Original Article

Comparison of central corneal thickness with four noncontact devices: An agreement analysis of swept-source technology

Erhan Özyol, Pelin Özyol[1]

Purpose: The purpose of this study was to compare the central corneal thickness (CCT) measurements of four noncontact devices in healthy eyes. **Materials and Methods:** In a sample of 45 healthy controls, CCT was measured using an optical biometer (IOLMaster 700) based on swept-source optical coherence tomography (SS-OCT), high-resolution rotating Scheimpflug camera system (Pentacam HR), spectral-domain OCT (SD-OCT) device with an anterior segment module (Spectralis), and noncontact pachymetry (NCP) device (Topcon TRK-2P). Agreement among the devices was analyzed using mean differences (i.e., bias) and Bland–Altman analysis with 95% limits of agreement (LoA). **Results:** Mean CCT measurements were 537.5 ± 47.5 μm for SS-OCT optical biometer, 532.3 ± 43.8 μm for Scheimpflug system, 521.3 ± 44.7 μm for SD-OCT device, and 518.0 ± 43.1 μm for NCP ($P < 0.001$). The SD-OCT device and NCP showed the closest agreement, with a bias of 2.6 μm (95% LoA, −3.6–8.8 μm), whereas the SS-OCT optical biometer and NCP showed the least agreement, with a bias of 18.7 μm (95% LoA, −2.1–39.5 μm). Bias was 16.1 μm (95% LoA, −3.1–35.3 μm) for SS-OCT optical biometer and SD-OCT, 5.1 μm (95% LoA, −6.8–17.0 μm) for SS-OCT optical biometer and Scheimpflug system, 10.9 μm (95% LoA, −15.1–36.9 μm) for SD-OCT device and Scheimpflug system, and 13.6 μm (95% LoA, −5–32.2 μm) for Scheimpflug system and NCP. **Conclusions:** SS-OCT optical biometer overestimates CCT measurements compared to Scheimpflug system, SD-OCT device, and NCP. Given mean differences and range variations in CCT measurements between devices, SS-OCT optical biometer and Scheimpflug system are interchangeable as are SD-OCT and NCP.

Key words: Anterior segment optical coherence tomography, central corneal thickness, noncontact pachymetry, Scheimpflug analysis system, swept-source optical biometer

Access this article online

Website: www.ijo.in

DOI: 10.4103/ijo.IJO_618_16

Quick Response Code:

Accurate, reliable corneal thickness measurements are crucial for diagnosing corneal diseases, assessing glaucoma, and screening and planning refractive surgery.[1-5] At present, ultrasound pachymetry is the most commonly used clinical method and gold standard for measuring central corneal thickness (CCT).[6,7] However, ultrasound pachymetry poses several limitations, including that is a contact method and thus requires topical anesthesia and user skill with probe placement.[7,8] Indeed, both drawbacks have prompted a search for noninvasive alternative solutions that do not risk epithelial lesions or the transmission of infection.

Several new, more sophisticated techniques, including the rotating Scheimpflug camera, optical biometry based on swept-source optical coherence tomography (SS-OCT), and anterior segment spectral-domain OCD (SD-OCT), provide rapid, convenient, and objective measurements of CCT minimizing the user influence and providing a noninvasive measurement. Moreover, various studies have verified the high reproducibility and repeatability of those devices in measuring CCT.[2,8-11] However, for clinical practice, it is also necessary to determine the interchangeability of those devices and their measurements.

Department of Ophthalmology, Mugla Sitki Kocman University Training and Research Hospital, [1]Department of Ophthalmology, Faculty of Medicine, Mugla Sitki Kocman University, Muğla, Turkey

Correspondence to: Dr. Erhan Özyol, Department of Ophthalmology, Mugla Sitki Kocman University Training and Research Hospital, Muğla, Turkey. E-mail: erhanozyol@mynet.com

Manuscript received: 06.08.16; Revision accepted: 16.05.17

In response, the current study aimed to quantify the agreement of CCT measurements taken with four different noncontact modalities: SS-OCT-based optical biometry device, high-resolution rotating Scheimpflug camera system, SD-OCT device with an anterior segment module, and noncontact pachymetry (NCP) device in healthy eyes.

Materials and Methods

Participants and measurements

Performed in accordance with the Declaration of Helsinki and approved by a local Ethical Committee, this study involved a sample of 45 healthy controls, all with normal eyes without corneal abnormalities as verified by slit lamp examination. Exclusion criteria were any corneal abnormality affecting measurement, poor cooperation, history of contact lens wear, or prior ocular surgery.

CCT was determined with four different devices: SS-OCT optical biometer device, Scheimpflug system, SD-OCT device, and NCP. Three consecutive measurements with each device were taken by the same experienced examiner according to the

Cite this article as: Özyol E, Özyol P. Comparison of central corneal thickness with four noncontact devices: An agreement analysis of swept-source technology. Indian J Ophthalmol 2017;65:461-5.

manufacturer's recommendations, and the order of modalities used for measurement was randomly assigned to each eye using computer-generated sequences. To minimize any diurnal variation, measurements were taken between 10:00 am and 12:00 pm, with a 10-min interval before using a different device. To ensure a smoothly spread tear film, between measurements, participants were asked to sit back and blink several times. Measurements taken on the right eye of each participant were used for statistical analysis.

Devices

Using a rotating Scheimpflug camera (180°) and monochromatic slit light source (i.e., blue LED lights at 470 nm) combined with a static camera, the Pentacam HR (Oculus, Wetzlar, Germany) can provide a three-dimensional model of the anterior segment, elevation maps of the anterior and posterior corneal surfaces, pachymetry maps, biometric measurements of the anterior segment, and anterior and posterior corneal power calculations. Only scans with an examination quality specification of "OK" were retained for analysis. The pupil center pachymetric value automatically provided by the software was recorded.

IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany), a newly available SS-OCT-based optical biometry device, uses SS-OCT technology – that is, a laser with variable wavelength – to generate optical B-scans, or optical cross sections, to determine biometric eye data. The device can obtain multiple measurements for each of the various parameters in a single capturing process and present their average value. More specifically, from a single OCT image aligned with the eye's visual axis, SS-OCT technology can measure CCT, anterior chamber depth, anterior aqueous depth, lens thickness, and axial length. In this study, after quality control, criteria were checked for SS-OCT-based optical biometric measurements in accordance with manufacturer recommendations, CCT values were recorded for analysis.

With an axial resolution of 7 μm, transverse resolution of 14 μm, and scanning speed of 40,000 A-scans per second, the SD-OCT device (Spectralis; Heidelberg Engineering, Heidelberg, Germany) with an anterior segment module allows high-resolution images of the cornea. It acquires images of sufficient resolution and definition to differentiate the epithelium, Bowman's layer, stroma, and endothelium. In this study, the pupil center was measured, and the CCT was manually obtained from that position.

The Topcon TRK-2P (Topcon Corp., Tokyo, Japan) employs an automated, noncontact technique using optical pachymetry to determine CCT, which involves using a tangential slit of light directed onto the cornea at a known angle. The illuminated slit is measured, and corneal thickness is calculated using trigonometry. All parameters, including horizontal and vertical alignment and vertex distance, are determined by the instrument. In this study, measurements were obtained using the full screening mode, which yields intraocular pressure, keratometry, autorefraction, and pachymetric results. When gauging CCT, the Topcon TRK-2P captures three readings, which in this study were averaged and recorded.

Statistical analysis

The Statistical Package for the Social Sciences version 18.0 (SPSS Inc., Chicago, IL, USA) was used for data analysis. The normality of data was confirmed using the Kolmogorov–Smirnov test. CCT measurements obtained with the four devices were compared using repeated-measures analysis of variance (ANOVA), and pairwise comparisons were performed using the Bonferroni adjustment for multiple comparisons. A $P < 0.05$ was considered to be statistically significant. The bias and agreement of the devices were assessed using Bland–Altman analysis. Repeatability was assessed using intraclass correlation coefficients (ICCs). The repeatability standard deviation (SD) was estimated by the square root of the estimated variance due to measurement error, based on the random-effect ANOVA model. The coefficient of variability (CoV) was calculated by the quotient of the SD from repeatability and the mean of all used measurements.

Results

Included in analyses were measurements of 45 eyes of 45 healthy controls (26 female, 19 male), whose mean age was 36.8 ± 7.9 years (range: 21–47 years). The mean spherical error of the 45 eyes was −0.52 ± 1.27 D (range: −4.00–3.25 D), and in general, the difference in CCT measurements among the devices was statistically significant ($P < 0.001$). Table 1 shows the mean CCT measurements of the devices, and Table 2 shows interdevice differences.

The SD-OCT device and NCP showed the closest agreement, with a bias of 2.6 μm (95% limits of agreement [LoA], −3.6–8.8 μm), whereas the SS-OCT optical biometer and NCP showed the least, with a bias of 18.7 μm (95% LoA, −2.1–39.5 μm). Bias was 16.1 μm (95% LoA, −3.1–35.3 μm) for the SS-OCT optical biometer and SD-OCT device, 5.1 μm (95% LoA, −6.8–17.0 μm) for the SS-OCT optical biometer and Scheimpflug system, 10.9 μm (95% LoA, −15.1–36.9 μm) for the Scheimpflug system and SD-OCT device, and 13.6 μm (95% LoA, −5–32.2 μm) for the Scheimpflug system and NCP. Fig. 1 displays the corresponding Bland–Altman plots.

Table 3 shows the results of the repeatability assessments obtained with the devices. Repeatability of consecutive measurements performed during the same visit was excellent for all devices.

This study provided an 85% power to detect a difference of 10 μm between the devices with 42 evaluable eyes assuming a SD of 8.0 μm and an α-level of 0.05 based on previous studies.[12,13]

Discussion

The need for precise measurements of anterior segment characteristics has always promoted the innovation of reliable

Table 1: Descriptive statistics for central corneal thickness measurements

	Mean±SD	Minimum	Maximum	95% CI
SS-OCT optical biometer (μm)	537.4±47.4	464	623	525.9-548.9
Scheimpflug system (μm)	532.3±43.7	458	611	522.5-542.1
SD-OCT (μm)	521.3±44.7	452	595	511.2-531.4
Noncontact pachymetry (μm)	518.0±43.1	451	591	508.8-527.2

SS-OCT: Swept-source optical coherence tomography, SD-OCT: Spectral-domain optical coherence tomography, SD: Standard deviation, CI: Confidence interval

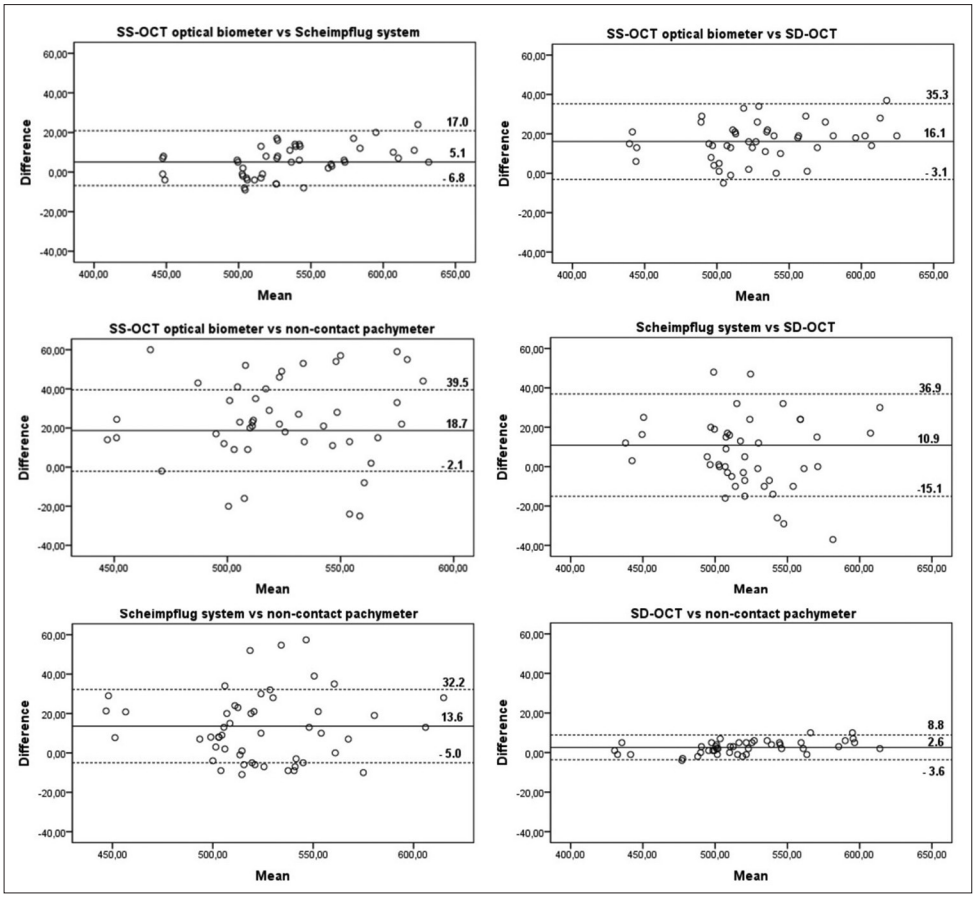

Figure 1: Bland-Altman plots for central corneal thickness measurements in each pairwise device comparison

Table 2: Mean differences between the devices used to determine central corneal thickness, their standard deviations, and confidence intervals (all values in μm)

Pairwise comparison	Mean paired difference		95% CI of mean difference (μm)	
	Mean±SD	*P**	Lower	Upper
SS-OCT optical biometer versus Scheimpflug system	5.1±8.1	<0.001	2.69	7.57
SS-OCT optical biometer versus SD-OCT	16.1±9.8	<0.001	13.1	19.0
SS-OCT optical biometer versus NCP	18.7±10.6	<0.001	15.5	21.9
Scheimpflug system versus SD-OCT	10.9±8.0	<0.001	8.5	13.3
Scheimpflug system versus NCP	13.6±7.5	<0.001	11.3	15.8
SD-OCT versus NCP	2.6±3.2	<0.001	1.65	3.59

*Repeated-measures ANOVA using Bonferroni adjustment for multiple comparisons. SS-OCT: Swept-source optical coherence tomography, SD-OCT: Spectral-domain optical coherence tomography, NCP: Noncontact pachymetry, SD: Standard deviation, CI: confidence interval, ANOVA: Analysis of variance

measurement devices. However, with those various devices available, it is also essential to know their interchangeability in clinical practice. Accordingly, this research evaluated the comparability of CCT measurements taken with various modalities in healthy controls. According to results, the SD-OCT device and NCP demonstrate the closest agreement, whereas the SS-OCT optical biometer and NCP show the least. Although numerous studies have been performed to compare different pachymetry methods, to our knowledge, no study has directly compared these four devices used in this study. As such, it remains unclear whether measurements taken with those systems match and whether the devices themselves can be used interchangeably. In that sense, another significant finding of this study is that the SS-OCT optical biometer overestimated CCT in healthy eyes compared to the NCP, SD-OCT device, and Scheimpflug system. Most likely, tear film and working principles of the noncontact devices have an important role on the different CCT measurements. Pentacam HR and SS-OCT measure the CCT including tear film. However, an SD-OCT enables the measurement of CCT from epithelium to the endothelium without including tear film by manually using caliper. In addition, the NCP measures the CCT trigonometrically using an illuminated tangential slit on the cornea and differs from other optical systems.

Repeatability limits of the device in healthy controls may be another reason of differences in CCT measurements. In previous studies, repeatable and reliable results are reported for Pentacam HR, SS-OCT, SD-OCT, and NCP systems. CoV and ICC values were reported as 0.67% and 0.981 by Nam *et al*.[8] for Pentacam and as 0.48% and 0.987 by Chen *et al*.[13] for Pentacam HR. High repeatability for SS-OCT with a CoV

Table 3: Intraobserver repeatability of the devices for central corneal thickness measurements

Device	CoV (%)	ICC	95% CI
Pentacam	0.52	0.981	0.969-0.993
SS-OCT	0.49	0.965	0.946-0.984
SD-OCT	3.75	0.996	0.994-0.998
Noncontact pachymetry	2.82	0.974	0.971-0.978

SS-OCT: Swept-source optical coherence tomography, SD-OCT: Spectral-domain optical coherence tomography, CoV: Coefficient of variability, ICC: Intraclass correlation coefficient, CI: Confidence interval

of 0.41% by Kunert *et al*.[14] has also been reported. Similarly, excellent repeatability was reported by Pierro *et al*.[15] with a CoV of 0.069% and an ICC of 0.998 for SD-OCT. In another study with SD-OCT, ICC was reported as 0.999 with a CoV of 4.82% for CCT.[16] Hahn *et al*.[17] reported a CoV of 0.69% with an ICC of 0.984 and in another study, CoV was found 5.5% for a NCP system.[18] Similarly, our results demonstrated high intraobserver repeatability for CCT measurements by Pentacam HR, SS-OCT, SD-OCT, and NCP in healthy controls.

Results indicated that the range of LoA was narrow with less bias in the SD-OCT device compared to the NCP and in the SS-OCT optical biometer compared to the Scheimpflug system. Biases were greater and ranges of LoA wider for other pairs of devices. These findings are clinically relevant, for it is known that intraocular pressure measurements are influenced by CCT. Accurate CCT measurements are also important in planning refractive surgery, in which the underestimation of corneal thickness can cause the exclusion of eligible patients from refractive surgery. At the same time, overestimation of corneal thickness can misguide surgeons, thereby resulting in overablation and iatrogenic keratectasia. Monitoring CCT in patients after refractive surgery is also critical, because postoperative intraocular pressure readings are lower than preoperative values, as a result of a thinner postoperative cornea. False low intraocular pressure readings risk the delay of the diagnosis of future glaucoma in patients who undergo refractive surgery. Given the importance of accurate CCT measurements in various clinical settings,[1,19] the SS-OCT optical biometer and Scheimpflug system should not be used interchangeably with the SD-OCT device or NCP due to the wide range of LoA with greater bias. Gorgun *et al*.[20] compared four noncontact methods (Visante OCT, Pentacam, OrbscanIIz, and slit-lamp OCT) for CCT measurements. They reported higher Pentacam readings than Orbscan IIz, Visante, and slit-lamp OCT. However, the authors also found poor agreement that seems to be clinically important between methods.

Although noncontact technique seems to allow relatively objective measurements through automatic processing, unsatisfactory agreement among devices may result from poor fixation, corneal abnormalities, or severe tear film problems.[21] Because this study compared only noncontact pachymetric methods, its findings may not be interpreted in the context of ultrasound pachymetric measurements. Many studies have compared measurements obtained by noncontact methods with those of ultrasound pachymetry, yet with varying results,[21-23] and some studies suggest that ultrasound pachymetry overestimates CCT measurements compared to noncontact methods such as with slit-lamp OCD, SD-OCT, optical low coherence reflectometry, partial coherence interferometry, and Scheimpflug systems.[21,24-27] On the other hand, in normal corneas, Uçakhan *et al*.[28] found the mean Scheimpflug's CCT measurements thicker than that of ultrasound pachymetry and Hahn *et al*.[17] reported ultrasound pachymetry underestimates CCT measurements than NCP.

Although the repeatability and reproducibility of SS-OCT optical biometer measurements have been reported,[11] fewer reports have compared CCT measurements with various devices. In a recent study, Kunert *et al*.[14] reported that CCT measurements taken with an SS-OCT optical biometer and optical low coherence reflectometry biometer did not differ significantly with a bias of 0.15 μm (95% LoA, −8.69–8.99 μm). In our previous study,[29] SS-OCT and Pentacam HR showed a statistical difference in CCT measurements (bias: 5.05 μm; with a 95% LoA, 9.9–−19.9 μm); however, it was comparable to those demonstrating the reliability of the devices in the current clinical use. Similar difference in CCT between SS-OCT and Pentacam HR was found in the current study with a bias of 5.1 μm (95% LoA, −6.8–17.0 μm).

The Scheimpflug system with the Pentacam HR also overestimated CCT measurements compared to the NCP and SD-OCT device as consistent with previous reports. Similar results by Chen *et al*.[13] (bias: 10.9 μm, 95% LoA, −0.7–22.5 μm) and Yap *et al*.[30] (bias: −21.9 μm; 95% LoA, −1.14–−42.6 μm) were reported using the Pentacam HR and Fourier-domain OCT. Grewal *et al*.[26] compared the CCT measurements taken with SD-OCT system and Pentacam and reported less difference between devices (bias: 1.5 μm; 95% LoA, −16.32–13.34 μm), whereas Szalai *et al*.[31] reported a bias of −12.46 μm (95% LoA, −35.78–10.87 μm) using swept-light source Fourier-domain OCT and Pentacam for CCT measurements. Although the difference of measurements between devices is comparable on average, it is also important to consider the range of variation to gauge the interchangeability of two devices. In comparing various anterior segment-OCT devices with the Scheimpflug system, most studies reveal similar variation ranges, with a clinically insignificant difference in bias among them.

This study posed a few limitations. First, only healthy eyes were included in the study, meaning that the results may differ in eyes that have experienced refractive surgery or keratoconus. The second limitation was that CCT measurements with the anterior segment SD-OCT device were taken manually, which could have caused variability in the measurements.

Conclusions

Results suggest that, in healthy controls, the SS-OCT optical biometer overestimates CCT measurements compared to the high-resolution Scheimpflug system, SD-OCT device, and NCP. When considering the interchangeability of noncontact devices for CCT measurements, the SS-OCT optical biometer and Scheimpflug system on the one hand and the SD-OCT device and NCP on the other hand, can be used interchangeably with healthy controls. However, all other device pairs are liable to produce different measurements that could affect subsequent clinical applications. Further work is required to assess the agreement of CCT measurements in abnormal corneas, such as keratoconus cornea, postrefractive surgery cornea, and others.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Gordon MO, Beiser JA, Brandt JD, Heuer DK, Higginbotham EJ, Johnson CA, *et al.* The Ocular Hypertension Treatment Study: Baseline factors that predict the onset of primary open-angle glaucoma. Arch Ophthalmol 2002;120:714-20.
2. Huang J, Ding X, Savini G, Pan C, Feng Y, Cheng D, *et al.* A comparison between Scheimpflug imaging and optical coherence tomography in measuring corneal thickness. Ophthalmology 2013;120:1951-8.
3. Jorge J, Rosado J, Díaz-Rey J, González-Méijome J. Central corneal thickness and anterior chamber depth measurement by Sirius® Scheimpflug tomography and ultrasound. Clin Ophthalmol 2013;7:417-22.
4. Price FW Jr., Koller DL, Price MO. Central corneal pachymetry in patients undergoing laser *in situ* keratomileusis. Ophthalmology 1999;106:2216-20.
5. Randleman JB, Woodward M, Lynn MJ, Stulting RD. Risk assessment for ectasia after corneal refractive surgery. Ophthalmology 2008;115:37-50.
6. Marsich MW, Bullimore MA. The repeatability of corneal thickness measures. Cornea 2000;19:792-5.
7. Miglior S, Albe E, Guareschi M, Mandelli G, Gomarasca S, Orzalesi N. Intraobserver and interobserver reproducibility in the evaluation of ultrasonic pachymetry measurements of central corneal thickness. Br J Ophthalmol 2004;88:174-7.
8. Nam SM, Im CY, Lee HK, Kim EK, Kim TI, Seo KY. Accuracy of RTVue optical coherence tomography, Pentacam, and ultrasonic pachymetry for the measurement of central corneal thickness. Ophthalmology 2010;117:2096-103.
9. de Sanctis U, Missolungi A, Mutani B, Richiardi L, Grignolo FM. Reproducibility and repeatability of central corneal thickness measurement in keratoconus using the rotating Scheimpflug camera and ultrasound pachymetry. Am J Ophthalmol 2007;144:712-8.
10. Huang J, Pesudovs K, Yu A, Wright T, Wen D, Li M, *et al.* A comprehensive comparison of central corneal thickness measurement. Optom Vis Sci 2011;88:940-9.
11. Srivannaboon S, Chirapapaisan C, Chonpimai P, Loket S. Clinical comparison of a new swept-source optical coherence tomography-based optical biometer and a time-domain optical coherence tomography-based optical biometer. J Cataract Refract Surg 2015;41:2224-32.
12. Lattimore MR Jr., Kaupp S, Schallhorn S, Lewis R 4th. Orbscan pachymetry: Implications of a repeated measures and diurnal variation analysis. Ophthalmology 1999;106:977-81.
13. Chen S, Huang J, Wen D, Chen W, Huang D, Wang Q. Measurement of central corneal thickness by high-resolution Scheimpflug imaging, Fourier-domain optical coherence tomography and ultrasound pachymetry. Acta Ophthalmol 2012;90:449-55.
14. Kunert KS, Peter M, Blum M, Haigis W, Sekundo W, Schütze J, *et al.* Repeatability and agreement in optical biometry of a new swept-source optical coherence tomography-based biometer versus partial coherence interferometry and optical low-coherence reflectometry. J Cataract Refract Surg 2016;42:76-83.
15. Pierro L, Iuliano L, Gagliardi M, Ambrosi A, Rama P, Bandello F. Central corneal thickness reproducibility among ten different instruments. Optom Vis Sci 2016;93:1371-9.
16. López de la Fuente C, Sánchez-Cano A, Segura F, Hospital EO, Pinilla I. Evaluation of total corneal thickness and corneal layers with spectral-domain optical coherence tomography. J Refract Surg 2016;32:27-32.
17. Hahn IK, Kim JY, Kim MJ, Tchah H, Moon CH. Validity of tono-pachymetry for measuring corrected intraocular pressure in non-surgical and post-photorefractive keratectomy eyes. Korean J Ophthalmol 2017;31:44-51.
18. Schiano Lomoriello D, Lombardo M, Tranchina L, Oddone F, Serrao S, Ducoli P. Repeatability of intra-ocular pressure and central corneal thickness measurements provided by a non-contact method of tonometry and pachymetry. Graefes Arch Clin Exp Ophthalmol 2011;249:429-34.
19. Utine CA, Altin F, Cakir H, Perente I. Comparison of anterior chamber depth measurements taken with the Pentacam, Orbscan IIz and IOLMaster in myopic and emmetropic eyes. Acta Ophthalmol 2009;87:386-91.
20. Gorgun E, Yenerel NM, Dinc UA, Oncel B, Kucumen RB, Oral D, *et al.* Comparison of non-contact methods for the measurement of central corneal thickness. Ophthalmic Surg Lasers Imaging 2011;42:400-7.
21. Hashemi H, Roshani M, Mehravaran S, Parsafar H, Yazdani K. Effect of corneal thickness on the agreement between ultrasound and Orbscan II pachymetry. J Cataract Refract Surg 2007;33:1694-700.
22. Beutelspacher SC, Serbecic N, Scheuerle AF. Assessment of central corneal thickness using OCT, ultrasound, optical low coherence reflectometry and Scheimpflug pachymetry. Eur J Ophthalmol 2011;21:132-7.
23. Cheng AC, Rao SK, Lau S, Leung CK, Lam DS. Central corneal thickness measurements by ultrasound, Orbscan II, and Visante OCT after LASIK for myopia. J Refract Surg 2008;24:361-5.
24. Li H, Leung CK, Wong L, Cheung CY, Pang CP, Weinreb RN, *et al.* Comparative study of central corneal thickness measurement with slit-lamp optical coherence tomography and visante optical coherence tomography. Ophthalmology 2008;115:796-801.e2.
25. Zhao PS, Wong TY, Wong WL, Saw SM, Aung T. Comparison of central corneal thickness measurements by visante anterior segment optical coherence tomography with ultrasound pachymetry. Am J Ophthalmol 2007;143:1047-9.
26. Grewal DS, Brar GS, Grewal SP. Assessment of central corneal thickness in normal, keratoconus, and post-laser *in situ* keratomileusis eyes using Scheimpflug imaging, spectral domain optical coherence tomography, and ultrasound pachymetry. J Cataract Refract Surg 2010;36:954-64.
27. Prospero Ponce CM, Rocha KM, Smith SD, Krueger RR. Central and peripheral corneal thickness measured with optical coherence tomography, Scheimpflug imaging, and ultrasound pachymetry in normal, keratoconus-suspect, and post-laser *in situ* keratomileusis eyes. J Cataract Refract Surg 2009;35:1055-62.
28. Uçakhan OO, Ozkan M, Kanpolat A. Corneal thickness measurements in normal and keratoconic eyes: Pentacam comprehensive eye scanner versus noncontact specular microscopy and ultrasound pachymetry. J Cataract Refract Surg 2006;32:970-7.
29. Özyol P, Özyol E. Agreement between swept-source optical biometry and scheimpflug-based topography measurements of anterior segment parameters. Am J Ophthalmol 2016;169:73-8.
30. Yap TE, Archer TJ, Gobbe M, Reinstein DZ. Comparison of central corneal thickness between fourier-domain OCT, very high-frequency digital ultrasound, and scheimpflug imaging systems. J Refract Surg 2016;32:110-6.
31. Szalai E, Berta A, Hassan Z, Módis L Jr. Reliability and repeatability of swept-source Fourier-domain optical coherence tomography and Scheimpflug imaging in keratoconus. J Cataract Refract Surg 2012;38:485-94.