Comparison of anterior segment measurements by 3 Scheimpflug tomographers and 1 Placido corneal topographer

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PURPOSE: To compare the anterior segment measurements provided by 3 Scheimpflug tomographers and a Placido corneal topographer.

SETTING: Private clinical ophthalmology practice.

DESIGN: Evaluation of diagnostic test or technology.

METHODS: In a sample of 25 consecutive patients having either refractive or cataract surgery, the anterior eye segment was analyzed by means of a rotating Scheimpflug camera (Pentacam), 2 devices with a Scheimpflug camera combined with a Placido disk (Sirius and TMS-5), and a Placido disk corneal topographer (Keratron). Measurement results were compared using analysis of variance. Agreement was assessed using Bland-Altman plots.

RESULTS: The mean simulated keratometry (K) was different between the 4 instruments ($P<.0001$), with Keratron providing the highest value (44.43 diopters [D] ± 1.28 [SD]). The Pentacam and Sirius provided the lowest values (44.05 ± 1.21 D and 44.05 ± 1.27 D, respectively), without statistical difference (posttest). The mean posterior corneal power and minimum corneal thickness were statistically different between the 3 Scheimpflug cameras ($P<.0001$ and $P=.0210$, respectively); 95% limits of agreement, however, were narrow for posterior corneal power and large for corneal thickness. The only 2 devices measuring the distance between the corneal endothelium and the anterior lens surface showed a statistically but not clinically significant difference (2.90 ± 0.48 mm and 2.94 ± 0.47 mm, respectively). There were no statistically significant differences in anterior corneal asphericity between the 4 instruments.

CONCLUSION: Although the measurements of some parameters by different instruments were similar, caution is warranted before using them interchangeably.

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The Scheimpflug principle allows documentation of an object that is not parallel to the lens and image planes of a camera, such as the anterior eye segment imaged by slitlamp photography, with the maximally possible depth of focus and minimal image distortion. In the human eye, Scheimpflug cameras provide focused images from the anterior corneal surface to the posterior lens surface.[1]

The Scheimpflug principle was introduced in ophthalmology in the 1960s,[2] and the first instruments (EAS 1000, Nidek Co. Ltd.; SL-45, Topcon Corp.) were made commercially available at the end of the 1980s.[3,4] However, the first Scheimpflug camera that gained wide clinical popularity was the Pentacam (Oculus Optikgeräte GmbH), which was introduced in 2002 and included software to analyze the captured cross-sectional images and transform them into a 3-dimensional model and related quantitative measurements (eg, anterior and posterior corneal curvature, central and peripheral corneal thickness, anterior chamber depth and volume) that could aid the anterior segment surgeon. Many studies have reported clinically acceptable repeatability of the automatic measurements obtained with this instrument for most parameters.[5–12] More recently, in 2007, another instrument was introduced—the Galilei

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dual-Scheimpflug analyzer (Ziemer Group); this device combines 2 Scheimpflug cameras and a Placido-disk topography system and has also been shown to provide repeatable measurements.[13,14] Finally, 2 instruments that have a single Scheimpflug camera and a Placido disk—the Sirius (Costruzione Strumenti Oftalmici) and TMS-5 (Tomey Corp.)—were developed. To our knowledge, there are no published studies of these devices.

The present study compared the automatic measurements provided by the Pentacam device; those provided by the 2 newest Scheimpflug cameras, the Sirius and TMS-5; and those provided by a validated Placido disk-based corneal topographer (Keratron, Optikon 2000 SpA).

PATIENTS AND METHODS

A sample of consecutive patients having preoperative analysis for refractive or cataract surgery was prospectively enrolled on condition that each eye was imaged by all 4 devices; that is, the Pentacam (rotating Scheimpflug device), Sirius (Scheimpflug–Placido device S), TMS-5 (Scheimpflug–Placido device T), and Keratron (Placido topographer). All measurements were taken by the same ophthalmologist between 10 AM and 4 PM to minimize diurnal change. The study was performed in accordance with the ethical standards stated in the 1964 Declaration of Helsinki and approved by the local clinical research ethics committee. All patients provided informed consent.

Of the parameters measured by the 4 instruments, this study compared the simulated keratometry (K) obtained by converting the measured radius into diopters (D) using the standard keratometric refractive index of 1.3375 and the corneal asphericity (measured as the Q value at 8.0 mm). The following were calculated for the Scheimpflug systems only: posterior corneal power (calculated with the refractive index of 1.376 for the cornea and of 1.336 for the aqueous), the anterior-to-posterior corneal curvature ratio (calculated as the mean of each eye's individual ratio), the thinnest corneal thickness, and the distance between the corneal endothelium and the anterior lens surface, which is defined as the "internal anterior chamber" in the rotating Scheimpflug device and as the "aqueous depth" in Scheimpflug–Placido device S.

For each instrument, measurements were performed according to the manufacturer's guidelines. Each device was brought into focus, and the patient's eye was aligned along the visual axis by a central fixation light. Patients were instructed to blink completely just before each measurement. The following paragraphs briefly report the technical features of all devices evaluated.

Pentacam

The Pentacam is a rotating Scheimpflug camera with a slit light that successively illuminates 25 meridional slits through the cornea while rotating for each slit by 1/25 of 360 degrees around the apex. The cells of the cornea disperse the light diffusely. Thus, the anterior and posterior surfaces of the cornea can be detected. This allows calculation of the corneal radii for each point on the topographic surface map. Via triangle calculation, topographic data are computed. Scans were repeated if the quality specification provided by the instrument was other than "OK." Software version 1.17 was used in this study. The following measurements were evaluated: mean simulated K (calculated from the anterior corneal radius measured at 3.0 mm), mean posterior corneal power, thinnest corneal thickness, and distance between the corneal endothelium and the lens.

Sirius

The Sirius combines a rotating Scheimpflug camera and a small-angle Placido-disk topographer with 22 rings. The scanning process acquires a series of 25 Scheimpflug images (meridians) and 1 Placido top-view image. The ring edges are detected on the Placido image so that height, slope, and curvature data are calculated using the arc-step method with conic curves. The profiles of anterior cornea, posterior cornea, anterior lens, and iris are derived from the Scheimpflug images. Data for the anterior surface from the Placido image and the Scheimpflug images are merged using a proprietary method. All the other measurements for internal structures (posterior cornea, anterior lens, and iris) are derived solely from Scheimpflug data. Analysis of present data was performed using software version 1.0 and included mean simulated K (calculated by averaging the axial curvature from the fourth to the eighth Placido ring), posterior corneal power, thinnest corneal thickness, and distance between the corneal endothelium and the lens.

TMS-5

The TMS-5 uses a combination of a rotating Scheimpflug camera and a wide-angle Placido ring topographer (with 31 rings). It first captures the ring topography and then the 32 slit-scan images. The 2 acquisition steps are separate, and the data are merged at the end of the examination.

Keratron

The Keratron is a wide-angle Placido-disk corneal topographer that uses an arc-step algorithm to reconstruct the corneal profile as a series of arcs that would reflect the rays from the mires to the keratoscope's lens.[15] The instrument illuminates the cornea via a wide-angle cone that projects 26 equally spaced rings to cover almost the entire cornea from a radius of 0.165 mm for the first ring to a radius of 4.29 mm for the last ring. Similar to all topographers, the Keratron derives curvature data from the measured distances between the rings projected onto the cornea; specifically, the simulated K is calculated as the mean between

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the power of the flattest meridian at the 3.0 mm diameter and the power of the meridian 90 degrees away from it, independently from its curvature; therefore, the latter is not the steepest meridian.

Statistical Analysis

For patients having bilateral surgery, only the right eye was considered for statistical purposes. The level of agreement between the 4 instruments was evaluated according to the method described by Bland and Altman,[16] who suggest plotting the differences between measurements (y-axis) against their mean (x-axis). Bland and Altman plots allow evaluation of systematic difference between measurements (ie, fixed bias). The mean difference is the estimated bias, and the standard deviation (SD) of the differences measures the random fluctuations around this mean. If the mean value of the difference differs significantly from 0, as determined on the basis of a 1-sample t test, it indicates a fixed bias. The 95% limits of agreement (LoA) were defined as the means ± 2 SD of the differences between the 2 measurement techniques. Further statistical analyses were performed using Graphpad Instat for Macintosh software (version 3a, Graphpad Software). Mean values were compared by repeated-measures analysis of variance with the Bonferroni posttest. In case of nonparametric data, the Friedman test was used and if only 2 measurements were compared, the paired t test was performed. A P value less than 0.05 was considered statistically significant.

RESULTS

Twenty-five eyes of 25 patients (mean age 57.9 years ± 21.2 [SD]) were enrolled. Table 1 shows the results of the comparative analysis.

The mean simulated K was significantly different between the 4 instruments ($P < .0001$). The Placido topographer produced the highest mean value and the rotating Scheimpflug device and Scheimpflug–Placido device S, the lowest. Post-test analysis showed no statistically significant differences between the rotating Scheimpflug device and Scheimpflug–Placido device S or between Scheimpflug–Placido device T and the Placido topographer. The 95% LoA between the rotating Scheimpflug device and Scheimpflug–Placido device S (from −0.59 to +0.59 D), between the rotating Scheimpflug device and Scheimpflug–Placido device T (from −0.74 to +0.28 D), and between Scheimpflug–Placido device T and the Placido topographer (from −0.30 to +0.75 D) were relatively small. Larger 95% LoA were calculated between the rotating Scheimpflug device and the Placido topographer (from −1.14 to +0.38 D), between Scheimpflug–Placido device S and the Placido topographer (from −1.06 to +0.31 D), between Scheimpflug–Placido device S and Scheimpflug–Placido device T (from −0.89 to +0.42 D). Figure 1 shows Bland-Altman plots with 95% LoA for simulated K measurements.

A statistically significant difference was detected in the mean posterior corneal power values ($P < .0001$), with steeper values for the rotating Scheimpflug device and flatter values for the 2 Scheimpflug–Placido devices; posttest analysis did not detect a statistical difference between the latter 2 devices. The clinical relevance of these findings, however, seems negligible because the 95% LoA were narrow in all cases: from −0.31 to +0.12 D between the rotating Scheimpflug device and Scheimpflug–Placido device S, from −0.26 to +0.10 D between the rotating Scheimpflug device and Scheimpflug–Placido device T, and from −0.15 to +0.19 D between Scheimpflug–Placido device S and Scheimpflug–Placido device T.

The differences in measured anterior and posterior corneal curvature between the 3 Scheimpflug cameras produced statistically significantly different mean ratios between the anterior radius and the posterior radius ($P < .0001$). The ratio was higher with rotating Scheimpflug device, whereas posttest analysis did not detect significant differences between Scheimpflug–Placido device S and Scheimpflug–Placido device T.

Mean pachymetric measurements relative to the thinnest point were statistically significantly different ($P = .0210$); posttest analysis shows that the only significant difference was detected between Scheimpflug–

Table 1. Mean values of the parameters measured by the 4 devices.

Parameter	Mean ± SD Pentacam	Sirius	TMS-5	Keratron	P Value
Sim K (D)	44.05 ± 1.21	44.05 ± 1.27	44.28 ± 1.25	44.43 ± 1.28	<.0001
Posterior corneal power (D)	−6.32 ± 0.20	−6.22 ± 0.21	−6.24 ± 0.19	—	<.0001
Anterior to posterior corneal curvature ratio	1.22 ± 0.02	1.19 ± 0.02	1.19 ± 0.02	—	<.0001
Corneal pachymetry, thinnest point (μm)	547.84 ± 28.26	554.96 ± 35.06	530.60 ± 29.27	—	.0210
Distance between corneal endothelium and anterior lens surface (mm)	2.90 ± 0.48	2.94 ± 0.47	—	—	.0003
Anterior Q value (at 8.0 mm)	−0.24 ± 0.15	−0.22 ± 0.14	—	−0.20 ± 0.14	NS

NS = not significant; Q = corneal asphericity; Sim K = simulated keratometry

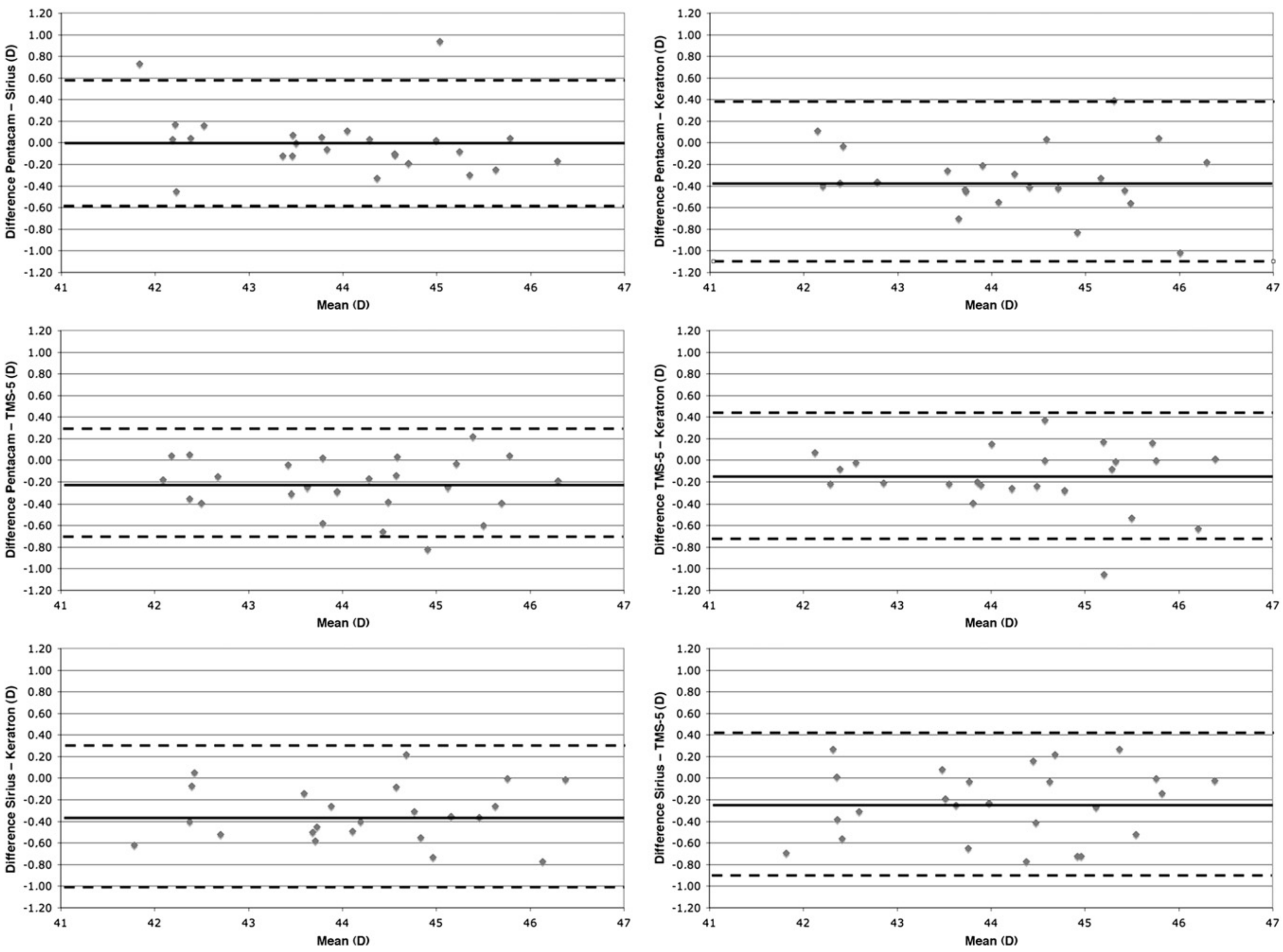

Figure 1. Bland-Altman plots for simulated K measurements by the 4 devices. The difference is plotted versus the mean. The dotted lines show the 95% LoA. The bold horizontal line shows the mean value of the differences.

Placido device S, which gave the thickest mean value, and Scheimpflug–Placido device T, which gave the thinnest mean value. The 95% LoA were large between Scheimpflug–Placido device S and Scheimpflug–Placido device T (from −20.30 to +69.02 μm) and between Scheimpflug–Placido device S and the rotating Scheimpflug device (from −34.63 to +48.87 μm) and narrower between Scheimpflug–Placido device T and the rotating Scheimpflug device (from −41.19 to +6.71 μm).

There was also a statistically significant difference in the mean distance between the corneal endothelium and the anterior lens surface measured by the rotating Scheimpflug device and Scheimpflug–Placido device S ($P = .0003$). The Scheimpflug–Placido device T does not provide an automatic measurement of this distance. Nevertheless, such a small difference is not clinically meaningful and, given that the 95% LoA were small (from −0.10 to +0.04 mm), the results of the rotating Scheimpflug device and Scheimpflug–Placido device S can be considered clinically equivalent.

No statistically significant between-device differences were observed in the anterior corneal asphericity at 8.0 mm.

DISCUSSION

This study found that different instruments, sharing in some cases the same technology and devoted to measuring the same parameters, produced different results. Therefore, many of their measurements cannot be considered interchangeable. The greatest differences and poorest agreement were found for simulated K and corneal pachymetry. Other parameters, such as posterior corneal power and the distance between the corneal endothelium and the anterior lens surface, showed statistically significant differences that may not be clinically significant. The only parameter that did not show a statistically significant difference was the asphericity of the anterior corneal curvature.

The mean simulated K calculated by the conventional corneal topographer (Keratron) was higher than the corresponding value produced by the 3 Scheimpflug-based systems, including those combined with Placido-disk technology. The difference was more evident between the Keratron topographer on 1 side and the Pentacam device and Sirius device on the other side. The latter devices also showed the poorest agreement with corneal topography; the Bland-Altman plots showed that a difference of up to about 1.50 D could be expected in 95% of eyes. The smallest difference between the 4 instruments was observed between the Sirius and Pentacam devices, which measured the same mean value and showed narrow 95% LoA (from −0.59 to +0.59 D). The mean simulated K value measured by the TMS-5 device was the average of the 4 instruments.

The difference between Keratron and Pentacam devices was similar to that reported by Kawamorita et al.,[7] who also found higher mean values for the corneal topographer. Conversely, the results in the present study do not fully agree with those previously reported by our own group because we did not find a statistically significant difference between the mean simulated K of the 2 devices, although in both studies we calculated a large 95% LoA.[17] The reason for such a discrepancy is not clear. It may be because the 2 analyses were performed on 2 different samples, which might have had a different prevalence of dry eye, which is known to influence the corneal reflection of Placido rings and might have influenced our results.[18,19] Further studies should be performed to explore the performance of Scheimpflug and Placido technologies in eyes with tear deficiency. Other possible explanations that cannot be excluded may be related to differences in alignment effect (if the populations had different mean cylinder) and in device calibration.

Taken together, these results lead us to suggest the following: (1) Simulated K measurements by the standard Placido corneal topography and Scheimpflug imaging devices examined are not interchangeable. (2) Simulated K measurements by the Pentacam and Sirius devices may be considered interchangeable, although agreement may be population specific and should be confirmed by studies with larger samples. (3) Given that simulated K is usually adopted for intraocular lens power calculation, the differences between the various devices make constant optimization necessary when interchanging instruments to measure corneal power.

Posterior corneal power measurements were statistically different between the 3 Scheimpflug cameras. The Pentacam device produced steeper values than the Sirius and TMS-5 devices. However, the difference was low (≤0.1 D) and, given the narrow 95% LoA, not clinically significant. The mean power of the posterior corneal surface measured by the Pentacam device in this study (−6.32 ± 0.20 D) is equal to that measured by a dual Scheimpflug analyzer in a previous study of healthy eyes (−6.32 ± 0.24 D)[14] and to that measured with the Pentacam device by Ho et al.[20] (−6.32 ± 0.28 D); very close measurements with the Pentacam device were also reported by Hashemi et al.[21] (−6.22 ± 0.30 D) and Jin et al.[22] (6.22 ± 0.24 D).

The ratio of the anterior-to-posterior radius measured by the 3 Scheimpflug cameras was slightly (but significantly) different. The ratio obtained with the Pentacam device (1.22 ± 0.02) is the same as that previously reported for the same device.[14,17] The ratio obtained with Sirius and TMS-5 devices (1.19 ± 0.02 for both) is lower and is related to the larger posterior radius measured in the present study with both instruments. However, the values obtained with the newest Scheimpflug cameras are close to those reported by other authors who used different technologies.[23–25]

Corneal thickness measurements yielded statistically and clinically significant differences between the 3 Scheimpflug cameras. The greatest difference and poorest agreement was between the Sirius and the TMS-5 devices; the mean measurements with Sirius were 24 μm thicker than those with TMS-5. The agreement was also poor between the Sirius and the Pentacam instruments (95% LoA from −34.63 to +48.87 μm), although the difference between the mean values of the 2 devices was not statistically significant. Slightly better agreement was found between TMS-5 and Pentacam devices. Thus, we suggest caution before using their measurements interchangeably.

It is not possible to state which is the most accurate Scheimpflug camera for corneal pachymetry. Ultrasound (US) pachymetry has always been considered the gold standard for corneal thickness assessment, and previous studies of healthy eyes have shown good agreement between US pachymetry and the Pentacam measurement, with slightly thinner values provided by the latter in most cases.[26–28] In these eyes, therefore, the difference between US measurements and Pentacam measurements would seem to have little clinical relevance and, accordingly, it has been suggested that the 2 technologies can be used interchangeably in such cases.[29] Unfortunately, comparative data between US pachymetry and that measured with the Sirius and TMS-5 devices are lacking. However, because the Pentacam device is reported to underestimate corneal thickness slightly with respect to US pachymetry and the Sirius device provided slightly higher measurements than the Pentacam device, it may be postulated that Sirius and US pachymetry measurements have good agreement, which can be confirmed in further studies.

Measurements of the distance between the corneal endothelium and the anterior surface of the lens by the Pentacam and Sirius devices showed little difference and good agreement. Thus, based on this study, the measurements can be considered interchangeable.

The last parameter evaluated in this study was the asphericity of the anterior corneal surface. This was measured by all instruments except the TMS-5. The mean Q values at 8.0 mm were not statistically different and ranged from −0.20 to −0.24. These values are close to the mean Q-value (−0.26) calculated by Budak et al.[30] in an analysis of several previous studies.

This study has limitations. First, a larger sample size might have led to slightly different results; we could not enroll more eyes because we had use of the TMS-5 for a limited period of time. Second, the Sirius device (whose measurements have shown excellent repeatability in a paper that has just been accepted for publication[31]) and the TMS-5 device have not yet been fully validated. Third, we did not include in our analysis all the parameters provided by these instruments, such as the true net power, the equivalent K reading and the total refractive power (Pentacam), the mean pupil power (Sirius), and the real power (TMS-5). Each of these calculated values deserves a specific study. Fourth, these results can be applied only to unoperated normal eyes because we did not include eyes with previous refractive surgery or keratoconic eyes.

In conclusion, we found that the 3 Scheimpflug tomographers and the corneal topographer provided measurements that in many cases cannot be considered interchangeable. The main exceptions (ie, data that can be considered interchangeable) seem to be the simulated K of the Sirius and Pentacam devices; the posterior corneal power of the Pentacam, Sirius, and TMS-5 device; the distance between the corneal endothelium and the lens of the Sirius and Pentacam devices; and the Q values of Sirius, Pentacam, and Keratron devices.

REFERENCES

1. Wegener A, Laser-Junga H. Photography of the anterior eye segment according to Scheimpflug's principle: options and limitations – a review. Clin Exp Ophthalmol 2009; 37:144–154. Available at: http://onlinelibrary.wiley.com/doi/10.1111/j.1442-9071.2009.02018.x/pdf. Accessed March 31, 2011
2. Drews RC. Depth of field in slit lamp photography; an optical solution using the Scheimpflug principle. Ophthalmologica 1964; 148:143–150
3. Hockwin O, Dragomirescu V, Laser H, Wegener A, Eckerskorn U. Measuring lens transparency by Scheimpflug photography of the anterior eye segment: principle, instrumentation, and application to clinical and experimental ophthalmology. J Toxicol Cutan Ocular Toxicol 1987; 6:251–271
4. Wegener A, Hockwin O, Laser H, Strack C. Comparison of the Nidek EAS 1000 system and the Topcon SL-45 in clinical application. Ophthalmic Res 1992; 24(suppl 1):55–62
5. Shankar H, Taranath D, Santhirathelagan CT, Pesudovs K. Anterior segment biometry with the Pentacam: comprehensive assessment of repeatability of automated measurements. J Cataract Refract Surg 2008; 34:103–113
6. Chen D, Lam AKC. Intrasession and intersession repeatability of the Pentacam system on posterior corneal assessment in the normal human eye. J Cataract Refract Surg 2007; 33:448–454
7. Kawamorita T, Nakayama N, Uozato H. Repeatability and reproducibility of corneal curvature measurements using the Pentacam and Keratron topography systems. J Refract Surg 2009; 25:539–544
8. 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; 144:712–718
9. Jain R, Dilraj G, Grewal SPS. Repeatability of corneal parameters with Pentacam after laser in situ keratomileusis. Indian J Ophthalmol 2010; 55:341–347. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2636025/?tool=pubmed. Accessed March 31, 2011
10. Nam SM, Im CY, Lee HK, Kim EK, Kim T-I, Seo KY. Accuracy of RTVue optical coherence tomography, Pentacam, and ultrasound pachymetry for the measurement of central corneal thickness. Ophthalmology 2010; 117:2096–2103
11. Labiris G, Gkika M, Katsanos A, Fanariotis M, Alvanos E, Kozobolis V. Anterior chamber volume measurements with Visante optical coherence tomography and Pentacam: repeatability and level of agreement. Clin Exp Ophthalmol 2009; 37:772–774
12. Piñero DP, Saenz Gonzáles C, Alió JL. Intraobserver and interobserver repeatability of curvature and aberrometric measurements of the posterior corneal surface in normal eyes using Scheimpflug photography. J Cataract Refract Surg 2009; 35:113–120
13. Wang L, Shirayama M, Koch DD. Repeatability of corneal power and wavefront aberration measurements with a dual-Scheimpflug Placido corneal topographer. J Cataract Refract Surg 2010; 36:425–430
14. Savini G, Carbonelli M, Barboni P, Hoffer KJ. Repeatability of automatic measurements performed by a dual Scheimpflug analyzer in unoperated and post-refractive surgery eyes. J Cataract Refract Surg 2011; 37:302–309
15. Tripoli NK, Cohen KL, Holmgren DE, Coggins JM. Assessment of radial aspheres by the Arc-Step algorithm as implemented by the Keratron keratoscope. Am J Ophthalmol 1995; 120:658–664
16. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; Feb 8; 1:307–310. Available at: http://www-users.york.ac.uk/~mb55/meas/ba.pdf. Accessed March 31, 2011
17. Savini G, Barboni P, Carbonelli M, Hoffer KJ. Agreement between Pentacam and videokeratography in corneal power assessment. J Refract Surg 2009; 25:534–538
18. de Paiva CS, Lindsey JL, Pflugfelder SC. Assessing the severity of keratitis sicca with videokeratoscopic indices. Ophthalmology 2003; 110:1102–1109
19. Kojima T, Ishida R, Dogru M, Goto E, Takano Y, Matsumoto Y, Kaido M, Ohashi Y, Tsubota K. A new noninvasive tear stability analysis system for the assessment of dry eyes. Invest Ophthalmol Vis Sci 2004; 45:1369–1374. Available at: http://www.iovs.org/cgi/reprint/45/5/1369.pdf. Accessed March 31, 2011
20. Ho J-D, Tsai C-Y, Tsai RJ-F, Kuo L-L, Tsai I-L, Liou S-W. Validity of the keratometric index: evaluation by the Pentacam rotating Scheimpflug camera. J Cataract Refract Surg 2009; 34:137–145

21. Hashemi H, Mehravaran S. Corneal changes after laser refractive surgery for myopia: comparison of Orbscan II and Pentacam findings. J Cataract Refract Surg 2007; 33:841–847
22. Jin H, Holzer MP, Rabsilber T, Borkenstein AF, Limberger I-J, Guo H, Auffarth GU. Intraocular lens power calculation after laser refractive surgery; corrective algorithm for corneal power estimation. J Cataract Refract Surg 2010; 36:87–96
23. Fam H-B, Lim K-L. Validity of the keratometric index: large population-based study. J Cataract Refract Surg 2007; 33:686–691
24. Dubbelman M, Sicam VADP, van der Heijde GL. The shape of the anterior and posterior surface of the aging human cornea. Vision Res 2006; 46:993–1001
25. Tang M, Li Y, Avila M, Huang D. Measuring total corneal power before and after laser in situ keratomileusis with high-speed optical coherence tomography. J Cataract Refract Surg 2006; 32:1843–1850
26. O'Donnell C, Maldonado-Codina C. Agreement and repeatability of central thickness measurement in normal corneas using ultrasound pachymetry and the OCULUS. Pentacam. Cornea 2005; 24:920–924
27. Lackner B, Schmidinger G, Pieh S, Funovics MA, Skorpik C. Repeatability and reproducibility of central corneal thickness measurement with Pentacam, Orbscan, and ultrasound. Optom Vis Sci 2005; 82:892–899. Available at: http://www.oculus.de/chi/downloads/dyn/sonstige/sonstige/lackner_pachymetry.pdf. Accessed March 31, 2011
28. Amano S, Honda N, Amano Y, Yamagami S, Miyai T, Samejima T, Ogata M, Miyata K. Comparison of central corneal thickness measurements by rotating Scheimpflug camera, ultrasonic pachymetry, and scanning-slit corneal topography. Ophthalmology 2006; 113:937–941
29. Uçakhan ÖÖ, Özkan 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; 32:970–977
30. Budak K, Khater TT, Friedman NJ, Holladay JT, Koch DD. Evaluation of relationships among refractive and topographic parameters. J Cataract Refract Surg 1999; 25:814–820
31. Savini G, Barboni P, Carbonelli M, Hoffer KJ. Repeatability of automatic measurements by a new Scheimpflug camera combined with Placido topography. In press, J Cataract Refract Surg 2011

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