A Comparative Study of Total Corneal Power Using a Ray Tracing Method Obtained from 3 Different Scheimpflug Camera Devices

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• PURPOSE: We sought to assess the agreement of ray-traced corneal power values by 3 Scheimpflug tomographers tp construct the corresponding arithmetic adjustment factor in comparison with an automated keratometer (IOLMaster) and a conventional Placido-based topographer (Allegro Topolyzer).

• DESIGN: Prospective reliability analysis.

• METHODS: A total of 74 eyes from 74 healthy subjects who underwent corneal power measurements using Pentacam, Sirius, Galilei, IOLMaster, and Allegro Topolyzer were included. Ray-traced corneal power values, such as total corneal refractive power (TCRP), mean pupil power (MPP), total corneal power (TCP), mean keratometry (Km), and simulated keratometry (SimK) were recorded respectively and analyzed using one-way analysis of variance (ANOVA) and Bland-Altman plots.

• RESULTS: Among the 3 ray-traced corneal power values, TCRP and MPP did not differ significantly ($P = 0.81$), whereas TCP presented a slightly significant larger value ($P < 0.001$). Compared to Km or SimK, corneal power measurements by the ray tracing method exhibited significantly lower values ($P < 0.001$). Bland-Altman plots disclosed that the 3 Scheimpflug tomographers showed similar 95% limits of agreement after arithmetic adjustment compared with Km (−0.40 to 0.40 D, −0.39 to 0.39 D, and −0.35 to 0.34 D) or SimK (−0.50 to 0.51 D, −0.43 to 0.42 D, and −0.46 to 0.46 D).

• CONCLUSIONS: Ray-traced corneal power values obtained using 3 Scheimpflug tomographers with default diameter settings were similar, indicating that they could be used interchangeably in daily clinical practice. The 3 Scheimpflug tomographers were satisfactory in agreement after arithmetical adjustment compared with conventional automated keratometer or Placido-based topographer. (Am J Ophthalmol 2020;216:90–98.

RAY TRACING TECHNOLOGY IS PRIMARILY USED FOR the design of imaging and illumination systems. Because of the similarity of the optical system of the eye, the technology has also been used in ophthalmology, where it has been found to improve the accuracy of corneal power measurements and intraocular lens (IOL) power calculation, especially after corneal refractive surgery.[1,2] Using the real corneal refractive index ($n = 1.376$), without relying on any assumption and tracing the light through the anterior and posterior corneal surfaces and all ocular refractive media up to the fovea, the limitation of the arbitrary keratometric index ($n = 1.3375$) used routinely in conventional keratometry and IOL formulas can be overcome.[2,3]

The ray tracing technology for corneal power assessment can be categorized into 2 types: 1 relies on specific software, such as Zemax (Zemax LIC, Redmond, Washington, USA),[3–6] and the other is integrated directly into commercially available instruments, such as scan-slit tomographers, namely Orbscan (Bausch & Lomb, Rochester, New York, USA)[1] or Scheimpflug camera devices, like Pentacam (Oculus, Wetzlar, Germany),[7–10] Galilei (Ziemer Ophthalmics AG, Port, Switzerland),[3,4,11] and Sirius (CSO, Florence, Italy),[12] or devices using optical coherence tomography (OCT) combined with Placido-based topography, like the anterior segment OCT MS-39 (CSO, Florence, Italy).[13] All of these instruments can measure the curvature of both anterior and posterior corneal surfaces. To the best of our knowledge, none of the published studies have systematically investigated the agreement of corneal power values measured by ray tracing method obtained with different devices. Furthermore, modern IOL formulas have been constructed on the assumption that a fictitious keratometric index of 1.3375 estimated the diopters (D) of the entire cornea without knowing the actual posterior corneal information. Thus, although the ray tracing technology might represent the most accurate method to evaluate the corneal power, a specific conversion is essential before it is used as an equivalent corneal power. Strikingly, the customized conversion factors have not yet been explored.

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TABLE 1. Total Corneal Power and Anterior and Posterior Corneal Curvature Provided by 3 Scheimpflug Camera Devices in Normal Eyes (n = 74)

Parameters	Pentacam	Sirius	Galilei	*P* Value[a]
Total corneal power (D)	42.55 ± 1.35	42.58 ± 1.36	42.68 ± 1.35	<0.001
Anterior corneal curvature (mm)	7.83 ± 0.24	7.85 ± 0.24	7.83 ± 0.25	<0.001
Posterior corneal curvature (mm)	6.36 ± 0.23	6.50 ± 0.28	6.42 ± 0.23	<0.001
Anterior to posterior corneal curvature ratio	1.23 ± 0.02	1.21 ± 0.03	1.22 ± 0.02	<0.001

D = diopter; SimK = simulated keratometry.
[a]Bonferroni corrected.

Given the potential relevance of ray-traced corneal power for IOL power calculation and the lack of information about agreement among measurements by different instruments, we aimed to assess such agreement among 3 Scheimpflug cameras (Pentacam, Sirius, and Galilei). Moreover, in order to be able to use these measurements for IOL power calculation we developed a conversion factor for each instrument, so that ray-traced corneal powers do not show any systematic difference with respect to those provided by an automated keratometer, the IOLMaster (Carl Zeiss, Jena, Germany), and a Placido disc–based topographer, the Allegro Topolyzer (Wavelight Technologie AG, Erlangen, Germany).

SUBJECTS AND METHODS

SEVENTY-FOUR HEALTHY VOLUNTEERS WERE ENROLLED IN the current prospective study at the Eye Hospital of Wenzhou Medical University. Informed consent was obtained from all subjects after the nature and purpose of the study were explained. The inclusion criteria were as follows: minimum age of 18 years and absence of any ocular disease other than ametropia. The exclusion criteria were as follows: 1) previous ocular surgery or trauma; 2) corneal or other ocular diseases that could affect outcomes; 3) inability to fixate the targets; 4) contact lens wear during the last 4 weeks. The study was performed in accordance with the tenets of the Declaration of Helsinki and approved by the Ethics Committee and Institutional Review Board of Eye Hospital of Wenzhou Medical University.

• **INSTRUMENTS AND PARAMETERS:** The following instruments were used: first, the Pentacam (software version 1.20r112) is a noninvasive anterior segment analyzer featuring a rotating Scheimpflug camera and a short-wavelength slit light that can image the cornea, anterior chamber, and anterior lens. The total corneal power (TCP) measured using ray tracing in Pentacam is called total corneal refractive power (TCRP) and is exhibited in the "Power Distribution Display," with a diameter of 1.0 mm-8.0 mm on a ring or over a circular area (zone). Herein, the TCRP with a diameter of 4.0 mm, within the zone and centered on the pupil was recorded for analysis.

Second, we used the Sirius Scheimpflug-Placido topographer (software version 2.0), which combines a single Scheimpflug camera and a Placido disc–based topographer and that can acquire 25 Scheimpflug images and 1 Placido top-view image with 35,632 points for the anterior corneal surface and 30,000 points for the posterior corneal surface. The data for the anterior corneal surface from the Placido and Scheimpflug images are merged using a proprietary method, and all the other measurements for the internal structures are derived solely from the Scheimpflug data.[14] TCP is presented as mean pupil power (MPP). The Sirius provides a series of values according to the entrance pupil diameters (range 2.5 mm-7.00 mm), and the one with the default 4.5-mm diameter was collected for statistical analysis in the present study.

Third, we used the Galilei dual Scheimpflug analyzer (software version 5.2.1), which acquires images of the anterior segment of the eye using 2 Scheimpflug cameras integrated with Placido technology. Similar to the Sirius tomographer, the anterior corneal measurements are performed using a proprietary method by merging the Placido and Scheimpflug data, whereas all the other measurements for anterior segment structure are obtained using the Scheimpflug technology.[15] In the Galilei system, the TCP calculated by the ray tracing method is expressed as TCP. This software provides options of TCP values over the 1.0 mm-4.0 mm zone, the central zone (0.0 mm-4.0 mm), the paracentral zone (4.0 mm-7.0 mm), and the peripheral zone (7.0 mm-8.0 mm). TCP is calculated using the corneal index of refraction (n = 1.376) and the focal length determined with the reference plane of the anterior corneal surface. In the current study, the default TCP within the central 4.0-mm zone centered on the pupil was selected for subsequent analysis.

Fourth, we used the IOLMaster (software version 5.4), an automated keratometer that measures corneal power by analyzing the reflections of light projected at 6 points on the cornea at a diameter of approximately 2.5 mm, depending on the corneal curvature.[16,17] Mean

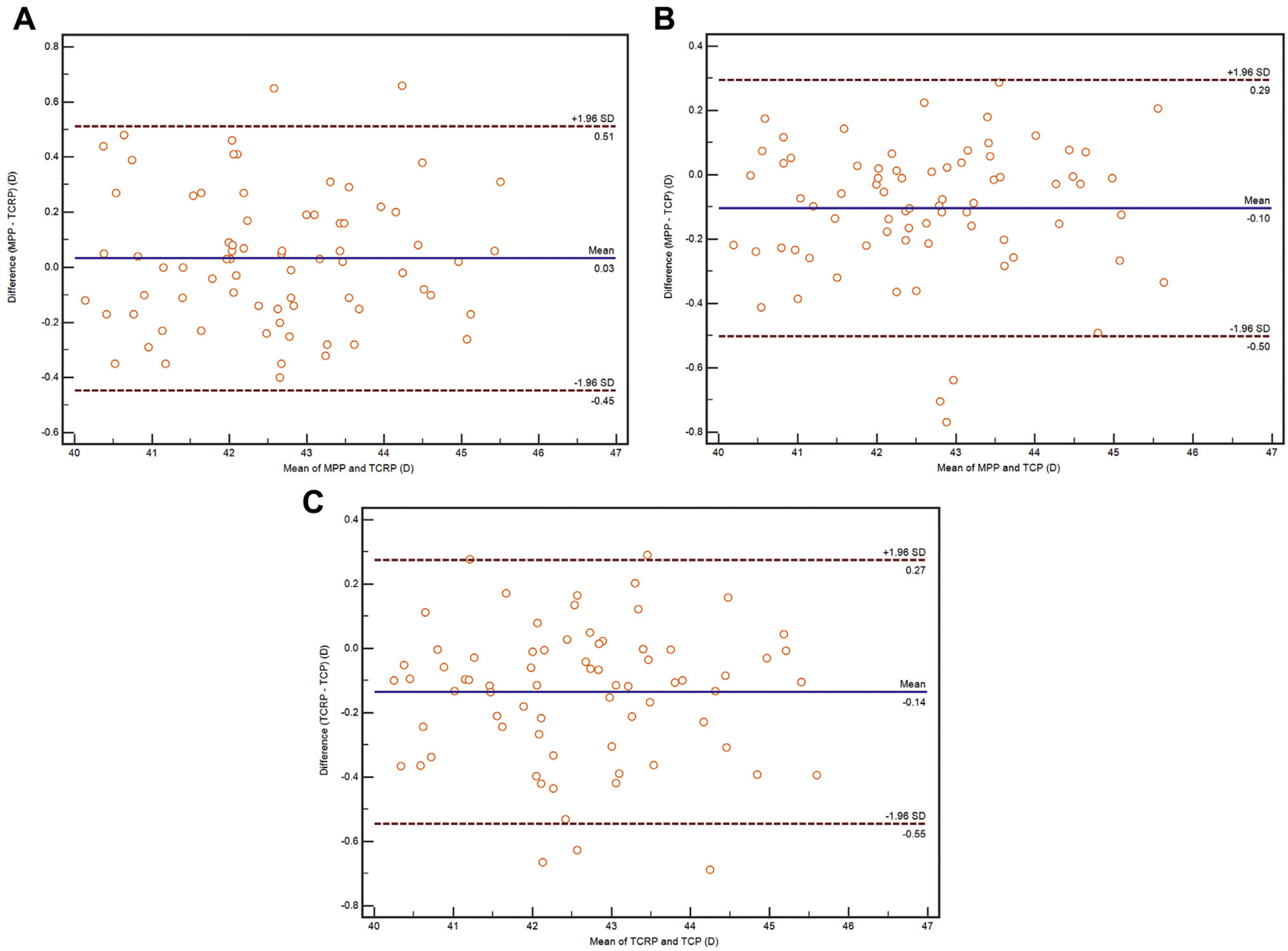

FIGURE 1. Bland-Altman plots for ray-traced corneal power values by 3 different Scheimpflug tomographers (A-C represent modified TCRP and MPP, TCP and MPP, TCRP and TCP, respectively). The solid line represents the mean difference (bias). MPP = mean pupil power by Sirius; TCP = total corneal power by Galilei; TCRP = total corneal refractive power by Pentacam.

keratometry (Km) was provided by IOLMaster using the mean anterior corneal curvature and the standardized keratometric index (n = 1.3375).

Finally, we used the Allegro Topolyzer (software version 1.59), a conventional Placido-based topographer, which uses an arc-step algorithm to reconstruct the corneal profiles as a series of arcs that would reflect the rays from the mires to the lens of the keratoscope.[18] The device consists of 22 rings. High-resolution data of the corneal surface is obtained with 22,000 points, and simulated keratometry (SimK) is calculated using the anterior axial curvature measurements derived from the fourth to the eighth Placido ring (with a diameter around 3.0 mm) and the standardized keratometric index (n = 1.3375).

In addition, the anterior corneal curvature, the posterior corneal curvature, and the anterior:posterior curvature ratio provided by 3 Scheimpflug camera instruments were recorded for analysis.

Similar to the arithmetic adjustment method proposed by Seo and associates,[7] based on the postulation that each keratometric reading would represent a specific equivalent corneal power by ray tracing method, we transferred each ray tracing–based corneal power value into the corresponding keratometric reading by adding the mean difference separately.

The examination of the right eye of each subject was carried out by 1 experienced examiner (C.P.) under dim lighting, according to the manual guidelines on the same day; the measurements were taken between 10:00 AM and 5:00 PM to minimize the diurnal variation. The sequence of the measurements using the 5 devices was randomly chosen to avoid methodologic bias. Each device was calibrated by the manufacturer before measurements. Considering the high repeatability of the instruments mentioned above, only the first measurement with specific quality or without artifacts was recorded and used for statistical analysis.[14,15,19,20]

TABLE 2. Total Corneal Power Values Using Ray Tracing Method by 3 Scheimpflug Camera Devices Compared with an Automated Keratometer (IOLMaster) in Normal Eyes (n = 74)

Parameters	Total Corneal Power Values (D)	Mean Difference vs Km (D)	*P* Value[a]	Correlation Coefficient	*P* Value
Km	43.24 ± 1.36	—	—	—	—
TCRP	42.55 ± 1.35	−0.69 ± 0.21	<0.001	0.988	<0.001
MPP	42.58 ± 1.36	−0.66 ± 0.20	<0.001	0.990	<0.001
TCP	42.68 ± 1.35	−0.55 ± 0.18	<0.001	0.992	<0.001

D = diopter; Km = mean keratometry by IOLMaster; MPP = mean pupil power by Sirius; TCP = total corneal power by Galilei; TCRP = total corneal refractive power by Pentacam.
[a]Bonferroni corrected.

• **SAMPLE SIZE:** The sample size was calculated using PS Power and Sample Size Calculation software (version 3.1.2; Vanderbilt University, Nashville, Tennesses, USA). The results of a recent study of ray-traced corneal power measurements obtained by different instruments demonstrated that the pooled standard deviation (SD) of the differences in corneal power between devices was approximately 0.22 D.[19] Thus, using a 2-sided level of significance (α) = 5% and power (1-β) = 99%, a sample size of 60 eyes was required to detect a difference of 0.125 D between the instruments.

• **STATISTICAL ANALYSIS:** All data were analyzed using MedCalc version 11.4.2 (MedCalc Software, Ostend, Belgium) for Windows. A Kolmogorov-Smirnov test was performed before parameters were expressed as mean ± SD. The corneal power values were compared using one-way analysis of variance (ANOVA) for repeated measures with Bonferroni multiple comparisons. The Pearson test was used to evaluate the correlation between any 2 ray tracing–derived corneal power values and between ray tracing–derived corneal power values and Km or SimK. The agreement between any 2 ray tracing–derived corneal power values and between ray tracing–derived corneal power values and Km or SimK were assessed by the Bland-Altman plots.[21] $P < 0.05$ was considered statistically significant.

RESULTS

THE RIGHT EYES OF 74 VOLUNTEERS (40 FEMALES, 54.05%), were included in the analysis. The mean age of the cohort was 28.78 ± 4.52 years (range 19-40 years). The mean spherical equivalent refraction was −3.94 ± 2.38 D (range 0.75 to −10.25 D).

• **TCP COMPARISON AMONG 3 SCHEIMPFLUG CAMERA DEVICES USING RAY TRACING METHOD:** Table 1 shows the 3 types of ray-traced corneal power values provided by 3 Scheimpflug tomographers in normal eyes. Analysis of variance revealed significant differences among the 3 categories of corneal power values by ray tracing method ($P < 0.001$). Compared with TCP, TCRP and MPP significantly underestimated the corneal power values by −0.14 ± 0.21 D and −0.10 ± 0.20 D, respectively ($P < 0.001$), while the mean difference (0.03 ± 0.24 D) between MPP and TCRP was not statistically significant ($P = 0.81$).

Excellent agreement was established between any 2 ray-traced corneal power values by Bland-Altman plots, with 95% limits of agreement (LoAs) of −0.45 D to 0.51 D between TCRP and MPP, −0.55 D to 0.27 D between TCRP and TCP, and −0.50 D to 0.29 D between MPP and TCP (Figure 1).

• **TCP USING RAY TRACING METHOD BY 3 SCHEIMPFLUG CAMERA DEVICES IN COMPARISON WITH AN AUTOMATED KERATOMETER (IOLMASTER):** Compared to Km provided by IOLMaster, significant differences were observed in 3 ray tracing–derived corneal power values ($P < 0.001$). TCP showed the lowest disparity (−0.55 D), whereas TCRP and MPP exhibited similar discrepancies (−0.69 D and −0.66 D, respectively) (Table 2).

Any significant difference was not detected among the 3 modified ray tracing–derived corneal power values and Km ($P = 1.000$) with mean difference of −0.0005 ± 0.21 D between (TCRP + 0.69) and Km, 0.001 ± 0.20 D between (MPP + 0.66) and Km, and −0.005 ± 0.18 D between (TCP + 0.55) and Km. The modified ray tracing–derived corneal power and Km obtained by Bland-Altman plots were similar with 95% LoA (−0.40 D to 0.40 D, −0.39 D to 0.39 D, and (−0.35 D to 0.34 D, respectively) (Figure 2).

• **TCP USING RAY TRACING METHOD BY 3 SCHEIMPFLUG CAMERA DEVICES IN COMPARISON WITH A PLACIDO DISC–BASED TOPOGRAPHER (ALLEGRO TOPOLYZER):** Compared with the conventional SimK provided by Allegro Topolyzer, significant differences were detected in 3 ray tracing–derived corneal power values ($P < 0.001$); TCP showed minimal disparity (−0.38 D), whereas TCRP and MPP exhibited similar discrepancy (−0.52 D and −0.48 D, respectively) (Table 3).

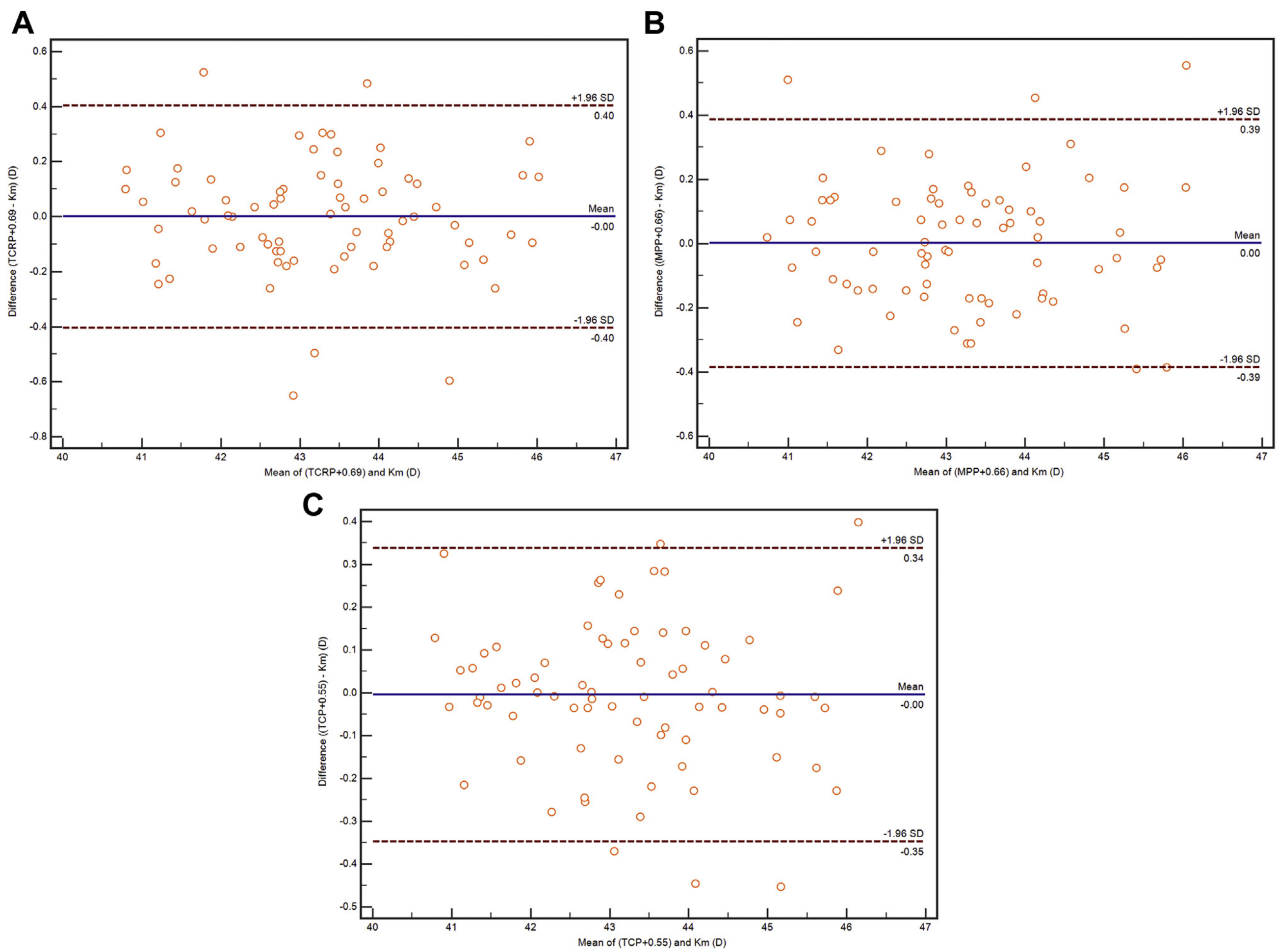

FIGURE 2. Bland-Altman plots for modified ray-traced corneal power values by 3 different Scheimpflug tomographers compared with mean keratometry obtained by IOLMaster (A-C represent modified TCRP, MPP, and TCP, respectively). The solid line represents the mean difference (bias). The upper and lower lines represent the 95% limits of agreement (95% limits of agreement are shown with the dashed lines). Km = mean keratometry by IOLMaster; MPP = mean pupil power by Sirius; TCP = total corneal power by Galilei; TCRP = total corneal refractive power by Pentacam.

No significant difference was detected among the 3 modified ray tracing–derived corneal power values and SimK ($P = 0.992$) with mean difference of 0.004 ± 0.26 D between (TCRP + 0.52) and SimK, −0.005 ± 0.22 D between (MPP + 0.48) and SimK, and 0.0002 ± 0.24 D between (TCP + 0.38) and SimK. Interestingly, Bland-Altman plots exhibited an excellent agreement between the modified ray tracing–derived corneal power values and SimK with 95% LoA of (−0.50 D to 0.51 D, −0.43 D to 0.42 D, and −0.46 D to 0.46 D, respectively) (Figure 3).

DISCUSSION

IN THE CURRENT STUDY, WE FIRST EVALUATED THE AGREEment between 3 different Scheimpflug tomographer-derived corneal power values by ray tracing technology. Agreement was excellent between the 2 single Scheimpflug cameras and high between these and the dual Scheimpflug analyzer, although the latter provided slightly higher mean values.

The 2 single Scheimpflug camera instruments, Pentacam and Sirius, presented almost identical results (mean difference 0.03 D) with 95% LoA of −0.45 D to 0.51 D, considering that disparity within ±0.50 D is clinically acceptable in daily practice. To the best of our knowledge, only 1 study has compared the ray-traced corneal power measurements by these 2 Scheimpflug camera devices and found that the Sirius provided slightly higher values as compared with the Pentacam HR (43.19 ± 1.52 D vs 43.06 ± 1.46 D).[13] These values were calculated over a diameter of 3.00 mm, rather than 4.00 mm-4.50 mm diameter used in the present study, and this difference may contribute to the discrepancy with respect to current results. Moreover,

TABLE 3. Total Corneal Power Values Using Ray Tracing Method by 3 Scheimpflug Camera Devices Compared with a Placido Disc–Based Topographer in Normal Eyes (n = 74)

Parameters	Total Corneal Power Values (D)	Mean Difference vs SimK (D)	*P* Value[a]	Correlation Coefficient	*P* Value
SimK	43.06 ± 1.33	—	—	—	—
TCRP	42.55 ± 1.35	−0.52 ± 0.26	<0.001	0.982	<0.001
MPP	42.58 ± 1.36	−0.48 ± 0.22	<0.001	0.987	<0.001
TCP	42.68 ± 1.35	−0.38 ± 0.24	<0.001	0.985	<0.001

D = diopter; MPP = mean pupil power by Sirius; SimK = simulated keratometry by Allegro Topolyzer; TCP = total corneal power by Galilei; TCRP = total corneal refractive power by Pentacam.

[a]Bonferroni corrected.

such discrepancy may also be related to the examiner; only 1 experienced operator performed all measurements in the current study, whereas no related information was provided in the previous study.[13] The dual Scheimpflug camera device obtained slightly higher values with a mean difference of about 0.10 D. The different imaging technologies used by different devices (dual Scheimpflug vs single Scheimpflug camera) may contribute to the small disparity. Conversely, Aramberri and associates[19] stated that TCP underestimated TCRP by 1.58 D, which could be partially explained by the different refractive index (1.376 of cornea vs 1.336 of aqueous) selected for corneal power measurements. The 95% LoA from −0.55 D to 0.27 D indicated that the TCP provided by Galilei could be used interchangeably with the other 2 single Scheimpflug camera instruments in virgin corneas. Caution should be raised that the current study adopted the defaulted 4.5 mm MPP, not the uniform 4.0 mm MPP for analysis. Based on a previous study by our team, the mean difference between 4.5 mm MPP (42.52 ± 1.52 D) and 4.0 mm MPP (42.42 ± 1.52 D) in virgin corneas was statistically significant but not clinically significant.[22] Currently, TCP is the only ray-traced corneal power that may be entered into the post–laser in situ keratomileusis IOL power calculator of the American Society of Cataract and Refractive Surgery. Based on the findings of the current study, we conjecture that the corresponding values by the 2 single Scheimpflug tomographers (MPP and TCRP) may be used as an alternative option for TCP assessment should the Galilei not be available. Further studies conducted in postoperative eyes are required to confirm this hypothesis.

Furthermore, the present study only included the Scheimpflug imaging technology. Different technologies such as OCT might present different results. Savini and associates[13] reported that the corneal power estimated by a new anterior segment OCT combined with Placido topography had significantly larger values (43.32 ± 1.50 D) as compared with the Pentacam HR (43.06 ± 1.46 D) and the Sirius (43.19±1.52 D). Although the differences (0.26 D and 0.13 D) were not clinically significant, the 95% LoA (−0.23 to 0.75 D and −0.31 to 0.56 D) was less satisfactory than that in the present study. Caution should be exercised when interpreting ray-traced corneal power values from different techniques using various imaging principles. Moreover, one possibly mandatory precondition is that the parameters involved in the calculation of ray-traced power, the anterior corneal curvature, and the posterior corneal curvature show identical results. Also, the 3 different Scheimpflug tomographers presented statistically different but not clinically relevant outcomes in the current study.

In the second part of this study, we compared 3 ray-traced corneal power measurements to Km obtained by IOLMaster, which is the most widely used automated keratometer and accepted as the benchmark for the calculation of IOL power in normal eyes.[23] All ray-traced corneal power values underestimated the automated keratometric values; underestimation from the 2 single Scheimpflug camera devices was close to 0.70 D, which is coincidentally the conversion factor proposed by Seo and associates[7] to achieve a keratometric reading comparable to the Pentacam-derived SimK. Another study[24] comparing the IOLMaster and the Galilei disclosed a similar result (0.50 D) with respect to the present study (0.55 D). In the current study, excellent agreement with respect to the IOLMaster measurements was achieved after adjusting the 3 different Scheimpflug tomographer–derived corneal power values: this suggests that the adjusted ray-traced corneal power could be entered into modern IOL power calculation formulas. In addition, TCP has to be considered a useful option for eyes with previous corneal refractive surgery or with keratoconus, where the ratio between the anterior and posterior corneal curvature is altered and the fictitious keratometric index is no longer valid.[2–5,7–9,11,12] A similar approach has been recently followed by Zeiss using the so-called total keratometry.[25]

Table 4 shows previous studies that compared the corneal power values by ray tracing method with Km/SimK.[7,8,10,11,24,26–30] In comparison to the conventional Placido-based topographer, Savini and associates[27] reported that 3.0-mm TCRP underestimated SimK by 0.66 D (0.52 D in this study, 4.0 mm TCRP instead of 3.0 mm

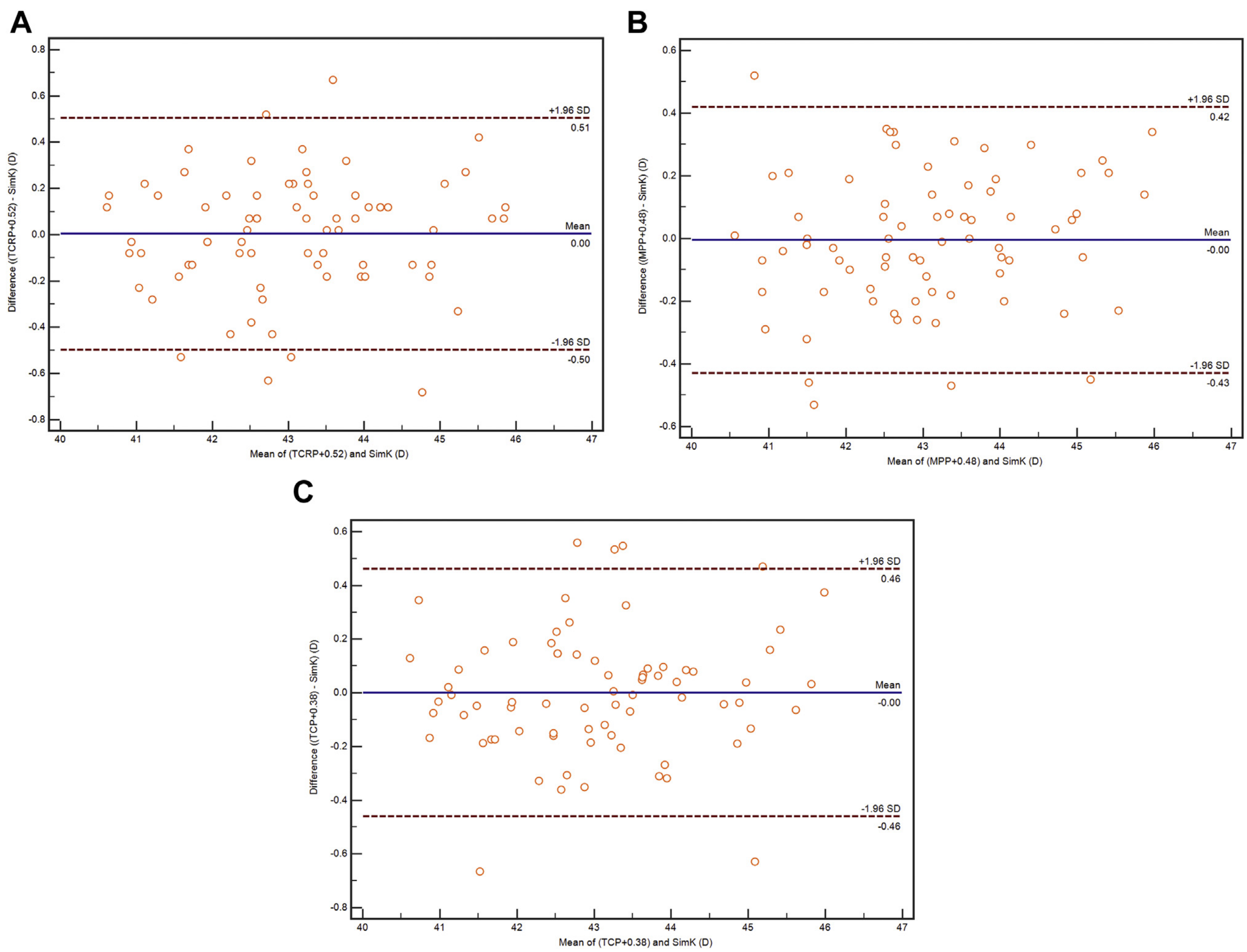

FIGURE 3. Bland-Altman plots for modified ray-traced corneal power values by 3 different Scheimpflug tomographers compared with simulated keratometry obtained by Allegro Topolyzer (A-C represent modified TCRP, MPP, and TCP, respectively). The solid line represents the mean difference (bias). The upper and lower lines represent the 95% limits of agreement (95% limits of agreement are shown with the dashed lines). MPP = mean pupil power by Sirius; SimK = simulated keratometry by Allegro Topolyzer; TCP = total corneal power by Galilei; TCRP = total corneal refractive power by Pentacam.

TCRP). The disparity related to MPP vs SimK was 0.48 D in our study vs 0.80 D stated by Savini and associates.[28] The dissimilarity might be attributed to the differences in the measurements of the zone diameter, Placido disc–based devices, sample sizes (38 subjects in the previous study vs 74 subjects in our study), and ethnic composition. Moreover, in the present study, all measurements were performed by 1 experienced operator, whereas in the other studies, we found the limitation of ≥2 operators or the lack of information to verify this basic precondition for the comparison of the measurements. Two studies by Shirayama and associates[24] and Savini and associates[11] have involved the comparison between TCP by Galilei and SimK, with a mean difference of 0.48 D and 0.60 D, respectively, showing a small discrepancy from the current study (0.38 D). Based on the aforementioned studies, the conventional keratometric power usually overestimates ray-traced corneal power by approximately 0.50 D (range 0.47-0.80 D). The difference would be higher in keratoconic corneas, where the overestimation by keratometry may exceed 1.0 D or 2.0 D.[31] The intrinsic advantage of ray-traced TCP in keratoconus raised researchers' interest in using TCP to follow-up eyes undergoing cross-linking and to calculate IOL power.[32]

The current study has some limitations. First, we selected the default 4.5-mm diameter for the MPP of Sirius, which is slightly larger compared with the other 2 Scheimpflug instruments. Further study with the same diameter should be conducted to confirm the current conclusions. Second, we did not include the altered corneas (ie, postrefractive corneas and keratoconus corneas), which might be valuable in another future study. Third, we had not validated the current results in the IOL power calculation in the elderly. A study conducted on elderly patients undergoing

TABLE 4. Previous Studies Including Comparison of Corneal Power by Ray Tracing Method Versus Km/SimK

Previous Studies	Year	Eyes	Km/SimK (Instruments)	Total Corneal Power (Instruments)	Difference Compared with Km/SimK (Mean ± SD)
Shirayama and associates	2010	75	43.87 ± 1.22 (IOLMaster)	43.37 ± 1.28 (Galilei, 4.0 mm)	−0.50
			43.85 ± 1.24 (Atlas)		−0.48
Savini and associates	2011	43	44.04 ± 1.69 (Keraton)	43.44 ± 1.70 (Galilei, 4.0 mm)	−0.60
			43.83 ± 1.66 (Galilei)		−0.39
Savini and associates	2012	38	43.67 ± 1.45 (Keraton)	42.87 ± 1.54 (Sirius, 3.0 mm)	−0.80
			43.46 ± 1.45 (Sirius)		−0.59
Savini and associates	2013	41	43.88 ± 1.56 (Keraton)	43.22 ± 1.58 (Pentacam, 3.0 mm)	−0.66
			43.85 ± 1.59 (Pentacam)		−0.63
Saad and associates	2013	50	43.68 ± 1.68 (IOLMaster)	43.21 ± 1.32 (Pentacam, 4.0 mm)	−0.47 ± 0.34
			43.77 ± 1.33 (Pentacam)		−0.56
Seo and associates	2014	100	N/A (Pentacam)	N/A (Pentacam, 4.0 mm)	0.7 ± 0.3
Oh and associates	2014	49	43.47 ± 1.02 (Pentacam)	42.76 ± 1.05 (Pentacam, 3.0 mm)	0.71
				43.13 ± 1.12 (Pentacam, 4.0 mm)	0.37
Naeser and associates	2015	951	43.42 ± 1.49 (Pentacam)	42.79 ± 1.50 (Pentacam, 3.0 mm)	0.63
				42.91 ± 1.51(Pentacam, 4.0 mm)	0.51
Savini and associates	2017	114	43.64 ± 1.44 (Sirius)	43.07 ± 1.41 (Sirius, 3.0 mm)	−0.56 ± 0.23
Savini and associates	2018	68[a]	43.63 ± 1.27 (Galilei)	43.08 ± 1.21 (Galilei, TCP1)	0.55
				41.84 ± 1.18 (Galilei, TCP2)	1.79
		50[b]	43.88 ± 1.57 (Galilei)	43.18 ± 1.53 (Galilei, TCP1)	0.70
				41.92 ± 1.46 (Galilei, TCP2)	1.96
Kamiya and associates	2018	25	43.78 ± 1.89 (Pentacam HR)	43.29 ± 1.91 (Pentacam HR, 3.0 mm)	0.49

Km = mean keratometry; SD = standard deviation; SimK = simulated keratometry; TCP 1 = total corneal power calculated using the refraction index of cornea (n = 1.376); TCP 2 = total corneal power calculated using the refraction index of aqueous (n = 1.336).
[a]Italian group.
[b]Japanese group.

cataract surgery would be warranted to validate the present conclusion.

In conclusion, the ray-traced corneal power values obtained using 3 different Scheimpflug tomographers with default diameter settings were in good agreement, indicating that they could be used interchangeably in daily clinical practice, although the dual Scheimpflug camera displayed a slightly higher value compared with 2 single Scheimpflug tomographers. The 3 different Scheimpflug tomographers presented similarly satisfactory agreement after arithmetical adjustment compared with a conventional automated keratometer or a Placido-based topographer.

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