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ORIGINAL ARTICLE

Comparison of the reliability and repeatability of central corneal thickness measurements from four different non-contact devices

Sema Malgaz, Huseyin Mayali, Mustafa Erdogan, Muhammed Altinisik, Suleyman Sami Ilker

Department of Opthalmology, Celal Bayar University Faculty of Medicine, Manisa, Turkey

Abstract

Purpose: To compare the reliability and repeatability of central corneal thickness (CCT) values from four different non-contact measurement devices.

Methods: The study was conducted in 130 right eyes of 130 subjects with no ophthalmological pathology other than refractive errors. For each eye, data were recorded by making three consecutive measurements with a Scheimpflug camera (Pentacam, Oculus Optical gerate GmbH, Wetzlar, Germany), specular microscope (SM) (Cellchek XL; Konan Medical USA, Torrance, CA, USA), Lenstar LS 900® (Haag-Streit AG, Switzerland), and anterior segment optical coherence tomography (AS-OCT) (Carl Zeiss Meditec, Inc. Dublin, CA, USA). All measurements were analyzed using intraclass correlation coefficients (ICC), ANOVA or Friedman test, and Bland-Altman plots.

Results: There were no statistically significant differences among the three consecutive measurements made with four devices (p=0.449, p=0.270, p=0.540, p=0.881, respectively). ICC values were 0.972, 0.997, 0.998, and 0.998, respectively. The closest agreement between measurements was a difference of 12.87 µm (95% limits of agreement [LoA]: −5.41, 20.33 µm) between AS-OCT and Pentacam, while the lowest agreement was between SM and Lenstar measurements, which had a difference of 31.92 µm (95% LoA: −21.80, 42.04 µm). This difference was 14.66 µm (95% LoA: −19.18, 10.14 µm) for AS-OCT and Lenstar, 31.86 µm (95% LoA: −17.22, 46.50 µm) for AS-OCT and SM, 30.22 µm (95% LoA: −23.04, 37.40 µm) for SM and Pentacam, and 17.28 µm (95% LoA: −14.34, 20.22 µm) for Pentacam and Lenstar.

Conclusion: The CCT measurements of the four different devices are highly consistent and have high repeatability. The highest ICC values were obtained with the SM, while the lowest ICC value was obtained with AS-OCT. Differences in average CCT values were similar between the AS-OCT, Lenstar, and Pentacam devices, while the difference was greater with SM. In clinical practice, CCT measurements obtained with SM should not be used interchangeably with measurements obtained with the other three devices.

Keywords: Bland-Altman plot; central corneal thickness; pachymetry; repeatability.

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Correspondence: Mustafa Erdogan, M.D. Department of Opthalmology, Celal Bayar University Faculty of Medicine, Manisa, Turkey
Phone: +90 236 233 85 86 **E-mail:** doctormustafa@hotmail.com
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Central corneal thickness (CCT) measurement is an increasingly important clinical assessment in ophthalmology practice. It is used in the diagnosis and follow-up of corneal diseases such as keratoconus and Fuchs' endothelial dystrophy, for evaluating patients' eligibility for keratorefractive surgery, for determining flap, and residual stromal bed thicknesses, and in postoperative complication follow-up.[1,2] Furthermore, CCT is an independent risk factor for glaucomatous optic nerve injury and is critical in assessing the risk of ocular hypertension progressing to glaucoma.[3–5]

CCT can also be considered an indicator of the physiological state of the corneal endothelium and can provide information about endothelial function before and after cataract surgery. Serial CCT measurements can be used for follow-up and evaluation of treatment in patients with corneal edema.[6]

At present, CCT can be measured by various methods. Ultrasound pachymetry (UP), which has long been the gold standard, is inexpensive and practical but has several disadvantages. Contact between the probe and cornea introduces the risk of epithelial lesions and infection and necessitates topical anesthesia before measurement. In addition, there is no fixation light for gaze stability and the method is operator-dependent. Moreover, the mechanical pressure applied during measurement may result in a thinner CCT measurement compared to devices that measure optically.[3,4] Therefore, as technology has developed, non-contact methods have become more preferred.[7] Some of these methods and devices are the Orbscan II (Bausch and Lomb), Pentacam (OCULUS Inc, Wetzlar, Germany), specular microscope (SM), confocal microscope, anterior segment optical coherence tomography (AS-OCT), and Lenstar LS900 (Haag-Streit, Koeniz, Switzerland).

In this study, we investigated the agreement between and repeatability of non-contact CCT measurements acquired using the Pentacam, SM, AS-OCT, and Lenstar optical biometry analysis systems.

Materials and Methods

The right eyes of 130 patients with no ocular problems other than refractive error were included in the study. Approval was obtained from the Manisa Celal Bayar University Faculty of Medicine Ethics Committee before the study.

Patients over 18 years of age with best-corrected visual acuity (BCVA) of 20/20 (Snellen chart), no pathology detected on the anterior segment and fundus examination, and no history of regular systemic or topical drug use, refractive surgery, or intraocular surgery were included in the study.

Detailed systemic and ophthalmological histories were obtained from all patients. After a detailed ophthalmological examination with autorefractometry (Canon RK-F1, Tokyo, Japan), BCVA was assessed by Snellen chart, and slit-lamp anterior segment examination and dilated fundus examination were performed. All CCT measurements were made prior to the detailed ophthalmological examination to avoid the possible effects of topical drops used.

CCT measurements were acquired using SM, AS-OCT, Lenstar, and Pentacam devices. All measurements were repeated three consecutive times on each device by the same observer during the same session. To avoid the effect of diurnal variations in the cornea, the scans were performed in the morning between 9:00 and 12:00. Between the repeated measurements, patients were instructed to lift their heads from the chin rest, blink their eyes for 5 s, return to the examination position, and focus again. If applicable, rigid contact lenses were removed 1 week before and soft contact lenses were removed at least 24 h before measurement.

Measurement Devices

The Cellchek XL SM (Konan Medical USA, Torrance, CA, USA) is a non-invasive imaging technique that enables visualization and analysis of the corneal endothelium. Specular reflections arise from light reflected from the interfaces of media with different refraction indices. An image occurs when the light's angle of incidence equals the angle of reflection. It presents a qualitative and quantitative morphometric analysis of endothelial cells.[8,9]

The Pentacam HR (Oculus, Wetzlar, Germany) is an optical system consisting of a rotating Scheimpflug camera and a 475 nm blue light-emitting diode light source that enables detailed evaluation of the anterior segment structures. The Scheimpflug camera rotates 360° around the optic axis and image the entire cornea and anterior segment at intervals of 7–8° angles.[10–12]

The AS-OCT Cirrus (Carl Zeiss Meditec, Inc. Dublin, CA, USA) provides high-resolution images (up to 5–10 µm) using a diode laser with a wavelength of 1310 nm. The long-wavelength allows visualization of the lens and ciliary structures along with the anterior segment structures. Thickness measurement is obtained automatically by scanning the central 6-mm corneal area in the pachymetric maps.[13]

The Lenstar LS 900® (Haag-Streit AG, Switzerland) is a non-invasive, non-contact biometry device with optical low-coherence reflectometry technology that can obtain

Table 1. CCT values measured with four different non-contact devices

Device	Average CCT* (μm), mean±SD	Minimum (μm)	Maximum (μm)
Specular microscope	553.61±42.71	469.67	709.00
Pentacam	546.42±34.77	473.67	640.33
Anterior segment optical coherence tomography	538.96±35.97	463.00	638.33
Lenstar	543.48±35.45	465.33	643.67

*Average of 3 consecutive measurements. CCT: Central corneal thickness; SD: Standard deviation.

16 consecutive measurements in a single acquisition using an 820 nm superluminescent diode laser. CCT is measured by the device as the distance between the endothelial and epithelial layers.[14,15]

Statistical Analysis

The results were presented as mean ± standard deviation (SD). Statistical analysis of the results was performed using Statistical Package for the Social Sciences for Windows version 15.0 (SPSS, Chicago, IL, USA) statistical software. CCT measurements obtained using the four different pachymetry devices were compared using ANOVA and Friedman tests, with a $p<0.05$ regarded as statistically significant. Repeatability of the measurements was evaluated by intraclass correlation coefficient (ICC) analysis. Bland-Altman plots and 95% limits of agreement (LoA) were used to analyze the agreement between CCT values obtained by the different measurement methods. The repeatability coefficient (RC) was calculated using standards established by Bland and Altman. RC is calculated as 1.96 times the SD of the difference between measurements made by the same person with the same device, divided by the mean of the measurements. A low RC indicates high consistency.

Table 2. The ICC and p-values for average CCT measurements of the four different devices

Device	ICC	ICC 95% CI	p-value
SM	0.972	0.962–0.979	0.449[1]
Pentacam	0.997	0.995–0.998	0.270[2]
AS-OCT	0.998	0.997–0.998	0.540[1]
Lenstar	0.998	0.997–0.998	0.881[2]

P<0.005, [1]Friedman Test, [2]ANOVA. SM: Specular microscope; AS-OCT: Anterior segment optical coherence tomography; ICC: Intraclass correlation coefficient; CCT: Central corneal thickness; CI: Confidence interval.

Results

The mean age of subjects included in the study was 27.81±8.28 years (range, 20–71 years). Forty-four were men (33.8%) and 86 were women (66.2%). Mean CCT values were 553.61±42.71 μm with SM, 546.42±34.77 μm with Pentacam, 543.48±35.45 μm with Lenstar, 538.96±35.97 μm with AS-OCT. Of the four devices, the Pentacam and Lenstar had the most similar measurements, while the highest CCT values were obtained with SM. The mean CCT values measured with the SM, Pentacam, AS-OCT, and Lenstar devices are shown in Table 1.

ICC values for the devices were between 0.81 and 1.0, indicating excellent repeatability and similar repeatability levels. The ICC values were 0.972 for SM, 0.997 for Pentacam, and 0.998 for both AS-OCT and Lenstar. The results of repeatability analyses of CCT measurements are shown in Table 2.

Bland-Altman plots of the CCT values obtained from the four different devices are shown in Figure 1. AS-OCT and Lenstar biometry measurements were within the 95% confidence interval (95% LoA: –19.18, 10.14 μm) and the difference between measurements (14.66 μm) was clinically acceptable. Measurements acquired with the SM and Pentacam devices were also within the 95% confidence

Table 3. Bland-Altman, repeatability coefficient, and ICC values of the central corneal thickness measurements obtained using four different pachymetry devices

	Bland-Altman 95% LOA (±1.96×SD; μm)	Repeatability coefficient (%)	ICC*	ICC 95% CI
AS-OCT versus LENSTAR	14.66	2.70	0.985	0.961–0.992
SM versus PENTACAM	30.22	5.49	0.951	0.908–0.971
SM versus AS-OCT	31.86	5.83	0.923	0.627–0.970
SM versus LENSTAR	31.92	5.82	0.939	0.844–0.969
PENTACAM versus AS-OCT	12.87	2.37	0.980	0.783–0.994
PENTACAM versus LENSTAR	17.28	3.17	0.982	0.972–0.988

*P<0.001. CI: Confidence interval; LOA: Limits of agreement; SM: Specular microscope; AS-OCT: Anterior segment optical coherence tomography; ICC: Intraclass correlation coefficient; SD: Standard deviation.

interval (95% LoA: –23.04, 37.40 μm), but the difference between measurements (30.22 μm) was clinically unacceptable. Similarly, SM and AS-OCT measurements were within a 95% confidence interval (95% LoA: –17.22, 46.50 μm) but the difference between measurements (31.86 μm) was clinically unacceptable. Although SM and Lenstar biometry measurements were within a 95% confidence interval (95% LoA: –21.80, 42.04 μm), the difference between measurements (31.92 μm) was clinically unacceptable. Pentacam and AS-OCT measurements were within a 95% confidence interval (95% LoA: –5.41, 20.33 μm) and the difference between measurements (12.87 μm) was clinically acceptable. Similarly, Pentacam and Lenstar biometric measurements were within a 95% confidence interval (95% LoA: –14.34, 20.22 μm) and the difference between measurements (17.28 μm) was clinically acceptable.

Another parameter demonstrating the repeatability of device measurements is the RC. Available RC values indicate that measurements from all devices had high reliability and the most compatible devices were AS-OCT, Pentacam, and Lenstar biometry (Table 3).

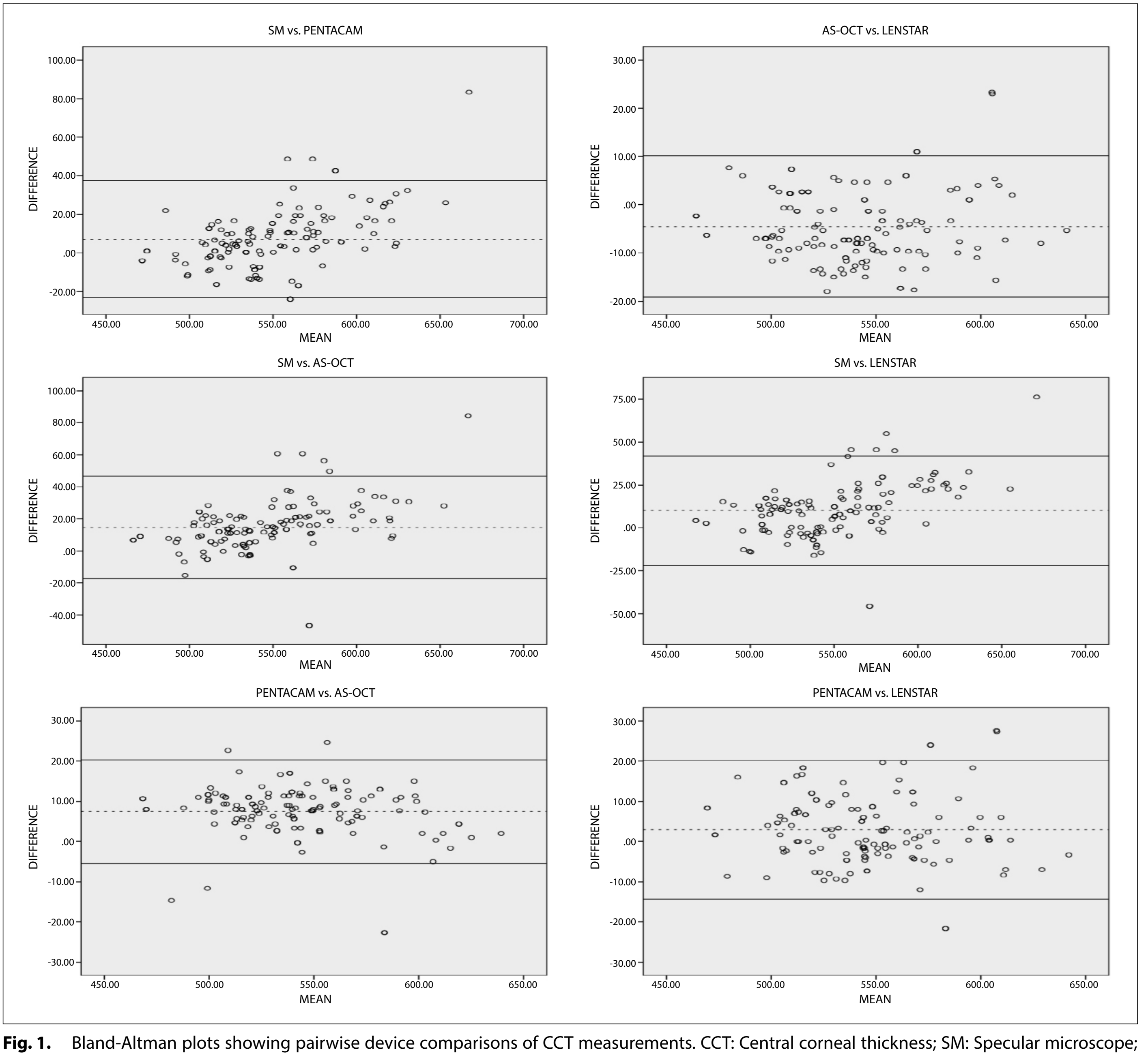

Fig. 1. Bland-Altman plots showing pairwise device comparisons of CCT measurements. CCT: Central corneal thickness; SM: Specular microscope; AS-OCT: Anterior segment optical coherence tomography.

Discussion

Accurate and reliable CCT measurement is important in the diagnosis of corneal diseases, keratorefractive surgery planning, and evaluation of glaucoma and ocular hypertension. It has been shown in the literature that increased CCT causes IOP measurements to be artificially high.[16] These minor differences in CCT can lead to significant changes in the diagnosis and treatment stages. Therefore, the devices used in clinical practice must provide accurate and repeatable measurements. Furthermore, it is important to determine whether values obtained from measurements of the same parameter with different devices can be used interchangeably. Due to the wide variety of devices in the clinic that can measure CCT, it is necessary to know whether measurements made with these devices can be used interchangeably during patient follow-up.[17,18]

O'Donnell et al.[17] compared CCT measurements from AS-OCT, Pentacam, and Lenstar devices and observed high agreement between Pentacam and Lenstar (LoA: 15.53 µm) but poor agreement between AS-OCT and Lenstar (LoA: 40.78 µm) and between AS-OCT and Pentacam (LoA: 25.61 µm. In another study comparing anterior segment parameters measured by Lenstar and AS-OCT, the mean CCT value was found to be thinner with the Lenstar (537.84±31.46 µm versus 559.39±32.02 µm). The Bland-Altman 95% LoA between the two devices were found to be −44.80 and 1.71 µm.[18] In contrast, in our study, the CCT values obtained with the Lenstar were higher than with AS-OCT (543.48±35.45 µm versus 538.96±35.97) and the Bland-Altman 95% LoA between the two devices were −19.18 and 10.14 µm.

Doors et al.[19] compared CCT measurements from Pentacam and AS-OCT and showed that the Pentacam measurements were higher. Chen et al.[20] also compared the CCT measurements from the Pentacam and AS-OCT by taking two repeated measurements and reported high repeatability for both devices (ICC 0.997 and 0.987, respectively) and high agreement on Bland-Altman plots, with a difference of 10.90 µm. Beutelspacher et al.[21] compared the mean CCT values with four different devices (UP, Lenstar, AS-OCT, Pentacam) and determined that the Pentacam yielded the highest measurements (mean, 568.4 µm). In all of these studies, CCT values were found to be higher with the Pentacam device compared to AS-OCT. Similarly, in our study, we found that CCT values were higher with the Pentacam compared to AS-OCT, though both the Pentacam and AS-OCT devices produced highly repeatable measurements (ICC: 0.997; 0.998) and showed good agreement with each other (LoA: 12.87 µm).

In our study, Bland-Altman analysis indicated good agreement between the Pentacam and Lenstar (LoA: 17.28 µm), which supports the findings of many previous studies. Barkana et al.[22] reported high repeatability of CCT values in the Pentacam and Lenstar (ICC: 0.995, 0.985), and Bland-Altman plot showed a difference of 18.5 µm between the two devices. O'Donnell et al.[17] also determined a difference of 15.53 µm between Pentacam and Lenstar measurements on Bland-Altman plot and concluded that the devices were consistent with each other. Tai et al.[23] observed mean CCT values of 507.8±30.2 µm, 538.4±31.7 µm, and 531.8±31.4 µm with the SM, Pentacam, and Lenstar devices, respectively, and showed that Lenstar and Pentacam CCT measurements were comparable and could be used interchangeably in clinical practice. However, they noted that repeatability was highest with the Lenstar and lowest with the Pentacam. Barkana et al.[22] obtained similar results in their study. Huang et al.[24] demonstrated good agreement between Lenstar and Pentacam measurements and higher repeatability with the Lenstar than the Pentacam. In addition, they reported that the Lenstar yielded lower CCT values compared to the Pentacam. They attributed this result to the fact that CCT is calculated using a single measurement in the Pentacam and is based on an average of three measurements in the Lenstar, which can lead to deviations in the measurements.[24]

Fujioka et al.[25] reported that CCT values measured with SM were thinner than those obtained with the Pentacam. Al-ageel et al.[26] determined mean CCT values of 511.9±38.6 µm with SM and 552.6±36.8 µm with the Pentacam, and found the 95% LoA between the Pentacam and SM with Bland-Altman graphs were 20.8 and 60.5 µm. Tai et al.[23] showed that the measurements made with SM were thinner than with the Lenstar, Pentacam, and UP, leading to lower agreement between the devices. González-Pérez et al.[27] reported that the thinnest values were obtained with SM. Although all of these studies indicate that measurements taken with SM are thinner, other studies in the literature have reported contradictory findings. Cinar et al.[28] compared UP, SM, Pentacam, and Lenstar measurements and found the highest CCT values with SM. Erdur et al.[29] compared the CCT values obtained with SM and AS-OCT devices and reported that the measurement values obtained with AS-OCT were lower. In comparison with Bland-Altman plot, a difference of 8.1 µm was found between the measurement values of the two devices. Scotto et al.[30] compared AS-OCT and SM measurements and determined mean CCT values of 535.8±35.5 and 547.7±38.2 µm, respectively, and reported that SM measurements tended to be higher. Of the four devices used in our study, the highest CCT values were obtained with SM. In a study by Tekin et al.,[31] the mean CCT value was 543.9±43.6 µm with AS-OCT and 520.7±39.8 µm with SM, and there was high agreement between the two devices.

As we mentioned above, in the literature, thicker or thinner mean values were obtained in CCT measurements made with SM compared to other devices. The reason for these different results may be related to the differences in the distribution of corneal thickness in the cases as well as the wide reliability interval of SM mesurements. In the Bland-Altman plots in our study, we mostly see values below the average in thin corneas and above the average in thick corneas in the measurements made with SM. In CCT measurements made with SM, thin corneas may be detected as thinner and thick corneas may be detected as thicker. Studies designed in this direction are needed to confirm this interpretation.

Tai et al.[23] compared CCT measurements with UP, Lenstar, Pentacam, and SM devices in healthy individuals and reported that the largest mean difference was 21.8 µm between SM and Lenstar. Borrego-Sanz et al.[32] showed a difference of 5.82 µm between Lenstar and SM measurements (95% confidence interval: −16.32 µm, 27.95 µm). In our study, the largest mean difference was 31.86 µm between SM and AS-OCT. The differences in measurements obtained with SM may be due to the use of different brands of SM in each of the studies. Different types of SM may record corneal parameters such as magnification, refractive index, and anterior corneal curvature differently.[32,33]

A limitation of our study was that measurements were only obtained from the healthy corneas of healthy individuals. Therefore, we do not have data from pathological and postoperative corneas regarding the agreement between these methods, which operate on the principle of measuring scattering in light reflected from the corneal tissues. The differences between the four systems may be greater in such circumstances.

Conclusion

The results of this study showed that the four non-contact methods were consistent and highly repeatable in terms of CCT measurement. The comparable measurement values obtained with AS-OCT, Lenstar, and Pentacam suggest that these devices can be used interchangeably. Due to the higher values obtained with SM, we believe that SM should not be used interchangeably with the other devices for CCT measurement.

Ethics Committee Approval: This study was approved by Manisa Celal Bayar University Faculty of Medicine Ethics Committee (date: 31.12.2020; number: 121).

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