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Comparison of central corneal thickness measurements with three different optical devices

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Abstract

Purpose: The purpose of this study was to compare and evaluate the agreement of central corneal thickness (CCT) values obtained with three different devices working according to optical principle in healthy eyes.

Methods: 60 eyes of 60 individuals (30 men and 30 women) were enrolled in this study. CCT measurements performed with Scheimpflug–Placido topographer (Sirius), spectral-domain optical coherence tomography (RTVue) with an anterior segment module, and optical biometer (AL-Scan) were compared. Bland–Altman analysis was used to demonstrate agreement between methods.

Results: The mean age was 30.07 ± 7.313 years (range, 18–47 years). The mean CCT values obtained by RTVue, Sirius, and AL-Scan were 518.25 ± 36.38 µm, 526.08 ± 36.33 µm, and 513.50 ± 39.09 µm, respectively. The mean differences in CCT were 7.83 ± 14.15 µm between Sirius and RTVue, 12.58 ± 11.87 µm between Sirius and AL-Scan, and 4.75 ± 4.50 µm between RTVue and AL-Scan. The mean CCT was statistically different among the three groups ($p < 0.05$). All three modalities of CCT measurements correlated closely with each other, with Pearson's correlation coefficients ranging from 0.924 to 0.961. The 95% limits of agreement were −19.90 to 35.56 µm between Sirius and RTVue, −10.69 to 35.85 µm between Sirius and AL-Scan, and −4.07 to 13.58 µm between RTVue and AL-Scan.

Conclusion: Different results could be obtained through different noncontact devices in CCT measurements. Although the measurement values obtained by these devices show a high level of correlation, it would be a more correct approach to not use them directly interchangeably in clinical practice. Evaluation and follow-up of CCT should be performed using the same device.

Keywords: AL-Scan, central corneal thickness, pachymetry, RTVue, Sirius

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Introduction

Corneal pachymetry has become an important method for diagnosis and guidance of treatment of various eye diseases. The Goldmann applanation tonometer (GOT) is considered the gold standard for intraocular pressure (IOP) measurement.[1] However, IOP measured using GOT changes depending on central cornea thickness (CCT). While IOP is measured lower than normal in thin corneas, it is measured higher than normal in thick corneas. Doughty and Zaman's[2] meta-analysis showed that a 10% change in CCT could cause a change of about 3.4 mmHg in IOP. The Ocular Hypertension Treatment Study revealed that CCT is a strong marker for primary open-angle glaucoma in patients with ocular hypertension.[3] Also, the precise measurement of CCT is important for the preoperative evaluation and planning of all keratorefractive surgical procedures except glaucoma. Risk of iatrogenic keratectasia development increases in corneas that are thinned with increased tissue loss from the stromal bed as a result of inaccurate measurements.[4]

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There are various modalities for the measurement of CCT. These devices are based on optical and ultrasonic principles. Today, ultrasound pachymetry (UP) is still recognized as the gold standard in CCT measurements, and it is the most commonly used method.[5,6] However, this technique has some disadvantages and limitations. Some of these factors are as follows: it contacts the cornea, it requires topical anesthesia, it includes the risk of infection because it is a contact method, the thickness is measured from only one point in each contact, and the epithelial layer could be damaged in repeated measurements.[5,7,8] In addition, the inability to centralize the pachymetry probe to cornea depending on the user, the lack of a fixation light for gaze control, the oblique position of the probe to the cornea, and the pressure to cornea during measurements could cause inaccurate thickness measurements.[9] Nowadays, new optical devices have enabled the noncontact, fast, and more objective measurement of CCT by minimizing user error. CCT measurements in these devices showed that repeatability was high.[8–14] In addition, optical methods could be preferred as they eliminate the anesthesia requirement and mechanical problems caused by indentation. However, it is necessary to determine the interchangeability of those devices.

The purpose of this study was to compare and evaluate the agreement of the CCT values obtained by three different devices working according to optical principle (RTVue, Sirius, AL-Scan) in healthy eyes.

Methods

60 healthy individuals aged 18–50 years without any known ocular and systemic diseases were enrolled in this observational, cross-sectional study. 30 participants were men (50%) and 30 were women (50%). Measurements were taken from the right eye of each participant (total: 60 eyes). Patients with ocular pathology such as keratoconus/glaucoma, ±1 dioptric spherical and/or cylindrical refraction error, IOP exceeding 20 mmHg, pregnancy, contact lens use or history, and any ocular surgery or trauma were excluded. The best-corrected visual acuity of all participants was 10/10 or above according to Snellen chart. All the measurements were performed at least 2 h after waking up, between 13:30 and 16:00, to minimize the thickness increase in the sleep period and the diurnal variation. The manufacturer's instructions were followed. The measurements were performed by the same experienced examiner under dim lighting conditions. The participants were asked to sit back and blink a few times between measurements, leaving 5 min between each device to ensure a smoothly spread tear film layer. Three consecutive measurements were taken with each device and averaged. The measurements were completed within 30 min for each participant. The order of application for RTVue optical coherence tomography (OCT), Sirius topography, and AL-Scan optical biometer devices was randomized for each participant. The measurements taken from only the right eye of each participant were used for statistical analysis.

Optical coherence tomography

RTVue (Optovue Inc., Fremont, California, USA) is a spectral-domain OCT that performs 26,000 scans with a depth of 5 µm and transversally of 15 µm. CCT measurement was performed with a wide-angle anterior segment module (Cam-L) that can analyze the area of 6 mm diameter at 0.32 s. Real-time video images of the eyes were used in standardizing the target circular ring to the pupil. The pachymetry value in the central 2 mm zone was taken as the CCT.

Scheimpflug–Placido topography

Sirius topography (CSO, Florence, Italy) is an anterior segment analysis system that enables 360° rotation and combines the Scheimpflug camera and 22-ring Placido disk. It takes 25 segments from the cornea and anterior camera. In all, 35,632 points from the anterior surface and 30,000 points from the posterior surface of the cornea are analyzed using 475 nm blue LED light. It gives the tangential and axial curvature data of anterior and posterior surface of cornea, gives the global refractive strength of cornea, and provides the pachymetry mapping and wavefront analysis.

Optical biometer

The AL-Scan (Nidek CO, Aichi, Japan) biometric device, which combines optical interference and the Scheimpflug principle, was introduced in 2012. Six parameters, including CCT, anterior chamber depth (ACD), axial length, corneal keratometry (2.4 mm and 3.3 mm diameter area), white-to-white distance, and pupil diameter, can be measured in a short period of 10 s. The device uses Scheimpflug imaging principle to measure CCT and ACD.

Table 1. Descriptive analysis of central corneal thickness (μm) measurements.

Device	Mean ± SD	Minimum	Maximum	95% CI
Sirius	526.08 ± 36.33	444	612	508.85–527.65
RTVue	518.25 ± 36.38	445	621	503.40–523.60
AL-Scan	513.50 ± 39.09	424	625	516.70–535.47

Abbreviations: CI, confidence interval; SD, standard deviation.

Table 2. Interdevice comparison of central corneal thickness (μm) measurements.

Pairwise comparison	Main difference		95% CI of mean difference		Pearson's correlation	
	Mean ± SD	*p	Lower	Upper	R	**p
Sirius and RTVue	7.83 ± 14.15	<0.001	3.33	12.34	0.924	<0.001
Sirus and AL-Scan	12.58 ± 11.87	<0.001	8.81	16.36	0.953	<0.001
RTvue and AL-Scan	4.75 ± 4.50	0.004	1.29	8.21	0.961	<0.001

Abbreviations: CI, confidence interval; SD, standard deviation.
*Repeated-measures ANOVA using Bonferroni adjustment for multiple comparisons. **Pearson correlation analysis.

Statistical analysis

Statistical analyses were performed using SPSS for Windows (version 24.0; SPSS, Inc., Chicago, IL, USA). Descriptive statistics are presented as mean ± standard deviation (SD). The normality of data was confirmed using the Kolmogorov–Smirnov test. The association between the measurements using various devices is calculated and expressed as Pearson's correlation coefficients. The measurements performed with the three devices were compared by repeated-measures analysis of variance (ANOVA). Pairwise comparisons were performed using the Bonferroni adjustment for multiple comparisons. Bland–Altman plots were used to assess agreement among the various devices. The 95% limits of agreement (LoA) were calculated as mean difference ± (1.96 × SD). A p value of less than 0.05 was considered statistically significant.

Results

The mean age was 30.07 ± 7.31 (18–47) years. The mean spherical equivalent was −0.214 ± 0.472 (−1.50 to 0.50) diopter, and the mean axial length was 23.60 ± 0.62 (22.30–25.32) mm with AL-Scan. The mean CCT with Sirius was 526.08 ± 36.33 μm, with RTVue was 518.25 ± 36.38 μm, and with AL-Scan was 513.50 ± 39.09 μm. Table 1 shows the mean CCT readings and 95% confidence intervals (CIs) of the devices. Pairwise comparisons are presented in Table 2. It was found that all differences between pairs of mean CCT for the devices are statistically significant (Sirius and RTVue $p < 0.001$, Sirius and AL-Scan $p < 0.001$, RTVue and AL-Scan $p = 0.004$). All three devices strongly correlated closely with each other (Sirius and RTVue $r = 0.924$, Sirius and AL-Scan $r = 0.953$, RTVue and AL-Scan $r = 0.961$; all ps < 0.001). Bland–Altman plots of paired CCT differences against the mean values and the 95% LoA are shown in Figure 1. The 95% LoA were −19.90 to 35.56 μm between Sirius and RTVue with a bias of 7.83 μm (Figure 1(a)), −10.69 to 35.85 μm between Sirius and AL-Scan with a bias of 12.58 μm (Figure 1(b)), and −4.07 to 13.58 μm between RTVue and AL-Scan with a bias of 4.75 μm (Figure 1(c)). No proportional bias was detected between Sirius and RTVue in linear regression analysis ($p = 0.752$; 95% CI = −45.9 to −63.25). The proportional bias between Sirius and AL-Scan, and RTVue and AL-Scan was weak ($p = 0,018$; 95% CI = 9.14–93.94 and $p = 0.030$; 95% CI = 4.16–80.77 respectively).

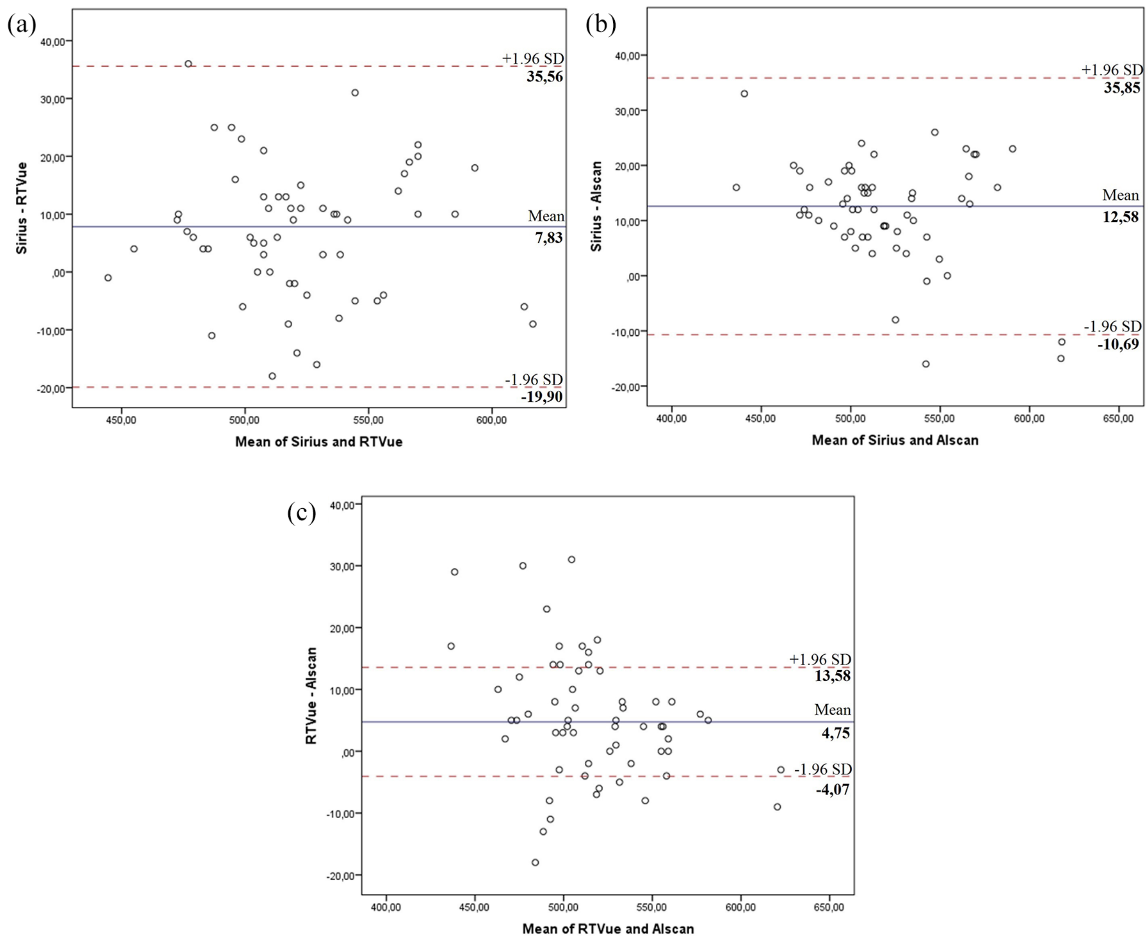

Figure 1. Bland–Altman plots comparing central corneal thickness (μm) measurements between (a) Sirius and RTVue, (b) Sirius and AL-Scan, and (c) RTVue and AL-Scan (c). The 95% limits of agreement are shown as dashed lines, and the solid line represents the difference between these measurements.

Discussion

An ideal corneal pachymetry application should have some features. It should give sensitive and accurate measurements that are safe, rapid, easily applied, and repeatable. Maximum patient comfort should be enhanced, and it should be cost-effective.[15] The ophthalmology market includes various devices with different working principles produced to measure the CCT. Different measurement values can be obtained through the use of different devices.

Repeatability is the ability of an instrument or technique to give similar values on different occasions. In previous studies, it has been demonstrated that Sirius, AL-Scan, and RTVue provide high intraobserver repeatability of CCT. High intraclass correlation coefficient (ICC) values were reported as 0.9884 by Bayhan and colleagues[9] and 0.992 by Gokcinar and colleagues[11] for Sirius. High repeatability for Al-Scan with an ICC of 0.999 has been reported by Mansoori and Balakrishna.[16] Similarly, excellent repeatability was reported by Bayhan and colleagues[9] with an ICC of 0.9979 and by Nam and colleagues[8] with an ICC of 0.996 for RTVue. Huang and colleagues[13] found high intraobserver repeatability, interobserver reproducibility, and intersession reproducibility for each devices when measuring CCT, thinnest corneal thickness, and midperipheral corneal thickness (with a distance of 1 mm and 2.5 mm from the corneal apex) with Pentacam, Sirius, Galilei, and RTVue. But midperipheral superior quadrant showed the lower precision. They reported more quite variability of measurements for midperipheral corneal thickness than for CCT.

The mean CCT obtained by all three devices operating based on optical principles was significantly different from each other in this study. CCT obtained by Sirius was found to be significantly thicker compared with AL-Scan (12.58 ± 11.87 μm;

$p < 0.001$). Similar to this study, compared with AL-Scan, CCT measured with Sirius was found to be significantly thicker (10.64 µm by Çağlar and colleagues;[17] 19.759 µm by Duman and colleagues,[10] and 17.6 µm by Doğan and Ertan,[18] $p < 0.001$). Considering the fact that both AL-Scan and Sirius use the Scheimpflug principle to measure the CCT, these results were surprising. The Sirius measures CCT in a central 10 mm area of the cornea, and AL-Scan measures CCT in 6 mm areas. The measurements were obtained when a vertical white line along the center of the cornea was visible. Duman and colleagues[10] attributed this divergence to alignment differences, measurement area, and study population.

Regarding the comparison between the CCT using RTVue and Sirius, we showed that the mean CCT was significantly thicker by Sirius with a mean difference of 7.83 µm. Köşker and colleagues[19] found that the mean CCT was thicker with Sirius than RTVue with a mean difference of 22 µm. In another study, Ishibazawa and colleagues[20] reported that mean CCT was thicker with Pentacam than RTVue with a mean difference of 22 µm. In a study, pupil-centered CCT and apical CCT obtained by Pentacam were found to be thicker than RTVue in patients who underwent LASIK (15.28 and 11.47 respectively).[14] Unlike this study, Bayhan and colleagues[9] and Şimşek and colleagues[21] found the mean CCT identical in both devices. Scheimpflug–Placido topographer measures the corneal thickness between the air–tear film interface and the posterior corneal surface.[22] These measurements are also affected by tear film quality. Besides, the operating principle depends on the reflectivity of light beams and differs substantially from the OCT systems. RTVue has higher scanning speed, which may overcome the eye motion–related artifacts and higher resolution which may help in the detection of corneal edges.[20] In our comparison between Sirius and RTVue, the higher resolving power of OCT may explain the lower results of CCT obtained by RTVue.

In our study, we found that the mean CCT obtained by RTVue was slightly but significantly thicker than AL-Scan with a mean difference of 4.75 µm. Unlike this study, Mansoori and Balakrishna[16] reported mean CCT of 496.72 ± 32.75 for RTVue 100 XR-OCT and 507.43 ± 33.54 µm for AL-Scan in 127 eyes of 127 healthy subjects with a mean difference of −10.709 ± 5.64 µm. In another study, Tuncer and colleagues[23] reported that the mean CCT was significantly thicker with AL-Scan than RTVue with a mean difference of 14.74 µm. Both Mansoori and Balakrishna[16] and Tuncer and colleagues[23] speculated that AL-Scan may include the tear film in the measurement of CCT as the anterior reflecting surface. Studies that compared CCT with RTVue and Lenstar also reported significantly lower results of RTVue.[9,21] On the contrary, Gokcinar and colleagues[11] compared CCT measurements obtained by Nidek RS-3000 Advance OCT and AL-Scan in 150 eyes of 150 subjects. The mean CCT with RS-3000 Advance OCT (544.60 ± 29.56 µm) was significantly thicker than those with AL-Scan (528.29 ± 29.45) with a mean difference of 16.30 ± 0.98 µm. In a study performed with a custom-built ultra-high-resolution OCT system based on titanium:sapphire laser, the average tear film thickness at a location close to the corneal apex was found to be 4.79 µm (3.8–6.8 µm). A decrease in the central tear film thickness was observed when thickness measurements were performed over a longer time. The authors proposed that a decrease in tear film thickness was related to tangential flow.[24] CCT measurement with RTVue is a faster modality than Al-Scan. Although it is claimed that six clinical parameters can be measured in 10 s with AL-Scan, we observed that this period often takes more than 10 s due to patient incompatibility and alignment errors. Perhaps due to the relatively prolonged time of the measurements with AL-Scan, the mean CCT may be lower by decreasing the tear film thickness with tangential flow. In addition, our study was conducted at a high-altitude region (5800 ft). As it is known, the evaporation rate increases at high altitudes.[25] The high evaporation rate might be a factor that could influence tear film thickness, hence the CCT in comparison between RTVue and AL-Scan.

In our study, considering the 95% LoA obtained from Bland–Altman plots for these comparisons, the RTVue and AL-Scan measurements displayed the smallest range of LoA (−4.07 to 13.58 µm). The LoA were the widest for CCT measurements with Sirius and RTVue (−19.90 to 35.56 µm).

As this study used only noncontact optical devices, the data could not be compared with gold standard UP. Many studies have reported that CCT measurements obtained by noncontact optical devices are lower than UP.[9,11,26–28] It has been suggested that UP cannot accurately locate the reflection on the posterior surface of the cornea due to the thicker measurement of UP compared with other pachymetry methods.[29] Gao and colleagues[30] found that the use of eye drops significantly increases corneal thickness by more than 20 µm in up to 63% of patients. Nam and colleagues[31] reported that the CCT increased 8.6 µm following proparacaine and then returned to the baseline level within 80 s. Hence, anesthetic drops used before UP can overestimate CCT. In addition, misplacement of the probe might result in considerable measurement errors.

This study has some limitations. First, repeatability and reproducibility of the measurements were absent. However, this is not a major lack as high repeatability and reproducibility of those devices were confirmed by the previous studies.[8,9,11,13,14,16] The second limitation of this study is that we did not evaluate the CCT in patients with corneal diseases such as keratoconus, post-contact lens wear, and post-refractive surgery. The results could be different in this patient population. Also, we did not measure and compare CCT with UP, which is considered to be the gold standard for CCT measurement.

Conclusion

In conclusion, different results could be obtained through different noncontact devices in CCT measurements. The mean CCT differences between noncontact optical devices may not be clinically significant, but the agreement expressed by the 95% LoA values is slightly broad. The range of these differences should be kept in mind to avoid potential complications in patients with borderline CCT in medical or surgical procedures. Although the measurement values obtained by these devices show a high level of correlation, it would be a more correct approach to not use them directly interchangeably in clinical practice. The evaluation and follow-up of CCT should be performed using the same device.

Author's note

This study has been presented in 31. Turkish Ophthalmology Society Summer Symposium in Van in September 2018.

Conflict of interest statement

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics statement

The study followed the tenets of the Declaration of Helsinki. Ethical board approval was obtained from the Ethical Committee of Kafkas University Faculty of Medicine, Kars, Turkey with number 80576354-99/31 before the study was initiated. Written informed consents were obtained from all participants.

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