Analysis of Anterior Segment Parameters and Wavefront Aberrations of the Myopic Eyes Using Two Scheimpflug-based Devices: The Pentacam vs Sirius

Ali Mirzajani  
IUMS: Iran University of Medical Sciences

Rasoul Amini Vishteh  
IUMS: Iran University of Medical Sciences

Rezvan Masroor (✉ Rezvanmasroor@gmail.com)  
VESC: Vanak Eye Surgery Center  https://orcid.org/0000-0002-5934-9974

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Abstract

**Purpose:** To measurements, comparisons, and agreement of the anterior segment parameters and wavefront aberrations of the myopic eyes through the Pentacam and Sirius tomography systems.

**Methods:** The Pentacam and Sirius were used to measure the corneal anterior segment tomography and wavefront aberrations of the myopic eyes with a mean age of 25.66±3.77 (range from 19 to 31 years). Various parameters such as the anterior keratometric reading of the flattest meridian K1, anterior K2, thinnest corneal thickness, corneal surface asphericity Q-value, anterior chamber depth, Root mean square (RMS) of higher-order aberrations, RMS of lower-order aberrations, and RMS of total aberrations were analyzed. Also, the agreement between the Pentacam and Sirius was assessed by calculating 95% limits of agreement and plotting the Bland–Altman graphs.

**Results:** One eye of 99 myopic subjects (49 men, 50 women) aged 19 to 31 years was randomized and evaluated. All measured parameters of the Pentacam and Sirius tomography systems were statistically significant (p<0.001) in comparison with each other expect the mean values of K1, K2, and thinnest corneal thickness (p>0.05). The thinnest corneal thickness findings showed the poorest agreement (95% limit of agreement from -8.71 to 24.21) and the greatest difference (mean difference: 7.75).

**Conclusions:** The differences between the gained measurement results of the devices suggests that they should not be used interchangeably for corneal tomography imaging in clinical practice and surgery decision.

Introduction

Accurate and precise measurement of the corneal anterior segment is needed to perform and design effective refractive surgery procedures [1, 2]. In addition, since wavefront errors provide fundamental explanations for the optical quality of an optical system [3], its evaluation in refractive surgery candidates is very valuable, moreover many previous studies [4–9] have shown changes in high- and low-order errors after these types of surgeries. In recent years, various techniques and instruments such as Scheimpflug imaging, slit-scanning tomography, and Placido disk have been commonly used in clinical practice to evaluate the anterior segment of the cornea.

The analysis of the anterior eye segment has been possible with the introduction of the Pentacam (Oculus Optikgeräte GmbH, Wechsler, Germany) in 2002 as the first rotating Scheimpflug camera [10, 11]. It provides a cross-sectional image showing the cornea, anterior chamber, iris, lens, and three-dimensional representation of the corneal shape of the patient [12]. Also, tomography and pachymetry of the entire anterior and posterior surface of the cornea from limbus to limbus are calculated and depicted. Besides this, the relatively new corneal tomographer called the Sirius Scheimpflug–Placido tomographer (Costruzione Strumenti Oftalmici, Florence, Italy), which combines a rotating Scheimpflug camera and a Placido disk, can evaluate the anterior segment, anterior and posterior corneal tomography, wavefront analysis, and corneal pachymetry simultaneously in a single scan [11, 13].
The Scheimpflug technology in systems such as the Pentacam and Sirius is superior to Placido-based corneal topography because of accurate measurement of parameters beyond the anterior surface of the cornea [14], and also, the discrepancy between the results of previous related studies of this two system of corneal imagining, all led to do this study to evaluate the measurements of the various anterior segment parameters of the eye such as corneal thickness, anterior chamber depth, the thinnest corneal thickness, Q-value, keratometric parameters and wavefront error by the two Pentacam high resolution (HR) and the Sirius Scheimpflug camera-based imaging system in the myopic eyes. In fact, the aim of this study was to compare the measurement accuracy of the Pentacam and Sirius tomographic systems for different anterior corneal parameters before doing refractive surgery. Also, this study assessed the agreement of the HR Pentacam with Sirius tomographic system.

Materials And Methods

Ethical statement

The tenets of the Declaration of Helsinki were followed, and informed consent was obtained from all participants after they were fully informed of the nature of the study. The study was approved by the institutional review board of the Iran University of Medical Sciences and the Steering Committees of the School of Rehabilitation Sciences.

Study design and participant

One eye of 99 myopic patients with a mean age of 25.66±3.77 (range from 19 to 31 years) and mean spherical equivalent of -3.22±1.62 diopters (range from -0.75 to -9.75 diopters) and mean cylindrical errors of -1.44±1.22 (range from 0.00 to -5.00 diopters) were recruited from the subjects who came to the Vanak Eye Surgery Center to receive refractive surgery advisement.

Exclusion criteria

The patients with a history of any ocular surgery, any ocular or systemic disease, best-corrected visual acuity not achieving 6/6 and any history of contact lens wearing (lack of discontinuing the use of soft and hard contact lenses for 2 and 4 weeks, respectively), were excluded from the study.

Imaging conditions

All participants underwent a complete refractive examination that included non cycloplegic subjective refraction, measurement of best-corrected visual acuity using chart projector (HCP-7000; Huvitz, Gyeonggi-do, Korea) at 6 meters far from the patient, and to evaluate refractive error an auto refractometer KR-800 (Topcon Medical Systems, Inc., Fukuoka, Japan) were used.
**Study devices**

Corneal tomography and aberrometry were taken using the Pentacam (Oculus Optikgeräte GmbH, Wechsler, Germany) and the Sirius Scheimpflug camera systems (Costruzione Strumenti Oftalmici, Florence, Italy) one after the other with five minutes’ rest in the same day in natural pupil diameter condition at a single visit in identical lighting condition by a same skilled operator (R.M). For each instrument, the measurements were performed manually according to the manufacturer’s guidelines.

**Image Acquisition**

The eye of the patients was aligned through the visual axis using a central fixation light. Patients were informed to blink completely before the measurements began and also between every shot to help the tear film stability.

The HR Pentacam system (Oculus Optikgeräte GmbH, Wechsler, Germany) is a rotating Scheimpflug camera. The rotational measuring procedure generates Scheimpflug images in three dimensions, with the dot matrix fine-meshed in the center due to the rotation. It takes a maximum of two seconds to generate a complete image of the anterior eye segment. Any eye movement is detected by a second camera and corrected in the process. The Pentacam calculates a three dimensional model of the anterior eye segment from as many as 138,000 distinct elevation points. Software version 1.03 was used in the present study.

Five minutes after the acquisition with the Pentacam, measurements were being started using the running Phoenix software (version 3.4.0.73) of the Sirius tomography system. This is an anterior segment analysis system combining a monochromatic 360-degree rotating Scheimpflug camera with a 22-ring Placido disc. This system enables a measurement of 35,632 points of the anterior corneal surface and 30,000 points of the posterior corneal surface in a high-resolution mode in approximately less than 1 second.

**Statistical analyses**

The following parameters were measured by both tomographic system and compared in the present study: anterior keratometric reading of the flattest meridian K1, anterior K2, thinnest corneal thickness, corneal surface asphericity Q-value, anterior chamber depth, Root Mean Square (RMS) of higher-order aberrations, RMS of lower-order aberrations, and RMS of total aberrations.

All analyses were been conducted using the SPSS software version 21 (SPSS Inc, Chicago, IL, USA). The normality of the distributions was assessed with the Kolmogorov-Smirnov test and all data followed the normal distribution. Quantitative data were represented as mean and standard deviation. An independent sample t-test was used to compare the mentioned parameters between the two tomographic systems. Bland–Altman plots were used to assess the agreement between the measurements provided by the
Pentacam and Sirius tomography systems. The limits of agreement were calculated as the mean difference in measurements obtained by the two tomographic devices ±1.96*SD of the differences. The significance level was set at 0.05.

Results

Intergroup difference

The mean values, standard deviation, differences of the means and 95% confidence intervals for anterior segment parameters are summarized in “Table 1”.

As shown in “Table 1”, a comparison of the mean values of anterior keratometric K1, K2, and thinnest corneal thickness between two tomographic systems of the Pentacam and Sirius was not statistically significant (p>0.05).

The mean of anterior chamber depth obtained by two devices revealed that relevant values were higher in the Pentacam than Sirius and these differences were statistically significant (p<0.001). Also, the mean anterior Q-value results showed a significant difference between the two systems (p<0.001). The comparison of the RMS of the lower, higher and total order aberrations between the two tomographic systems showed a significant difference (p<0.001) so that the Pentacam values were higher in comparison to Sirius in all relevant aberrations.

The difference between the mentioned parameter findings of the Pentacam and Sirius are plotted against the mean of these parameters in “Fig 1”.

Bland–Altman plots show agreement between the Pentacam and the Sirius for anterior keratometric reading of the flattest meridian K1, anterior K2, thinnest corneal thickness, corneal surface asphericity Q-value, anterior chamber depth, RMS of higher-order aberrations, RMS lower-order aberrations, and RMS of total aberrations results. According to the Bland and Altman plots in “Fig 1” and the related findings in “Table 1”, the systematically higher values of the Pentacam in comparison to the Sirius occurred across all values of the scale being measured. Besides, the higher mean difference and 95% limit of agreements were related to thinnest corneal thickness values.

Discussion

In this study, the same parameters were evaluated by using two corneal tomographic systems of the Pentacam and Sirius in myopic eyes. It should be noted that in the present study, in addition to evaluating the parameters of the anterior segment of the cornea, the RMS of wavefront errors were investigated because these evaluations were less studied in the myopic eyes by using the Pentacam and Sirius devices in previous studies.
Comparisons

The measured findings of the two devices showed a significant difference in many parameters. According to the results of the present study, the mean values corneal surface asphericity (Q-value), anterior chamber depth, RMS of higher-order aberrations, RMS of lower-order aberrations, and RMS of total aberration using the Pentacam were higher than the mean Sirius values, although, the results showed the lack of difference between the Pentacam and Sirius findings in terms of the keratometric parameters of K1, K2, and thinnest corneal thickness.

Keratometry is extensively used in the diagnosis and the management of eye diseases and also measuring the parameters of keratometry are crucial for several surgical interventions such as refractive surgery [15, 16].

As the results showed, the differences between the Pentacam and Sirius measurements for keratometric parameters of K1 and K2 were not statistically significant. In addition, the agreement between the Pentacam and Sirius for measurements of K1 and K2 was good, as the narrow 95% LoA ranged from -0.64 to 0.54 diopters and -0.63 to 0.61 diopters, respectively. Consistent with the results of the present study, some studies [17, 18] showed no difference in the keratometry findings of the Pentacam and Sirius. However, many previous studies [19-23] have shown contradictory results to the findings of the present study such as the significant differences in the measurements between the Pentacam and Sirius or higher mean keratometric values of the Pentacam than those of the Sirius. One of the causes of this discrepancy may be related to the different age of the participants in the relevant studies, as the younger subjects have a better fixation and stability of the tear film than the older ones [19-24]. In agreement with the result of De la Parra-Colin’s et al. study [23], it should be considered that the Pentacam and the Sirius systems have shown that provide interchangeable keratometric readings according to the findings of the present study. Regarding the 95% limits of agreement, it should be said that the present study showed a better agreement for keratometric parameters than the Gaith et al. findings [23], however, the wider range was obtained in the present study compared to the result of De la Parra-Colin’s et al. study [23]. Besides, the results of the present study revealed that the thinnest corneal thickness values of the HR Pentacam system and Sirius tomographic system were not significantly different from each other.

Conversely, the results of thinnest corneal thickness in the present study do not agree with those previously reported, so that many previous studies [17, 20-23, 25-27] showed a significant difference in thinnest corneal thickness measurements between the two devices, in that in most cases the thinnest corneal thickness findings of the Pentacam were higher than the Sirius tomographic system. In contrast, Savini et al. [18] reported that the Sirius tomography system results of thinnest corneal thickness were slightly higher than those obtained by the Pentacam system.

The thinnest corneal thickness findings of the present study suggest that the assessments obtained by the two Scheimpflug camera-based systems cannot be used interchangeably because of the thinnest corneal thickness result of the Pentacam was significantly higher than the Sirius topography system.
In agreement evaluation of the thinnest corneal thickness parameter, the findings of the present study showed better agreement between the Pentacam and Sirius concerning previous studies. The Savini et al. [17] (from −34.6 µm to +48.9 µm) and Hosseini et al. [28] (from −10.4 µm to +27.3 µm) reported wider 95% limit of agreements than those determined in the present study (from -9.0 to +18.7 µm). The shorter range could be attributed to the better ocular surface and fixation conditions resulting from the lower mean age of the participants in the present study compared to mentioned previous studies of Huang et al. [29] and Savini et al. [18].

The next parameter that has been evaluated in the present study was the asphericity of the anterior corneal surface (Q-value). As could be seen in table 1, the mean Q values of two tomographic systems of the Pentacam and the Sirius at 8.0 mm were statistically different with a slightly more prolate cornea in the Pentacam than the Sirius. Savini et al. [18] reported that the evaluation of anterior corneal surface Q-value with the 3 Scheimpflug tomographers and a Placido corneal topographers showed no statistically significant differences between these four instruments.

In contrast to the result of the present study, the findings of the Savini's et al. [30] study showed more negative values of preoperative anterior corneal surface asphericity Q-values using Sirius than the Pentacam. While the average difference between the Pentacam and Sirius is small (-0.07 µm), the 95% limits of agreement of 0.29 suggested these two systems cannot be used interchangeably.

Precise anterior chamber depth measurements are important in calculating Intraocular lens power and phakic Intraocular lens implantation, [31-34] and analyzing the properties of the anterior segment of the glaucomatous patients [35]. Anterior chamber depth measurements yielded statistically significant differences between the two Scheimpflug-based tomographers in the present study, so that the Pentacam device provided slightly higher values than the Sirius tomographic system. Conversely, the results in the present study do not agree with the many previously reported studies [16, 21, 36, 37] so that these studies showed the mean anterior chamber depth values from the Sirius were higher than those from the Pentacam. The results of some studies [23, 26] also indicated that there was no significant difference between the two mentioned tomographic systems. Besides, according to the results, anterior chamber depth values showed wide limits of agreement (range from +0.24 to +0.71) in compared to the results of Anayol et al. [21] (range from +0.02 to +0.06), Wang et al. [19] (range from -0.12 to +0.04), and Shetty et al. [20] (range from -0.23 to +0.07) studies. Range of variation of 0.50 mm in anterior chamber depth measurement may be too large for some clinical applications such as phakic Intraocular lens implantation, so these two devices may not be used interchangeably in anterior chamber depth measurements in terms of results of the present study.

The last parameters evaluated in the present study were the RMSs of the wavefront errors. Evaluation of the wavefront errors plays an important role in determining the appropriate cases and correct algorithms for refractive surgery [38]. The difference in the RMS of the higher-order aberrations, lower-order aberrations, and total aberrations obtained by the Pentacam and Sirius was statistically significant so that the Pentacam findings were higher than the results of the Sirius in all RMS of wavefront errors. The
wavefront error measurements (except that the RMS of the higher-order aberrations) that acquired by the Pentacam and Sirius devices can be used interchangeably (the 95% limits of agreement were quite narrow for RMS of lower-order aberrations and total aberrations), notwithstanding the statistically significant overestimation by the Pentacam device. In contrast to the findings of the present study, Ramirez-Miranda [39] and colleagues found that there was no inter-device agreement for total higher-order aberrations between the Sirius and HR Pentacam. Although the higher mean value of the relevant parameters of the Sirius than the Pentacam was statistically significant. Shankar et al. [10] found that the assessment of anterior corneal wavefront aberrations using the Pentacam may present problems due to the large variability found in the raw anterior corneal elevation data, especially for the peripheral data, because the Pentacam software incorporates the missing elevation data from the peripheral of the cornea and between samples in the periphery which in turn be the source of the differences in measurements of the wavefront errors between two Scheimpflug camera-based systems.

By mentioning several reasons, the discrepancy between the measurements of the Pentacam and Sirius tomographic systems may be clarified.

First, two Scheimpflug-based tomography systems use different accuracy standards for the measurement of relevant parameters.

Second, the imaging mechanism in both tomographic devices is different, so that the HR Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany) uses a rotating Scheimpflug camera and the Sirius tomography system (Costruzioni Strumenti Oftalmici, Florence, Italy) combines two mechanisms of the Scheimpflug rotating camera with Placido disk topography to image the anterior segment of the eye.

Third, the measurements with Sirius and Pentacam were done with a different type of soft wares, so the different algorithms used by the manufacturers lead to different results for the evaluation procedure.

Forth, the elevation points evaluated in these two systems also differ from each other. The Sirius system can measure more than 30,000 points of the corneal surface in approximately five seconds compared to 138,000 points measured by HR Pentacam in approximately less than two seconds.

Fifth, for a detailed analysis of the cornea up to 100 Scheimpflug images can be captured with the HR Pentacam during the rotating scan, while the 25 Scheimpflug images and 1 Placido disc image captured using the Sirius.

Conclusions

The results of the Pentacam and Sirius are different in many cases, which is expected due to the different natures of the imaging system of those two devices, and it should be considered that these tomographic systems could not be used interchangeably in the clinical diagnosis and follow-up.

Declarations
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Conflict of interest/Competing interests

The authors declare that they have no conflict of interest.

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Authors’ contributions

All authors contributed to the study conception and design. The study was designed by Ali Mirzajani. Data were provided by Rezvan Masroor as the head of the contributing department. Also, data collection was performed by Rezvan Masroor, and statistical analysis were performed by Ali Mirzajani and Rasoul Amini Vishteh. The first draft of the manuscript was written by Rasoul Amini Vishteh and Rezvan Masroor, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability

The manuscript has no associated data in a data repository.

Compliance with ethical standards

Ethical approval

All procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the ethical standards of the Institutional Review Board of the Iran University of Medical Sciences and the Steering Committee of the School of Rehabilitation Sciences.

Animal Research (Ethics)

This article does not contain any studies with animal participants performed by any of the authors.

Consent to Participate

Informed consent was obtained from all individual participants included in the study.

Consent to Publish
The authors affirm that human research participants provided informed consent for publication of the images in Figure(s) 1A, 1B, 1C, 1D, 1E, 1F, 1G, and 1H.

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Tables
Table 1
Mean and standard deviation measured values with the Pentacam and Sirius

| Parameters                      | Device     | mean ± SD | Means Differences | 95% Confidence Interval of Differences of the Means | p-value |
|---------------------------------|------------|-----------|-------------------|----------------------------------------------------|---------|
| K1                              | Pentacam   | 43.30 ± 1.86 | -0.05             | -0.64 to 0.54                                      | 0.851   |
|                                 | Sirius     | 43.35 ± 1.87 |                   |                                                    |         |
| K2                              | Pentacam   | 45.00 ± 2.02 | -0.01             | -0.63 to 0.61                                      | 0.974   |
|                                 | Sirius     | 45.01 ± 2.10 |                   |                                                    |         |
| Thinnest corneal thickness      | Pentacam   | 525.91 ± 38.67 | 7.75             | -8.71 to 24.21                                     | 0.166   |
|                                 | Sirius     | 518.16 ± 39.66 |                 |                                                    |         |
| Q-value                         | Pentacam   | -0.32 ± 0.13 | -0.06             | -0.21 to 0.08                                      | 0.01    |
|                                 | Sirius     | -0.26 ± 0.14 |                   |                                                    |         |
| Anterior chamber depth          | Pentacam   | 3.60 ± 0.34  | 0.48              | 0.24 to 0.71                                       | < 0.001 |
|                                 | Sirius     | 3.12 ± 0.33  |                   |                                                    |         |
| Higher-order RMS                | Pentacam   | 0.43 ± 0.11  | 0.17              | -0.02 to 0.36                                      | < 0.001 |
|                                 | Sirius     | 0.26 ± 0.08  |                   |                                                    |         |
| Lower-order RMS                 | Pentacam   | 2.26 ± 0.96  | 1.00              | 0.17 to 1.83                                       | < 0.001 |
|                                 | Sirius     | 1.25 ± 0.85  |                   |                                                    |         |
| Total RMS                       | Pentacam   | 2.31 ± 0.95  | 1.01              | 0.20 to 1.82                                       | < 0.001 |
|                                 | Sirius     | 1.29 ± 0.84  |                   |                                                    |         |

SD: standard deviation.

*Statistically significant (independent samples t-test)
Figure 1

Bland–Altman plots for the eight parameters measured by the Pentacam and Sirius. The mean difference is represented by the solid dark line and 95% limits of agreement are presented by the solid red lines. A) Anterior keratometric K1. B) Anterior Keratometric K2. C) thinnest corneal thickness. D) corneal surface...
asphericity Q-value. E) Anterior chamber depth. F) RMS of higher-order aberration. G) RMS of lower-order aberration. H) RMS of total aberration.