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ORIGINAL PAPER

Agreement and repeatability of central corneal thickness measurements by four different optical devices and an ultrasound pachymeter

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Abstract

Purpose To compare the repeatability and agreement of central corneal thickness (CCT) measurements by spectral-domain optical coherence tomography (OCT), corneal topography (CT) with a combined Scheimpflug–Placido system, optical biometry (OB), specular microscopy (SM), and ultrasound pachymetry (UP).

Methods A single observer measured CCT twice in 150 eyes of 150 subjects with each of five devices: Nidek RS-3000 Advance OCT, CSO Sirius combined Scheimpflug–Placido disc system CT, Nidek AL-Scan partial coherence interferometry-based OB, Tomey EM-3000 SM, and Reichert iPac ultrasonic pachymeter. Pachymetry values corrected by the SM device software were also recorded. Levels of agreement between devices were evaluated by Bland–Altman plots with 95% limits of agreement, and repeatability for each device was analysed with intraclass correlation coefficients.

Results The mean CCTs measured by OCT, CT, OB, SM, corrected SM, and UP were 544.60 ± 29.56, 536.19 ± 32.14, 528.29 ± 29.45, 524.88 ± 32.38, 537.88 ± 32.38, and 545.29 ± 30.75 µm, respectively. Mean CCT differed significantly between the devices ($p < 0.05$) apart from between OCT and UP, and between CT and corrected SM. Mean paired differences between devices ranged between 0.68 and 20.41 µm. Repeatability with all devices was excellent (> 0.99). The range of limits of agreement was the least between OCT and UP.

Conclusions Different CCT measurement techniques produce quite different results, so CCT evaluation and follow-up should be performed using the same device or devices with close compatibility.

Keywords Central corneal thickness · Corneal topography · Optical coherence tomography · Optic biometry · Specular microscopy · Ultrasonic pachymeter

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Introduction

Measuring central corneal thickness (CCT) is important for the diagnosis and follow-up of corneal diseases and glaucoma, as well as for refractive surgery [1]. Until recently, ultrasonic pachymetry (UP) was the most commonly used and relied-upon clinical method for measuring CCT [2], widely

accepted as the gold standard [3]. Handheld ultrasound-based systems offer the advantages of portability and relative ease of use [1], but this technique has several important limitations. First, UP requires probe–corneal contact. Compression of the cornea or displacement of the tear film may yield slightly thinner readings as a result of tissue indentation. Conversely, the residue of the anaesthetic drop may result in slightly increased measurements. In addition, centralisation of the probe is highly operator dependent, which may be an issue in some cases [4].

Recently, several noninvasive techniques and devices have been introduced for anterior segment measurements. These include anterior segment optical coherence tomography, Scheimpflug–Placido disc system corneal topography, partial coherence interferometry-based optic biometry, and specular microscopy (SM) [5, 6]. Most of these are optical-based devices that do not require corneal contact or topical anaesthesia. They are user-friendly and do not rely on the probe being centralised correctly. However, the advantages and disadvantages of these new techniques are not yet fully known.

Anterior segment optical coherence tomography (OCT) adapts the technology used for imaging of the posterior segment to apply it to the anterior segment. It is based on measuring the delay of infrared light reflected from the tissue to determine tissue depth and thickness.

Scheimpflug–Placido disc system corneal topography (CT) is a high-precision technique for imaging the anterior ocular segment and for three-dimensional cornea analysis. It combines Scheimpflug technology, which allows measurement of the internal ocular structures, with Placido topography for the measurement of elevation and curvatures. In high-resolution mode, it can measure 35,632 points on the anterior corneal surface and 30,000 on the posterior corneal surface in approximately 5–6 s, using these point-by-point surface data to construct a pachymetric map.

Partial coherence interferometry-based optic biometry (OB) is based on partial coherence interferometry. It uses partial coherence superposition of light waves emitted from a superluminescent diode laser to measure biometric features of the eye such as axial length, corneal diameter, and keratometry. It uses the Scheimpflug principle to measure CCT.

Specular microscopy (SM) is used to visualise the endothelium by illuminating it at a specular angle from the axis of the camera. It measures CCT from the reflection of light waves from the anterior and posterior corneal surfaces.

The aim of this study was to investigate the repeatability of CCT measurements by these four optical devices and an ultrasound pachymeter and to evaluate the level of agreement between the devices. We posed three questions: 1. Can CCT measurements taken by different devices be used interchangeably? 2. How closely do the optical device measurements agree with those of the ultrasonic pachymeter and with each other? 3. How repeatable are the measurements for each device? We hypothesised that the optical devices would be as reliable as the ultrasonographic pachymeter. To the best of our knowledge, this is the first study to compare CCT measurements between these five techniques and within each technique.

Methods

Subjects

This was a comparative, cross-sectional, observational study. The protocol followed the tenets of the Declaration of Helsinki, and informed consent was obtained from all the enrolled patients. After receiving ethical approval (Kırıkkale University Clinical Research Ethical Committee, Date: 10.11.2015, Number: 25/08), subjects aged 18–75 years were recruited to the study from the Department of Ophthalmology of Kırıkkale University School of Medicine as a part of their routine examinations. The following exclusion criteria were applied: a refractive error of more than ± 5 D of spherical equivalent or more than ± 2 D of astigmatism, corneal topography revealing irregular astigmatism, keratoconus or keratoconus suspect, the use of contact lenses within 72 h prior to the assessment, best corrected visual acuity less than 20/25 (Snellen), intraocular pressure above 21 mmHg, and a history of ocular surgery. In total, 150 right eyes of 150 subjects were included in the analysis.

Protocol

The CCT measurements were taken using the five techniques sequentially in the following order: anterior segment spectral-domain OCT (Nidek RS-3000,

Nidek Co., Ltd., Gamagori, Japan), partial coherence interferometry-based OB (Nidek AL-Scan, Nidek Co., Ltd., Gamagori, Japan), combined Scheimpflug–Placido disc system CT (CSO Sirius, CSO Inc., Florence, Italy), noncontact SM (Tomey EM-3000 Tomey Corporation, Nagoya, Japan), and UP (Reichert iPac, Reichert, Inc. Depew, NY, USA). The UP was the final measurement to avoid any effect of probe–corneal contact on the optical measurements. All measurements were taken by a single observer at the same time of day (between 1:00 and 2:00 p.m.). The entire procedure lasted 25–40 min for each subject. For all measurements, the subject was seated and properly aligned, as per standard clinical practice. Two sequential examinations were made for each eye with each device, separated by a 15-s interval of blinking.

All subjects underwent a complete ophthalmologic examination, including visual acuity assessment, refractive error, slit-lamp biomicroscopy, intraocular pressure (after the central corneal thickness measurement), and fundus examination.

Devices

The RS-3000 used for OCT takes a maximum of 53,000 A-scans/s, with a depth resolution of 20 μm and a transverse resolution of 7 μm. Its anterior OCT module lens allows a 6 × 6 mm corneal scan. The device's software calculated the subject's CCT from the scan that passed through the centre of the cornea.

The AL-Scan optical biometer uses light interference to measure CCT, with a measurement area of 200–1200 μm. It has three-dimensional autotracking and autoshot features to simplify use. The subject was seated with the head stabilised using a chin rest and brow bar and was asked to fixate on the internal fixation light while the measurements were taken. The instrument was aligned according to the image on the monitor. Blinking or loss of fixation was detected automatically by the device, and the measurement repeated.

Sirius Scheimpflug–Placido disc system CT measurements were taken with the subject's eye aligned along the visual axis by a central fixation light. The device was realigned after each measurement. The subject was instructed to blink twice between measurements. CT determines the CCT by measuring the front and back surfaces of the cornea.

The SM measurements with the EM-3000 were taken with the subject's chin on a chin rest. The subject was asked to look at the red target, and the head position was adjusted so that the pupil was in clear focus on the monitor. The autoalignment and autoshot functions were used to take photographs. CCT readings were analysed by the automated software and were considered acceptable if the endothelial cells were clearly visible without any endothelial cell loss or cornea guttata and the bright corneal light reflection was centred on the monitor.

The iPac ultrasonic pachymeter was the last device to be used. The cornea was anaesthetised with topical 0.5% proparacaine hydrochloride (Alcaine; Alcon Laboratories, Istanbul, Turkey). With the subject in a sitting position and fixating on a distant target, the pachymeter probe was sterilised and aligned perpendicularly and centrally to the pupil as precisely as possible. Two consecutive measurements were taken.

Statistical analysis

The data were analysed using SPSS (version 21.0; SPSS, Inc.) and MedCalc (version 11.6.0.0; MedCalc Software bvba). The Kolmogorov–Smirnov test was used to test the normality of the distribution of CCT data for each device. Descriptive statistics are presented as mean ± standard deviation. The CCT data for all devices were analysed by repeated-measures analysis of variance (ANOVA), with the Bonferroni correction applied to post hoc pairwise comparisons. Bland–Altman plots were used to evaluate the agreement between the methods, with 95% limits of agreement (LoA) calculated as mean difference ± (1.96 × SD). Intraclass correlation coefficients were calculated for the correlation analysis of CCT measurements between each pair of devices. Intraexaminer repeatability for each device was also assessed by intraclass correlation coefficients. A p value below 0.05 was considered to be statistically significant.

Results

In total, 150 eyes of 150 subjects were included in the study. The mean age of the subjects was 42.45 ± 17.01 years (range 18–75 years). The male/female ratio was 0.8:1. The mean age was

41.11 ± 16.11 years for the women and 44.06 ± 18.02 years for the men.

The mean, minimum, and maximum CCT data for each device are presented in Table 1. The SM device's software calculated acoustic corrections for the CCT measurements by adding 13 μm; these corrected SM data were also included in the analysis. UP gave the highest mean CCT value, followed by OCT, corrected SM, CT, and OB. The lowest mean CCT value was with SM.

Pairwise comparisons and mean paired differences are presented in Table 2. A repeated-measures ANOVA showed that mean CCT differed significantly among all the devices ($p < 0.001$, F value = 128.44), although post hoc testing showed no significant difference between OCT and UP, and between CT and corrected SM. The mean paired differences between devices ranged between 0.68 and 20.41 μm, with the least difference between OCT and UP and the greatest between SM and UP. But, when the corrected data of the SM device were taken into account instead of raw data, the greatest paired difference was between OB and UP devices (Table 2). There were statistically significant correlations between all pairs of devices ($p < 0.001$) (Table 3). The repeatability analysis for each device is presented in Table 4. Repeatability was excellent for all the devices; in all cases, the intraclass correlation coefficient was > 0.99 ($p < 0.001$). Bland–Altman plots of the paired CCT differences (least and greatest) between devices, with the means and 95% LoA, are shown in Fig. 1. In Bland–Altman plots, a linear fit line was given to demonstrate the correlation of the difference in CCT between two devices with the magnitude of CCT (Fig. 1). The pair of devices with significant correlation between the difference in CCT and the mean CCT were as follows: CSM and OB ($r = 0.238$, $p = 0.003$); CT and OB ($r = 0.208$, $p = 0.01$); UP and OCT ($r = 0.179$, $p = 0.028$); OCT and SM ($r = -0.242$, $p = 0.003$); OCT and CSM ($r = -0.242$, $p = 0.003$); OCT and CT ($r = -0.225$, $p = 0.006$); OB and SM ($r = -0.238$, $p = 0.003$).

Discussion

Recently, there has been an increase in studies on novel techniques for CCT measurement and their reliability and repeatability. The gold standard for such measurements has been ultrasonic pachymetry, but advancing technology has brought new imaging devices based on different physical principles to the field of anterior segment measurement. However, it is important that these new techniques show good agreement in interdevice comparisons and for repeated measurements taken by each device. In this study, therefore, we evaluated the correlation of CCT measurements between devices, the repeatability of measurements for each device, and the agreement in results between devices. We found the repeatability for each device to be excellent and the measurements taken by all the devices were highly correlated with each other. However, pairwise comparisons showed that the only devices that could be used interchangeably were OCT and UP, and CT and corrected SM. Several studies have compared CCT measurements between different brands of optical imaging devices and ultrasound pachymeters. Some have reported that UP underestimates or overestimates CCT when compared to optical pachymetry [7–10]. Apart from OCT,

Table 1 The mean, minimum, and maximum CCT (μm) for each device

Device/method	Mean CCT ± SD (μm)	Minimum (μm)	Maximum (μm)
UP	545.29 ± 30.75	467	638
OCT	544.60 ± 29.56	473	636
CSM	537.88 ± 32.38	456	623
CT	536.19 ± 32.14	469	637
OB	528.29 ± 29.45	466	613
SM	524.88 ± 32.38	443	610

CCT central corneal thickness, *UP* ultrasonic pachymeter, *OCT* optical coherence tomography, *CSM* corrected data of specular microscopy, *CT* corneal topography, *OB* optic biometry, *SM* specular microscopy

Table 2 Pairwise comparisons and mean paired differences between devices

Pairwise comparison	Mean paired difference ± SE	95% confidence interval for difference		*p* value[a]
		Lower bound	Upper bound	
UP-OCT	0.68 ± 0.54	− 0.93	2.30	1.0 (> 0.05)
UP-CT	9.09 ± 0.99	6.14	12.04	< 0.001
UP-OB	16.99 ± 1.07	13.79	20.18	< 0.001
UP-SM	20.41 ± 0.99	17.43	23.37	< 0.001
UP-CSM	7.47 ± 0.99	4.43	10.37	< 0.001
OCT-CT	8.40 ± 0.95	5.56	11.24	< 0.001
OCT-OB	16.30 ± 0.98	13.35	19.25	< 0.001
OCT-SM	19.72 ± 0.96	16.83	22.60	< 0.001
OCT-CSM	6.72 ± 0.96	3.83	9.60	< 0.001
CSM-CT	1.68 ± 1.14	− 1.71	5.08	1.0 (> 0.05)
CSM-OB	9.58 ± 1.02	6.52	12.64	< 0.001
CSM-SM	13 ± 0.00	13	13	–
CT-OB	7.90 ± 1.07	4.68	11.11	< 0.001
CT-SM	11.31 ± 1.14	7.91	14.71	< 0.001
OB-SM	3.41 ± 1.02	0.35	6.47	0.017

UP ultrasonic pachymeter, *OCT* optical coherence tomography, *CT* corneal topography, *OB* optic biometry, *SM* specular microscopy, *CSM* corrected data of specular microscopy

[a]Repeated measures analysis of variance (ANOVA) with Bonferroni correction

Table 3 Intraclass correlation coefficients for the correlation analysis of central corneal thickness measurements between each pair of devices

Pairwise comparison	Intraclass correlation coefficient	95% confidence interval		*p* value[a]
		Lower bound	Upper bound	
UP-OCT	0.988	0.983	0.991	< 0.001
UP-CT	0.961	0.947	0.972	< 0.001
UP-OB	0.950	0.931	0.964	< 0.001
UP-SM	0.961	0.947	0.972	< 0.001
UP-CSM	0.961	0.947	0.972	< 0.001
OCT-CT	0.963	0.949	0.973	< 0.001
OCT-OB	0.956	0.939	0.968	< 0.001
OCT-SM	0.962	0.948	0.973	< 0.001
OCT-CSM	0.962	0.948	0.973	< 0.001
CSM-CT	0.951	0.932	0.964	< 0.001
CSM-OB	0.957	0.941	0.969	< 0.001
CSM-SM	1.000	1.000	1.000	–
CT-OB	0.952	0.934	0.965	< 0.001
CT-SM	0.951	0.932	0.964	< 0.001
OB-SM	0.957	0.941	0.969	< 0.001

UP ultrasonic pachymeter, *OCT* optical coherence tomography, *CT* corneal topography, *OB* optic biometry, *SM* specular microscopy, *CSM* corrected data of specular microscopy

[a]Intraclass correlation test

the optical devices in our study underestimated CCT obtained from UP. We found that UP and OCT measurements could be used interchangeably, as reported by previous studies [6, 11–13]. This may be explained by the high resolution of the operating system. Conversely, there have been reports of brands of UP and OCT devices that did not produce measurements in close agreement [14–16], whereas another study found good agreement between UP measurements and those of optical devices such as a rotating Scheimpflug camera and scanning-slit topography [17].

Modies et al. [18] compared CCT measurements taken with a Pentacam HR imaging system (Oculus, Wetzlar, Germany) and with UP (AL-2000; Tomey, Tennenlohe, Germany). The measurements with the Pentacam system (572 ± 33 and 575 ± 31 μm) were significantly higher than those with the ultrasound device (546 ± 27 and 548 ± 28 μm; $p < 0.0001$, by paired Student's t test). They concluded that these two devices could not be used interchangeably.

Bao et al. [19] compared three noncontact specular microscopes, EM-3000 (Tomey Inc., Nagoya, Japan), SP-02 (CSO, Florence, Italy), and Topcon SP-3000P (Topcon, Japan), with UP (Tomey SP-3000P, Tomey Inc., Nagoya, Japan). The mean CCT values measured by Topcon SP-3000P, EM-3000, SP-02, and Tomey SP-3000 were 513.66 ± 33.14, 529.12 ± 33.22, 549.06 ± 40.27, and 539.01 ± 35.73 μm, respectively. Repeatability was very good for all the devices, but there were statistically significant differences between all pairs of devices, and the 95% limits of agreement were broad. The authors suggested that these devices should not be used interchangeably.

Fig. 1 Bland–Altman plots comparing the measurements ▶ obtained with ultrasound pachymetry (UP), specular microscopy (SM), optic coherence tomography (OCT), partial coherence interferometry-based optic biometry (OB), corrected data of specular microscopy (CSM), and corneal topography (CT) devices. The 95% limits of agreement are shown with dashed lines, and the solid line represents the mean difference between these devices. The plots were arranged according to the decreasing order of the mean difference between the devices. The oblique dashed linear fit lines were given if the difference in CCT between two devices was correlated with the magnitude of CCT. The range of LoA was 0 between SM and CSM because of the default acoustic correction

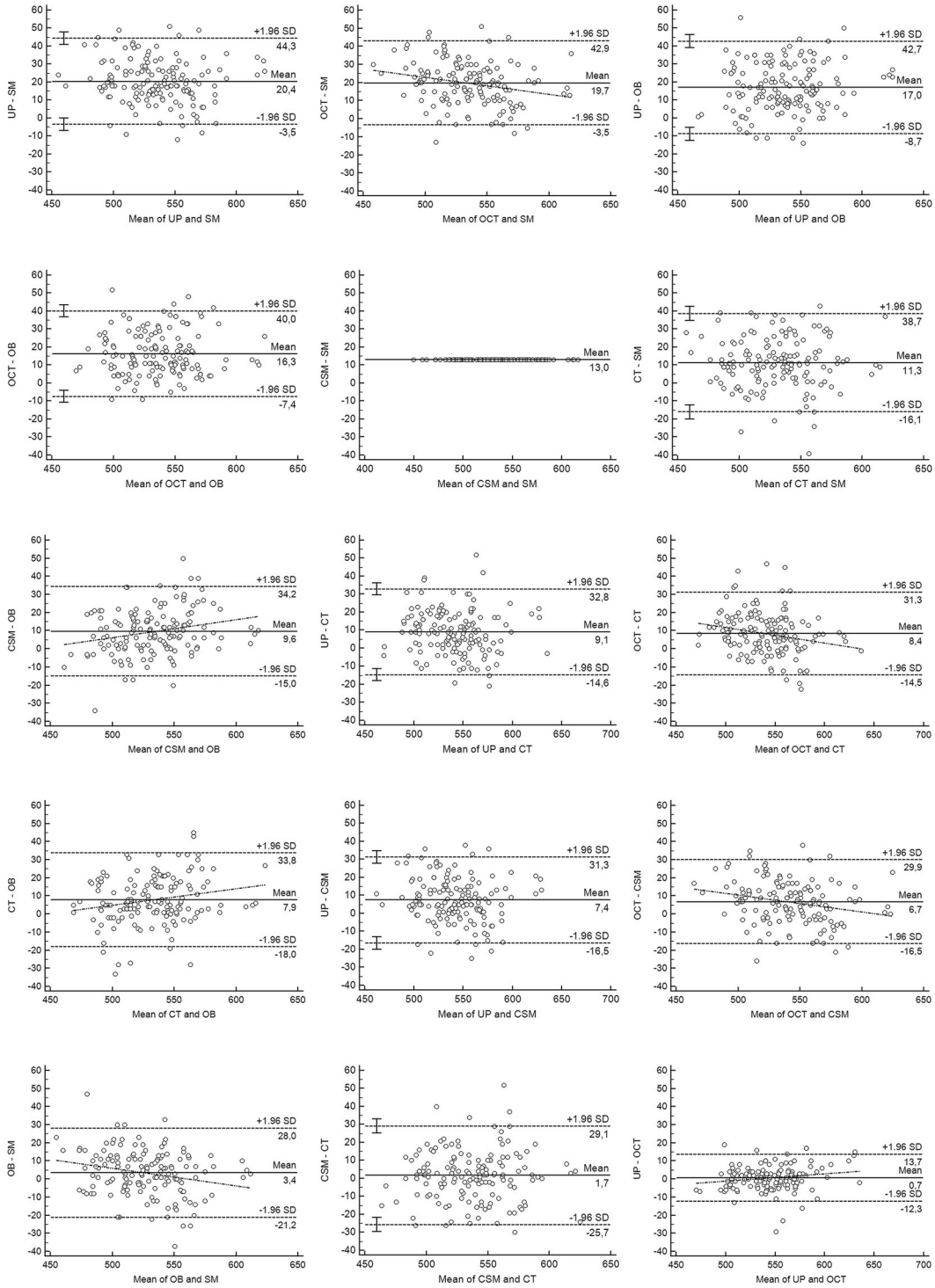
Beutelspacher et al. [13] compared CCT measurements taken with four devices: Orbscan II (Bausch & Lomb, Germany), a scanning-slit Scheimpflug-based corneal analysis system; IOPac (Reichert/Heidelberg Engineering, Germany), an ultrasound-based pachymeter; SL-OCT (Heidelberg Engineering, Germany), a slit-lamp-mounted, anterior segment OCT-based analysis system; and an optical low coherence reflectometry (OLCR) pachymeter (Haag Streit, Switzerland). The mean CCT values obtained from these devices were 568.4 ± 50.55, 551.9 ± 35.38, 559 ± 39.95, and 543.2 ± 35.82 μm, respectively. Although repeatability was very good for each device and the mean CCT values were generally similar, the authors suggested that caution should be taken when using the Orbscan device, which could overestimate the results.

Table 4 Intraexaminer repeatability of CCT for each device

Device	Intraclass correlation coefficient	95% confidence interval		p value[a]
		Lower bound	Upper bound	
OCT	0.995	0.993	0.996	< 0.001
UP	0.994	0.992	0.996	< 0.001
CT	0.992	0.989	0.994	< 0.001
OB	0.992	0.989	0.994	< 0.001
SM	0.992	0.989	0.994	< 0.001
CSM	0.992	0.989	0.994	< 0.001

CCT central corneal thickness, *OCT* optical coherence tomography, *UP* ultrasonic pachymeter, *CT* corneal topography, *OB* optic biometry, *SM* specular microscopy, *CSM* corrected data of specular microscopy

[a]Intraclass correlation test


UP - SM
+1.96 SD
44,3
Mean
20,4
-1.96 SD
-3,5
Mean of UP and SM
OCT - SM
+1.96 SD
42,9
Mean
19,7
-1.96 SD
-3,5
Mean of OCT and SM
UP - OB
+1.96 SD
42,7
Mean
17,0
-1.96 SD
-8,7
Mean of UP and OB
OCT - OB
+1.96 SD
40,0
Mean
16,3
-1.96 SD
-7,4
Mean of OCT and OB
CSM - SM
Mean
13,0
Mean of CSM and SM
CT - SM
+1.96 SD
38,7
Mean
11,3
-1.96 SD
-16,1
Mean of CT and SM
CSM - OB
+1.96 SD
34,2
Mean
9,6
-1.96 SD
-15,0
Mean of CSM and OB
UP - CT
+1.96 SD
32,8
Mean
9,1
-1.96 SD
-14,6
Mean of UP and CT
OCT - CT
+1.96 SD
31,3
Mean
8,4
-1.96 SD
-14,5
Mean of OCT and CT
CT - OB
+1.96 SD
33,8
Mean
7,9
-1.96 SD
-18,0
Mean of CT and OB
UP - CSM
+1.96 SD
31,3
Mean
7,4
-1.96 SD
-16,5
Mean of UP and CSM
OCT - CSM
+1.96 SD
29,9
Mean
6,7
-1.96 SD
-16,5
Mean of OCT and CSM
OB - SM
+1.96 SD
28,0
Mean
3,4
-1.96 SD
-21,2
Mean of OB and SM
CSM - CT
+1.96 SD
29,1
Mean
1,7
-1,96 SD
-25,7
Mean of CSM and CT
UP - OCT
+1.96 SD
13,7
Mean
0,7
-1.96 SD
-12,3
Mean of UP and OCT

Wong et al. [9] reported that mean CCT values measured by OCT (Humphrey Instruments, Carl Zeiss, Dublin, CA, USA), Orbscan version 3.10.31 (Orbtek Inc., Salt Lake City, UT, USA), and ultrasound pachymeter DGH-1000 (DGH Technology Inc., Exton, PA, USA) were 523.2 ± 33.54, 555.96 ± 32.41, and 555.11 ± 35.30 μm, respectively. The acoustic factor set for Orbscan was 0.92. The authors advised that 32 μm of acoustic correction should be added to achieve comparable results between devices.

Randleman et al. [16] compared CCT measurements by UP (Pachette II), scanning-slit (Orbscan II), Scheimpflug (Pentacam HR), and spectral-domain OCT (RTVue-100) obtained as both average values (OCT-A) and point measurements (OCT-P). The mean CCT values were 563.9 ± 36.1, 570.9 ± 36.1, 552.8 ± 33.8, 550.5 ± 32.7 (OCT-A), and 549.4 ± 32.7 μm (OCT-P), respectively. UP and the scanning-slit device produced significantly different results ($p < 0.0001$), and these were both significantly different from those of the other devices ($p < 0.0001$); conversely, the result from the Scheimpflug was similar to those from OCT-A and OCT-P ($p = 0.4$). The authors concluded that the CCT values of the devices in their study could not be used interchangeably.

Bayhan et al. [15] compared UP with three different optical devices: RTVue SD-OCT, Sirius Scheimpflug–Placido topographer, and Lenstar OLCR. The CCT values from SD-OCT and the Scheimpflug–Placido topographer were very similar ($p > 0.05$), but all other pairwise comparisons showed significant differences. These authors also suggested that UP could not be used interchangeably with the optical systems.

In a recent study by Scoto et al. [20], the mean CCT values by anterior segment OCT, noncontact SM, and UP were 535.8 ± 35.5, 547.7 ± 38.2, and 537.4 ± 37.5 μm, respectively. The authors suggested that OCT and UP could be used interchangeably, whereas noncontact SM could give quite different results.

In another study, Pierro et al. [21] measured CCT using one ultrasound device, seven SD-OCT devices, one time-domain OCT device, and one Scheimpflug camera. They evaluated the correlations between CCT measurements obtained from the ultrasound device and the optical instruments, as well as intra- and interoperator reproducibility. Intra- and interoperator reproducibilities were best with two of the SD-OCT devices and worst with the UP device. The authors suggested that SD-OCT devices might become the gold standard for CCT measurement. They calculated a calibration equation for each device but nevertheless suggested that follow-up examinations should be conducted by the same operator using the same device.

In the present study, we compared UP with four optical devices, each based on different physical principles. As in previous studies, we found that the repeatability for each device was excellent. Pairwise comparisons showed the results of UP and OCT to be very similar ($p = 1.00$). In addition, corrected data from the SM device were very similar to those from the CT device ($p = 1.00$). In other words, our results suggested that the CCT data from the UP and OCT devices in our clinic could be used interchangeably, as could the CT and corrected SM data. The pairwise comparisons showed statistically significant differences between all the other devices ($p < 0.05$). The UP and OCT devices not only had the smallest mean difference, but they also had the narrowest range of LoA in Bland–Altman plots. This finding suggests the agreement between the devices.

In our study, the difference in CCT between two devices was weakly dependent on the magnitude of the mean CCT in some of the paired comparisons. The direction of the correlation was positive for UP and OCT; CT and OB; CSM and OB comparisons. The correlation was negative for OCT and SM; OCT and CT; OCT and CSM; OB and SM comparisons (Fig. 1). The difference in CCT between CSM and OB devices and between CT and OB devices slightly increased with the increase in the mean CCT values. On the contrary, the difference in CCT between OCT and SM devices and between OCT and CT devices slightly decreased with the increase in the mean CCT values.

Although UP is considered to be the gold standard for the measurement of CCT, it is possible to obtain similar results with recently developed technology. The discrepancies in CCT measurements found in the various previous studies may be due to differences in brands of device, manufacturing processes, observers, study design, patient selection, and sample size. Each ophthalmology clinic uses different brands of devices and different settings. We therefore think that each clinic should ideally develop its own standards by conducting studies similar to the present one. For

example, we found that UP and OCT gave similar results for CCT measurements. New study designs with different brands of pachymetry devices and a greater number of subjects may produce valuable scientific information. Because OCT is more objective and user-friendly than other approaches, we think it will gain prominence once the resolution increases.

The limitation of our study was that we made two repeated examinations for each device. The number of consecutive measurements for a repeatability study is very important for the level of confidence. It must be below 20% in precision studies. The level of confidence for our repeatability results was 11.3% (< 20%) [22].

In conclusion, different CCT measurement techniques produce quite different results, so CCT evaluation and follow-up should be performed using the same device or devices with close compatibility.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest

Ethical approval All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The ethical approval was obtained from Kırıkkale University Clinical Research Ethical Committee, Date: 10.11.2015, Number: 25/08.

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

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