · Rui Ning · Jinjin Yu · Xiaomin Huang · Kexin Li · Yiran Wang · Giacomo Savini · Domenico Schiano-Lomoriello · Xingtao Zhou · Jinhai Huang

Received: July 12, 2023 / Accepted: September 5, 2023 / Published online: October 3, 2023

ABSTRACT

Introduction: The aim of this work is to evaluate the intraobserver repeatability and interobserver reproducibility of corneal power measurements obtained with a swept-source optical coherence tomographer (CASIA 2, Tomey, Japan) in healthy subjects.
Methods: A total of 67 right eyes from 67 healthy subjects were enrolled. Two experienced observers measured each eye three times consecutively with the CASIA 2. Corneal power values were recorded as simulated keratometry, anterior, posterior, and total corneal power. Parameters were flattest keratometry (K_f), steepest keratometry (K_s), mean keratometry (K_m), astigmatism magnitude, astigmatism power vectors J_0 and J_{45}. Intraobserver repeatability and interobserver reproducibility of the CASIA 2 were assessed by the within-subject standard deviation (S_w), test–retest repeatability (TRT), coefficients of variation (CoV), and intraclass correlation coefficients (ICCs). Double-angle plots were used for astigmatism vector analysis.
Results: The CASIA 2 had high repeatability for all corneal power values, with S_w values ≤ 0.17 diopters (D), TRT ≤ 0.46 D, and ICCs ranging from 0.866 to 0.998. Interobserver reproducibility was also high, showing all S_w values ≤ 0.10 D, TRT ≤ 0.27 D, and ICCs ≥ 0.944. The reproducibility of the average of three consecutive measurements (S_w 0.01–0.10 D, TRT

Chak Seng Lei, Xuanqiao Lin and Rui Ning contributed equally as first authors.

C. S. Lei · R. Ning · J. Yu · X. Huang · K. Li · Y. Wang · X. Zhou (✉) · J. Huang (✉)
Eye Institute and Department of Ophthalmology, Eye & ENT Hospital, Fudan University, No. 19 Baoqing Road, Xuhui District, Shanghai 200031, China
e-mail: doctzhouxingtao@163.com; xingtaozhou@fudan.edu.cn

J. Huang
e-mail: vip999vip@163.com; jinhaihuang@fudan.edu.cn

C. S. Lei · R. Ning · J. Yu · X. Huang · K. Li · Y. Wang · X. Zhou · J. Huang
NHC Key Laboratory of Myopia (Fudan University), Key Laboratory of Myopia, Chinese Academy of Medical Sciences, Shanghai, China

C. S. Lei · R. Ning · J. Yu · X. Huang · K. Li · Y. Wang · X. Zhou · J. Huang
Shanghai Research Center of Ophthalmology and Optometry, Shanghai, China

X. Lin
Eye Hospital and School of Ophthalmology and Optometry, Wenzhou Medical University, Wenzhou, Zhejiang, China

G. Savini · D. Schiano-Lomoriello
IRCCS Bietti Foundation, Rome, Italy

0.03–0.27 D, ICC 0.944–0.998) was higher than the reproducibility of single measurements (S_w 0.01–0.17 D, TRT 0.03–0.47 D, ICC 0.867–0.996).
Conclusions: The CASIA 2 showed high intraobserver repeatability and interobserver reproducibility for anterior, posterior, and total corneal power measurements in 6.0-mm diameter area. In addition, we suggest that using the average of three consecutive measurements can improve reproducibility between observers, compared to single measurements only.

Keywords: Swept-source optical coherence tomographer; Corneal power; Biometry

Key Summary Points

Why carry out this study?

Accurate measurement of corneal power is the basis of clinical diagnosis and treatment.

This study aimed to evaluate the intraobserver repeatability and interobserver reproducibility of corneal power measurements obtained with a swept-source optical coherence tomographer (CASIA 2, Tomey, Japan).

What was learned from the study?

The parameters of anterior, posterior, and total corneal power in 6.0-mm diameter area obtained by CASIA 2 showed high intraobserver repeatability and interobserver reproducibility in healthy people. The average of three consecutive measurements can improve reproducibility between observers, compared to single measurements only.

INTRODUCTION

Precise measurements of corneal power are crucial for various clinical applications in ophthalmology. In particular, the anterior and posterior corneal curvatures are essential for the early diagnosis of keratoconus and monitoring its progression [1]. Furthermore, the corneal power accounts for about two-thirds of the total dioptric power of the eye and is therefore essential when calculating the power of the intraocular lens (IOL) for cataract surgery. Any measurement errors will result in a prediction error in the IOL calculation formulae, giving patients less-than-ideal results [2–4]. Thus, a device that can accurately and consistently monitor corneal power values will give patients a better outcome.

Previously, keratometry was limited by the ability to measure only the anterior corneal surface curvature. In the absence of information about the posterior surface of the cornea, the power of the entire cornea has been traditionally estimated by applying the keratometric refractive index (n = 1.3375). This methodology is based on the assumption that the anterior and posterior surfaces of the cornea related to each other by a constant factor [5]. Most of the IOL calculation formulas were designed and built based on this variable [6]. Currently, both the anterior and posterior corneal curvatures can be directly measured, allowing for the calculation of the total corneal power using either ray-tracing or the Gaussian optics formula [7]. Technologies that are capable to achieve this include slit-scanning topography, Scheimpflug camera, color light-emitting diode (LED) reflection topography, and optical coherence tomography (OCT). The CASIA 2 (Tomey Corporation, Nagoya, Japan) is a swept-source optical coherence tomography (SS-OCT) based device, measuring the ocular anterior segment parameters using a swept laser 1310 nm wavelength with a maximum penetration depth of 13 mm and providing a fast scan rate of 50,000 A-scans per second.

Recent studies have already found high repeatability of CASIA 2 for corneal power measurements [8, 9]. Good agreement for corneal power values has been demonstrated between CASIA 2 and other SS-OCT devices or Scheimpflug cameras [8–12], but a low agreement has been found with respect to a spectral-domain OCT device [13]. However, as far as we know, the repeatability of astigmatism and the reproducibility of corneal power measurements have not yet been examined.

This study aimed to evaluate the intraobserver repeatability and interobserver reproducibility of the CASIA 2 in measuring corneal power of the anterior and posterior corneal surfaces as well as simulated keratometry and total corneal power. Moreover, we investigated whether averaging three consecutive measurements obtained by a single observer could improve the reproducibility between observers.

METHODS

Subjects

Sixty-seven right eyes of 67 healthy subjects were analyzed in this prospective study. Subjects were recruited at the Eye and ENT Hospital of Fudan University, Shanghai, China. All participants underwent comprehensive ophthalmologic examination, which consisted of subjective refraction, non-contact tonometry, slit-lamp examination, and ophthalmoscopy before they were considered candidates. Inclusive criteria were as follows: (1) they had to be older than 18 years of age, (2) the corrected distance visual acuity had to be equal to or better than 20/20, and (3) patients did not wear soft contact lenses within 2 weeks and rigid contact lenses within 4 weeks. Exclusive criteria were as follows: (1) previous ophthalmological surgery or ocular trauma, 2) history of the ophthalmic disease (such as keratoconus, cataract, and glaucoma), 3) dry eye disease (Schirmer's test < 5 mm/5 min) and (4) poor fixation during the scan.

This prospective study was approved by the Institutional Ethics Committee of the Eye and ENT Hospital of Fudan University (2021174) and conducted by the principles of the Declaration of Helsinki. All subjects signed an informed consent after understanding the purpose of the study.

Instruments and Parameters

The CASIA 2 is a Fourier-domain, SS-OCT using a swept laser 1310-nm wavelength with a maximum penetration depth of 13 mm and providing a fast scan rate of 50,000 A-scans per second. The "Corneal Map" mode under the "Anterior Segment" exam protocol was used, which comprises 16 consecutive meridional scans with 800 A-scans per line, a scan width of 16 mm, and a scan depth of 11 mm. Each measurement with a scan speed of 0.3 s can provide 4 corneal power measurements:

(1) *Simulated keratometry* this is calculated using 1.3375 as the refractive index of the cornea.
(2) *Anterior corneal power* this is calculated using the corneal refractive index (1.376).
(3) *Posterior corneal power* this is calculated using the refractive index of the cornea (1.376) and aqueous humor (1.336).
(4) *Total corneal power* this is calculated by adding the corneal thickness correction to the sum of the refractive powers of the anterior and posterior surfaces, according to the Gaussian optics formula:

$$\begin{aligned}\text{K-real} = &\ \text{K-anterior} + \text{K-posterior} \\ &- \left[d/\left(1.376 \times 10^{6}\right)\right] \times \text{K-anterior} \\ &- \times \text{K-posterior},\end{aligned}$$

where K-anterior and K-posterior refer to the keratometry of the anterior and posterior cornea and "d" refers to corneal thickness [12].

Corneal astigmatism was converted into two power vectors: J_0 and J_{45}. The calculation formulas were as follows:

$$J_0 = -(C/2) \times \cos(2\alpha), J_{45} = -(C/2) \times \sin(2\alpha),$$

where C is the cylinder power and α is the cylinder axis. In the Jackson cross cylinder, J_0 represents the cylinder axis at the 180° and 90° meridians and J_{45} represents the cylinder axis at the 45° or 135° meridians [14].

For each corneal power value, the following data were recorded: flattest keratometry (K_f), steepest keratometry (K_s), mean keratometry (K_m), astigmatism magnitude, J_0, and J_{45}. The

Table 1 Intraobserver repeatability of corneal power values by the CASIA 2

Parameter	Observer	Mean ± SD (D)	S_w (D)	TRT (D)	CoV (%)	ICC (95% CI)
K_f-Simulated	1st	43.00 ± 1.30	0.12	0.32	0.27	0.992 (0.988–0.995)
	2nd	42.97 ± 1.30	0.11	0.32	0.27	0.992 (0.988–0.995)
K_s-Simulated	1st	44.16 ± 1.49	0.11	0.30	0.24	0.995 (0.992–0.997)
	2nd	44.16 ± 1.49	0.10	0.29	0.24	0.995 (0.993–0.997)
K_m-Simulated	1st	43.58 ± 1.37	0.09	0.24	0.20	0.996 (0.994–0.997)
	2nd	43.56 ± 1.37	0.08	0.23	0.19	0.996 (0.994–0.998)
AST-Simulated	1st	1.16 ± 0.62	0.14	0.40	12.27	0.949 (0.925–0.967)
	2nd	1.20 ± 0.60	0.14	0.39	11.70	0.948 (0.924–0.966)
J_0-Simulated	1st	− 0.52 ± 0.32	0.07	0.20	–	0.950 (0.926–0.967)
	2nd	− 0.54 ± 0.32	0.07	0.20	–	0.950 (0.926–0.967)
J_{45}-Simulated	1st	0.09 ± 0.21	0.08	0.22	–	0.879 (0.825–0.919)
	2nd	0.09 ± 0.21	0.07	0.18	–	0.912 (0.872–0.942)
K_f-Anterior	1st	47.90 ± 1.45	0.12	0.33	0.25	0.993 (0.990–0.996)
	2nd	47.86 ± 1.45	0.13	0.36	0.27	0.992 (0.988–0.995)
K_s-Anterior	1st	49.19 ± 1.66	0.12	0.33	0.24	0.995 (0.992–0.997)
	2nd	49.19 ± 1.67	0.13	0.35	0.26	0.994 (0.991–0.996)
K_m-Anterior	1st	48.55 ± 1.52	0.09	0.25	0.19	0.996 (0.995–0.998)
	2nd	48.53 ± 1.52	0.10	0.27	0.20	0.996 (0.994–0.997)
AST-Anterior	1st	1.29 ± 0.69	0.15	0.43	11.93	0.951 (0.928–0.968)
	2nd	1.33 ± 0.67	0.17	0.46	12.53	0.942 (0.914–0.962)
J_0-Anterior	1st	− 0.58 ± 0.36	0.08	0.23	–	0.948 (0.924–0.966)
	2nd	− 0.60 ± 0.35	0.09	0.24	–	0.944 (0.917–0.963)
J_{45}-Anterior	1st	0.10 ± 0.24	0.08	0.23	–	0.888 (0.839–0.926)
	2nd	0.09 ± 0.24	0.07	0.20	–	0.913 (0.873–0.942)
K_f-Posterior	1st	− 5.99 ± 0.19	0.03	0.08	0.46	0.980 (0.971–0.987)
	2nd	− 5.99 ± 0.19	0.03	0.07	0.44	0.982 (0.972–0.988)
K_s-Posterior	1st	− 6.31 ± 0.22	0.03	0.09	0.49	0.981 (0.972–0.988)
	2nd	− 6.31 ± 0.23	0.03	0.07	0.42	0.986 (0.980–0.991)
K_m-Posterior	1st	− 6.15 ± 0.20	0.02	0.05	0.32	0.990 (0.986–0.994)
	2nd	− 6.15 ± 0.20	0.02	0.05	0.30	0.992 (0.988–0.995)
AST-Posterior	1st	− 0.31 ± 0.12	0.04	0.12	13.73	0.880 (0.827–0.920)
	2nd	− 0.31 ± 0.12	0.04	0.11	12.12	0.904 (0.861–0.937)

Table 1 continued

Parameter	Observer	Mean ± SD (D)	S_w (D)	TRT (D)	CoV (%)	ICC (95% CI)
J_0-Posterior	1st	0.15 ± 0.06	0.02	0.06	–	0.877 (0.822–0.918)
	2nd	0.15 ± 0.06	0.02	0.05	–	0.906 (0.863–0.938)
J_{45}-Posterior	1st	– 0.03 ± 0.04	0.01	0.03	–	0.888 (0.838–0.926)
	2nd	– 0.03 ± 0.04	0.01	0.03	–	0.918 (0.880–0.946)
K_f-Real	1st	42.01 ± 1.29	0.11	0.31	0.27	0.992 (0.989–0.995)
	2nd	41.98 ± 1.29	0.12	0.34	0.29	0.991 (0.987–0.994)
K_s-Real	1st	43.02 ± 1.47	0.12	0.33	0.28	0.994 (0.990–0.996)
	2nd	43.02 ± 1.47	0.12	0.33	0.28	0.993 (0.990–0.996)
K_m-Real	1st	42.51 ± 1.35	0.09	0.25	0.21	0.996 (0.993–0.997)
	2nd	42.50 ± 1.35	0.09	0.26	0.22	0.995 (0.993–0.997)
AST-Real	1st	1.01 ± 0.58	0.14	0.40	14.33	0.940 (0.911–0.960)
	2nd	1.04 ± 0.58	0.16	0.43	15.01	0.929 (0.896–0.954)
J_0-Real	1st	– 0.44 ± 0.31	0.08	0.21	–	0.942 (0.915–0.962)
	2nd	– 0.46 ± 0.31	0.08	0.22	–	0.939 (0.910–0.960)
J_{45}-Real	1st	0.08 ± 0.21	0.08	0.22	–	0.866 (0.807–0.910)
	2nd	0.07 ± 0.20	0.07	0.20	–	0.888 (0.838–0.926)

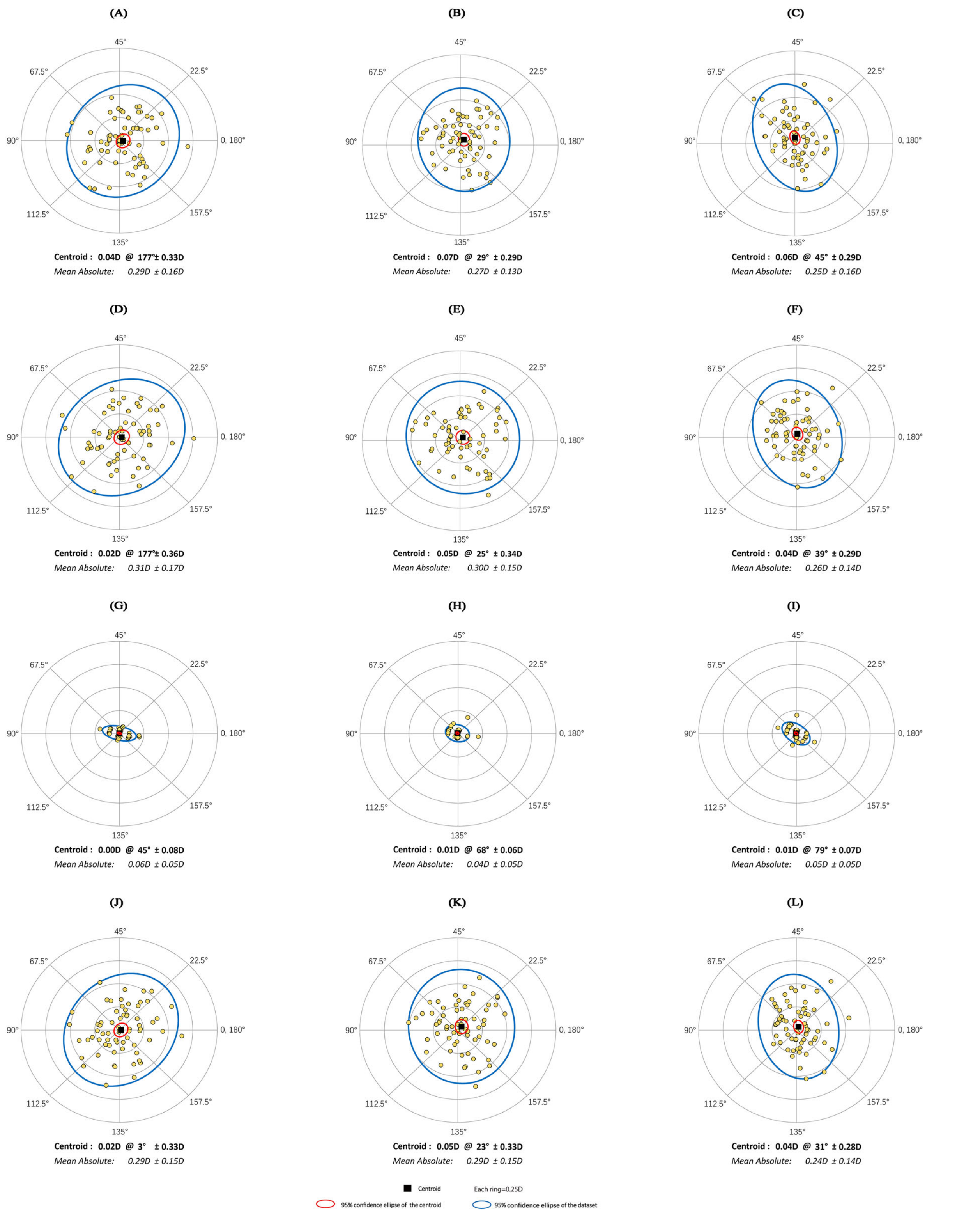
K_f flattest keratometry, K_s steepest keratometry, K_m mean keratometry, *AST* astigmatism magnitude, J_0 cylinder axis at the 180° and 90° meridians, J_{45} cylinder axis at the 45° and 135° meridians, *CI* confidence interval, *SD* standard deviation, S_w within-subject standard deviation, *TRT* test–retest repeatability (2.77 Sw), *CoV* within-subject coefficient of variation, *ICC* intraclass correlation coefficient

corneal area for analysis was 6.0 mm in diameter as stated in the instruction manual.

Measurement Technique

All subjects were measured under non-mydriatic conditions between 10:00 and 5:00 p.m. to minimize any influence of the normal diurnal variations of corneal curvature and thickness [15]. They were instructed to keep their chin and forehead in position and stare at the internal fixation light. Complete blink was required before each measurement. The device was realigned for subsequent scans to prevent interdependence of successive measurements. Only measurements with a Quality Statement "OK" were accepted, otherwise, the measurements were repeated.

Two experienced observers carried out three consecutive qualified measurements in a random order and the whole procedure was completed within 5 min. Three successive measurements of each observer were used to evaluate intraobserver repeatability. To assess the interobserver reproducibility, we utilized two methods: (1) Average: comparing the average of three consecutive measurements from each observer, and (2) Single: comparing the first measurements from each observer.


(A)
Centroid : 0.04D @ 177°± 0.33D
Mean Absolute: 0.29D ± 0.16D
(B)
Centroid : 0.07D @ 29° ± 0.29D
Mean Absolute: 0.27D ± 0.13D
(C)
Centroid : 0.06D @ 45° ± 0.29D
Mean Absolute: 0.25D ± 0.16D
(D)
Centroid : 0.02D @ 177°± 0.36D
Mean Absolute: 0.31D ± 0.17D
(E)
Centroid : 0.05D @ 25° ± 0.34D
Mean Absolute: 0.30D ± 0.15D
(F)
Centroid : 0.04D @ 39° ± 0.29D
Mean Absolute: 0.26D ± 0.14D
(G)
Centroid : 0.00D @ 45° ± 0.08D
Mean Absolute: 0.06D ± 0.05D
(H)
Centroid : 0.01D @ 68° ± 0.06D
Mean Absolute: 0.04D ± 0.05D
(I)
Centroid : 0.01D @ 79° ± 0.07D
Mean Absolute: 0.05D ± 0.05D
(J)
Centroid : 0.02D @ 3° ± 0.33D
Mean Absolute: 0.29D ± 0.15D
(K)
Centroid : 0.05D @ 23° ± 0.33D
Mean Absolute: 0.29D ± 0.15D
(L)
Centroid : 0.04D @ 31° ± 0.28D
Mean Absolute: 0.24D ± 0.14D
45°
22.5°
0, 180°
157.5°
135°
112.5°
90°
67.5°
Centroid
Each ring=0.25D
95% confidence ellipse of the centroid
95% confidence ellipse of the dataset

◀**Fig. 1** Double-angle plots showing intraobserver differences in astigmatism between the first observer's repeated measurements in each corneal power measurement. Each ring represents 0.25 diopters (D), and the outer ring represents 1.0 D. The small ellipses (*red*) show the 95% confidence ellipses for the centroid and the larger ellipses (*blue*) show the 95% confidence ellipse for the difference vectors of the dataset. *First row*: Simulated keratometry. *Second row*: Anterior corneal power. *Third row*: Posterior corneal power. *Fourth row*: Total corneal power. *First column*: difference between first and second measurements. *Second column*: difference between first and third measurements. *Third column*: difference between second and third measurements

Statistical Analysis

Statistical analysis was performed using SPSS (version 21.0, IBM Corporation, USA) and Microsoft Office Excel 365 (Microsoft Corp., USA). Before data analysis, the normality of the data distribution was assessed by the Kolmogorov–Smirnov test ($P > 0.05$). To determine the intraobserver repeatability and interobserver reproducibility of the CASIA 2, the mean ± standard deviation (SD), within-subject deviation (S_w), test–retest (TRT) repeatability, coefficients of variation (CoV) and intraclass correlation coefficients (ICCs) were calculated and analyzed. The S_w is also known as the standard deviation of repeated measurements [16]. The TRT is defined as $2.77 \times S_w$, representing an interval within which 95% of the differences between measurements are expected to lie [16]. The lower TRT represents better repeatability. The CoV was calculated as the ratio of the S_w to the overall mean. The lower CoV indicates higher repeatability [16]. The ICCs ranging from 0 to 1 are commonly classified as follows: < 0.75 indicates poor repeatability; 0.75 to < 0.90 indicates moderate repeatability; ≥ 0.90 indicates high repeatability. A closer ICC to 1 suggests better measurement consistency [17].

Given that astigmatism power vectors (J_0, J_{45}) have small magnitudes, which causes the CoV to be large, and can be either positive or negative, CoV cannot represent the actual variation among measurements. When the mean value of a parameter is near zero, the CoV is sensitive to small changes in the mean, limiting its usefulness [18]. For this reason, we excluded the CoV for assessing the precision for measurements of J_0 and J_{45}.

The differences in astigmatism between repeated measurements or between different observers were analyzed by double-angle plots. Double-angle plots were generated with the Astigmatism Double Angle Plot Tool available on the American Society of Cataract and Refractive Surgery website [19]. This particular methodology enables to display of both the magnitude and axis of the average astigmatism measurement differences (centroid), along with the confidence ellipse [20].

RESULTS

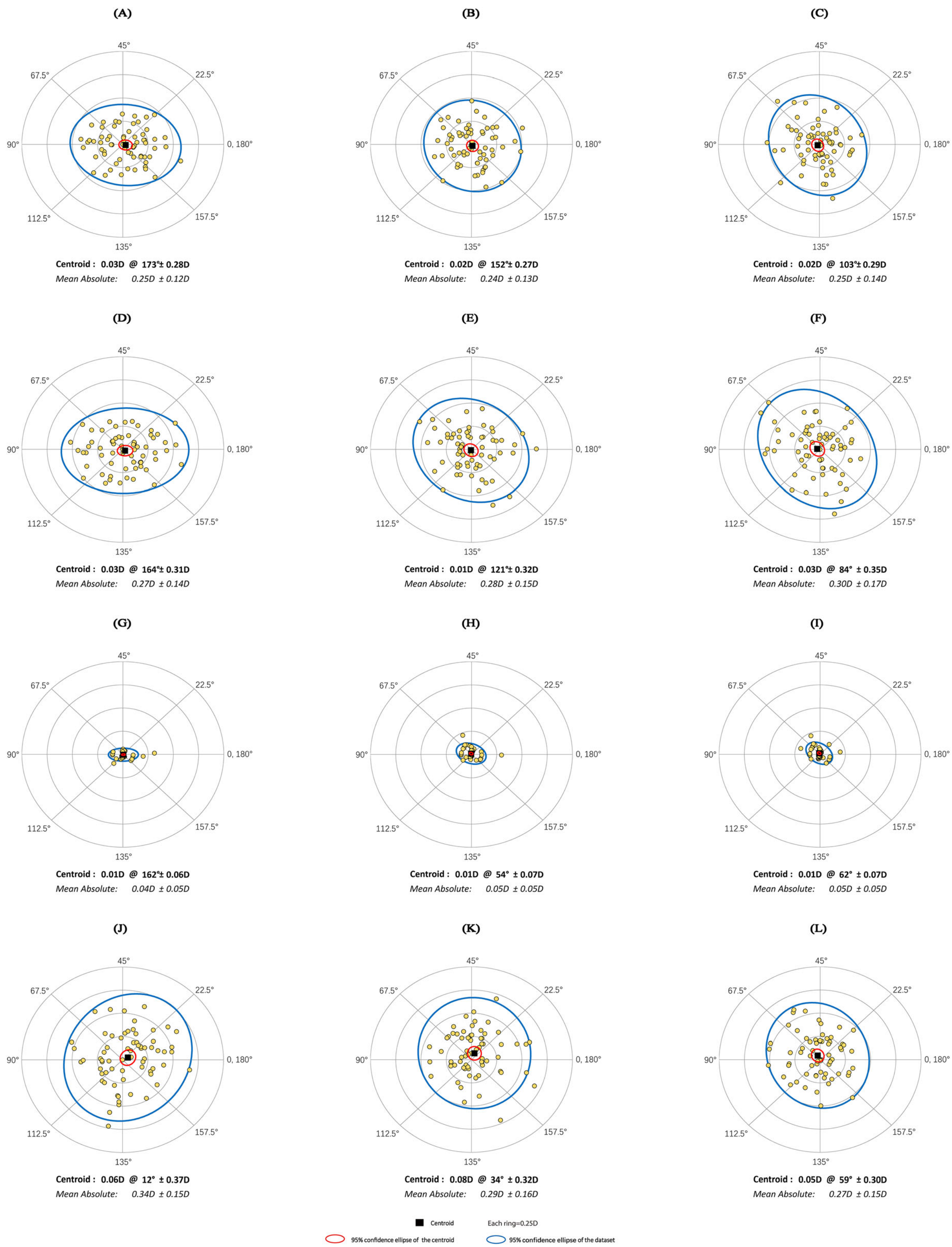
A total of 67 eyes from 67 healthy subjects (22 men and 45 women) with a mean age of 27.70 ± 6.04 (range 18–41) years were included in this study.

Intraobserver Repeatability

The intraobserver repeatability of the CASIA 2 measurements is reported in Table 1, demonstrating high intraobserver repeatability for both observers. The Sw of all measured parameters was ≤ 0.17 D and the TRT was ≤ 0.46 D. The CoV of K_f, K_s, K_m was $\leq 0.49\%$.

The ICCs were higher than 0.929 for all measured corneal power values, except for J_{45}-simulated (ICC 0.879–0.912), J_{45}-anterior (ICC 0.888–0.913), astigmatism-posterior (ICC 0.880–0.904), J_0-posterior (ICC 0.877–0.906), J_{45}-posterior (ICC 0.888–0.918), J_{45}-real (ICC 0.866–0.888). Meanwhile, the ICCs for keratometric parameters (K_f, K_s, K_m) were higher than 0.980. With the first observer, the ICCs were the highest in keratometric parameters (K_f, K_s, K_m), followed by astigmatism magnitude and J_0, whereas the worst was in J_{45}. The ICCs for posterior corneal power were slightly lower among these four powers. The second observer showed a similar trend.

As obtained by two observers, the differences in astigmatism between repeated measurements


(A)
Centroid : 0.03D @ 173°± 0.28D
Mean Absolute: 0.25D ± 0.12D
(B)
Centroid : 0.02D @ 152°± 0.27D
Mean Absolute: 0.24D ± 0.13D
(C)
Centroid : 0.02D @ 103°± 0.29D
Mean Absolute: 0.25D ± 0.14D
(D)
Centroid : 0.03D @ 164°± 0.31D
Mean Absolute: 0.27D ± 0.14D
(E)
Centroid : 0.01D @ 121°± 0.32D
Mean Absolute: 0.28D ± 0.15D
(F)
Centroid : 0.03D @ 84° ± 0.35D
Mean Absolute: 0.30D ± 0.17D
(G)
Centroid : 0.01D @ 162°± 0.06D
Mean Absolute: 0.04D ± 0.05D
(H)
Centroid : 0.01D @ 54° ± 0.07D
Mean Absolute: 0.05D ± 0.05D
(I)
Centroid : 0.01D @ 62° ± 0.07D
Mean Absolute: 0.05D ± 0.05D
(J)
Centroid : 0.06D @ 12° ± 0.37D
Mean Absolute: 0.34D ± 0.15D
(K)
Centroid : 0.08D @ 34° ± 0.32D
Mean Absolute: 0.29D ± 0.16D
(L)
Centroid : 0.05D @ 59° ± 0.30D
Mean Absolute: 0.27D ± 0.15D
45°
67.5°
22.5°
90°
0, 180°
112.5°
157.5°
135°
Centroid
Each ring=0.25D
95% confidence ellipse of the centroid
95% confidence ellipse of the dataset

◀**Fig. 2** Double-angle plots showing intraobserver differences in astigmatism between the second observer's repeated measurements in each corneal power measurement. Each ring represents 0.25 diopters (D), and the outer ring represents 1.0 D. The small ellipses (*red*) show the 95% confidence ellipses for the centroid and the larger ellipses (*blue*) show the 95% confidence ellipse for the difference vectors of the dataset. *First row*: Simulated keratometry. *Second row*: Anterior corneal power. *Third row*: Posterior corneal power. *Fourth row*: Total corneal power. *First column*: difference between first and second measurements. *Second column*: difference between first and third measurements. *Third column*: difference between second and third measurements

were mostly within 0.50 D in all corneal power measurements (Figs. 1 and 2).

Interobserver Reproducibility

Table 2 lists the interobserver reproducibility of all corneal power parameters obtained by averaging the three consecutive measurements from each observer (Average) or the first measurements from each observer (Single), demonstrating high interobserver reproducibility.

Regarding the average method, the high interobserver reproducibility was indicated by the low TRT values, with ≤ 0.21 D for K_f, 0.25 D for K_s, 0.19 D for K_m, 0.27 D for astigmatism magnitude, 0.15 D for J_0, and 0.14 D for J_{45}. The CoV for K_f, K_s, and K_m were ≤ 0.28%. The ICCs of all measured parameters were higher than 0.944 and mostly close to 1. Regarding the Single method, the TRT values were ≤ 0.34 D for K_f, 0.37 D for K_s, 0.27 D for K_m, 0.47 D for astigmatism magnitude, 0.24 D for J_0, and 0.22 D for J_{45}. The CoV for K_f, K_s, and K_m were ≤ 0.43%. The ICCs of all measured parameters ranged from 0.867 to 0.996.

Overall, for all simulated keratometry parameters, the TRT values of the Single method were approximately 65% higher than the TRT values of the Average method. Similar trends were also observed at anterior, posterior, and total corneal powers (Fig. 3). Likewise, for the CoV of all keratometric parameters (K_f, K_s, K_m), there was about 65% increment of the Single method compared to the average method (Fig. 4). For all corneal power measurements, the differences in astigmatism between averaged measurements of each observer were mostly within 0.50 D, whereas the differences in astigmatism between single measurements of each observer were dispersed in the range of 0.00–0.75 D (Fig. 5). These data indicate that the reproducibility of averaged measurements, as defined by S_w, TRT, CoV, and ICC, is higher than the reproducibility of the single measurements for all corneal power parameters.

DISCUSSION

In this present study, SS-OCT (CASIA 2) was utilized to analyze repeatability among and across observers of various corneal power values in healthy eyes. Previous studies have already confirmed the good reliability of CASIA 2 in measuring anterior segment parameters [21–23]. To the best of our knowledge, there was no research comprehensively analyzing the precision (repeatability and reproducibility) of the four corneal powers as provided by the CASIA 2.

Regarding the intraobserver repeatability, our data confirm the high repeatability with low S_w, TRT, and high ICCs (S_w ≤ 0.17 D, TRT ≤ 0.46 D, ICCs 0.866–0.998). Zhang et al. [9] previously revealed the good repeatability of the CASIA 2 by a low coefficient of repeatability (COR) in corneal powers. For total corneal power, Asawaworarit et al. [8] reported excellent repeatability for CASIA 2 (S_w 0.076 D, TRT 0.211 D, CoV 0.2%, ICC 0.996), which is close to our result (S_w 0.09 D, TRT 0.25 D, CoV 0.21%, ICC 0.996). Bao et al. [24] assessed six of the same posterior corneal parameters as ours by using two Scheimpflug–Placido analyzers (S_w 0.01–0.04 D, TRT 0.04–0.12 D). Likewise, we showed high repeatability for the posterior cornea (S_w 0.01–0.04 D, TRT 0.03–0.12 D). Moreover, the double-angle plots (Figs. 1 and 2) demonstrated consistent results: all the centroids were close to zero. When the centroid is infinitely close to zero, it means there is no systematic error in data distribution, and measurement errors are unlikely to be caused by identifiable factors [25, 26].

Table 2 Interobserver reproducibility of corneal power values by the CASIA 2

Parameter	Method	Mean ± SD (D)	S_w (D)	TRT (D)	CoV (%)	ICC (95% CI)
K_f-Simulated	Average	42.98 ± 1.30	0.06	0.18	0.15	0.998 (0.996–0.998)
	Single	43.00 ± 1.30	0.10	0.28	0.24	0.994 (0.990–0.996)
K_s-Simulated	Average	44.16 ± 1.49	0.08	0.21	0.17	0.997 (0.996–0.998)
	Single	44.17 ± 1.48	0.11	0.31	0.26	0.994 (0.990–0.996)
K_m-Simulated	Average	43.57 ± 1.36	0.06	0.15	0.13	0.998 (0.997–0.999)
	Single	43.59 ± 1.36	0.08	0.23	0.19	0.996 (0.994–0.998)
AST-Simulated	Average	1.18 ± 0.61	0.09	0.25	7.52	0.979 (0.966–0.987)
	Single	1.17 ± 0.60	0.14	0.38	11.69	0.950 (0.920–0.969)
J_0-Simulated	Average	− 0.53 ± 0.32	0.05	0.13	–	0.977 (0.963–0.986)
	Single	− 0.52 ± 0.32	0.07	0.20	–	0.948 (0.918–0.968)
J_{45}-Simulated	Average	0.09 ± 0.21	0.05	0.13	–	0.955 (0.927–0.972)
	Single	0.09 ± 0.22	0.08	0.21	–	0.886 (0.821–0.928)
K_f-Anterior	Average	47.88 ± 1.45	0.08	0.21	0.16	0.997 (0.995–0.998)
	Single	47.90 ± 1.45	0.12	0.34	0.26	0.993 (0.988–0.996)
K_s-Anterior	Average	49.19 ± 1.67	0.09	0.24	0.18	0.997 (0.996–0.998)
	Single	49.20 ± 1.66	0.13	0.37	0.27	0.994 (0.990–0.996)
K_m-Anterior	Average	48.54 ± 1.52	0.07	0.19	0.14	0.998 (0.997–0.999)
	Single	48.55 ± 1.52	0.10	0.27	0.20	0.996 (0.994–0.998)
AST-Anterior	Average	1.31 ± 0.68	0.10	0.27	7.40	0.980 (0.967–0.988)
	Single	1.30 ± 0.67	0.17	0.47	12.92	0.939 (0.903–0.962)
J_0-Anterior	Average	− 0.59 ± 0.35	0.05	0.15	–	0.977 (0.963–0.986)
	Single	− 0.58 ± 0.35	0.09	0.24	–	0.941 (0.906–0.963)
J_{45}-Anterior	Average	0.10 ± 0.23	0.05	0.14	–	0.953 (0.925–0.971)
	Single	0.10 ± 0.24	0.08	0.22	–	0.893 (0.832–0.933)
K_f-Posterior	Average	− 5.99 ± 0.19	0.02	0.05	0.28	0.993 (0.988–0.995)
	Single	− 6.00 ± 0.19	0.03	0.07	0.43	0.982 (0.971–0.989)
K_s-Posterior	Average	− 6.31 ± 0.22	0.01	0.03	0.19	0.997 (0.995–0.998)
	Single	− 6.31 ± 0.23	0.02	0.06	0.34	0.991 (0.986–0.995)
K_m-Posterior	Average	− 6.15 ± 0.20	0.01	0.03	0.15	0.998 (0.997–0.999)
	Single	− 6.15 ± 0.20	0.02	0.04	0.25	0.994 (0.990–0.996)
AST-Posterior	Average	− 0.31 ± 0.12	0.02	0.06	7.13	0.965 (0.943–0.978)
	Single	− 0.31 ± 0.12	0.04	0.10	11.50	0.914 (0.864–0.946)

Table 2 continued

Parameter	Method	Mean ± SD (D)	S_w (D)	TRT (D)	CoV (%)	ICC (95% CI)
J_0-Posterior	Average	0.15 ± 0.06	0.01	0.03	–	0.968 (0.948–0.980)
	Single	0.15 ± 0.06	0.02	0.05	–	0.913 (0.862–0.946)
J_{45}-Posterior	Average	– 0.03 ± 0.04	0.01	0.02	–	0.957 (0.931–0.973)
	Single	– 0.03 ± 0.04	0.01	0.03	–	0.936 (0.898–0.960)
K_f-Real	Average	41.99 ± 1.29	0.07	0.20	0.17	0.997 (0.995–0.998)
	Single	42.01 ± 1.29	0.11	0.32	0.27	0.992 (0.987–0.995)
K_s-Real	Average	43.02 ± 1.47	0.09	0.25	0.21	0.996 (0.994–0.998)
	Single	43.03 ± 1.47	0.13	0.35	0.30	0.992 (0.988–0.995)
K_m-Real	Average	42.51 ± 1.35	0.07	0.18	0.16	0.998 (0.996–0.999)
	Single	42.52 ± 1.35	0.09	0.25	0.22	0.995 (0.993–0.997)
AST-Real	Average	1.03 ± 0.57	0.10	0.27	9.40	0.972 (0.955–0.983)
	Single	1.02 ± 0.57	0.16	0.44	15.52	0.926 (0.882–0.954)
J_0-Real	Average	– 0.45 ± 0.31	0.05	0.15	–	0.969 (0.950–0.981)
	Single	– 0.44 ± 0.31	0.08	0.22	–	0.936 (0.899–0.960)
J_{45}-Real	Average	0.07 ± 0.20	0.05	0.13	–	0.944 (0.911–0.965)
	Single	0.07 ± 0.21	0.08	0.22	–	0.867 (0.792–0.916)

K_f flattest keratometry, K_s steepest keratometry, K_m mean keratometry, *AST* astigmatism magnitude, J_0 cylinder axis at the 180° and 90° meridians, J_{45} cylinder axis at the 45° and 135° meridians, *CI* confidence interval, *SD* standard deviation, S_w within-subject standard deviation, *TRT* test–retest repeatability (2.77 Sw), *CoV* within-subject coefficient of variation, *ICC* intraclass correlation coefficient

With respect to the interobserver reproducibility, high reproducibility was determined with low S_w, TRT values, high ICCs ($S_w \leq 0.10$ D, TRT ≤ 0.27 D, ICCs 0.944–0.998). Asawaworarit et al. [8] presented excellent reproducibility of CASIA 2 for total corneal power (S_w 0.062 D, TRT 0.172 D, CoV 0.1%, ICC 0.998) and we obtained a similar result (S_w 0.07 D, TRT 0.18 D, CoV 0.16%, ICC 0.998). For the posterior corneal power, our data (S_w 0.01–0.02 D, TRT 0.02–0.06 D) presents similar results with a previous study [24] of Scheimpflug–Placido analyzers (S_w 0.01–0.03 D, TRT 0.03–0.07 D). Mao et al. [27] revealed excellent reproducibility of Keratograph 4 (Oculus, Wetzlar, Germany) for simulated keratometry with low S_w, TRT, CoV values and our results are in good agreement with this study.

In addition, we found that the S_w, TRT, and CoV values of the Average method were lower than those of the Single method. The ICCs of the Average method were all higher than 0.90 (ICCs 0.944–0.998) representing high reproducibility whereas the ICCs of the Single method were slightly lower (ICCs 0.867–0.996). Even though the double-angle plots demonstrated the centroids were all near to zero (Fig. 5), the Average method yielded smaller 95% confidence ellipses for both the centroid and the dataset, as well as the overall distribution was more concentrated than that of the Single method. As reported by several researches

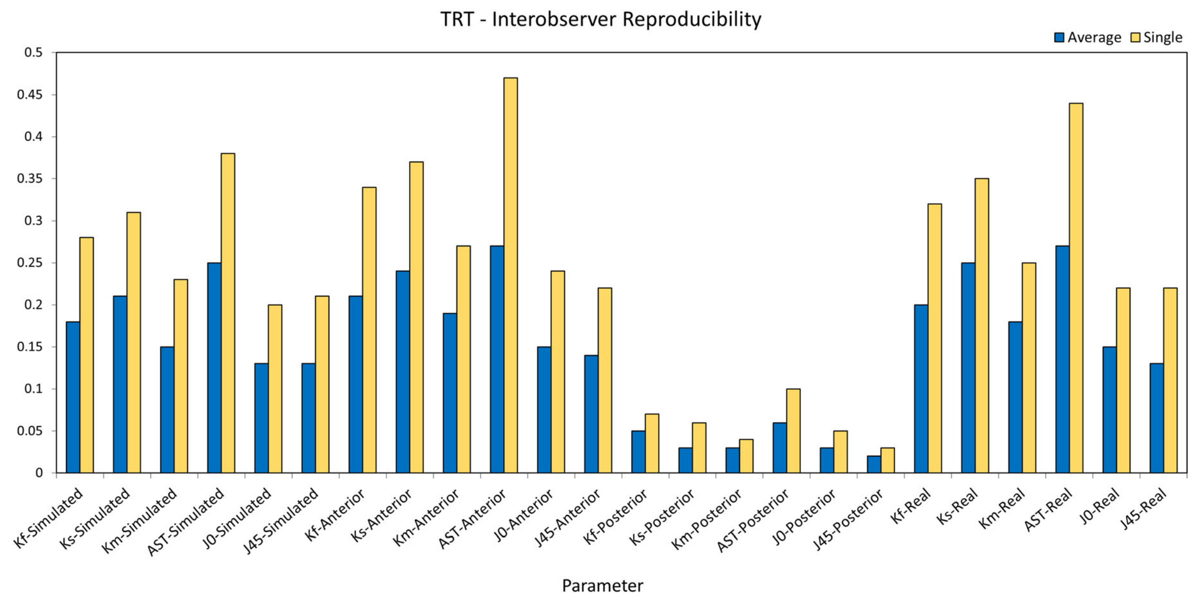


Fig. 3 Test–retest repeatability (TRT) values of all measured parameters for averaged measurements and single measurement. K_f flattest keratometry, K_s steepest keratometry, K_m mean keratometry, *AST* astigmatism magnitude, J_0 cylinder axis at the 180° and 90° meridians, J_{45} cylinder axis at the 45° and 135° meridians

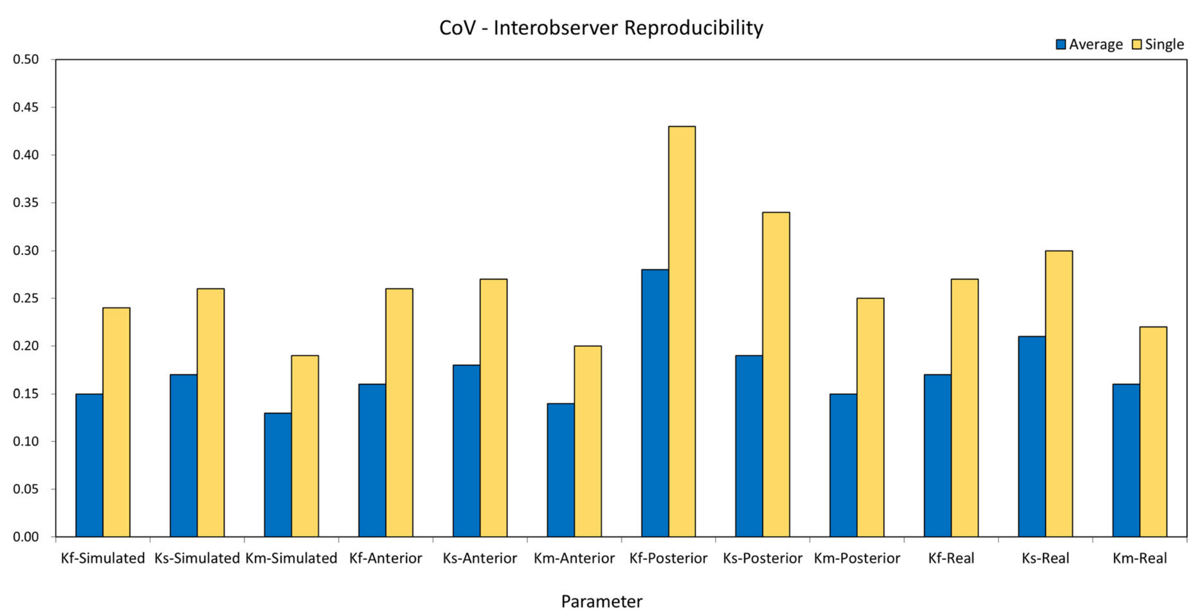


Fig. 4 Coefficients of variation (CoV) values of keratometric parameters for averaged measurements and single measurement. K_f flattest keratometry, K_s steepest keratometry, K_m mean keratometry

[18, 28, 31–36], the J_{45} vector always shows lower precision with a lower ICC value compared to other parameters. We obtained analogous results through evaluating the repeatability (ICC 0.866–0.918) and reproducibility by the Single method (ICC 0.867–0.936), nonetheless, the Average method achieved high reproducibility (ICC

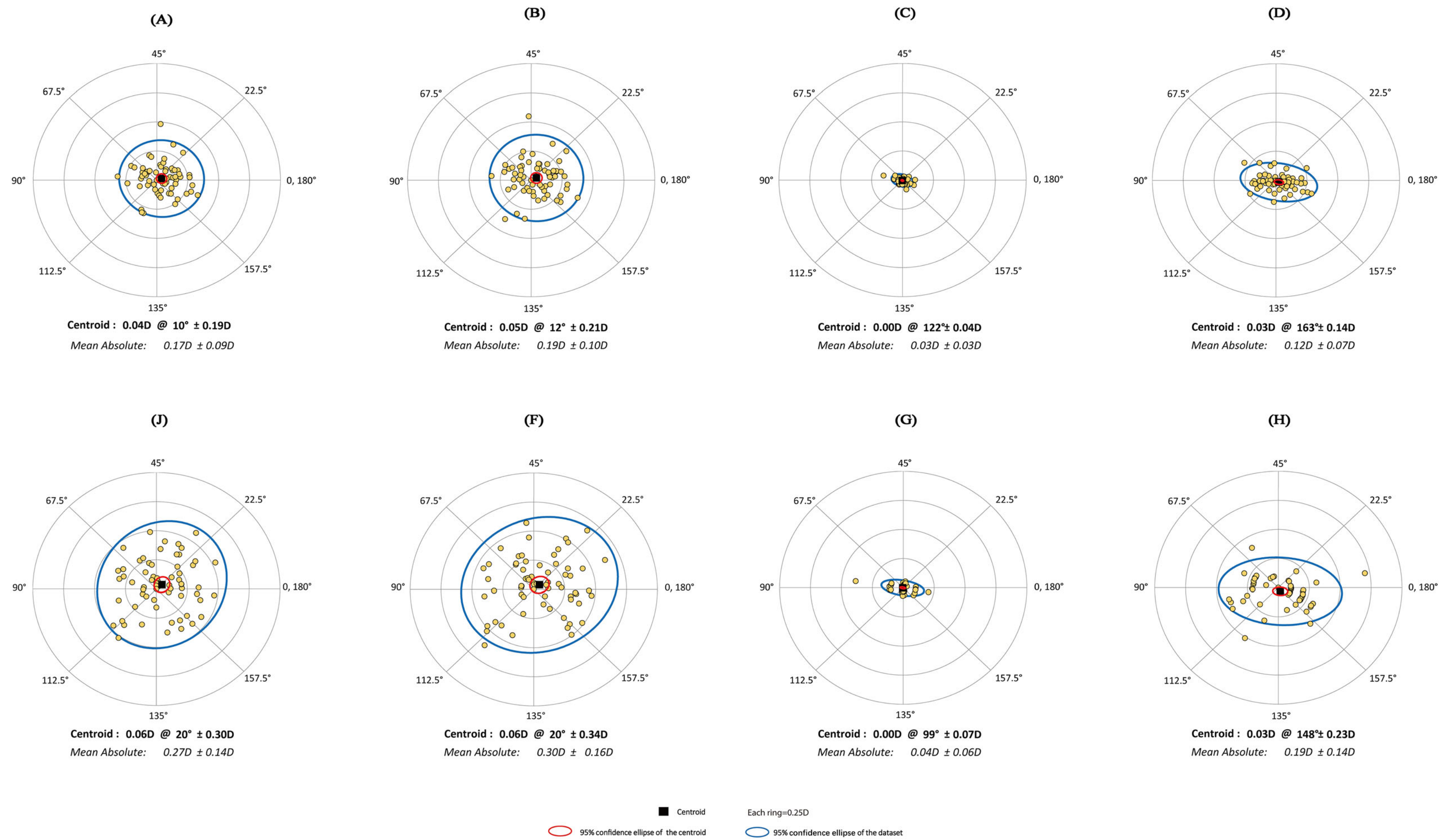


Fig. 5 Double-angle plots showing interobserver differences in astigmatism in each corneal power measurement. Each ring represents 0.25 diopters (D), and the outer ring represents 1.0 D. The small ellipses (*red*) show the 95% confidence ellipses for the centroid and the larger ellipses (*blue*) show the 95% confidence ellipse for the difference vectors of the dataset. *First row*: Average method. *Second row*: Single method. *First column*: Simulated keratometry. *Second column*: Anterior corneal power. *Third column*: Posterior corneal power. *Fourth column*: Total corneal power

0.944–0.957). These findings suggested that the Average method results in fewer discrepancies between observers. Correspondingly, Chen and Lam [28, 29] assessed the intersession repeatability of the Pentacam (Oculus, Wetzlar, Germany), showing the COR and the width of 95% limits of agreement (LoA) of averaged measurements were reduced and the authors concluded that using an average result improves intersession repeatability. Moreover, Read et al. [30] performed 20 consecutive measurements for each subject, showed that the standard deviation decreases with multiple measurements, the width of the 95% LoA substantially increases when fewer than three measurements from each instrument are used. Therefore, we recommend using the mean of three consecutive measurements to improve reproducibility for clinical application.

Concerning corneal astigmatism, the CoV of astigmatism magnitude was high (7.13–15.01%). Several studies have reported similar CoV (7.44–28.16%) with SS-OCT-based devices [35, 37, 38]. However, we still suggest the precision was good, as the ICCs of repeatability were higher than 0.866 and the ICCs of reproducibility were higher than 0.944 for magnitude and both vectors.

Our results show that simulated keratometry (43.57 ± 1.36D) provides higher values than total keratometry (42.51 ± 1.35D) measurements. Besides, the analysis area of CASIA 2 is 6 mm diameter, which is larger than the default setting of other devices [39], four corneal power measurements would be lower as the K values was steep in the central zone of normal cornea. These discrepancies will impact the prediction accuracy of IOL power calculation formulas unless specific constant optimization is carried out.

The main limitation of the present study is that we excluded eyes with corneal pathologies or previous surgery. The measurements for keratoconic eyes would likely be less reliable and repeatability be decreased with increasing keratoconus (KC) severity [40]. Therefore, further investigations should examine patients with KC or after undergoing any corneal refractive surgery. The second limitation is that our data were only generated from young healthy adults and did not include children.

CONCLUSIONS

In summary, our study revealed high intraobserver repeatability and interobserver reproducibility of all corneal power measurements provided by CASIA 2. Additionally, since the mean values of each observer's three consecutive measurements were more reproducible than the values from just one single measurement, we recommend using the mean value for clinical applications to optimize the consistency between different observers.

ACKNOWLEDGEMENTS

We thank the participants of the study.

Author Contributions. Contributors Design of the study (Chak Seng Lei, Xuanqiao Lin, Rui Ning, Xingtao Zhou, and Jinhai Huang); conduct of the study (Chak Seng Lei, Xuanqiao Lin, Rui Ning, and Jinjin Yu); data collection (Jinjin Yu, Xiaomin Huang, Kexin Li and Yiran Wang); analysis and interpretation (Chak Seng Lei, Rui Ning, Xingtao Zhou and Jinhai Huang); manuscript preparation and review (Chak Seng Lei, Xuanqiao Lin, Giacomo Savini, Domenico Schiano-Lomoriello, Xingtao Zhou and Jinhai Huang); read and approved the final version of the article (Chak Seng Lei, Xuanqiao Lin, Rui Ning, Jinjin Yu, Xiaomin Huang, Kexin Li, Yiran Wang, Giacomo Savini, Domenico Schiano-Lomoriello, Xingtao Zhou and Jinhai Huang).

Funding. This work was supported in part by the Project of National Natural Science Foundation of China (Grant No. 82271048); Shanghai Science and Technology (Grant No. 22S11900200, 23XD1420500); EYE & ENT Hospital of Fudan University High-level Talents Program (Grant No. 2021318); Clinical Research Plan of SHDC (Grant No. SHDC2020CR1043B); Project of Shanghai Xuhui District Science and Technology (Grant No. 2020–015); Program for Professor of Special Appointment (Eastern

Scholar, TP2022046) at Shanghai Institutions of Higher Learning; The contribution of IRCCS Bietti Foundation was supported by Fondazione Roma and the Italian Ministry of Health. The funders had no role in study design, data collection and analysis, decision to publish, or reparation of the manuscript. The Rapid Service Fee was funded by the authors.

Data Availability. The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest. Chak Seng Lei, Xuanqiao Lin, Rui Ning, Jinjin Yu, Xiaomin Huang, Kexin Li, Yiran Wang, Giacomo Savini, Domenico Schiano-Lomoriello, Xingtao Zhou, and Jinhai Huang have nothing to disclose.

Ethical Approval. This prospective study was approved by the Institutional Ethics Committee of the Eye and ENT Hospital of Fudan University (2021174), and conducted by the principles of the Declaration of Helsinki. All subjects signed an informed consent after understanding the purpose of the study.

REFERENCES

1. Tomidokoro A, Oshika T, Amano S, Higaki S, Maeda N, Miyata K. Changes in anterior and posterior corneal curvatures in keratoconus. Ophthalmology. 2000;107(7):1328–32. https://doi.org/10.1016/S0161-6420(00)00159-7.

2. Olsen T. Calculation of intraocular lens power: a review. Acta Ophthalmol Scand. 2007;85(5):472–85. https://doi.org/10.1111/j.1600-0420.2007.00879.x.

3. Hirnschall N, Findl O, Bayer N, et al. Sources of error in toric intraocular lens power calculation. J Refract Surg Thorofare NJ 1995. 2020;36(10):646–52. https://doi.org/10.3928/1081597X-20200729-03.

4. Koch DD, Ali SF, Weikert MP, Shirayama M, Jenkins R, Wang L. Contribution of posterior corneal astigmatism to total corneal astigmatism. J Cataract Refract Surg. 2012;38(12):2080–7. https://doi.org/10.1016/j.jcrs.2012.08.036.

5. Gutmark R, Guyton DL. Origins of the keratometer and its evolving role in ophthalmology. Surv Ophthalmol. 2010;55(5):481–97. https://doi.org/10.1016/j.survophthal.2010.03.001.

6. Hoffer KJ. The Hoffer Q formula: a comparison of theoretic and regression formulas. J Cataract Refract Surg. 1993;19(6):700–12. https://doi.org/10.1016/s0886-3350(13)80338-0.

7. Wang L, Mahmoud AM, Anderson BL, Koch DD, Roberts CJ. Total corneal power estimation: ray tracing method versus gaussian optics formula. Investig Opthalmology Vis Sci. 2011;52(3):1716. https://doi.org/10.1167/iovs.09-4982.

8. Asawaworarit R, Satitpitakul V, Taweekitikul P, Pongpirul K. Agreement of total corneal power between 2 swept-source optical coherence tomography and Scheimpflug tomography in normal and keratoconic patients. Mohan RR, ed. PLoS ONE. 2022;17(5): e0268856. https://doi.org/10.1371/journal.pone.0268856.

9. Zhang T, Zhou Y, Young CA, Chen A, Jin G, Zheng D. Comparison of a new swept-source anterior segment optical coherence tomography and a Scheimpflug Camera for measurement of corneal curvature. Cornea. 2020;39(7):818–22. https://doi.org/10.1097/ICO.0000000000002280.

10. Oh R, Oh JY, Choi HJ, Kim MK, Yoon CH. Comparison of ocular biometric measurements in patients with cataract using three swept-source optical coherence tomography devices. BMC

Ophthalmol. 2021;21(1):62. https://doi.org/10.1186/s12886-021-01826-5.

11. Ruan X, Yang G, Xia Z, et al. Agreement of anterior segment parameter measurements with CASIA 2 and IOLMaster 700. Front Med. 2022;9:777443. https://doi.org/10.3389/fmed.2022.777443.

12. Jin GM, Xiao B, Zhou YJ, Wang YY, Li XP, Zheng DY. Agreement of corneal curvature and central corneal thickness obtained from a swept-source OCT and Pentacam in ectopia lentis patients. Int J Ophthalmol. 2020;13(8):1244–9. https://doi.org/10.18240/ijo.2020.08.10.

13. Wylęgała A, Mazur R, Bolek B, Wylęgała E. Reproducibility, and repeatability of corneal topography measured by Revo NX, Galilei G6 and Casia 2 in normal eyes. Grzybowski A, ed. PLoS ONE. 2020;15(4): e0230589. https://doi.org/10.1371/journal.pone.0230589.

14. Thibos LN, Wheeler W, Horner D. Power vectors: an application of Fourier analysis to the description and statistical analysis of refractive error. Optom Vis Sci. 1997;74(6):367–75. https://doi.org/10.1097/00006324-199706000-00019.

15. Read SA, Collins MJ. Diurnal variation of corneal shape and thickness. Optom Vis Sci Off Publ Am Acad Optom. 2009;86(3):170–80. https://doi.org/10.1097/OPX.0b013e3181981b7e.

16. Bland JM, Altman DG. Statistics notes: Measurement error. BMJ. 1996;312(7047):1654–1654. https://doi.org/10.1136/bmj.312.7047.1654.

17. Müller R, Büttner P. A critical discussion of intraclass correlation coefficients. Stat Med. 1994;13(23–24):2465–76. https://doi.org/10.1002/sim.4780132310.

18. Wang L, Shirayama M, Koch DD. Repeatability of corneal power and wavefront aberration measurements with a dual-Scheimpflug Placido corneal topographer. J Cataract Refract Surg. 2010;36(3):425–30. https://doi.org/10.1016/j.jcrs.2009.09.034.

19. American Society of Cataract and Refractive Surgery. Astigmatism Double Angle Plot Tool. https://ascrs.org/astigmatism-double-angle-plot-tool. Accessed 2 Mar 2023.

20. Abulafia A, Koch DD, Holladay JT, Wang L, Hill W. Pursuing perfection in intraocular lens calculations: IV. Rethinking astigmatism analysis for intraocular lens-based surgery: Suggested terminology, analysis, and standards for outcome reports. J Cataract Refract Surg. 2018;44(10):1169–74. https://doi.org/10.1016/j.jcrs.2018.07.027.

21. Xu BY, Mai DD, Penteado RC, Saunders L, Weinreb RN. Reproducibility and agreement of anterior segment parameter measurements obtained using the CASIA2 and Spectralis OCT2 optical coherence tomography devices. J Glaucoma. 2017;26(11):974–9. https://doi.org/10.1097/IJG.0000000000000788.

22. Saito A, Kamiya K, Fujimura F, Takahashi M, Shoji N. Comparison of angle-to-angle distance using three devices in normal eyes. Eye. 2020;34(6):1116–20. https://doi.org/10.1038/s41433-019-0653-2.

23. Cheng SM, Zhang JS, tian LT, tong WZ, Wang P, Yu AY. Repeatability and agreement of two swept-source optical coherence tomographers for anterior segment parameter measurements. J Glaucoma. 2022;31(7):602–8. https://doi.org/10.1097/IJG.0000000000001989.

24. Bao F, Savini G, Shu B, et al. Repeatability, reproducibility, and agreement of two Scheimpflug-Placido anterior corneal analyzers for posterior corneal surface measurement. J Refract Surg Thorofare NJ 1995. 2017;33(8):524–30. https://doi.org/10.3928/1081597X-20170606-01.

25. Lebow KA, Campbell CE. A comparison of a traditional and wavefront autorefraction. Optom Vis Sci. 2014;91(10):1191. https://doi.org/10.1097/OPX.0000000000000378.

26. Alpins N. Astigmatism analysis by the Alpins method. J Cataract Refract Surg. 2001;27(1):31–49. https://doi.org/10.1016/s0886-3350(00)00798-7.

27. Mao X, Savini G, Zhuo Z, et al. Repeatability, reproducibility, and agreement of corneal power measurements obtained with a new corneal topographer. J Cataract Refract Surg. 2013;39(10):1561–9. https://doi.org/10.1016/j.jcrs.2013.04.029.

28. Chen D, Lam AK. Reliability and repeatability of the Pentacam on corneal curvatures. Clin Exp Optom. 2009;92(2):110–8. https://doi.org/10.1111/j.1444-0938.2008.00336.x.

29. Chen D, Lam AKC. Intrasession and intersession repeatability of the Pentacam system on posterior corneal assessment in the normal human eye. J Cataract Refract Surg. 2007;33(3):448–54. https://doi.org/10.1016/j.jcrs.2006.11.008.

30. Read SA, Collins MJ, Iskander RD, Davis BA. Corneal topography with Scheimpflug imaging and videokeratography: comparative study of normal eyes. J Cataract Refract Surg. 2009;35(6):1072–81. https://doi.org/10.1016/j.jcrs.2009.01.020.

31. Ventura BV, Al-Mohtaseb Z, Wang L, Koch DD, Weikert MP. Repeatability and comparability of

corneal power and corneal astigmatism obtained from a point-source color light–emitting diode topographer, a Placido-based corneal topographer, and a low-coherence reflectometer. J Cataract Refract Surg. 2015;41(10):2242–50. https://doi.org/10.1016/j.jcrs.2015.11.003.

32. Kim EJ, de Oca IM, Wang L, Weikert MP, Koch DD, Khandelwal SS. Repeatability of posterior and total corneal curvature measurements with a dual Scheimpflug-Placido tomographer. J Cataract Refract Surg. 2015;41(12):2731–8. https://doi.org/10.1016/j.jcrs.2015.07.035.

33. Hua Y, Xu Z, Qiu W, Wu Q. Precision (Repeatability and Reproducibility) and Agreement of corneal power measurements obtained by topcon KR-1W and iTrace. PLoS ONE. 2016;11(1): e0147086. https://doi.org/10.1371/journal.pone.0147086.

34. Huang J, Savini G, Chen H, et al. Precision and agreement of corneal power measurements obtained using a new corneal topographer OphthaTOP. PLoS ONE. 2015;10(1): e109414. https://doi.org/10.1371/journal.pone.0109414.

35. Savini G, Taroni L, Schiano-Lomoriello D, Hoffer KJ. Repeatability of total Keratometry and standard Keratometry by the IOLMaster 700 and comparison to total corneal astigmatism by Scheimpflug imaging. Eye. 2021;35(1):307–15. https://doi.org/10.1038/s41433-020-01245-8.

36. Chan TCY, Wan KH, Tang FY, Wang YM, Yu M, Cheung C. Repeatability and agreement of a swept-source optical coherence tomography-based biometer IOLMaster 700 versus a Scheimpflug imaging-based biometer AL-scan in cataract patients. Eye Contact Lens. 2020;46(1):35–45. https://doi.org/10.1097/ICL.0000000000000603.

37. Muzyka-Woźniak M, Oleszko A, Grzybowski A. Measurements of anterior and posterior corneal curvatures with OCT and Scheimpflug biometers in patients with low total corneal astigmatism. J Clin Med. 2022;11(23):6921. https://doi.org/10.3390/jcm11236921.

38. Sharma A, Batra A. Assessment of precision of astigmatism measurements taken by a swept-source optical coherence tomography biometer-IOLMaster 700. Indian J Ophthalmol. 2021;69(7):1760–5. https://doi.org/10.4103/ijo.IJO_2776_20.

39. Shirayama M, Wang L, Weikert MP, Koch DD. Comparison of corneal powers obtained from 4 different devices. Am J Ophthalmol. 2009;148(4):528-535.e1. https://doi.org/10.1016/j.ajo.2009.04.028.

40. Flockerzi E, Elzer B, Daas L, et al. the reliability of successive Scheimpflug imaging and anterior segment optical coherence tomography measurements decreases with increasing keratoconus severity. Cornea. 2021;40(11):1433–9. https://doi.org/10.1097/ICO.0000000000002657.