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ORIGINAL RESEARCH

Scheimpflug vs Scanning-Slit Corneal Tomography: Comparison of Corneal and Anterior Chamber Tomography Indices for Repeatability and Agreement in Healthy Eyes

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Video abstract

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Purpose: To evaluate and compare the repeatability and agreement of Scheimpflug vs scanning-slit tomography of the cornea and the anterior chamber in terms of keratometric and tomographic indices in healthy eyes.

Methods: The 20 eyes of 10 healthy participants underwent 3 consecutive measurements using both Scheimpflug-tomography and scanning-slit tomography, diagnostic devices. Multiple corneal and anterior chamber tomographic parameters were recorded and evaluated to include corneal keratometry and its axis; corneal best-fit sphere (BFS), pachymetry mapping, angle kappa, anterior chamber depth (ACD), pupil diameter, and location. Repeatability for each device was assessed using the within each subject standard deviation of sequential exams, the coefficient variation (CV) and the intraclass correlation coefficient (ICC). Agreement between the two devices was assessed using Bland–Altman plots with 95% limits of agreement (LoA) and correlation coefficient (r).

Results: Both devices were found to have high repeatability (ICC>0.9) both in keratometric and other tomographic measurements. Scheimpflug tomography's repeatability though appeared superior in the average keratometry values, anterior and posterior BFS, thinnest corneal pachymetry value and location ($p<0.05$). Agreement: Statistically significant inter-device differences were noted in the mean values of K1, K2, BFS, ACD and thinnest corneal pachymetry ($p<0.05$). Despite the agreement differences noted, the two devices were well correlated ($r>0.8$) in respective measurements with Scheimpflug delivering consistently lower values than the scanning-slit tomography device.

Conclusion: Scheimpflug-tomography repeatability was found to be superior to that of scanning-slit tomography in this specific study, in most parameters evaluated. Inter-device agreement evaluation suggests that reading from the two devices may not be used interchangeably in absolute values, yet they are well correlated with Scheimpflug delivering consistently lower values in most.

Keywords: Pentacam, Orbscan, Scheimpflug corneal tomography, scanning-slit corneal tomography

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Introduction

As new devices for measuring anterior segment parameters become available in the clinical practice, the need to compare measurements obtained using various different technologies for healthy and pathologic eyes emerges. By comparing intra-device agreement, it can be determined whether different

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devices can be used interchangeably or whether their readings are consistently correlated. The inter-device repeatability must also be assessed to determine how much of a deviation from normal, or average, represents true pathology and the magnitude of change required to be considered progression of disease rather than variability due to test re-test variance.

Corneal tomography has been evolving in the recent years with Scheimpflug-based tomography being the possible successor to scanning-slit tomography. Comparison in a healthy group of subjects should aim to evaluate their relative intra-device repeatability as well as their inter-device agreement. Having established comparisons in healthy corneas first, results could then function as a benchmark for studying pathologic corneas.

The clinical implications of the accuracy of these values is paramount, first considering that they are used clinically to define healthy from diseased, a task that we have previously reported on extensively.[1–15] Furthermore, refractive surgery both corneal and lens-based, and especially therapeutic-based refractive laser interventions, have long involved corneal, anterior chamber and pupillary imaging by evolving tomographic devices, as a means of customization of surgical accuracy and its effective assessment. We have also reported extensively on corneal imaging and specifically tomographic imaging used in naïve and/or irregular corneas as a customized-therapeutic surgical intervention.[16–37]

To date, comparisons between Scheimpflug and scanning-slit tomography devices in healthy corneas mainly focused on pachymetric measurements, showing variable results in terms of device agreement: some with good agreement, some with moderate agreement and others with poor agreement having been reported.[38–42]

Fewer studies have compared Scheimpflug and scanning-slit devices in keratometric measurements on healthy corneas, though all have found poor agreement.[40,43-45]

We herein present a prospective study of 20 eyes of 10 healthy subjects, comparing the intra-device repeatability and assessing the inter-device agreement of Scheimpflug vs Scanning-Slit tomography in terms of keratometric and topometric readings for the cornea and the anterior chamber.

Methods

This prospective comparative study was approved by the Ethics Committee of our Institution (Laservision Clinical and Research Eye Institute) and adhered to the tenets of the Declaration of Helsinki. This study was conducted in the clinical practice of Laservision, Clinical and Research Eye Institute. Inclusion criteria were healthy eyes with no other ocular pathology other than refractive error. Written informed consent was provided by all participants of the present study.

A Scheimpflug-tomography imaging device (model: Pentacam HRsystem, Oculus, Wetzlar, Germany) and a scanning-slit imaging device (model: Orbscan II, Bausch & Lomb, Rochester, NY) were employed. For each eye, three consecutive measurements were taken with each device. Subjects were instructed to blink immediately prior to each measurement. No eyedrops were applied prior to testing.

Scheimpflug-Tomography Imaging

More recently available corneal tomographers rely on the Scheimpflug-principle whereby imaging with a wide depth of focus allows a planar object that is not parallel to the image plane to be in focus. The specific Scheimplug-tomography device used in our study was the Pentacam HRsystem (Oculus, Wetzlar, Germany), that uses a single, rotating Scheimpflug camera, and monochromatic slit-light source, in combination with a static camera, in order to obtain 500 measurement points, from a total of 50 single slit-images, corresponding to specific angles along the optical axis, totaling 25,000 measurement points, and thus to generate a 3-dimensional image of the cornea. A quality score is provided for each scan, with an "OK" given for acceptable scans.[46]

Scanning-Slit Imaging

The Orbscan II device (Bausch & Lomb, Rochester, NY) was the scanning-slit tomography device used in our study, and uses both scanning-slit and Placido-disc technology to combine keratometry measurements with assessment of the anterior and posterior corneal surfaces which allows a three-dimensional reconstruction of the cornea.[47] The device projects 40 slits, 20 from each side, onto the cornea and records the backscattered light. The Orbscan II software does not provide a quality score; instead, it automatically assesses and discards measurements deemed to be of unacceptable quality.

Corneal and Anterior Segment Parameters Studied

Parameters studied with both devices included corneal keratometry: flat keratometry (K1), steep keratometry (K2), and maximum keratometry (Kmax), as well as the relevant astigmatic power for the central 5mm of the corneas studied, and its relevant axis; anterior and posterior corneal best-fit sphere (BFS), thinnest corneal point and its topographic location in regard to the corneal vertex, as well as the corneal vertex topographic location in regard to the center of the pupillary aperture and thus the hypothetical eye-geometric center, illustrated in the imaging background (x, y coordinates of angle kappa). Additionally, other anterior chamber tomographic values such as anterior chamber depth (ACD), pupil diameter, as well as its topographic relation of the pupillary center in regard to the superimposed cornea vertex and hypothetical line-of-sight.

Statistical Analysis

Repeatability, defined as test–retest variability, was evaluated using the within-subject standard deviation (SD), within-subject coefficient variation (CV) and the intraclass correlation coefficient (ICC). The within-subject CV was calculated as the SD divided by the overall mean and expressed as a percentage. ICC is defined is the ratio of the between-subject variance to the sum of the within and between-subject variance, ranging from 0 to 1, with 1 indicating perfect repeatability. Paired *t*-test was used to compare the repeatability of the scanning-slit device to that of the Scheimpflug-based device. Statistical p values <0.05 were considered significant.

Agreement between devices (inter-device agreement) was assessed using Bland–Altman plots,[11,12] the correlation coefficient (r) and a two tail *t*-test. Bland–Altman plots were generated by plotting the difference of the measurements from each device against their mean. Limits of agreement (LoA) were set at 95% (mean difference ± 1.96SD), defining the range within which most differences between measurements from the two devices will lay.

Results

Twenty eyes of 10 healthy subjects were included in this prospective comparative study. The mean age was 40.9 ± 22.7 years (8 females, 2 males). No eyes were excluded based on the quality of the scans. Figure 1 illustrates the images evaluated with both technologies in a random eye of the patients studied: all 3 scanning-slit tomography individual scans as well as all 3 respective Scheimpflug scans for that specific eye are included.

Repeatability

In terms of keratometric measurements, both devices were found to have high repeatability (ICC>0.9) in all keratometric readings except for the x and y axis of the kappa intercept (ICC<0.9). Scheimpflug tomography was found to be superior in repeatability to scanning-slit tomography in mean K2 (P=0.034) and mean K1 (P=0.027) while the two devices' repeatability showed no statistically significant difference in maximum kappa angle, x and y axis of the kappa intercept and the mean corneal power at the 5.0 mm zone.

The evaluation of the best-fit sphere, both devices showed high repeatability (ICC>0.9) with a superiority for Scheimpflug in both anterior (P=0.021) and posterior (P=0.039) BFS. Both devices were also found to have high repeatability in ACD, astigmatic power at the 5.0mm zone, steep axis and pupil diameter (ICC>0.9) with no statistically significant difference between them (P>0.05). Of note, steep axis had a remarkably lower ICC in both devices Scheimpflug being superior to slit scan (ICC: 0.7 vs 0.55).

Similarly, in terms of pachymetric measurements, both devices were found to have high repeatability measuring the thinnest cornea thickness (ICC>0.9) with Scheimpflug appearing superior to the scanning slit (P=0.038). When comparing thinnest location, Scheimflung's repeatability was statistically significantly higher both in the x axis (P=0.043) and y axis (P= 0.031) with ICC of 0.92 for the x axis and 0.87 for the y axis vs 0.43 and 0.65 for the scanning slit, respectively. These data are summarized in Table 1.

Agreement

Agreement was assessed using Bland–Altman plots for keratometric indices (Figure 2), pachymetric indices (Figure 3) and the rest of the parameters studied (Figure 4).

All keratometric measurements were found to be well correlated between the two devices (r >0.8) with the exception of the kappa intercept x (r=0.26) and y axis (r=0.17). Steep and flat keratometry yielded a statistically significant difference between the two devices (P=0.022 and P=0.04, respectively), with Scheimpflug readings being consistently lower than those derived from the scanning-slit device.

The anterior BFS was found to be different among devices (P=0.032) while it showed high correlation (r=0.96). Posterior BFS had no significant difference (P>0.05) and r=0.93.

Different values were procured between the devices for anterior chamber depth (ACD), astigmatic power and pupil diameter (P<0.001). ACD had the highest r among these parameters (r=0.99) while the rest proved lower than 0.9. Specifically, r=0.21 for astigmatic power, r=0.83 for pupil diameter and r =0.51 for steep axis.

Thinnest corneal thickness was found to be different between the two devices (p<0.001) with an r=0.99. The x axis value was also found to be statistically significant different between the devices (P=0.003) and r=0.66. The y axis value was not different and had an r=0.23. All keratometric and pachymetric readings evaluated are

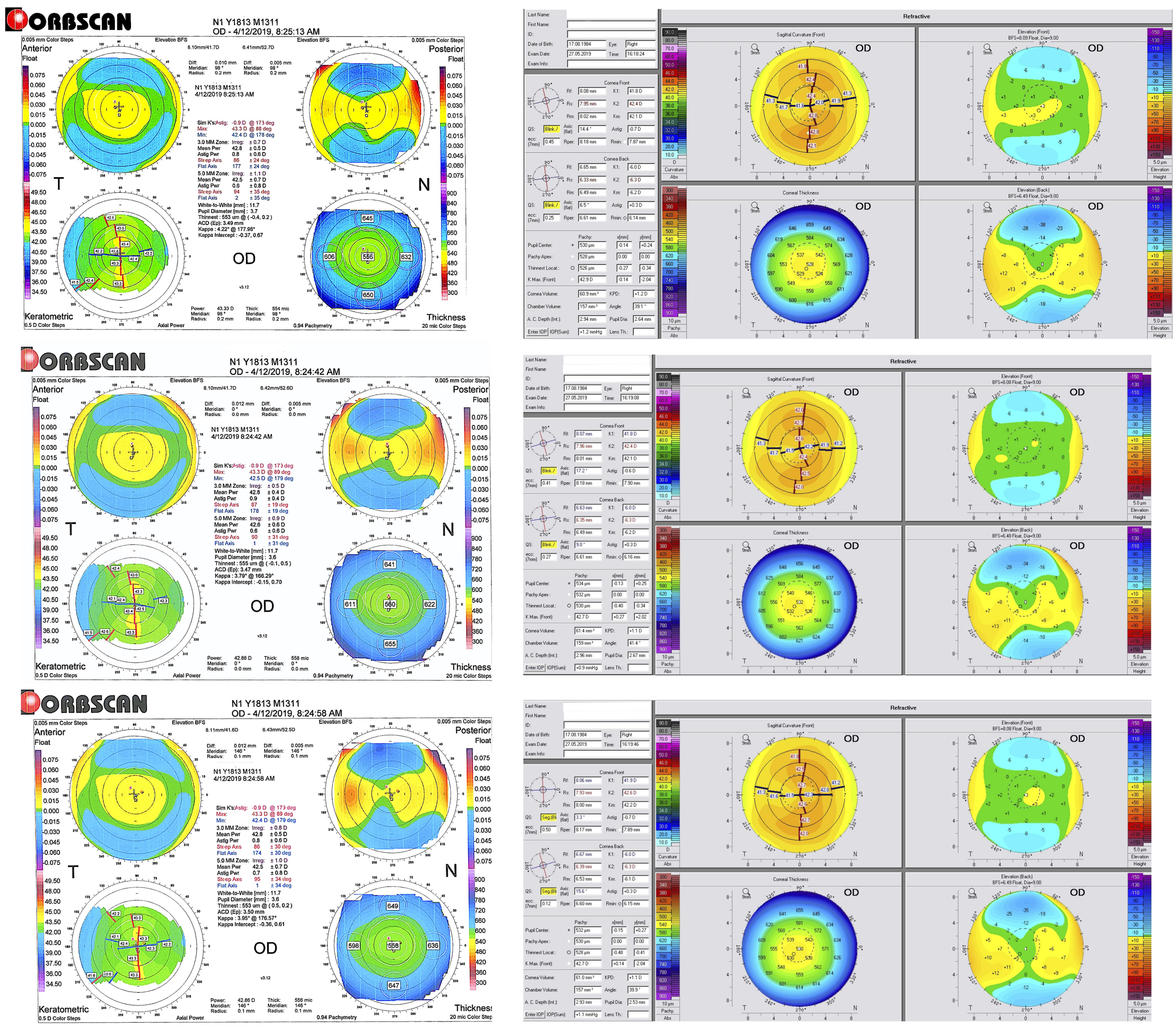

Figure 1 This image illustrates the scans evaluated with both technologies in a random eye of one the patients studied: all 3 scanning-slit tomography individual scans (on the left) as well as all 3 respective Scheimpflug scans (on the right) for that specific eye are included.

Table 1 Summary of the Comparative Statistical Analysis of the Parameters Studied

	SD Pentacam	SD Orbscan	CV (%) Pentacam	CV (%) Orbscan	ICC Pentacam	ICC Orbscan	P
K2 steep keratometry	0.11	0.17	0.25	0.39	0.99	0.98	0.034
K1 flat keratometry	0.10	0.16	0.23	0.37	0.99	0.98	0.027
Kmax Steepest	0.13	0.23	0.30	0.54	0.98	0.96	>0.05
X angle kappa	0.23	0.13	193.78	31.91	0.52	0.72	>0.05
Y Angle kappa	1.29	0.12	170.24	209.14	0.40	0.85	>0.05
K mean power	0.10	0.14	0.23	0.34	0.98	0.98	>0.05
BFS front	0.01	0.02	0.08	0.25	0.99	0.98	0.021
BFS posterior	0.02	0.03	0.30	0.45	0.99	0.98	0.039
ACD	0.01	0.01	0.43	0.29	0.99	0.99	>0.05
Astig power	0.08	0.12	14.33	16.85	0.98	0.93	>0.05
Steep Axis	6.89	6.11	9.47	6.86	0.7	0.55	>0.05
Pupil Diameter	0.09	0.10	0.57	0.97	0.8	0.98	>0.05
Thinnest pachymetry	3.19	5.73	0.57	0.97	0.99	0.99	0.038
Thinnest x from vertex	0.07	0.23	17.31	91.08	0.92	0.43	0.043
Thinnest y from vertex	0.07	0.23	47.59	159.59	0.87	0.65	0.031

shown in Tables 1 and 2 respectively along with their repeatability and agreement indices for each device.

Discussion

This comprehensive prospective comparative analysis of multiple keratometric and tomography measurements employing various statistical analysis indices such as within subject standard deviation (SD), within subject coefficient variation (CV) and intraclass correlation coefficient (ICC) for repeatability and Bland–Altman plots, correlation coefficient (r) and a two-tail *t*-test for agreement.

Our results suggest high repeatability of both Scheimpflug and Scanning-slit devices as previously reported in the literature.[50] In the current study, Scheimpflug tomography's repeatability was found to be superior in mean K1, and K2 keratometry, anterior and posterior best-fit sphere, and thinnest corneal thickness and location. ($p<0.05$). The higher test–retest variability of the scanning-slit measurements suggests that a significantly higher threshold for change, may be required to be considered genuine progression compared to the Scheimpflug device studied (Pentacam HR).[51]

Inter-device poor agreement in our study suggests the two devices may not be used interchangeably in absolute values measured; yet they were found to be well correlated with Scheimpflug delivering consistently lower values in K1, K2 keratometry, best-fit sphere, anterior chamber depth, and thinnest corneal thickness. These findings are in accordance with previous reports suggesting poor agreement between the devices in keratometric indices.[52] Our results on pachymetric measurements are in agreement with those reported by Sedaghat et al,[53] while other studies have reported thinner pachymetric readings with the

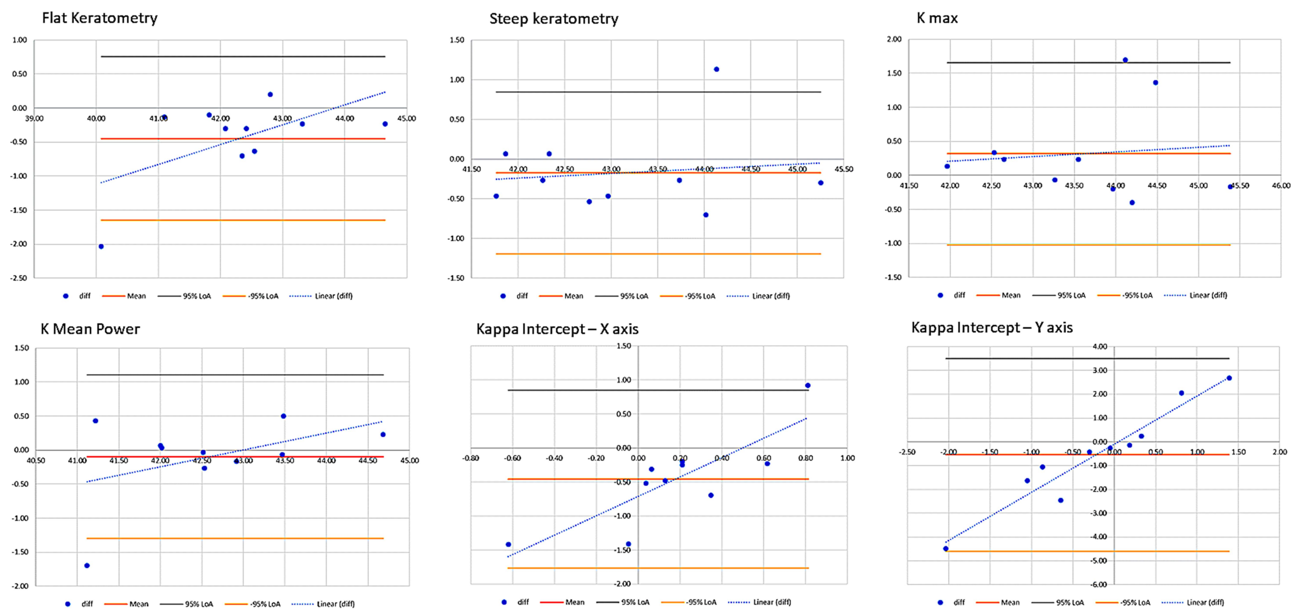

Figure 2 This image illustrates the Bland–Altman plots for the keratometric indices analyzed statistically.

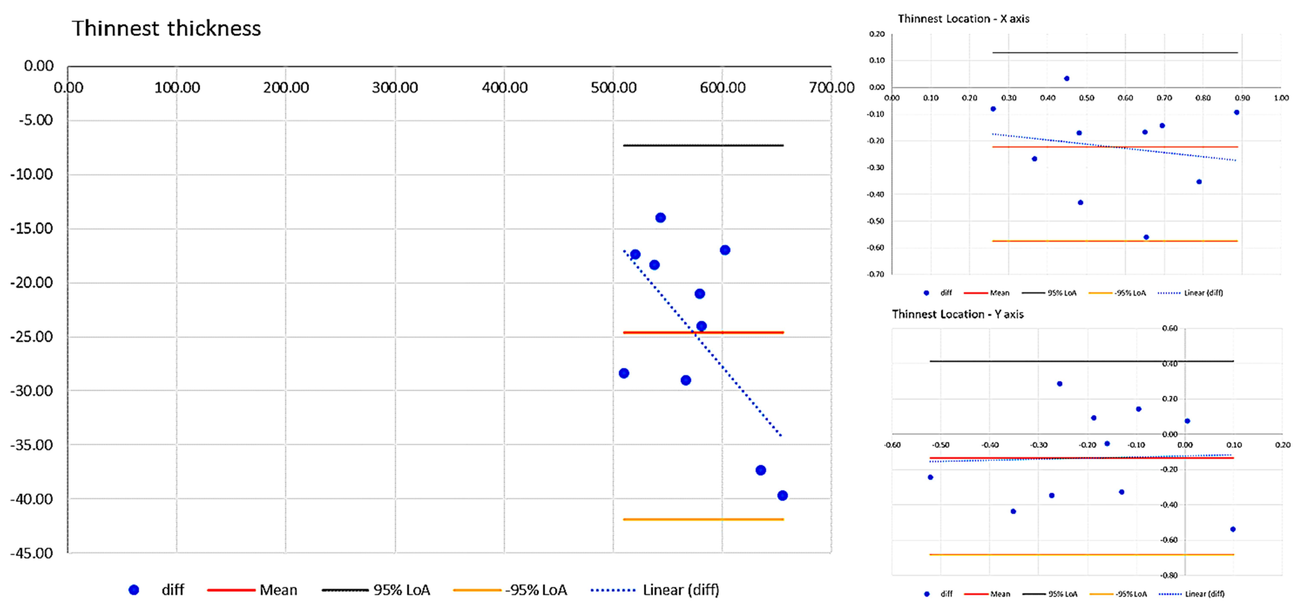

Figure 3 This image illustrates the Bland–Altman plots for the pachymetric indices analyzed statistically.

Orbscan II[39,54,55] or no statistically significant differences.[56,57]

These findings have clinically relevant implications, and may function as a benchmark, when using these different corneal tomography devices for the diagnosis, monitoring, and treatment of corneal diseases, especially ectasia and keratoconus. Corneal tomography has also become the gold standard in peri-operative evaluation of laser refractive surgery patients and lens-based refractive surgery patients.

In all the aforementioned clinical practices, the magnitude of change required to be considered true

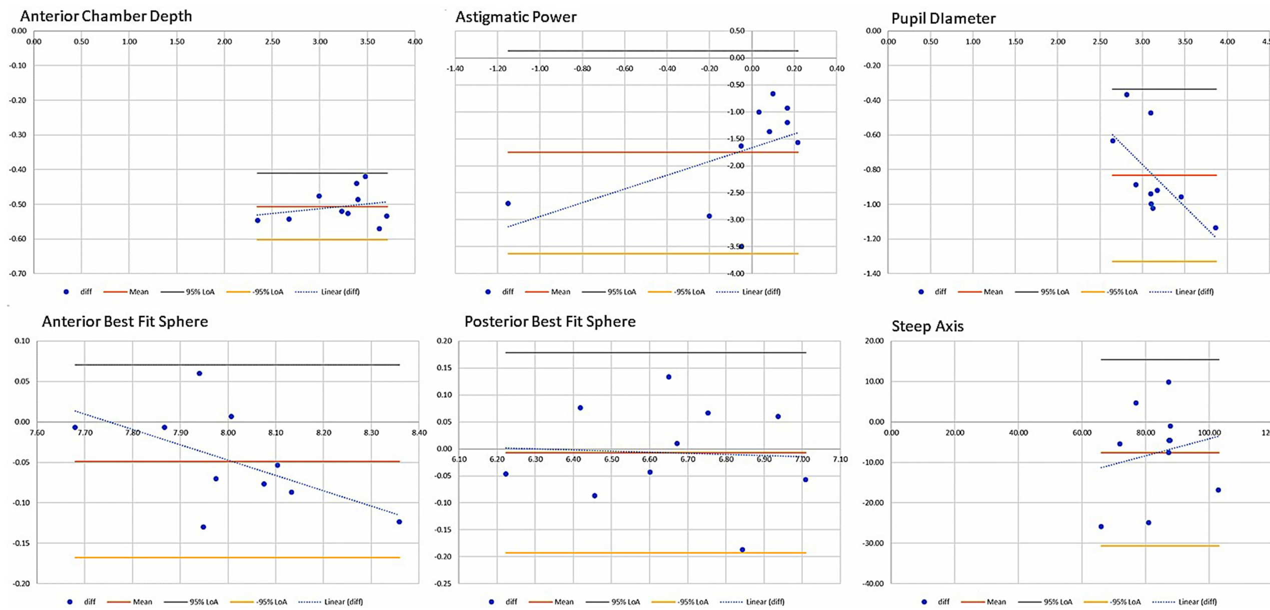

Figure 4 This image illustrates the Bland–Altman plots for the other indices studied, analyzed statistically.

clinical progression rather than either variability due to test re-test variance or poor inter-device agreement should be cautiously established.

Further comparative studies with large samples both of healthy and pathologic corneas should aim to establish a gold standard in corneal tomography which would then

Table 2 Statistical Analysis Correlation, Comparing the Parameters Studied Between the 2 Devices with the Correlation Coefficient r, and the 2-Tailed *t*-Test for the Parameters Studied

	r	P
K2 steep keratometry	0.94	0.022
K1 flat keratometry	0.92	0.04
Kmax (steepest)	0.8	>0.05
X angle kappa	0.26	>0.05
Y angle kappa	0.17	>0.05
Kmean power BFS front	0.88 0.96	>0.05 0.032
BFS posterior	0.93	>0.05
ACD	0.99	<0.001
Astigmatic power	0.21	<0.001
Steep axis angle	0.31	>0.05
Pupil diameter	0.83	<0.001
Thinnest Pachymetry	0.99	<0.001
Thinnest x from vertex	0.66	0.003
Thinnest y from vertex	0.23	>0.05

function as a reference both for diagnostic and possibly interventional imaging.

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Disclosure

This work was presented in part as a poster presentation at the 2019 annual AAO meeting, San Francisco, CA, USA.

Dr Kanellopoulos reports being a Consultant for Alcon, Avedro, i-Optics, Keramed, Zeiss, and ISP Surgical; and reports no other potential conflicts of interest for this work.

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