# Accuracy of Corneal Power Measurement Using Scheimpflug Camera After Myopic Refractive Surgery

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## ABSTRACT

**Purpose:** To investigate the accuracy of ray tracing (RT) using the Sirius rotating Scheimpflug camera (Sirius), combined with Placido disc corneal topography (CSO, Florence, Italy), to measure corneal power (CP) in eyes which had undergone excimer laser surgery for myopia.

**Materials and Methods:** We retrospectively reviewed the medical records of 59 eyes of 31 patients who had undergone refractive laser surgery for myopia. We collected different CP values calculated by RT according to entrance pupil diameter (ranging from 2.5 to 7.0 mm), which was called mean pupil power (MPP) by the manufacturer, and simulated keratometry (simK) value using the Sirius. We then compared these values with those obtained with the clinical history method (CHM).

**Results:** The mean refractive change after laser surgery was 3.14 ± 1.70 diopters (D). Using one-way analysis of variance with Dunnett's multiple comparisons test; 4.5 mm MPP, 5.0 mm MPP and 5.5 mm MPP values were similar to those obtained with the CHM (40.31 ± 1.99 D) [$p$> 0.05]. Using the Pearson correlation, 4.5 mm MPP, 5.0 mm MPP and 5.5 mm MPP values were significantly correlated with the CHM (r: 0.907, 0.906 and 0.905, respectively; $p$<0.05). SimK significantly overestimated CP, with an overestimation of 0.53 ± 0.84 D ($p$<0.001).

**Conclusion:** The direct measurement of CP within the diameter of entrance pupil 4.5 mm, 5.0 mm and 5.5 mm) using RT in eyes which had undergone excimer laser surgery for myopia gave similar and correlated results with those of the CHM.


**Keywords:** Corneal power, ray tracing, intraocular lens power calculation, myopic refractive surgery, Scheimpflug camera.

## INTRODUCTION

Obtaining precise corneal power (CP) is crucial for the accurate estimation of intraocular lens (IOL) power in cataract surgery. However, it is challenging after corneal refractive surgery for myopia due to several reasons. First, the central cornea becomes flatter than the paracentral cornea after corneal refractive surgery for myopia.[1] Manual keratometers perform keratometry (K), and most conventional corneal topographers calculate a simulated keratometry (simK) [when keratometry calculated by corneal topographers its referred to as simK] value at the paracentral cornea instead of the central cornea, which results in lower radius of curvature readings; this is called instrument error or radius error. Second, the assumed refractive index of the cornea is based on the relationship between the anterior and posterior corneal curvature ratio, which changes after corneal refractive surgery for myopia. When this keratometric index is used to convert measured radii (in millimetres [mm]) into diopters (D), the resulting values are not correct because, while the anterior cornea becomes flatter, the posterior cornea remains relatively unchanged after corneal refractive surgery for myopia. This is known as the keratometer index error.[1,2]

Many solutions have been developed for the accurate assessment of CP after corneal refractive surgery for myopia, but none of them has been proven to be the most accurate.[3-5] These solutions can be divided into three groups. The first group includes methods which use preoperative clinical data and the manifest refraction change resulting from surgery, such as the clinical history method[6] (CHM) and the Savini[7] method. The second group includes formulas which use current K values without preoperative data, such as the contact lens method[6,8], Koch and Wang[9] and Shammas[10] methods. The third group includes total

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optical power calculated by the Orbscan (Bausch & Lomb,-Orbtek, Rochester, New York) device.[11] The fourth group includes ray tracing (RT), which measures CP directly without any assumptions.[12,13] The CHM is the most recognised method and classically, has been considered the gold standard. Several recent studies have compared their results with those of the CHM.[14-17]

The Sirius rotating Scheimpflug camera (Sirius), combined with Placido disc corneal topography (CSO, Florence, Italy), is a relatively new anterior segment evaluation system and provides different CP values according to entrance pupil diameter (ranging from 2.5 to 7.0 mm), which was called mean pupil power (MPP) by the manufacturer. MPP is calculated by RT. The accuracy of RT for measuring CP in eyes which had undergone corneal refractive surgery has been evaluated using some devices in previous studies.[14,16-19] However, only a few studies have investigated the accuracy of the Sirius, and their results are conflicting.[15,20,21] Thus, the aim of the present study is to evaluate the validity of different CP values measured with the Sirius.

## MATERIALS AND METHODS

### Patients

The Medical Ethics Committee of the Bakirkoy Dr. Sadi Konuk Education and the Research Hospital of the Ministry of Health University approved the current study, which also adhered to tenets of the Declaration of Helsinki. The medical records of 59 eyes of 31 patients who had undergone laser in situ keratomileusis (LASIK) or photorefractive keratectomy (PRK) surgeries for the treatment of myopia and/or myopic astigmatism between August 2013 and November 2017 and who were followed up for more than three months and had complete preoperative or postoperative data were reviewed retrospectively. The inclusion criteria for the refractive surgery were age older than 18 and stable refraction for at least one year. The exclusion criteria for the present study were intraoperative complications, ocular diseases other than myopia and/or myopic astigmatism, retreatment, systemic diseases, autoimmune diseases, immunosuppressive treatment, pregnancy and breastfeeding.

All patients underwent a complete ocular examination preoperatively that included cycloplegic automated refractometry with Nidek ARK-510A autoref-keratometer (Nidek, Gamagori, Japan), slit-lamp evaluation of the anterior segment, air-puff tonometry and fundoscopy with mydriasis. Preoperative corneal topography was made with the Magellan Mapper corneal topographer (Nidek, Gamagori, Japan) (for the patients treated before January 2016) or the Sirius (for the patients treated after January 2016). Postoperatively, MPP measured on all the patients using a Sirius device. Laser vision correction was performed using the Technolas 217 Z 100 excimer laser (Bausch and Lomb, Munich, Germany) (for the patients treated before January 2016) and the MEL 90 excimer laser (Carl Zeiss Meditec, Jena, Germany) (for the patients treated after January 2016). The optical zone was between 4.5 to 7.0 mm according to the patient's refractive status, corneal topography and central corneal thickness. The Moria M2 microkeratome (Moria, Antony, France) with a 90 μm head was used to create superior hinged flaps for the LASIK patients.

### Definitions

Surgically-induced refractive change (SIRC) at the corneal plane: the difference between the preoperative cycloplegic refraction at the corneal plane and the postoperative cycloplegic refraction at the corneal plane.

The CHM calculates CP by algebraically subtracting the surgically-induced refractive change at the corneal plane from the preoperative average simK as follows: CP = preoperative average simK − SIRC.

### The Sirius data acquisition

We measured postoperative average simK and MPP using a Sirius-running Phoenix software (version 3.4.0.73) on all patients. The scanning process acquires a series of 25 Scheimpflug images and 1 Placido top-view image. The Sirius uses 475-nm wavelength blue LED flash illumination and derives the profiles of the anterior lens, iris and posterior cornea are solely from its Scheimpflug camera. Data for the anterior cornea obtained from both Placido disc and Scheimpflug camera images.

Average simK: the arithmetic mean of the steepest and flattest meridian keratometric values, which are calculated by corneal topography through converting the measured radii into diopters using to standard 1.3375 keratometric refractive index value.

MPP: MPP is the corneal power calculated by the Sirius using RT over an area with a diameter of 2 to 5 mm through the anterior and posterior corneal surfaces. For measuring MPP, the angle of incidence is calculated relative to the anterior surface normal for incoming parallel rays for each point on the map. The angle of refraction is obtained using the Snell law, with real refractive index numbers air: 1.0, cornea: 1.376. Then, this angle of refraction is used to determine the nonparallel direction of incoming rays relative to the posterior surface normal and to calculate angle of incidence for the posterior corneal surface using the Snell law, with refractive index numbers cornea: 1.376

and Aqueous: 1.336. This final angle of refraction is used to estimate the equivalent focal length and the corneal power for that point on the map.[22,23]

### Statistical analysis

Statistical analyses were performed using Prism 7 for Mac OS X software (Graphpad Software, Inc). The normality of the data was tested with the D'Agostino-Pearson normality test. Multiple comparisons were performed using one-way analysis of variance with Dunnett's multiple comparisons test. We evaluated the correlation using the Pearson correlation coefficient (r). Linear regression was performed to investigate the relationship between the amount of surgically-induced spherical equivalent change and the accuracy of the Sirius. We used Bland–Altman plots and 95% limits of agreement (LoA) to analyse the agreement between the methods. Statistical significance was defined as $p<0.05$.

## RESULTS

Table 1 presents the patient characteristics of our study population. The differences between the CHM (mean±standard deviation [SD]: 40.31±1.99 diopters [D]) and MPP 4.5 mm, MPP 5.0 mm and MPP 5.5 mm values obtained with the Sirius were statistically insignificant (mean difference±SD, 95% LoA: −0.20 ± 0.85, −1.47 to 1.87; 0.00 ± 0.85, −1.68 to 1.67; 0.24 ± 0.86, −1.91 to 1.44; respectively, $p>0.05$). The Pearson correlation showed that MPP 4.5 mm, MPP 5.0 mm and MPP 5.5 mm were consistent with the CHM (r: 0.907, 0.906 and 0.905, respectively; $p<0.001$). SimK significantly overestimated CP (0.53 ± 0.84 D, $p<0.001$). Other Sirius values had statistically different results from those of the CHM (MPP 2.5 mm, MPP 3.0 mm, MPP 3.5 mm, MPP 4.0 mm, MPP 6.0 mm, MPP 6.5 mm and MPP 7.0 mm). Figure 1

**Table 1.** *Patient clinical characteristics.*

| Parameter | Value |
|---|---|
| Age | |
| Mean±SD | 28.53 ± 9.35 |
| Range | 18-58 |
| Gender | |
| Male | 13 |
| Female | 18 |
| Type of refractive surgery LASIK/PRK | 47/12 |
| Optical zone of the treatment | |
| Mean | 6.139 mm |
| Range | 4.5-7 mm |
| Refractive change at corneal plane | |
| Mean±SD | -3.14 ± 1.70 |
| Range | -0.37 to -7.21 |
| Keratometric value before refractive surgery | |
| Mean±SD | 43.45 ± 1.60 |
| Range | 40.00 to 47.00 |
| Keratometric value after refractive surgery | |
| Mean±SD | 40.84 ± 1.83 |
| Range | 35.46 to 45.42 |

**SD:** standard deviation.

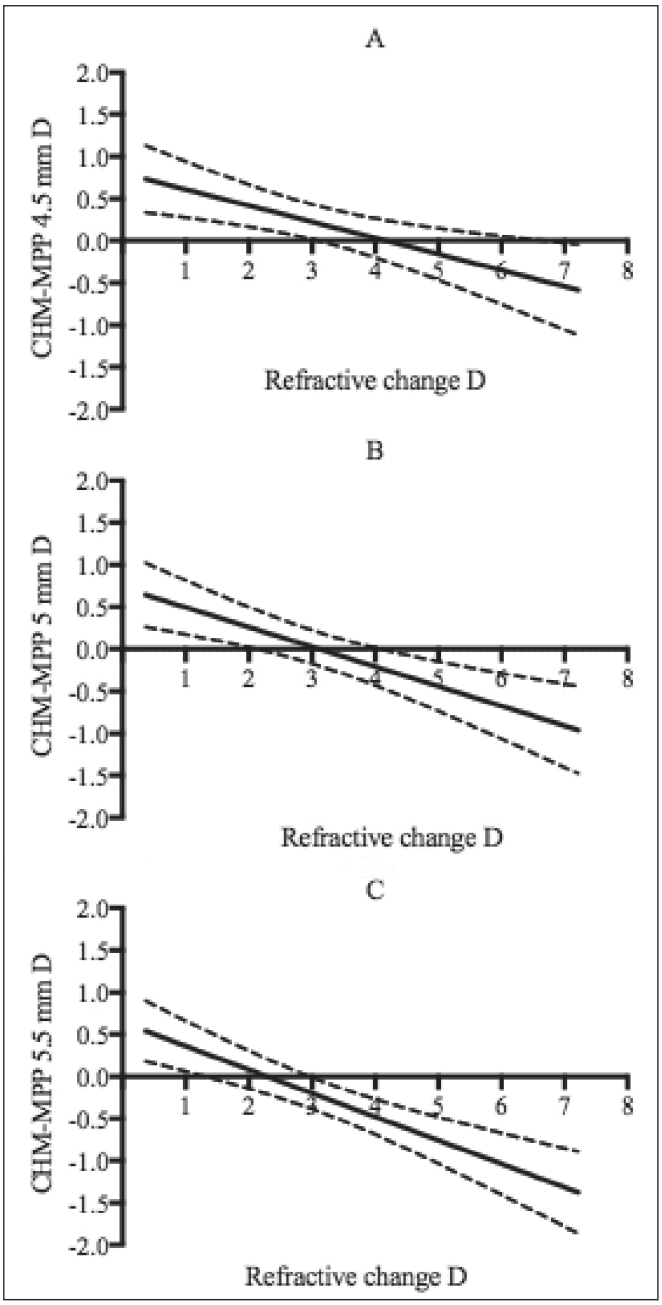


**Figure 1.** *The differences in the corneal power (CP) values obtained with mean pupil power (MPP) 4.5 mm* (A)*, MPP 5.0 mm* (B) *and MPP 5.5 mm* (C) *and the clinical history method (CHM), versus the refractive change induced by corneal refractive surgery.* D: *diopters*

shows the differences in the CP values obtained with MPP 4.5 mm, MPP 5.0 mm and MPP 5.5 mm and the CHM, versus the refractive change induced by corneal refractive surgery. Linear regression indicated that the amount of surgically-induced refractive change significantly influenced the difference between the CHM and MPP 4.5 mm, MPP 5.0 mm and MPP 5.5 mm values ($r^2$: 0.1479, 0.2194 and 0.3119, respectively; $p< 0.05$). Table 2 displays the mean CP value obtained with each method and the mean differences of these values from the CHM. Figure 2 illustrates the differences and means of the CP values obtained with the Sirius and with the CHM.

## DISCUSSION

Traditionally, the CHM has been the golden standard when assessing CP after laser refractive surgery for myopia. Additionally, McCarthy et al.[24] reported that the CHM provides accurate IOL power estimations when used with the Hoffer Q formula (85% of the eyes in the study were within the 1.0 D target refraction). On the other hand, because the CHM requires preoperative clinical data, which are usually unavailable, and current refraction, which cannot be obtained correctly due to dense cataracts, many other solutions have been suggested. Amongst them, RT has many advantages; it provides CP independent of any previous clinical data or assumptions, and it automatically calculates CP values without a requirement to enter a value into complex formulas.

The results of the present study revealed that the MPP 4.5 mm, MPP 5.0 mm and MPP 5.5 mm values obtained with the Sirius were not statistically different from the CP values obtained with the CHM; however, the other values obtained with the Sirius were statistically different. MPP 5.0 mm showed the best agreement with the values obtained with the CHM (0.00 ± 0.85 D, 95% LoA:−1.68 to 1.67). Linear regression indicated that the higher the surgically-induced refractive change, the higher the tendency of the Sirius to overestimate CP when compared to the CHM. Additionally, simK significantly overestimated CP, as shown in several other studies.[15,16] Pan et al.[15] compared postoperative Sirius measurements with the CHM. They concluded that 5.0 mm MPP (−0.24 ± 0.44, 95% LoA:−1.10 to 0.62) and 5.5 mm MPP (−0.01 ± 0.46, 95% LoA:−0.91 to 0.89) could be used as alternatives to the CHM. They used the WaveLight Allegretto W 400 Hz excimer laser suit (Alcon Laboratories, Inc, Fort Worth, TX, USA). Regression analysis also showed that the amount of surgically-induced refractive change significantly affected the accuracy of the Sirius for calculating CP. Savini et al.[20] showed that the 4.5 mm MPP value of the Sirius statistically significantly underestimated the postoperative refractive change as 0.20 D (95% LoA:−0.97 to 0.56); however, this did not seem to be clinically significant. Their study used three different laser platforms (the WaveLight Allegretto W 400 Hz, EX-500 [WaveLight Laser Technologie Ag] and the Amaris excimer laser [Schwind Eye-tech-Solutions GmbH and Co. KG]). In the present study, the 95% LoA values were

**Table 2.** *The mean corneal power (CP) values and their differences and correlations with those of the CHM for the studied methods.*

| Method | Mean D ± SD | ΔMean D ± SD | 95% CI | *p*# | r (*p*##) | %95 LoA |
|---|---|---|---|---|---|---|
| CHM | 40.31 ± 1.99 | | | | | |
| Sim K | 40.84 ± 1.83 | -0.53 ± 0.84 | -0.85 to -0.21 | <0.001 | 0.905 (<0.001) | -2.19 to 1.13 |
| MPP 2.5 mm | 39.63 ± 2.05 | -0.68 ± 1.14 | 0.25 to 1.11 | <0.001 | 0.842 (<0.001) | -1.55 to 2.90 |
| MPP 3 mm | 39.72 ± 2.00 | -0.59 ± 1.04 | 0.20 to 0.98 | <0.001 | 0.864 (<0.001) | -1.45 to 2.63 |
| MPP 3.5 mm | 39.82 ± 1.98 | -0.48 ± 0.96 | 0.12 to 0.84 | 0.0030 | 0.883 (<0.001) | -1.40 to 2.36 |
| MPP 4 mm | 39.95 ± 1.97 | -0.36 ± 0.89 | 0.02 to 0.70 | 0.03 | 0.899 (<0.001) | -1.39 to 2.10 |
| MPP 4.5 mm | 40.11 ± 1.96 | -0.20 ± 0.85 | -0.12 to 0.52 | 0.45* | 0.907 (<0.001) | -1.47 to 1.87 |
| MPP 5 mm | 40.31 ± 1.92 | 0.00 ± 0.85 | -0.32 to 0.32 | >0.999* | 0.906 (<0.001) | -1.68 to 1.67 |
| MPP 5.5 mm | 40.54 ± 1.90 | 0.24 ± 0.86 | -0.56 to 0.09 | 0.26* | 0.905 (<0.001) | -1.91 to 1.44 |
| MPP 6.0 mm | 40.82 ± 1.87 | 0.51 ± 0.88 | -0.84 to -0.18 | <0.001 | 0.898 (<0.001) | -2.24 to 1.22 |
| MPP 6.5 mm | 41.11 ± 1.81 | 0.82 ± 0.96 | -1.18 to -0.46 | <0.001 | 0.877 (<0.001) | -2.70 to 1.07 |
| MPP 7.0 mm | 41.5 ± 1.78 | 1.19 ± 1.05 | -1.58 to -0.79 | <0.001 | 0.851 (<0.001) | -3.24 to 0.87 |

**SD:** standard deviation; **Δ:** difference, **CI:** confidence interval; ***p*# values:** based on repeated measures of variance analysis using Dunnett's multiple comparisons test; ***:** $p>0.05$; r: the Pearson correlation coefficient; ***p*##:** $p$ values determined from the Pearson correlation test in comparison to the clinical history method (CHM); **LoA:** limits of agreement; **simK:** average simulated keratometry value obtained with the Sirius; **MPP:** mean pupil power value obtained with the Sirius.

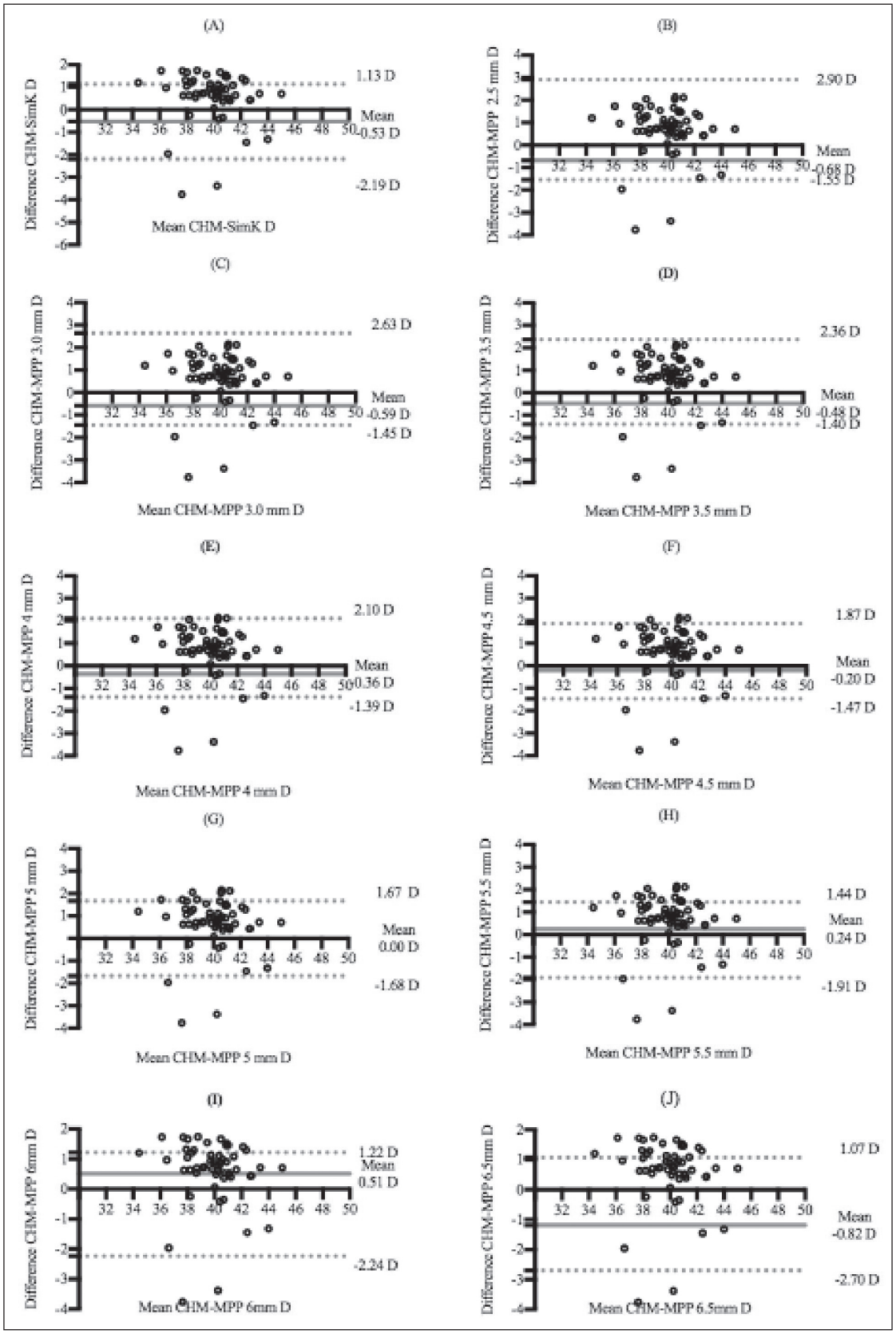


**Figure 2.** *Bland–Altman plots illustrating the differences and means of corneal power (CP) values obtained with the Sirius (*A: *simulated keratometry (simK),* B: *mean pupil power (MPP) 2.5 millimetres (mm),* C: *MPP 3.0 mm,* D: *MPP 3.5 mm,* E: *MPP 4.0 mm,* F: *MPP 4.5 mm,* G: *MPP 5.0 mm,* H: *MPP 5.5 mm,* I: *MPP 6.0 mm,* J: *MPP 6.5 mm and* K: *MPP 7.0 mm) and with the clinical history method (CHM). The upper and the lower dashed lines represent 95% limits of agreement (LoA) (calculated as the mean difference ± 1.96 × standard deviation]); the solid gray line represents the mean difference between the methods (bias).*

wider than for these two studies. The discrepancy might be due to the different laser platforms and optical zones used (the mean optical zone of treatment for the present study: 6.139 mm, ranging from 4.5 to 7.0 mm; for Pan et al.[15]: ranging from 6.5 to 7.0 mm; for Savini et al.[20]: unspecified). On the other hand, Lanza et al.[21] concluded that MPP underestimated the surgically-induced refractive change (−2.49 ± 1.12 D versus −4.9 ± 2.17 D).

In the studies which used the Pentacam (Oculus, Wetzlar, Germany) and the Galilei dual Scheimpflug Analyzer (Ziemer Ophthalmic Systems, Switzerland), Gyldenkerne et al.[18] found that the 4.0 mm zone of total corneal refractive power (TCRP) provided by the Pentacam accurately predicted the refractive change after surgery in patients who had undergone small incision lenticule extraction for myopia or femtosecond laser-assisted LASIK for myopia or hyperopic astigmatism (mean error 0 ± 0.50 D). Oh et al.[16] investigated 49 eyes which were treated with PRK and reported that 4.0 mm TCRP assessed the postoperative refractive change most accurately but still underestimated it as 0.28 ± 0.55 D (95% LoA:−0.82 to 1.38). Moreover, Baradaran-Rafii et al.[14] found that the total corneal power (TCP) measured within 4.0 mm using the Galilei gave consistent results with the CHM (0.17 ± 0.68, 95% LoA:−1.16 to 1.50). In contrast, Mello et al.[19] showed that TCP underestimated CP after corneal refractive surgery for myopia.

The present study has some limitations. First, we included both eyes of our patients into the study. This might have caused a bias because of intercorrelation of both eyes but provided more statistical power. Second, we used only one postoperative Sirius measurement of patients. This might be criticised; however, a high repeatability of Sirius measurements in post-corneal refractive surgery eyes has been reported by Savini et al.[25]. Finally, our sample size was small; and larger sample size was unfortunately not possible due to the retrospective nature of the study.

In conclusion, the present study showed that MPP 5.0 mm gives the CP values most consistent with those of the CHM. Additionally, a few recent studies have shown that RT can estimate IOL power correctly for patients who have undergone laser refractive surgery for myopia without requiring historical data.[12,13] Based on the present study, RT has the potential to resolve CP calculation problems for those patients. Further prospective studies with more patients will help to confirm the accuracy and validity of the Sirius.

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**Conflicts of Interest: YASSA ET,** None; **ÜNLÜ C;** None.

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