Agreement Between Pentacam and Videokeratography in Corneal Power Assessment

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ABSTRACT

PURPOSE: To investigate agreement between a rotating Scheimpflug camera (Pentacam, Oculus Optikgeräte GmbH) and two corneal topographers (TMS-2 Topography System, Tomey; and Keratron Scout, Optikon 2000 SpA) in measuring the corneal power of normal eyes.

METHODS: The mean corneal powers calculated by simulated keratometry (SimK) with each topographer were compared to those provided by the Pentacam in 71 patients. Specifically, the corneal power values of the Pentacam included in this analysis were the SimK (calculated using the measured anterior corneal radius and standard keratometric index of 1.3375) and the True net power (calculated using the anterior and posterior corneal curvatures and Gaussian optics formula for thick lenses, where the actual refractive index of the air, cornea, and aqueous humor are entered). Bland-Altman plots were used to investigate agreement and analysis of variance (ANOVA) was performed to detect statistical differences.

RESULTS: Although ANOVA did not disclose a statistically significant difference among the mean SimK values (TMS-2: 43.20±1.51 diopters [D], Keratron Scout: 43.29±1.48 D, Pentacam: 43.25±1.53 D), the 95% limits of agreement between the TMS-2 and Pentacam and between the Keratron Scout and Pentacam were wide (−1.05 to +0.94 D and −0.95 to +1.02 D, respectively). Agreement was even poorer when considering the mean True net power (42.00±1.54 D), which was significantly lower than the mean Pentacam SimK (P<.001).

CONCLUSIONS: Although corneal topography and the Pentacam provide similar SimK values, their data should not be used interchangeably as only moderate agreement exists between them. Corneal power values calculated by the True net power are significantly lower than any SimK and cannot be entered into intraocular lens power formulas. [*J Refract Surg*. 2009;25:534-538.]
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In 1991, Wilson and Klyce showed that the simulated keratometry (SimK) values determined from the power points on mires 7, 8, and 9 of videokeratography were significantly correlated to the measurements obtained by conventional keratometry.[1] Videokeratography has subsequently been used as an alternative to keratometry to measure the corneal power for intraocular lens (IOL) power calculation.[2-4]

In the past few years, the range of available technologies for the estimation of corneal power has been further increased by the addition of new devices such as the rotating Scheimpflug camera (Pentacam; Oculus Optikgerate GmbH, Wetzlar, Germany). In contrast to videokeratography, where curvature data are derived from the measured distances between the rings projected onto the cornea,[5] the Scheimpflug camera measures the corneal radius on the basis of acquired images of the cornea, via triangle calculation. This technology can provide several corneal measurements, including SimK and True net power. The former is calculated by entering the anterior corneal curvature radius (in meters) into the thin lens formula for paraxial imagery, which considers the cornea a single refractive sphere and reads as:

$$\text{corneal power} = (n - 1)/\text{corneal radius} \qquad (1)$$

where n = standard keratometric index of refraction (the assumed value of the refractive index of the cornea and aqueous humor combined, which is 1.3375 in the case of Pentacam), and 1.000 is the refractive index of air.[6]

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The latter is the result of the Gaussian optics formula for thick lenses, which reads as:

$$\text{corneal power} = (n_1-n_0)/r_1+(n_2-n_1)/r_2 - [(d/n_1) \times (n_1-n_0)/r_1 \times (n_2-n_1)/r_2] \quad (2)$$

where n_0 = refractive index of air (=1.000), n_1 = refractive index of the cornea (=1.376), n_2 = refractive index of the aqueous humor (=1.336), r_1 = radius of curvature of the anterior corneal surface (in meters), r_2 = radius of curvature of the posterior corneal surface (in meters), and d = corneal thickness (in meters).[6]

The purpose of this study was to compare the corneal power values calculated by the Pentacam and those calculated by two corneal topographers (TMS-2 Topography System, Tomey, Erlangen, Germany; and Keratron Scout, Optikon 2000 SpA, Rome, Italy) in normal eyes that had not undergone any corneal refractive surgery. Knowing the level of agreement among these instruments should help to understand whether surgeons can rely on the Pentacam measurements for IOL calculation.

PATIENTS AND METHODS

Seventy-one consecutive patients undergoing routine preoperative examinations for refractive or cataract surgery were enrolled in a private practice; one eye of each patient was randomly selected by a computer-generated, predetermined randomization schedule. Mean patient age was 54.9±22 years (range: 51 to 93 years). Exclusion criteria were keratoconus and pellucid degeneration, previous anterior segment surgery and a low degree of patient collaboration leading to unreliable Scheimpflug images, as determined when the quality specification provided by the instrument is other than "OK" (this occurred in 11 cases of the original sample of 82 eyes). Before being included in the study, each patient was informed of its purpose and gave his/her written consent. The study methods adhered to the tenets of the Declaration of Helsinki for the use of human participants in biomedical research.

Each eye underwent corneal topography performed with the TMS-2, Keratron Scout, and Pentacam (only one data set for each instrument was used for statistical analysis). The mean SimK values calculated by these devices using the standard keratometric index of 1.3375 and the measured radius of the anterior corneal curvature were assessed and compared. The analysis also included the corneal power obtained using the thick lens Gaussian optics formula, which is automatically computed by the Pentacam using the corneal thickness and mean anterior and posterior corneal radius in the 3.0-mm zone and is named True net power.

The level of agreement between the Pentacam and each topographer was evaluated according to the method described by Bland and Altman,[7] who suggest plotting the differences between measurements (y axis) against their mean (x axis). Bland and Altman plots allow us to investigate the existence of any 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 one-sample *t* test, this indicates the presence of fixed bias. The 95% limits of agreement were defined as means ±2 SD of the differences between the two measurement techniques. Further statistical analyses were performed using GraphPad InStat version 3a for Macintosh (GraphPad Software, San Diego, Calif). Analysis of variance (ANOVA) with Bonferroni multiple comparisons was used to compare the SimK values and other corneal power measurements. Values of $P<.05$ were considered statistically significant.

RESULTS

The mean values provided by each instrument are reported in Table 1. Although no statistically significant differences were detected among the mean SimK values obtained from the TMS-2, Keratron Scout, and Pentacam, and no fixed bias was revealed by Bland-Altman analysis with one-sample *t* test, only a moderate level of agreement was found: the 95% limits of agreement between the TMS-2 and Pentacam (Fig) and between the Keratron Scout and Pentacam were −1.05 to +0.94 diopters (D) and −0.95 to +1.02 D, respectively (these values were larger than the 95% limits of agreement between the two topographers, ie, −0.50 to +0.32 D).

The difference between the TMS-2 and Pentacam SimK measurements was within ±0.50 D in 54 (76%) of 71 eyes. In one case, the TMS-2 underestimated the SimK by >1.00 D (precisely, −1.09 D), and in one case, it overestimated the SimK by >1.00 D (precisely, +2.48 D). The difference between the Keratron Scout and Pentacam was within ±0.50 D in 55 (77.4%) of 71 eyes, with no Keratron Scout underestimations exceeding 1.00 D and one case of overestimation by >1.00 D (precisely, +2.49 D). Interestingly, this was the same patient (a 47-year-old woman with cataract, dry eye, and deep-set eye) whose SimK was overestimated by the TMS-2 as well. Given this considerable discrepancy, we also measured the corneal power by keratometry and obtained a mean value of 42.37 D, which was similar to the mean value given by the Pentacam (42.30 D). The latter value was chosen and entered into the Hoffer Q formula; a 28.50-D AcrySof MA60AC (Alcon

TABLE 1

Mean Corneal Powers Calculated by Pentacam and TMS-2 and Keratron Scout Topographers

	TMS-2	Keratron Scout	Pentacam	
	SimK (Keratometric Index = 1.3375)	SimK (Keratometric Index = 1.3375)	SimK (Keratometric Index = 1.3375)	True net power (Corneal Refractive Index = 1.376)
Mean±SD (D)	43.20±1.51	43.29±1.48	43.25±1.53	42.00±1.54
Limits of agreement with respect to Pentacam SimK	−1.05 to +0.94	−0.95 to +1.02	−2.33 to +0.18	

SD = standard deviation

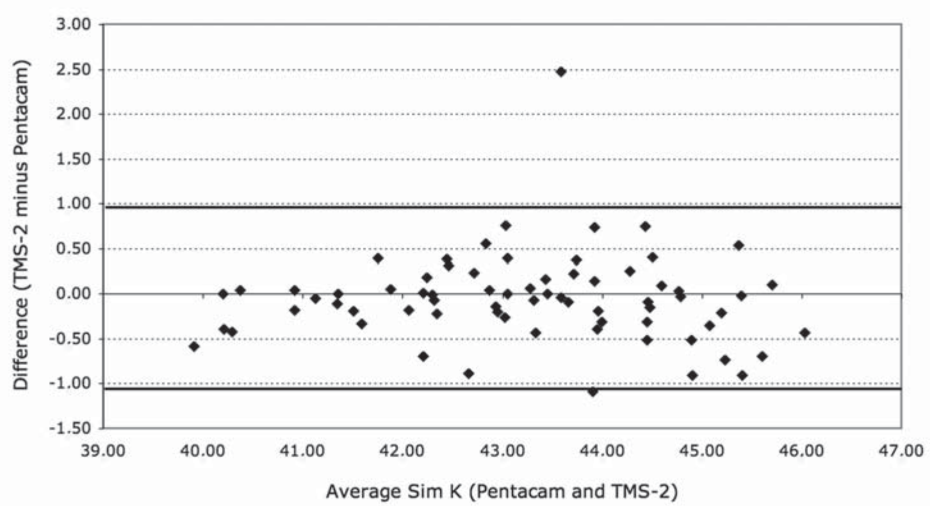

Figure. Bland-Altman plot illustrates the level of agreement between SimK measurements of Pentacam (Oculus Optikgeräte GmbH) and TMS-2 (Tomey). The bold horizontal lines represent the 95% limits of agreement (−0.95 to +1.02 D).

Laboratories Inc, Ft Worth, Tex) was selected to achieve a target refraction of −0.63 D. One month after surgery, the spherical equivalent refraction was −0.50 D, suggesting the accuracy (in this one case) of both keratometry and the Pentacam, and a poor reliability of videokeratography in the case of deep-set eyes with an unstable tear film.

The mean True net power was significantly lower than the mean SimK values obtained from the TMS-2, Keratron Scout, and Pentacam ($P<.001$ in all cases). Accordingly, Bland-Altman analysis revealed a fixed bias with wide 95% limits of agreement: −2.72 to +0.32 D (with respect to TMS-2), −2.80 to +0.22 D (with respect to Keratron Scout), and −2.33 to +0.18 D (with respect to Pentacam SimK).

As a secondary outcome, we also analyzed the mean anterior radius and posterior radius measured by the Pentacam in the 3.0-mm zone. The respective values were 7.81±0.28 mm and 6.4±0.24 mm; these values produced anterior/posterior radius ratios ranging between 1.14 and 1.31 mm, resulting in a mean of 1.22±0.02 mm. The Pentacam gave a mean corneal thickness reading of 558.3±41.73 µm. Using this value, the Gaussian optics formula resulted in a mean corneal power of 42.03±1.55 D, which was not statistically different compared to the mean automatic measurement, ie, the True net power (42.00±1.54 D). Entering the Gaussian optics formula–derived corneal power and the anterior radius of curvature into the formula for paraxial imagery (Eq[1]) gave a mean calculated keratometric index of 1.3285.

DISCUSSION

Accurate measurement of the corneal power is of utmost importance when calculating IOL power in the event of cataract surgery. Keratometry and videokeratography have been shown to be reliable methods.[2-4] Given that the mean SimK values provided by the Pentacam did not show any significant differences from those calculated by either of the topographers used in our study, Scheimpflug camera images may be considered an additional tool to measure the corneal power. However, although the lack of a statistically significant difference may suggest that these measurements can be used interchangeably, some degree of caution is warranted as the agreement between the Pentacam and the two

TABLE 2

Mean Anterior and Posterior Corneal Radii and Corresponding Keratometric Index as Reported in Previous Studies

	Mean±SD (Range)				
Study	Anterior Corneal Radius (mm)	Posterior Corneal Radius (mm)	A/P Ratio	Keratometric Index	Instrument
Present study	7.81±0.28 (7.3 to 8.4)	6.4±0.24 (5.98 to 6.81)	1.22±0.02	1.3285	Pentacam
Borasio*	7.81±0.24 (NA)	6.45±0.25 (NA)	1.211	1.3276	Pentacam
Fam et al[12]	7.87±0.25 (7.11 to 8.7)	6.46±0.26 (5.69 to 8.13)	1.22±0.03	1.3273	Orbscan II
Dubbelman et al[13]	7.79±0.25 (NA)	6.53±0.2 (NA)	1.19	1.3290	Scheimpflug
Tang et al[14]	7.67 (NA)	6.37 (NA)	1.20	1.3278	OCT
Garner et al[15]†	7.76 (NA)	6.41 (NA)	1.21	NA	Purkinje images
Ho et al[16]	7.75±0.28 (7.06 to 8.49)	6.34±0.28 (5.62 to 7.00)	1.22±0.03	1.3281	Pentacam
Gullstrand's schematic eye	7.70 (NA)	6.80 (NA)	1.13	1.3315	

SD = standard deviation, NA = not available
**Data do not appear in the original paper, but have been made available by the author.*
†Measurements taken only for the vertical meridian.

topographers is good, but not perfect. According to our data, the 95% limits of agreement are approximately ±1.00 D. In other words, a difference of up to 1.00 D can be expected in 95% of eyes—such a range can cause relevant differences in the prediction of IOL power.[8]

Further study is required to determine which of the above-mentioned instruments can assure the highest predictability in IOL power calculation, especially in those cases where the results given by each device differ considerably. A case in point is represented by the eye in our series where the difference between the values given by the two topographers and the Pentacam SimK was close to 2.50 D: if we had used the data from videokeratography to calculate the IOL power, the refractive outcome would have been far from the target refraction. Special attention should be given, for example, to dry eyes, where an unstable tear film is known to influence the reflection of the Placido-ring images (videokeratography has been intentionally used to assess the severity of dry eye)[9,10]; it is likely, but still unproven, that Scheimpflug images, which are not based on the reflection from the ocular surface, are not influenced by the tear film stability to the same extent.

The present study prompts additional considerations. The mean anterior and posterior corneal radii measured by the Pentacam in our sample and the ratio between them are close to previously reported values obtained by means of other technologies (Table 2). These data are encouraging, as obtaining similar values with different instruments provides increasing evidence that these measurements reflect the real corneal curvature.

Taken together, these studies also indicate that the classical ratio between the anterior and posterior corneal radii of Gullstrand's schematic eye (1.13) is lower than suggested by actual measurements, which range between 1.19 and 1.22.[11-16] The importance of this ratio lies in the fact that the keratometric index of refraction (needed to calculate the corneal power according to Eq[1]) strictly depends on it. Our own data, in agreement with the findings of previous investigations, showed that the actual keratometric index of refraction is lower than the standard values, which range between 1.3315 and 1.3375 (Table 2). In 1992, Dunne et al[17] reported a value (1.3283)—obtained using a Purkinje image technique —close to our own (1.3285), and in 1994, Eryildirim et al[18] found a mean value of 1.3304 using corneal pachymetry to assess the posterior corneal curvature. More recently, other authors have reported mean values between 1.3265 and 1.3290, obtained using either the Orbscan II (Bausch & Lomb, Rochester, NY) or a Scheimpflug camera.[7,12,13,16]

The discrepancy between the standard keratometric indices and the calculated values helps to explain why corneal power measurements derived by means of the thin lens formula for paraxial imagery (as in the case of videokeratography and manual keratometry) do not match those obtained using the Gaussian optics formula, where the standard index is not adopted. Studies have consistently shown videokeratography and manual keratometry values to be higher: the difference in our sample (+1.22 D) lies somewhere between that reported by Borasio et al[11] using the same instrument (+1.30 D) and that reported by Tang et al[14] using a prototype anterior segment optical coherence tomography device (+1.13 D). Unfortunately, because of this difference, the values calculated by means of the Gaussian optics formula cannot be entered into IOL power calculation formulas, although this would be desirable in eyes that had previously undergone refractive surgery, as they give a better estimation of corneal power changes.[11,14] Accordingly, different authors have suggested correcting and reoptimizing the current formulas so that the corneal power calculated by the Gaussian optics formula using the Pentacam data can be entered.[11,16,19]

Another interesting finding is the variability in the ratio between the two corneal curvature radii. Notwithstanding the small sample size, the range of values in our sample was considerably large (range: 1.14 to 1.31). Therefore, it can be argued that calculating the corneal power on the basis of the standard keratometric index, which assumes a stable relationship between the two corneal radii and does not take into account this variability, may work well for the average patient, but may induce unpredictable errors in eyes with an uncommon ratio.

This study has some limitations. Because we have been using videokeratography to measure corneal power in cataract and refractive surgery patients for over 10 years in our practice, we did not take manual keratometry readings in all eyes and therefore could not compare these to the videokeratography or Pentacam SimK values. Furthermore, the same operator performed all measurements (ie, the study was not masked).

Our analysis suggests that both videokeratography and Pentacam provide similar, non-statistically different values in the measurement of corneal power. Nevertheless, given that the limits of agreement are still wide, caution is recommended before routinely entering the values obtained from the Pentacam in IOL power calculation formulas. Further studies are needed to assess which technology can provide the best outcomes after phacoemulsification and IOL implantation.

AUTHOR CONTRIBUTIONS

Study concept and design (G.S., P.B., K.H.); data collection (G.S., M.C.); interpretation and analysis of data (G.S., M.C., K.H.); drafting of the manuscript (G.S.); critical revision of the manuscript (P.B., M.C., K.H.); statistical expertise (G.S.); supervision (P.B.)

REFERENCES

1. Wilson SE, Klyce SD. Quantitative descriptors of corneal topography. A clinical study. *Arch Ophthalmol*. 1991;109:349-353.
2. Cuaycong MJ, Gay CA, Emery J, Haft EA, Koch DD. Comparison of the accuracy of computerized videokeratography and keratometry for use in intraocular lens calculations. *J Cataract Refract Surg*. 1993;19:178-181.
3. Husain SE, Kohnen T, Maturi R, Er H, Koch DD. Computerized videokeratography and keratometry in determining intraocular lens calculations. *J Cataract Refract Surg*. 1996;22:362-366.
4. Alimisi S, Miltsakakis D, Klyce S. Corneal topography for intraocular lens power calculations. *J Refract Surg*. 1996;12:S309-S311.
5. Koch DD, Haft E. Introduction to corneal topography. In: Gills JP, Sanders DR, Thornton SP, Martin RG, eds. *Corneal Topography: The State of the Art*. Thorofare, NJ: SLACK Inc; 1995:3-15.
6. Olsen T. On the calculation of power from curvature of the cornea. *Br J Ophthalmol*. 1986;70:152-154.
7. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1:307-310.
8. McEwan JR, Massengill RK, Friedel SD. Effect of keratometer and axial length measurement errors on primary implant power calculations. *J Cataract Refract Surg*. 1990;16:61-70.
9. de Paiva CS, Lindsey JL, Pflugfelder SC. Assessing the severity of keratitis sicca with videokeratoscopic indices. *Ophthalmology*. 2003;110:1102-1109.
10. 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.
11. Borasio E, Stevens J, Smith GT. Estimation of true corneal power after keratorefractive surgery in eyes requiring cataract surgery: BESSt formula. *J Cataract Refract Surg*. 2006;32:2004-2014.
12. Fam HB, Lim KL. Validity of the keratometric index: large population study. *J Cataract Refract Surg*. 2007;33:686-691.
13. Dubbelman M, Van der Heijde GL. The shape of the anterior and posterior corneal surface of the ageing human cornea. *Vision Res*. 2006;46:993-1001.
14. 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.
15. Garner LF, Owens H, Yap MK, Frith MJ, Kinnear RF. Radius of curvature of the posterior surface of the cornea. *Optom Vis Sci*. 1997;74:496-498.
16. Ho JD, Tsai CY, Tsai RJF, Kuo LL, Tsai IL, Liou SW. Validity of the keratometric index: evaluation by the Pentacam rotating Scheimpflug camera. *J Cataract Refract Surg*. 2008;34:137-145.
17. Dunne MC, Royston JM, Barnes DA. Normal variations of the posterior corneal surface. *Acta Ophthalmol (Copenh)*. 1992;70:255-261.
18. Eryildirim A, Ozkan T, Eryildirim S, Kaynak S, Cingil G. Improving estimation of corneal refractive power by measuring the posterior curvature of the cornea. *J Cataract Refract Surg*. 1994;20:129-131.
19. Norrby S. Pentacam keratometry and IOL power calculation. *J Cataract Refract Surg*. 2008;34:3.