Research Square

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Agreement of four biometers measuring corneal astigmatism parameters in cataract eyes with low astigmatism

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Research Article

Keywords: Cataract, Corneal keratometry, Astigmatism, Agreement, Bland–Altman analysis

Posted Date: September 8th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10805911/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

To investigate the agreement of corneal astigmatism measurements in eyes with low corneal astigmatism using four devices: Pentacam, Sirius, IOLMaster 700, and iTrace.

Methods

This prospective observational study enrolled104 cataract eyes with corneal astigmatism ≤ 1.5D. All four devices were used to measure keratometry (Kf, Ks, Km), power vectors (J_0, J_{45}), and astigmatism classifications. The results were compared using the Friedman *t*est, Lin's concordance correlation coefficient (CCC), Cohen's kappa, and Bland-Altman analysis.

Results

Significant inter-device differences were found for Kf, Ks, and Km (all $P < 0.001$), but not for J_0 or J_{45}. Excellent CCC (> 0.95) was observed among Pentacam, Sirius, and IOLMaster 700 for keratometry, whereas comparisons with iTrace yielded lower CCC (0.784–0.853). For J_0 and J_{45}, CCC values were poor (≤ 0.135), with wide 95% limits of agreement. Agreement for astigmatism type and magnitude classifications was moderate (kappa: 0.352–0.573), with significant systematic asymmetry only between Pentacam and iTrace (McNemar-Bowker, $P = 0.006$).

Conclusions

Pentacam, Sirius, and IOLMaster 700 are interchangeable for anterior keratometry in low-astigmatism eyes, but their wide limits of agreement for vector parameters suggest a caution in toric IOL planning. iTrace shows systematic discrepancies and should not be used interchangeably without recalibration.

Background

Accurate measurement of corneal astigmatism is essential for optimal visual outcomes in cataract surgery, particularly with the increasing adoption of toric intraocular lenses (IOLs) and premium IOLs[1–3]. The precision of preoperative corneal astigmatism assessment directly influences the effectiveness of astigmatic correction and postoperative refractive outcomes, as errors in keratometry or axis determination can lead to residual astigmatism and reduced patient satisfaction[4–6].

Numerous optical biometers and tomographers based on different technologies, such as IOLMaster 500&700, Pentacam, CASIA2, Sirius, Lenstar 900, and iTrace, are now commercially available and have prompted several comparative studies[7–13]. Wang et al. reported that Pentacam was not interchangeable with IOLMaster 700, Lenstar 900, or iTrace in eyes with irregular corneal astigmatism due to vector differences exceeding 0.50 diopters(D) [14]. Ma et al. found strong correlations but wide limits of agreement (> 1 D) among IOLMaster 700, CASIA2, Pentacam, and iTrace in cataract patients, discouraging their interchangeability[15]. Jin et al. further demonstrated significant differences in total and posterior keratometry among IOLMaster 700, CASIA2, and Pentacam AXL[16]. All these studies primarily have focused on unselected cataract populations or irregular corneas, and their findings may not apply to eyes with low corneal astigmatism (< 1.5 D).

In such eyes, small measurement discrepancies can disproportionately affect toric IOL selection and the predicted residual astigmatism[17–19]. Moreover, because the corneal surface is generally more regular and tear film dynamics may exert a different influence, agreement patterns established in higher astigmatism or irregular corneas cannot be reliably extrapolated to low-astigmatism eyes—a subgroup that has remained unexplored.

Therefore, this prospective study evaluated the agreement of corneal astigmatism parameters—including keratometry (Ks, Kf and Km), power vectors (J_0 and J_{45}), and astigmatism type classification (with-the-rule [WTR], against-the-rule [ATR], and oblique [OBL])—

among IOLMaster 700, Sirius, iTrace, and Pentacam in eyes with low corneal astigmatism. The findings aim to guide clinicians in selecting appropriate devices and interpreting measurements for optimized refractive outcomes.

Methods

Study Design and Participants

This prospective, observational, cross-sectional study was conducted at Shenzhen People's Hospital between October 2022 and October 2024. The study protocol adhered to the principles of the Declaration of Helsinki and was approved by the Institutional Ethics Committee of Shenzhen People's Hospital (ID: LL-KY-2024193). Written informed consent was obtained from all participants prior to enrollment.

Inclusion criteria were: (1) age ≥ 18 years; (2) diagnosis of cataract; (3) preoperative corneal astigmatism ≤ 1.5 D as measured by IOLMaster 700; and (4) ability to cooperate with measurements from all four devices. Exclusion criteria included: (1) previous ocular surgery or trauma; (2) corneal pathologies such as keratoconus, pterygium, or corneal scarring; (3) severe dry eye disease (tear break-up time < 5 seconds); (4) irregular corneal astigmatism detected by any device; and (5) any systemic or ocular condition that could affect corneal curvature measurements. In patients with bilateral cataracts, only one eye was randomly selected for analysis to avoid inter-eye correlation bias; for unilateral cases, the operated eye was included.

Measurement Devices and Protocol

All measurements were performed under standardized procedures. Patients were instructed to blink completely before each acquisition. Only scans with a quality indicator of "OK" or equivalent (as defined by each device's internal software) were retained for analysis. Three consecutive readings were obtained for each eye per device, and the mean value was used for statistical analysis.

The following four devices were used:

A: Pentacam HR (Oculus Optikgeräte GmbH, Wetzlar, Germany): Scheimpflug tomography-based system. Simulated keratometry values from the 3.0 mm annular zone centered on the corneal apex were extracted.

B: Sirius (CSO, Florence, Italy): Combined Scheimpflug–Placido topographer. Anterior corneal curvature was recorded from the 3.0 mm ring.

C: IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany): Swept-source optical coherence tomography-based biometer. Telecentric keratometry values were obtained from the 2.5 mm corneal diameter zone.

D: iTrace (Tracey Technologies, Houston, TX, USA): Placido disk-based corneal topographer. Central corneal keratometry was derived from the 3.0 mm zone.

Astigmatic Vector Calculation

Corneal astigmatism was converted into power vector components, J_0 and J_{45}, using the recommended formulas [14 20 21]. The astigmatic magnitude was defined as the difference between steep keratometry (Ks) and flat keratometry (Kf), with its axis corresponding to the steep meridian. The J_0 and J_{45} vectors were calculated using the following formulas:

$J_0 = -(Ks - K f) / 2 \times \cos(2\alpha)$

$J_{45} = -(Ks - Kf) / 2 \times \sin(2\alpha)$

where (Ks − Kf) denotes the positive cylindrical power and α is the axis (in degrees) of the steepest meridian.

Statistical Analysis

Statistical analyses were performed using Stata 16.0 (StataCorp LLC, College Station, TX, USA) and SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Normality of continuous variables was assessed using the Shapiro–Wilk test and Q–Q plots. Normally distributed data are presented as mean ± standard deviation (SD); non-normally distributed data are expressed as median (interquartile range, IQR). Inter-device comparisons for keratometry and vector parameters were performed using the Friedman test for global differences, followed by post-hoc pairwise comparisons with Bonferroni correction for multiple testing. Agreement analysis was conducted using Lin's concordance correlation coefficient (CCC) with 95% confidence intervals (CI), computed using Fisher's z-transformation. CCC values were interpreted as: < 0.90 = poor to moderate, 0.90–0.95 = moderate to good, and > 0.95 = excellent agreement. For categorical variables (astigmatism type and magnitude classifications), agreement was assessed using Cohen's kappa coefficient with 95% CI, and symmetry of disagreement was evaluated using the McNemar-Bowker test. Bland–Altman analysis was performed for each pairwise comparison to estimate the mean difference (bias) and 95% limits of agreement (LoA), calculated as mean difference ± 1.96 × SD of differences. *P*-value < 0.05 was considered statistically significant for all analyses.

Results

Baseline characteristics

A total of 104 eyes from 104 patients (32 males, 72 females) with a mean age of 67.57 ± 10.61 years were included in the final analysis **(The flowchart is shown in Supplemental Fig. 1).** Of these, 50 eyes (48.08%) were right eyes. Baseline ocular biometry, measured by the IOLMaster 700, revealed a mean axial length of 23.63 ± 1.34 mm, central corneal thickness of 0.53 ± 0.04 mm, anterior chamber depth of 3.10 ± 0.52 mm, lens thickness of 4.34 ± 0.52 mm, and white-to-white distance of 11.65 ± 0.38 mm **(**Table 1**).**

Table 1
Baseline Characteristics of Participants

Characteristic	Value
Patients (Eyes), *n*	104(104)
Age, y	67.57 ± 10.61
Male, *n* (%)	32 (30.77%)
Right eye, *n* (%)	50 (48.08%)
Ocular biometry by IOLMaster 700	
AL,mm	23.63 ± 1.34
CCT,mm	0.53 ± 0.04
ACD,mm	3.10 ± 0.52
LT,mm	4.34 ± 0.52
WTW,mm	11.65 ± 0.38

AL, axial length; CCT, central corneal thickness; ACD, anterior chamber depth; LT, lens thickness; WTW, white-to-with distance.

Supplemental Fig. 1. The flowchart.

Agreement of Keratometry

The mean values of flat keratometry (Kf), steep keratometry (Ks), and mean keratometry (Km) across the four devices are summarized in Table 2. Significant global differences were observed among the four devices for Kf, Ks, and Km (Friedman test, all *P* < 0.001). Post-hoc pairwise comparisons revealed that Pentacam (A) and Sirius (B) showed statistically significant differences in Kf, Ks, and Km (all *P* < 0.001), and Pentacam versus IOLMaster 700 (C) also differed significantly across all three parameters (all *P* < 0.001). Pentacam versus iTrace (D) showed significant differences for Ks (*P* = 0.002) and Km (*P* = 0.010), but not for Kf (*P* = 0.079).

Sirius versus IOLMaster 700 showed no significant differences in Kf, Ks, or Km (all $P > 0.05$), except for a borderline difference in Ks ($P = 0.022$). Sirius versus iTrace showed no significant differences for Kf, Ks, or Km (all $P > 0.05$). IOLMaster 700 versus iTrace showed significant differences in Kf ($P = 0.038$) and Km ($P = 0.033$), but not in Ks ($P = 0.051$) **(**Table 2**).**

Table 2
Comparison of Keratometry and Astigmatism in cataract patients Obtained with four devices

Characteristic **Mean ± SD**	**Pentacam** **(A)**	**Sirius** **(B)**	**IOLMaster 700** **(C)**	**iTrace** **(D)**	***P value***						
					4 devices*	***A vs B**#*	***A vs C**#*	***A vs D**#*	***B vs C**#*	***B vs D**#*	***C vs D**#*
Kf, D	44.06 ± 1.62	44.15 ± 1.60	44.24 ± 1.70	43.92 ± 2.07	**< 0.001**	**< 0.001**	**< 0.001**	0.079	0.879	0.498	**0.038**
Ks, D	44.73 ± 1.65	44.93 ± 1.67	44.93 ± 1.68	44.66 ± 2.14	**< 0.001**	**< 0.001**	**< 0.001**	**0.002**	**0.022**	0.522	0.051
Km, D	44.39 ± 1.62	44.54 ± 1.61	44.59 ± 1.67	44.29 ± 2.10	**< 0.001**	**< 0.001**	**< 0.001**	**0.010**	0.137	0.350	**0.033**
J_0, D	0.00 ± 0.29	0.04 ± 0.35	-0.01 ± 0.29	0.00 ± 0.32	0.310	0.757	0.893	0.758	0.931	0.589	0.671
J_{45}, D	-0.04 ± 0.30	0.02 ± 0.33	-0.03 ± 0.29	0.01 ± 0.28	0.219	0.243	0.660	0.827	0.650	0.551	0.442

Kf, flat keratometry, Ks, steep keratometry; Km, mean keratometry; J_0, Jackson cross-cylinder at 0 and 90 degrees; J_{45}, Jackson cross-cylinder at 45 and 135 degrees; D, diopter; SD, standard error.

A=Pentacam, B=Sirius, C=IOLMaster 700, D= iTrace,

***** *P* values calculated using the Friedman test

*P* values calculated using Bonferroni multiple-comparison test

In terms of agreement **(**Table 3, Fig. 1**)**, Lin's CCC for Kf ranged from 0.843 (A vs. D) to 0.973 (A vs. C), with most pairwise comparisons showing excellent agreement (> 0.95) except those involving iTrace, which exhibited moderate-to-good agreement (CCC: 0.796–0.843). Similarly, for Ks, CCC values were excellent for comparisons among Pentacam, Sirius, and IOLMaster 700 (CCC: 0.948–0.971), but lower for comparisons with iTrace (CCC: 0.784–0.853). For Km, CCC values were excellent among Pentacam, Sirius, and IOLMaster 700 (CCC: 0.970–0.982), while comparisons with iTrace yielded moderate CCCs (0.797–0.852). Bland–Altman analysis revealed that the narrowest 95% LoA were observed for B vs. C in Km (− 0.522 to 0.647 D), whereas the widest LoA were found for B vs. D in Ks (− 2.266 to 2.658 D), indicating clinically relevant variability when iTrace was involved.

Table 3
Agreement and correlation of Keratometry and Astigmatism in cataract patients Obtained with four devices

Parameter	*CCC (95%CI)*	Mean Diff. ± SD	95%*LoA*	*P* value
Kf, D				
A vs. B	0.960 (0.944, 0.977)	-0.15 ± 0.43	-0.982, 0.688	**< 0.001**
A vs. C	0.973 (0.962, 0.984)	-0.13 ± 0.36	-0.838, 0.575	**< 0.001**
A vs. D	0.843 (0.774, 0.912)	-0.01 ± 1.05	-2.061, 2.051	**< 0.001**
B vs. C	0.968 (0.955, 0.981)	0.02 ± 0.41	-0.787, 0.828	**< 0.001**
B vs. D	0.796 (0.710, 0.882)	0.17 ± 1.17	-2.123, 2.460	**< 0.001**
C vs. D	0.820 (0.745, 0.895)	0.10 ± 1.15	-2.151, 2.345	**< 0.001**
Ks, D				
A vs. B	0.948 (0.927, 0.969)	-0.24 ± 0.47	-1.172, 0.684	**< 0.001**
A vs. C	0.971 (0.959, 0.982)	-0.12 ± 0.38	-0.866, 0.628	**< 0.001**
A vs. D	0.853 (0.788, 0.918)	-0.12 ± 1.04	-2.157, 1.924	**< 0.001**
B vs. C	0.966 (0.952, 0.979)	0.11 ± 0.42	-0.716, 0.925	**< 0.001**
B vs. D	0.784 (0.691, 0.877)	0.20 ± 1.26	-2.266, 2.658	**< 0.001**
C vs. D	0.820 (0.747, 0.893)	0.04 ± 1.16	-2.231, 2.319	**< 0.001**
Km, D				
A vs. B	0.970 (0.957, 0.982)	-0.20 ± 0.34	-0.866, 0.475	**< 0.001**
A vs. C	0.982 (0.975, 0.989)	-0.13 ± 0.28	-0.677, 0.427	**< 0.001**
A vs. D	0.852 (0.786, 0.917)	-0.06 ± 1.03	-2.076, 1.954	**< 0.001**
B vs. C	0.982 (0.975, 0.989)	0.06 ± 0.30	-0.522, 0.647	**< 0.001**
B vs. D	0.797 (0.711, 0.884)	0.18 ± 1.19	-2.134, 2.499	**< 0.001**
C vs. D	0.824 (0.752, 0.897)	0.07 ± 1.14	-2.154, 2.295	**< 0.001**
J_0, D				
A vs. B	0.102 (-0.105, 0.309)	-0.05 ± 0.43	-0.897, 0.792	0.333
A vs. C	0.135 (-0.340, 0.070)	0.01 ± 0.44	-0.850, 0.861	0.196
A vs. D	-0.088 (-0.336, 0.159)	-0.01 ± 0.44	-0.862, 0.842	0.485
B vs. C	-0.046 (-0.244, 0.152)	0.05 ± 0.46	-0.850, 0.952	0.650
B vs. D	-0.033 (-0.278, 0.212)	0.07 ± 0.48	-0.874, 1.009	0.793
C vs. D	0.089 (-0.147, 0.325)	-0.03 ± 0.39	-0.806, 0.739	0.460
J_{45}, D				
A vs. B	-0.167 (-0.039, 0.373)	-0.05 ± 0.41	-0.845, 0.755	0.112
A vs. C	-0.140 (-0.064, 0.345)	-0.02 ± 0.39	-0.776, 0.745	0.177
A vs. D	0.044 (-0.206, 0.294)	0.01 ± 0.38	-0.743, 0.758	0.731
B vs. C	0.065 (-0.137, 0.266)	0.04 ± 0.43	-0.804, 0.881	0.528
B vs. D	-0.012 (-0.259, 0.235)	0.00 ± 0.43	-0.831, 0.838	0.925

Parameter	*CCC (95%CI)*	Mean Diff. ± SD	95%*LoA*	*P* value
C vs. D	-0.025 (-0.265, 0.214)	-0.05 ± 0.41	-0.849, 0.755	0.836

CCC, Lin's concordance correlation coefficient.; *CI*, confidence interval; D, diopter; Diff, Difference; J_0, Jackson cross-cylinder at 0 and 90 degrees; J_{45}, Jackson cross-cylinder at 45 and 135 degrees; Kf, flat keratometry, Ks, steep keratometry; Km, mean keratometry; *LoA*, limits of agreement; SD, standard error.

A=Pentacam, B=Sirius, C=IOLMaster 700, D= iTrace,

Agreement of Power Vectors (J_0 and J_{45})

Global comparisons among the four devices for J_0 and J_{45} showed no statistically significant differences (Friedman test, $P = 0.310$ and $P = 0.219$, respectively) (Table 2). All pairwise post-hoc comparisons also yielded no significant differences for either vector component (all $P > 0.05$) .

However, agreement analysis (Table 3, Fig. 1) demonstrated poor-to-negligible concordance for both J_0 and J_{45} across all device pairs. CCC values for J_0 ranged from − 0.088 (A vs. D) to 0.135 (A vs. C), and for J_{45} from − 0.167 (A vs. B) to 0.065 (B vs. C), with the upper 95% CI frequently crossing zero, indicating no meaningful agreement. The mean differences (bias) were small (ranging from − 0.05 to 0.07 D for J_0 and − 0.05 to 0.04 D for J_{45}), but the 95% LoA were wide (e.g., for J_0, A vs. C: −0.850 to 0.861 D; for J_{45}, B vs. C: −0.804 to 0.881 D), suggesting substantial individual variability despite low group-level bias.

Agreement of Astigmatism Type Classification

The distribution of regular astigmatism types (WTR, ATR, and OBL) across the four devices is presented in Fig. 2A **and Supplemental Table 1.** Pentacam classified 45.16% as WTR, 33.33% as ATR, and 21.51% as OBL; Sirius showed 40.43% WTR, 42.55% ATR, and 17.02% OBL; IOLMaster 700 showed 40.59% WTR, 41.58% ATR, and 17.82% OBL; and iTrace showed 35.29% WTR, 50.00% ATR, and 14.71% OBL.

Supplemental Table 1. Distribution of regular astigmatism type classification in cataract patients Obtained with four devices

Regular astigmatism (%)	Pentacam	Sirius	IOLMaster 700	iTrace
WTR	45.16	40.43	40.59	35.29
ATR	33.33	42.55	41.58	50.00
OBL	21.51	17.02	17.82	14.71
WTR, with-the-rule astigmatism; ATR, against-the-rule astigmatism;				

OBL, oblique astigmatism.

Agreement for astigmatism type classification is summarized in **Supplemental Table 2.** The observed agreement between devices ranged from 58.73% (A vs. D) to 73.12% (B vs. C). Cohen's kappa values indicated moderate agreement for most comparisons: A vs. B (κ = 0.523, 95% CI: 0.369–0.677), A vs. C (κ = 0.481, 95% CI: 0.332–0.630), B vs. C (κ = 0.573, 95% CI: 0.423–0.723), and C vs. D (κ = 0.492, 95% CI: 0.314–0.671). Lower kappa values were observed for A vs. D (κ = 0.352, 95% CI: 0.177–0.526) and B vs. D (κ = 0.419, 95% CI: 0.237–0.599). All kappa values were statistically significant ($P < 0.001$ for all). The McNemar-Bowker test for symmetry was non-significant for all comparisons except A vs. D ($P = 0.006$), indicating a systematic asymmetry in disagreement patterns between Pentacam and iTrace for astigmatism type classification.

Supplemental Table 2. Agreement of astigmatism type classification among four devices

Comparison	*Observed Agreement (%)*	Cohen's Kappa (95% CI)	*P* (Kappa)	*Symmetry P-value*
A vs. B	69.41	0.523 (0.369, 0.677)	**< 0.001**	0.614
A vs. C	66.67	0.481 (0.332, 0.630)	**< 0.001**	0.240
A vs. D	58.73	0.352 (0.177, 0.526)	**< 0.001**	**0.006**
B vs. C	73.12	0.573 (0.423, 0.723)	**< 0.001**	0.902
B vs. D	63.49	0.419 (0.237, 0.599)	**< 0.001**	0.287
C vs. D	68.66	0.492 (0.314, 0.671)	**< 0.001**	0.475

CI calculated as Kappa ± 1.96 × SE. P-values for Kappa test the null hypothesis that Kappa = 0. Symmetry P-values derived from McNemar-Bowker test.

A=Pentacam, B=Sirius, C=IOLMaster 700, D= iTrace.

Agreement of Preoperative Corneal Astigmatism Magnitude Classification

The distribution of preoperative corneal astigmatism magnitude categories (≤ 0.5 D, > 0.5–≤1.0 D, > 1.0–≤1.5 D, > 1.5–≤2.0 D, and > 2.0 D) is shown in Fig. 2B **and Supplemental Table 3.** Pentacam recorded the highest proportion of eyes with ≤ 0.5 D (50.54%), whereas iTrace recorded the highest proportion in the > 0.5–≤1.0 D category (41.18%). Sirius recorded the highest proportion in the > 1.5–≤2.0 D and > 2.0 D categories (9.57% and 5.32%, respectively).

Supplemental Table 3. Distribution of preoperative corneal astigmatism magnitude categories in cataract patients Obtained with four devices

Preoperative corneal astigmatism (%)	Pentacam	Sirius	IOLMaster 700	iTrace
≤ 0.5D	50.54	43.62	34.65	35.29
> 0.5D, ≤ 1.0D	29.03	30.85	38.61	41.18
> 1.0D, ≤ 1.5D	13.98	10.64	26.73	20.59
> 1.5D, ≤ 2.0D	3.23	9.57	0	2.94
> 2.0D	3.23	5.32	0	0
D, diopter				

Agreement for magnitude classification **(Supplemental Table 4)** was comparable to that for type classification. Observed agreement ranged from 58.73% (A vs. D) to 73.12% (B vs. C). Cohen's kappa values were moderate: A vs. B (κ = 0.523, 95% CI: 0.369–0.677), A vs. C (κ = 0.481, 95% CI: 0.332–0.630), B vs. C (κ = 0.573, 95% CI: 0.423–0.723), and C vs. D (κ = 0.492, 95% CI: 0.314–0.671), with lower values for A vs. D (κ = 0.352, 95% CI: 0.177–0.526) and B vs. D (κ = 0.418, 95% CI: 0.237–0.599). All kappa values were statistically significant ($P < 0.001$). The McNemar-Bowker test indicated significant asymmetry only for the A vs. D comparison ($P = 0.006$), consistent with the findings for astigmatism type classification.

Supplemental Table 4. Agreement of preoperative corneal astigmatism magnitude classification among four devices

Comparison	*Observed Agreement (%)*	Cohen's Kappa (95% CI)	*P* (Kappa)	*Symmetry P-value*
A vs. B	69.41	0.523 (0.369, 0.677)	**< 0.001**	0.614
A vs. C	66.67	0.481 (0.332, 0.630)	**< 0.001**	0.240
A vs. D	58.73	0.352 (0.177, 0.526)	**< 0.001**	**0.006**
B vs. C	73.12	0.573 (0.423, 0.723)	**< 0.001**	0.902
B vs. D	63.49	0.418 (0.237, 0.599)	**< 0.001**	0.287
C vs. D	68.66	0.492 (0.314, 0.671)	**< 0.001**	0.475

CI calculated as Kappa ± 1.96 × SE. P-values for Kappa test the null hypothesis that Kappa = 0. Symmetry P-values derived from McNemar-Bowker test (asymptotic). A=Pentacam, B=Sirius, C=IOLMaster 700, D= iTrace.

Discussion

Accurate preoperative assessment with corneal topography is considered crucial for the selection of a premium IOL, the calculation of IOL power and in planning the location and size of the incision in some cases [7]. While numerous studies have compared biometers and topographers in general cataract populations, eyes with low corneal astigmatism (≤ 1.5 D) represent a unique and clinically challenging subgroup. In such eyes, even minor measurement errors can proportionally amplify residual astigmatism misestimation, potentially negating premium IOL benefits. To our knowledge, this is the first prospective study to comprehensively evaluate the inter-device agreement of keratometry, astigmatic vectors, and categorical classifications among Pentacam, Sirius, IOLMaster 700, and iTrace specifically in eyes with low corneal astigmatism. Our findings reveal three key messages: (i) the three tomographer/biometer-based devices (Pentacam, Sirius, IOLMaster 700) show interchangeable agreement for anterior corneal curvature; (ii) despite low mean differences, the wide limits of agreement for astigmatic vectors and moderate categorical agreement preclude their uncritical interchangeability for toric axis planning; and (iii) iTrace consistently deviates from the other devices, suggesting it should not be used as a substitute.

Our anterior keratometry results are largely consistent with previous comparative studies but demonstrate superior agreement specifically in this low-astigmatism cohort. Wang et al. reported excellent correlations (r > 0.935) among CASIA2, IOLMaster 700, and Pentacam for anterior corneal power in 200 cataract eyes[22]. Similarly, Muzyka-Woźniak et al. found that mean anterior and total corneal curvature measurements were not interchangeable between Scheimpflug and SS-OCT biometers in patients with low total astigmatism (< 1.5 D), and that device differences had a greater impact on low astigmatism values[23]. In our cohort, Pentacam, Sirius, and IOLMaster 700 demonstrated excellent CCCs (0.948–0.982) for Kf, Ks, and Km, with narrow 95% LoA (e.g., for Km, A vs. C: −0.677 to 0.427 D; B vs. C: −0.522 to 0.647 D). These narrow LoA suggest that keratometry values from these three devices are interchangeable for spherical power calculation in low-astigmatism eyes, as the small mean differences (e.g., − 0.13 to 0.06 D for Km) are clinically negligible. In contrast, Gill et al. found high agreement among Lenstar LS900 and other devices in eyes with ≥ 1 D astigmatism, concluding they were interchangeable[24]. This discrepancy may be explained by the fact that in more regular corneas with low astigmatism, systematic biases inherent to different measurement principles (Scheimpflug tomography vs. SS-OCT) are minimized.

Song et al. found no significant differences in Kf, Ks, Km, and J_0 among Pentacam, Sirius, and IOLMaster 700 in a myopic population, but identified significant differences in J_{45}[25]. Zhang et al. reported no significant differences among iTrace, IOLMaster, and Pentacam in astigmatism magnitude, cardinal component, and oblique component, but found that iTrace wavefront and simulated keratometry differed significantly in magnitude and oblique component[26]. Ma et al. found that J_0 (ICC = 0.887) and J_{45} (ICC = 0.725) showed good-to-excellent and moderate-to-good agreement, respectively, among four devices (IOLMaster 700, CASIA2, Pentacam, iTrace)[15]. In contrast, our vector and categorical analyses uncover population-individual gap. Although no global differences in J_0 and J_{45} were detected by the Friedman test, which suggesting similar population-level means, pairwise CCCs were relatively low (ranging from − 0.167 to 0.135), and 95% LoA were relatively wide (e.g., for J_0, B vs. C: −0.850 to 0.952 D). This indicates that vector components, being axis-sensitive, can cancel out at the group level while revealing profound individual

discordance. In low-astigmatism corneas, where the signal-to-noise ratio is inherently low, minor axis misalignments or measurement variability can lead to large vector disagreements. This may explain why previous studies concluded these devices are interchangeable; their broader astigmatism ranges likely masked the noise from low-astigmatism eyes with a stronger "signal." Our findings suggest that when analysis is restricted to this subgroup, individual-level agreement deteriorates differently, a nuance not previously recognized.

Cohen's kappa values for astigmatism type and magnitude classifications were only moderate (0.352–0.573), with observed agreements ranging from 58.73% to 73.12%. Lee et al.[27] and Beato et al.[28] similarly reported only moderate axis agreement between Pentacam and IOLMaster, with 30–42% of eyes showing axis differences > 10 degrees. For a clinician planning toric IOL surgery, disagreement in classifying WTR versus ATR, or assigning a patient to a ≤ 0.5 D versus > 0.5–1.0 D magnitude group, can directly alter the surgical plan, potentially leading to overcorrection, undercorrection, or a reversed axis of correction. The systematic asymmetry observed between Pentacam and iTrace (McNemar-Bowker P = 0.006 for both type and magnitude) warrants attention. This contrasts with Wang et al.'s finding in irregular corneas, where iTrace was interchangeable with IOLMaster 700 but Pentacam was not[14]. This inversion suggests that device performance may reverse depending on corneal morphology. In our regular low-astigmatism cohort, iTrace tended to classify more eyes as ATR (50.00%) and in the > 0.5–1.0 D group (41.18%), whereas Pentacam classified more as WTR (45.16%) and in the ≤ 0.5 D group (50.54%). This systematic bias likely stems from fundamental technological differences: Pentacam, a Scheimpflug tomography system, reconstructs the entire anterior segment and is less susceptible to tear film irregularities, whereas iTrace, a Placido disk-based topographer, relies on tear film reflection. In low-astigmatism, relatively spherical corneas, Placido-based systems may be more vulnerable to subtle tear-film breakup or micro-irregularities, introducing a shift toward ATR readings. The excellent agreement between Sirius (a Placido-Scheimpflug hybrid) and IOLMaster 700 (telecentric keratometry) suggests that incorporating tomographic data may mitigate these tear-film effects. Ashena et al.[29] also found no correlation in J0 (r = − 0.01, P = 0.93) between Pentacam and iTrace, further supporting this fundamental discordance.

This study has several strengths, including being the first four-device comparison specifically in the ≤ 1.5 D astigmatism population and employing a multi-dimensional assessment framework (CCC, LoA, Kappa, and McNemar-Bowker testing) that provides a comprehensive agreement profile. However, several limitations must be acknowledged. First, our findings may not generalize to higher-astigmatism or irregular corneas. Second, we did not evaluate posterior or total corneal astigmatism, which are increasingly important for toric IOL calculations. Third, single-center, single-examiner measurements, while minimizing inter-operator variability, may limit external validity. Fourth, although the 2.5 mm versus 3.0 mm zone discrepancy between IOLMaster 700 and other devices had minimal impact on keratometry CCCs, it might contribute to vector variability. Fifth, we did not systematically assess tear film status, which is particularly relevant for Placido-based devices. Finally, we did not directly link these measurement discrepancies to predicted residual astigmatism or postoperative refraction, a critical area for future research.

Conclusions

Pentacam, Sirius, and IOLMaster 700 are interchangeable for anterior keratometry in low-astigmatism eyes, supporting their use for spherical power calculation. We found that individual-level vector agreement is substantially worse than population-level agreement, which has not been adequately recognized. The moderate categorical agreement and wide vector LoA underscore the need for caution in toric IOL planning. iTrace exhibits systematic bias in regular low-astigmatism corneas, favoring ATR and higher magnitude classifications, and should not be used interchangeably without careful cross-validation. Clinicians should consider using at least two tomographic/biometric devices to cross-validate astigmatic parameters in this subgroup. Future research should focus on posterior corneal astigmatism agreement across devices and quantifying the impact of tear film status on Placido disk-based measurements.

Abbreviations

ACD
Anterior chamber depth
AL
Axial length

ATR
Against-the-rule astigmatism
CCC
Lin's concordance correlation coefficient
CCT
Central corneal thickness
CI
Confidence interval
D
Diopter
IOL
Intraocular lens
IQR
Interquartile range
J_0
Jackson cross-cylinder at 0 and 90 degrees
J_{45}
Jackson cross-cylinder at 45 and 135 degrees
Kf
Flat keratometry
Km
Mean keratometry
Ks
Steep keratometry
LoA
Limits of agreement
LT
Lens thickness
OBL
Oblique astigmatism
OCT
Optical coherence tomography
SD
Standard deviation
SS-OCT
Swept-source optical coherence tomography
WTR
With-the-rule astigmatism
WTW
White-to-white distance

Declarations

Acknowledgments

We thank the participants of the study.

Author contributions The authors confirm contribution to the paper as follows: study conception and design: Yali Gao; data collection: Yingshi Zou, Yingyue Xiong; analysis and interpretation of results: Tianhong Luo, Jianan Xu; draft manuscript preparation: Yingshi Zou, Yingyue Xiong. All authors reviewed the results and approved the final version of the manuscript.

Funding Not applicable.

Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding authors on reasonable request, subject to institutional approval and applicable ethical and privacy restrictions.

Ethical Approval This study complied with the requirements of the Ethics Committee of Shenzhen People's Hospital (LL-KY-2024193) and adhered to the principles of the Declaration of Helsinki.

Declarations of interest: none

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Figures

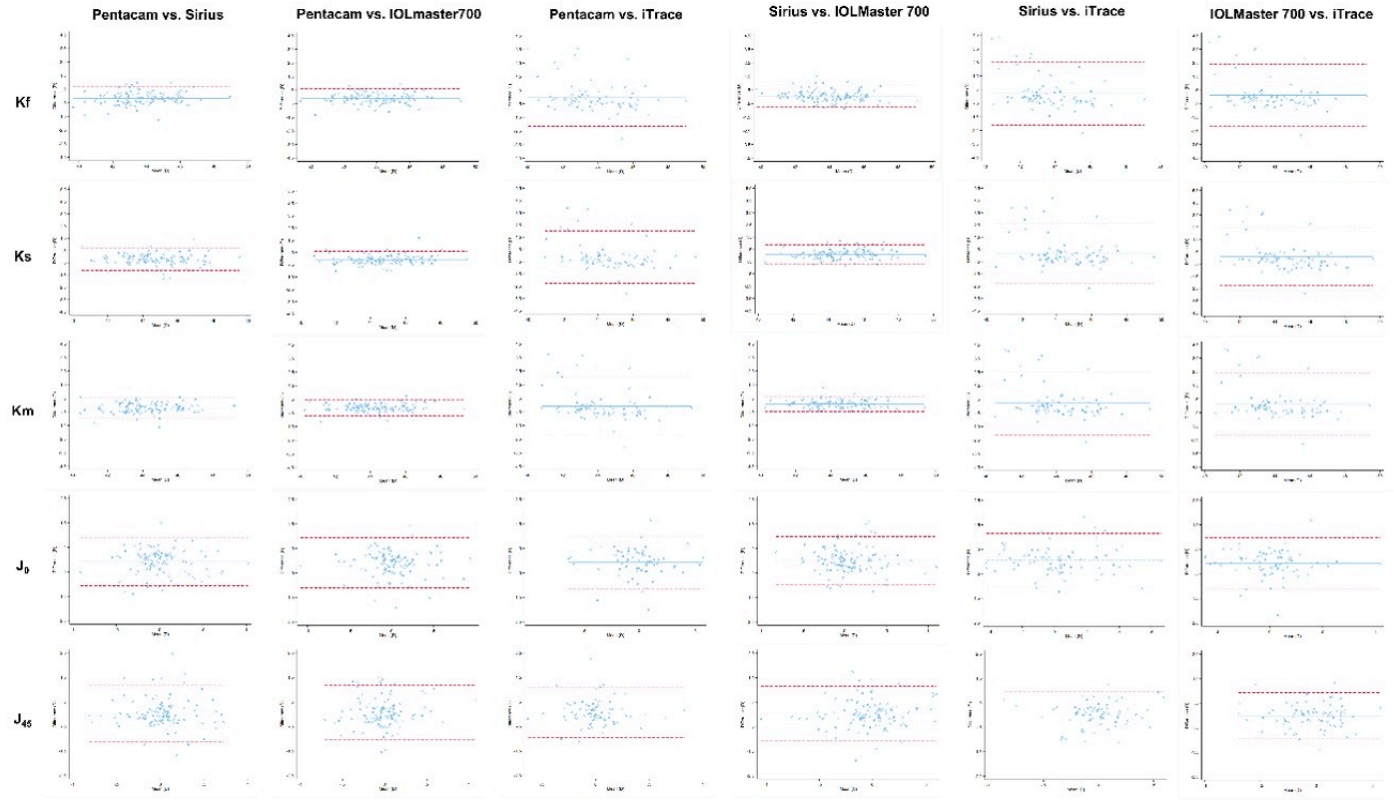


Figure 1

Bland-Altman plots of keratometry (Kf, Ks, Km), power vectors (J_0, J_{45}) among Pentacam, Sirius, IOLMaster 700, and iTrace.

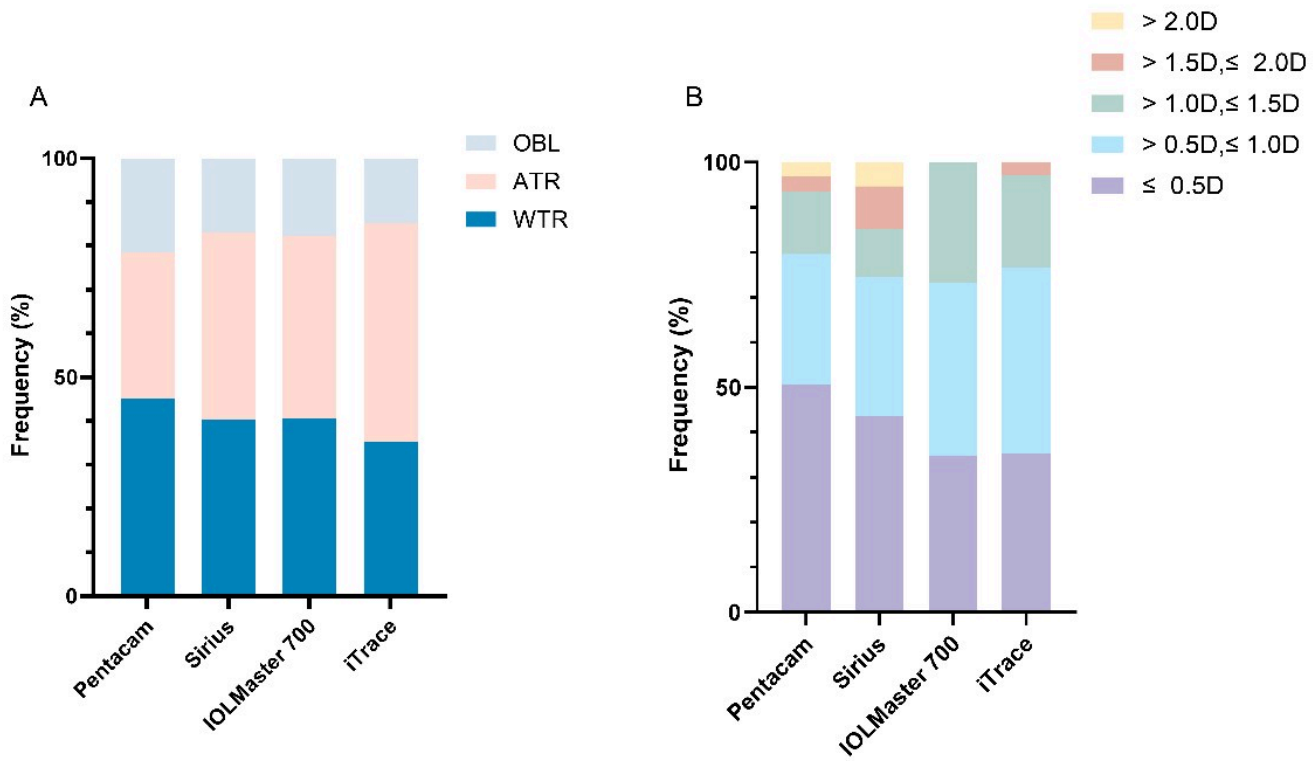


Figure 2

Stacked bar chart. A. Distribution of regular astigmatism type classification in cataract patients as obtained with four devices (Pentacam, Sirius, IOLMaster 700, and iTrace). B. Distribution of preoperative corneal astigmatism magnitude categories in cataract patients Obtained with four devices (Pentacam, Sirius, IOLMaster 700, and iTrace).

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