Original Article

Differences and Limits of Agreement among Pentacam, Corvis-ST, and IOL-Master 700 Optical Biometric Devices regarding Central Corneal Thickness Measurements

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Abstract

Purpose: To investigate the differences and limits of agreement in measuring corneal thickness using Pentacam, Corvis, and intraocular lens (IOL)-Master 700 devices.

Methods: This study was conducted on 37 right eyes of 21 males and 16 females ($n = 37$) with a mean age of 52.11 ± 6.30 years. The central corneal thickness was measured using three optical biometric devices, including Pentacam, Corvis, and IOL-Master 700. The inclusion criteria were normal eyes without any ophthalmological abnormalities, history of ocular pathology, or ocular surgery. The data obtained from these three devices were compared two by two. The correlation and agreement limits among them were analyzed using statistical techniques.

Results: The mean standard deviation differences between Pentacam and Corvis, Pentacam and IOL-Master 700, as well as Corvis and IOL-Master 700 regarding the corneal thickness measurement, were 22.13 ± 8.05, 7.91 ± 8.02, and 14.21 ± 9.85 µm, respectively, which were statistically significant ($P < 0.0001$). Based on the investigation of the limits of agreement according to the Bland Altman method, the corresponding values between Pentacam and Corvis, Pentacam and IOL-Master 700, and Corvis and IOL-Master 700 were -16.2 to +15.4, -15.8 to +16.3, and -20.1 to +20.0 µm, respectively. Furthermore, the correlation coefficients of the measurements obtained by Pentacam and Corvis, Pentacam and IOL-Master 700, as well as Corvis and IOL-Master 700 were determined 0.957, 0.964, and 0.948, respectively ($P < 0.0001$).

Conclusion: The results from this study indicate that the interchangeable use of these three devices is not appropriate due to statistically significant differences and broad limits of agreement among the three devices, especially between Corvis and IOL-Master 700.

Keywords: Corneal thickness, Corvis, IOL-Master 700, Pentacam, Scheimpflug, Swept-source optical coherence tomography

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Introduction

Corneal thickness is one of the most important ocular biometric parameters. The exact measurement of this thickness is very important. This parameter is one of the fundamental factors in the diagnosis of important ocular diseases including corneal ectasia (e.g., Keratoconus) and corneal edema (e.g., Fuchs dystrophy).[1,2] Moreover, precise information on the corneal thickness is crucial for the selection of the right patients for refractive corneal surgery, feasibility of performing surgeries, selection of the appropriate surgery, and prediction of probable postoperative side effects.[3] Furthermore, this parameter has

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vital importance in various corneal implant replacement surgeries.[4] Central corneal thickness (CCT) is also important in the diagnosis of glaucoma which is considered a key risk factor in open-angle glaucoma.[5] On the other hand, the amount of intraocular pressure, which is an important diagnostic factor for glaucoma, should be adjusted based on the corneal thickness.[6]

Various methods have so far been proposed for corneal thickness measurement that utilizes different principles. For example, Scheimpflug imaging is one of the commonly used methods in which the Pentacam imaging system utilizes a rotating Scheimpflug camera for corneal imaging and provides a complete corneal tomography and topography evaluation.[7] Corvis is another device for the measurement of CCT and assesses corneal biomechanics through a dynamic Scheimpflug analyzer.[8] In addition, intraocular lens (IOL)-Master 700 provides a complete evaluation of ocular biometrics and corneal thickness using the swept-source optical coherence tomography (OCT).[9]

Many comparisons have been made so far to measure different ocular parameters, including keratometry, anterior chamber depth, and corneal thickness using different devices. The previous studies have been mainly focused on the comparison of the depth of the anterior chamber using Scheimpflug and interferometry methods yielding inconsistent results. However, some have reported no difference between Pentacam and IOL-Master 700 in terms of anterior chamber depth and corneal thickness measurements.[9,10] The results of other studies indicated significant differences between these two devices and suggested that they could not be used interchangeably.[11,12] According to our information, there is only one study comparing the corneal thickness with Pentacam and Corvis which also reported no difference between the two devices.[13] It should be noted that no study has investigated the differences (discrepancies) between IOL-Master 700 and Corvis devices regarding corneal thickness measurement. Similarly, there is no study to compare Corvis, Pentacam, and IOL-Master 700 devices concurrently. Given the contradictory results obtained from the comparison of these three devices in terms of corneal thickness and anterior chamber depth, and a lack of research in this regard, conducting a study to compare and investigate the agreement limits among the three devices appears to be necessary.

Methods

This study was conducted at Iran University of Medical Sciences, Tehran, Iran, in 2020. The study protocol was approved by the Ethical Committee of Iran University of Medical Sciences, Tehran, Iran, (IR.IUMS.REC.1399.418). The tenets of the Declaration of Helsinki were followed in all stages of the study, and informed written consent was obtained from all participants. The participants of the study were randomly selected from among the peoples who referred to the ophthalmology clinic of Bank Melli Hospital. The inclusion criteria were normal eyes without any ophthalmological abnormalities, history of ocular pathology, or ocular surgery. The patient's unwillingness to continue the study was considered the exclusion criterion.

In this study, the corneal thickness was measured using three devices: Pentacam (Pentacam HR, Oculus, Wetzlar, Germany), Corvis (Corvis ST, Oculus, Wetzlar, Germany), and IOL-Master 700 (IOL-Master 700, Carl Zeiss Meditec, Jena, Germany). Pentacam is one of the anterior segment imaging devices which uses the Scheimpflug principles. Its imaging system has a rotating Scheimpflug camera making 100 images every 2 s and carried out different scans of the anterior segment and also reconstructs the anterior segment images through the analysis of these scans, measuring important anterior segment parameters.[13] This device provides complete corneal tomography and topography data, including keratometry, elevations, and pachymetry, etc. Furthermore, it measures the central and peripheral corneal thickness and provides the results in colorful maps and numerical data.

Similar to Pentacam, Corvis uses Scheimpflug principles for corneal imaging; however, it is not a topographer but devised to measure the biomechanical status of the cornea.[8] This device employs a dynamic Scheimpflug analyzer to record the different statuses of the cornea while moving. Besides the corneal biomechanical reports, it provides corneal thickness values. The Corvis Scheimpflug camera captures 4330 images/s. It has a measuring range of the central thickness of the cornea from 200 to 1200 microns. Corvis measures 576 points in each image. Although the important role of Corvis is to determine the actual intraocular pressure, in determining this factor, CCT and dynamic corneal response need be measured, and therefore, CCT is one of the outputs of this instrument. The IOL-Master 700 device is an optical biometry method designed to measure biometric parameters of the eye including axial length, depth of anterior chamber, keratometry, corneal thickness, crystalline lens thickness, etc.[12] The IOL-Master 700, routinely used to measure IOL power, also provides comprehensive information of anterior segment of the eye, including CCT, based on swept-source OCT technology. The light source in this instrument is a tunable laser. Two equal coaxial beams enter the eye, where reflections take place at the corneal and retinal interfaces. On leaving the eye, the difference in the frequency is detected by a photoreceptor and provides a full-length OCT image showing anatomical details of the eye on a longitudinal cut through the entire eye. CCT in this device is measured from 200 to 1200 microns with a step of 1 micron. It should be noted that the position of CCT measurement in this equipment is the corneal apex or optical axis so the thickness between the anterior and posterior cornea at this point is recorded as CCT.

It should be noted that in IOL-Master 700, there is an option that before starting the measurement, the calibration of the device can be checked using a schematic eye located in the chin rest area. With regard to other devices, they are re-calibrated before the start of the examinations. All measurements and

imaging stages were carried out by an experienced and trained optometrist. Initially, the patient was examined by an ophthalmologist and an optometrist to ensure that they met the inclusion criteria. Having taken a complete history concerning eye diseases or surgeries, the researchers carried out a complete biomicroscopic examination of the anterior segment using the slit-lamp. The participants who met the inclusion criteria were included in the study. To do so, initially, the thickness measurement was carried out using the IOL-Master 700 device. The patient was then asked to keep his/her head motionless at the given place on the device and focus on the fixation point. The device conducted the measurement automatically; then the thickness value was extracted and recorded in the medical examination sheet as a printout. Thirty minutes after this examination, the patient was reevaluated using the Pentacam device. The patient's head was set in a specified place, and then he/she was asked to look at the fixation point of the device. The imaging was then carried out automatically by pressing a joystick. Then, the CCT was extracted and recorded in the output section of pachymetry. The last measurement was conducted by Corvis, 30 min after the completion of the second examination. In the same way, the patient's head was placed in the device, and the corneal thickness was observed and recorded in the device printout. It is important to note that three measurements were performed with each device, and the average was considered.

Statistical analyses

The data were analyzed with the SPSS software (SPSS 16 IBM corporation, Chicago, USA), and a $P < 0.05$ was considered statistically significant. A Bland–Altman plot is a method of data plotting used in analyzing the agreement between two different assays. Bland and Altman make the point that any two methods that are designed to measure the same parameter (or property) should have a good correlation when a set of samples are chosen such that the property to be determined varies considerably. A high correlation for any two methods designed to measure the same property could thus in itself just be a sign that one has chosen a widespread sample. A high correlation does not necessarily imply that there is good agreement between the two methods.

The agreement of devices was examined in pairs with the Bland–Altman plot and 95% limits of agreement were calculated for them. Moreover, correlation analysis was used to investigate the correlation among the measurement results obtained from the devices. Finally, regression analysis was utilized to investigate the power of the values obtained from each device to predict those of other devices. Agreement limits (95%) among devices were calculated using the following formula:

Mean difference ± 1.96 × standard deviation (SD).

Results

This study was carried out on 37 participants (age range, 34–60 years, with a mean age of 52.11 ± 6.30 years).

Tables 1 and 2 present the quantity and range of measuring in devices studied as well as the mean ± SD values of differences among three devices using a two-by-two comparison.

Table 2 indicates that the biggest difference in measurement among devices was between Pentacam and Corvis. The smallest difference, on the other hand, was between Pentacam and IOL-Master 700. It should be noted that all three differences were statistically significant ($P < 0.0001$).

The limits of agreement among the devices (two-by-two/paired comparisons) obtained by the Bland-Altman plot are presented in Figures 1-3.

The correlation between the measurement values was analyzed calculating the correlation coefficient [Figures 4-6]. The values obtained by Pentacam and Corvis, Pentacam and IOL-Master 700, as well as Corvis and IOL-Master 700, were 0.957 ($P < 0.0001$), 0.964 ($P < 0.0001$), and 0.948 ($P < 0.0001$), respectively.

The regression equations for the prediction of the measured corneal thickness values in three devices based on the other device are as follow:

1. CCT (IOL-Master 700) = 1.1 CCT (Corvis) - 38.77
2. CCT (Pentacam) = 1.03 CCT (Corvis) + 8.53
3. CCT (Pentacam) = 0.89 CCT (IOL-Master 700) + 66.56.

Discussion

This study was carried out on the corneal thickness evaluation using three important devices. Considering the critical importance of corneal thickness in many diagnostic, surgical, and treatment measures, along with the popularity of the studied devices in the area of corneal evaluation worldwide, the findings of this study would certainly be beneficial for the diagnosis and treatment programs. The present study is the first one that has compared the Corvis and IOL-Master 700 results regarding the corneal thickness measurements. In addition, no

Table 1: Quantity and range of measurements in the studied devices

	n	Minimum	Maximum	Mean±SD
CCT_Pentacam_OD	37	484	606	540.32±27.626
CCT_IOL-Master_OD	37	478	602	532.41±29.937
CCT_Corvis_OD	37	466	568	518.19±25.758
Valid N (listwise)	37			

SD: Standard deviation, CCT: Central corneal thickness, IOL: Intraocular lens

Table 2: Mean and standard deviation of measurement differences in the studied devices

Mean±SD (μm)		
Pentacam - Corvis	IOL-Master - Corvis	Pentacam - IOL-Master
22.13±8.05	14.21±9.85	7.91±8.02

IOL: Intraocular lens, SD: Standard deviation

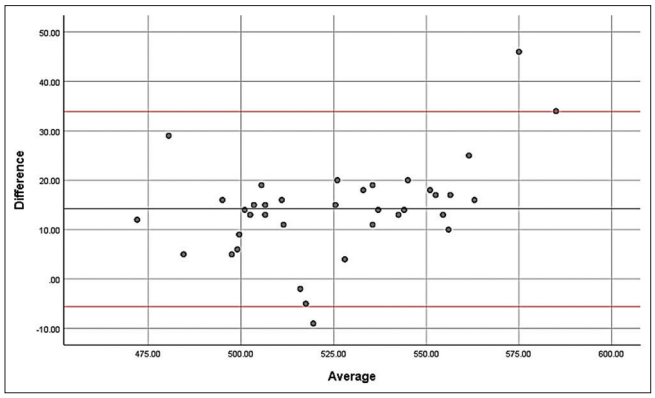

Figure 1: Bland-Altman plot for the assessment of the limits of agreement between Corvis and intraocular lens-Master 700 devices (95% limits of agreement: −20.1 to +20.0 μm)

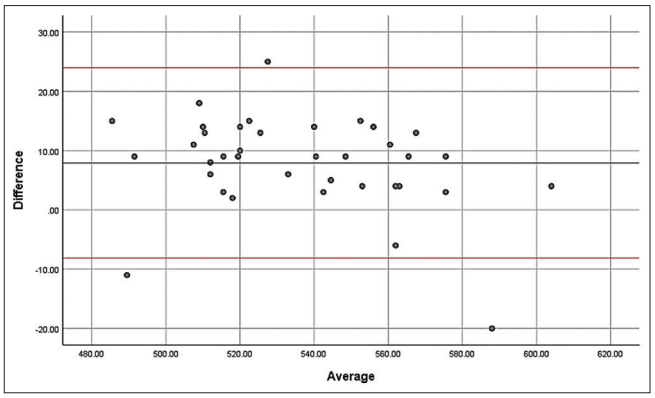

Figure 2: Bland-Altman plot for the assessment of the limits of agreement between Pentacam and Corvis devices (95% limits of agreement: −15.8 to +16.3 μm)

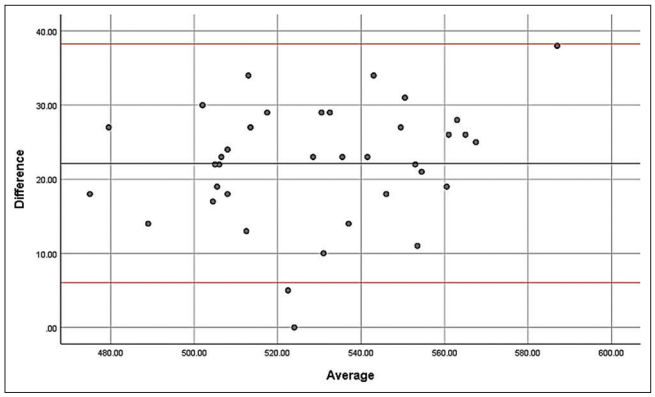

Figure 3: Bland-Altman plot for the assessment of the limits of agreement between intraocular lens-Master 700 and Pentacam devices (95% limit of agreement: −15.8 to +16.3 μm)

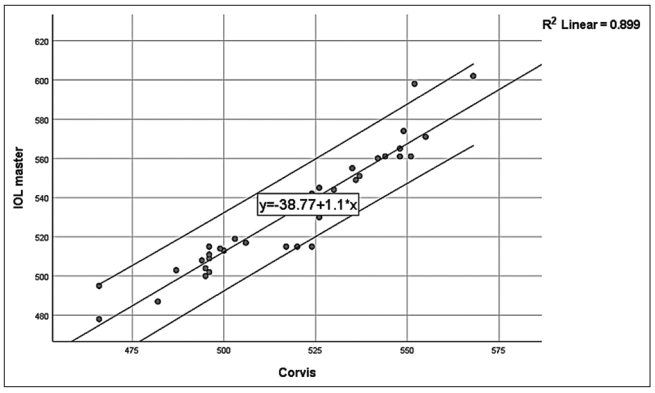

Figure 4: Correlation plot of measurements by intraocular lens-Master 700 and Corvis (regression equation: Y = −38.77 Intraocular 1.1x)

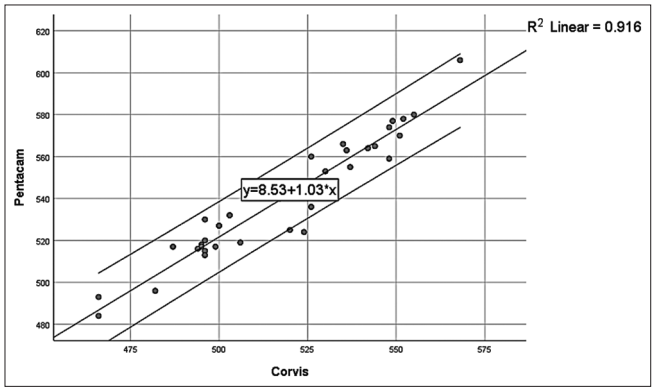

Figure 5: Correlation plot of measurements by Pentacam and Corvis (regression equation: Y = 8.53 +1.03x)

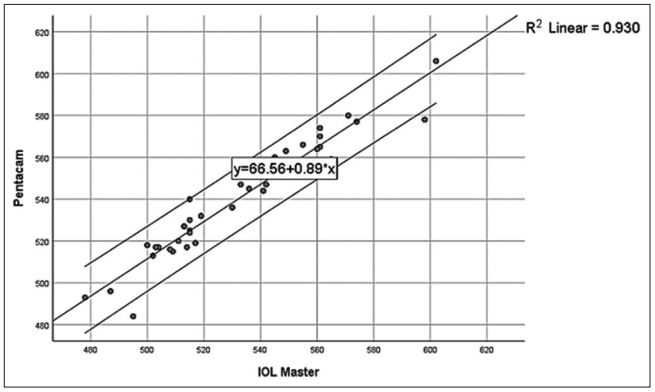

Figure 6: Correlation plot of measurements by intraocular lens-Master 700 and Pentacam (regression equation: Y = 66.56 +0.89x)

previous study has compared IOL-Master 700, Corvis, and Pentacam concurrently.

It should be noted that although the Corvis instrument is not a routine tool for measuring corneal thickness, in some instances such as glaucoma, diabetics, or people whose corneal biomechanics are involved, it is also used to check the real intraocular pressure, bIOP (biomechanical intraocular pressure), and CCT. Since CCT is an influential factor in clinical decisions for all examiners, especially in the management of glaucoma patients, so meaningful accuracy of this factor in Corvis or knowing the correction factor in accordance with other standard CCT equipment, can be useful to both the examiner and the patient (to save time and perform other tests). On the other hand, some patients present Corvis output in which having the CCT factor as well as determining

the actual amount of CCT, can be important in therapeutic interventions.

The results of this study showed that the average findings of the corneal thickness measured by the Pentacam device were larger than other devices. For example, the lowest values of thickness were obtained with Corvis. Based on these differences, it can be stated that on average, both Corvis and IOL-Master 700 have presented findings that underestimate the corneal thickness measured by Pentacam. The findings of the present study are not in line with the previous study regarding the comparison between Pentacam and Corvis devices, however, it accords with the findings of the previous study considering the Pentacam and IOL-Master 700. Our findings are not the same as those of Yu *et al*.[13] regarding a comparison between Pentacam and Corvis. Yu *et al*. aimed to compare Pentacam and Corvis regarding corneal thickness measurements using two Scheimpflug methods including Pentacam and Corvis. According to their results, the corneal thickness value obtained from the Pentacam was, on average, 3.2 ± 6.5 μm larger than the values measured by Corvis, while a higher mean value was obtained in our study (22.13 ± 8.05 μm).

In another study conducted by Kiraly *et al*.,[14] they aimed to compare four devices in terms of corneal thickness measurements. Having compared the corneal thickness measurements done by Pentacam and IOL-Master 700, they reported that the values obtained by Pentacam were, on average, 10.9 μm higher than ones measured by the IOL-Master 700 device, which was statistically significant. However, the present study evaluated the differences between Pentacam and IOL-Master 700 to be 7.91 μm which does not differ substantially from the results of Kiraly's study. It should be noted that this is the first study conducted to compare the corneal thickness measurements by IOL-Master 700 and Corvis; therefore, it is not possible to compare the results with previous studies.

According to the investigations on the limits of agreement (95%) among the studied devices, as seen in Bland-Altman plots, broad limits of agreement were observed. As these values (95% limits of agreement: About 40 μm), particularly between Corvis and IOL-Master, are higher than daily corneal thickness variations (22 μm), (variation range, −11 to ± 11).[15,16] Therefore, it seems that these devices cannot be utilized interchangeably. Nevertheless, given the high correlation among the measurement values obtained by these three devices, their measurement differences should be considered in case they are going to be used interchangeably. In addition, the proposed regression formulas in this study should be employed to predict the measurement values of each device is compared with other devices. It should be noted that this study was performed for normal eyes, and the results cannot be generalized to edematous corneas caused by corneal diseases.

Yu *et al*. investigated the limits of agreement between Corvis and Pentacam devices regarding the corneal thickness measurements in 2015 reported a lower limit of agreement than our obtained value.[13]

Given the obtained narrow 95% limits of agreement, they concluded that the two devices could be used interchangeably. However, our results do not confirm this recommendation due to the larger difference and narrower agreement. In another study conducted by Kiraly *et al*. comparing Pentacam and IOL-Master 700 devices regarding the corneal thickness measurements, their results, similar to our results, indicated a comprehensive 95% limits of agreement. They recommended that these two devices should not be used interchangeably. In the same vein, a review study was conducted by Rozema *et al*.[11] To investigate the limits of agreement among different devices regarding the measurement of corneal biometric indices. They evaluated 70 studies utilizing a meta-analysis approach to collect data considering the comparison of the results obtained from different optical biometrical devices to measure different parameters including corneal thickness. They advised against using different devices interchangeably. This review study, however, merely focused on Pentacam; therefore, Corvis and IOL-Master 700 were not included in their study. Since the present study is the first attempt to investigate the differences and agreement limits between Corvis and IOL-Master 700 in terms of the corneal thickness measurements, it should be stated that these two devices are not considered equivalents in this regard and therefore should not be used interchangeably.

In general, the results of the current study indicated statistically significant differences among the results obtained from the corneal thickness measurements using three devices. Therefore, the obtained broad 95% limit of agreement indicated a week agreement among these three devices, particularly between Corvis and IOL-Master 700. Despite a significant correlation among the values obtained from these devices, they should not be used interchangeably for the measurement of corneal thickness. However, in the case of interchangeable use, the proposed regression equations should be employed for the modification of the obtained values from each device as well as the prediction of the values from other devices.

Since knowing CCT is extremely important in clinical decisions such as refractive surgery, glaucoma management, corneal surgery, etc., when the facilities of the clinic or hospital are insufficient or when the patient has the print out of each of these devices alone, this study can be used to determine CCT close to reality and make more accurate decisions, hence, saving time and money for the patient. It should be noted that one of limitation of this study is the lack of generalization of results in corneas with abnormality. For example, the results are not applicable to edematous corneas.

Last but not least, although the reference for measuring the central thickness of the cornea in all devices used in this study was the corneal apex and optical axis, due to different size mechanisms, the accurate central thickness of the cornea measured with above devices still is challenging.

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Conflicts of interest
There are no conflicts of interest.

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