Evaluation of Keratometry With a Novel Color-LED Corneal Topographer

Stijn Klijn, MD; Nicolaas J. Reus, MD, PhD; Victor Arni D. P. Sicam, PhD

ABSTRACT

PURPOSE: To assess the performance of a novel keratometer based on reflections of colored light-emitting diodes (LEDs) and compare it with devices based on Placido rings, monochromatic LEDs, and Scheimpflug images.

METHODS: Sixty-three eyes of 63 patients with virgin corneas underwent keratometry with color-LED corneal topography (Cassini; i-Optics, The Hague, The Netherlands) and with devices based on Placido ring reflections (Keratron; Optikon, Rome, Italy), monochromatic LED reflections (Lenstar; Haag-Streit, Koeniz, Switzerland), and Scheimpflug imaging (Pentacam; Oculus Optikgeräte, Wetzlar, Germany). Three repeated measurements were performed with each device. Comparability and repeatability of corneal power and cylinder measurements were assessed. The Bonferroni-corrected α-threshold for statistical significance was 0.016.

RESULTS: Corneal power measurements with the Cassini topographer were not statistically significantly different from those with the Pentacam (P = .64). They were statistically significantly lower than those with the Keratron and Lenstar (P < .01), but the differences were of negligible clinical relevance. Cylinder measurements with the Cassini topographer were not statistically significantly different from those with any other device (P = .46). Repeatability of Cassini corneal power measurements was not statistically significantly different from that of the Keratron (P = .02), but was statistically significantly lower than that of the Lenstar and Pentacam (P < .001). Repeatability of Cassini cylinder measurements was statistically significantly higher than that of the Pentacam and Keratron (P < .001), but was not statistically significantly different from that of the Lenstar (P > .05).

CONCLUSIONS: Corneal power and cylinder measurements with color-LED corneal topography yielded values that were comparable to those of other commonly used devices. Repeatability of corneal power measurements was lower compared to some devices, but repeatability of cylinder measurements was relatively high. This may be of particular interest when using toric intraocular lenses.


A good refractive outcome in cataract and refractive surgery relies on accurate and precise keratometry, particularly in procedures to correct astigmatism. Erroneous keratometric measurements may be a source of intraocular lens (IOL) power calculation errors,1,2 which lead to postoperative refractive surprises. In addition, appropriate measurement of cylinder axis is important in toric IOL implantation because every degree of misalignment reduces the corrective effect.3,4

The manual Javal-Schiotz keratometer, invented in the late 19th century, has largely given way to a variety of automated keratometers. These devices employ different techniques to provide automated analogues of traditional, manual keratometry readings. Commonly used keratometers are based on reflections of Placido rings, reflections of monochromatic light-emitting diodes (LEDs), Scheimpflug images, or a combination of these. Although of proven clinical value, topography based on Placido rings holds the disadvantage of neglecting skew rays,5 which may lead to inaccuracies in measuring features of the cornea that are not rotationally symmetric (eg, corneal cylinder).6-8 This may be solved by using a corneal reflection source that allows for point-to-point reconstruction.9,10 Simulations have shown that such a technique might be more accurate and precise than topography based on Placido rings.11

From Rotterdam Ophthalmic Institute, Rotterdam, The Netherlands (SK, NJR, VADPS); and Amphia Hospital, Department of Ophthalmology, Breda, The Netherlands (NJR).

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Correspondence: Stijn Klijn, MD, Rotterdam Ophthalmic Institute, P.O. Box 70830, Rotterdam 3000 LM, The Netherlands. E-mail: S.Klijn@oogziekenhuis.nl doi:10.3928/1081597X-20150212-01
A possible disadvantage of Scheimpflug-based topography may be its sensitivity to eye movements due to the relatively long acquisition time. It has been shown that the repeatability of such measurements is lower than that of instantaneous measurements.12

Recently, the Cassini corneal topographer (i-Optics, The Hague, The Netherlands) was released.13 The Cassini topographer takes instantaneous measurements and analyzes corneal shape based on point-to-point reconstruction of specular reflections of 679 colored LEDs. The Cassini topographer provides keratometry and measurements of lower- and higher-order corneal aberrations based on the Zernike polynomials. The purpose of this study was to assess the performance of keratometry with color-LED corneal topography and compare it to that of topographers based on Placido rings (Keratron; Optikon, Rome, Italy), monochromatic LEDs (Lenstar; Haag-Streit, Koeniz, Switzerland), and Scheimpflug images (Pentacam; Oculus Optikgeräte, Wetzlar, Germany).

**PATIENTS AND METHODS**

**Participants**

This prospective comparative study was conducted at the Rotterdam Ophthalmic Institute, Rotterdam, The Netherlands. Sixty-three eyes of 63 participants with virgin corneas were enrolled. Participants were either patients with cataract awaiting cataract surgery or volunteers without any history or symptoms of ocular disease. One eye was randomly selected from each subject. Exclusion criteria were corneal diseases (eg, keratoconus, corneal scarring, or pterygium), previous corneal surgery, or inability to fixate on the instrument’s fixation target. The study adhered to the tenets of the Declaration of Helsinki. Institutional review board approval was obtained, and informed consent was received from all participants.

**Measurements**

For each eye, keratometry was performed with the Cassini topographer and three other devices by one of two experienced operators. The Cassini topographer (software version 1.4.0) analyzes specular reflections of 679 colored LEDs and calculates corneal curvatures at the 3.0-mm central zone. The Keratron (software version 2.1.0) analyzes reflections of 28 Placido rings and calculates corneal curvatures at the 3.0-mm central zone (simulated keratometry). The Lenstar (software version 4.0.0) uses reflections of 28 Placido rings and analyzes corneal shape based on point-to-point reconstruction of specular reflections of 679 colored LEDs. The Pentacam (software version 6.07r12) analyzes tomographic images obtained with a rotating Scheimpflug camera and calculates corneal curvatures at the 3.0-mm central zone (simulated keratometry). Three repeated measurements were performed with each device. The participants were asked to fixate on the instrument’s fixation target and blink before each measurement. For each measurement, the calculated steepest and flattest radius of curvature and corresponding meridians were recorded.

**Initial Data Processing**

Radii of curvature were converted to meridional power using a keratometric index of 1.3375. Subsequently, corneal power was calculated as the average power of the principal meridians, and cylinder magnitude was calculated as the difference between the powers of the principal meridians.

Corneal power is a scalar quantity. Corneal cylinder, on the other hand, can be considered as either two independent scalar quantities (ie, magnitude and steepest or flattest meridian orientation) or a combination of two (mutually dependent) orthogonal components, such as a vector or a set of polar values.14 In the case of a vector, vector length represents cylinder magnitude and vector direction represents cylinder steepest (or flattest) meridian orientation. Valid calculations with cylinders require that they are decomposed in orthogonal components. Nevertheless, clinicians may have a particular interest in the accuracy and repeatability of only cylinder steepest meridian measurements (eg, when planning implantation of a toric IOL). Therefore, we have applied both vector and scalar analysis of cylinder measurements. The vector X and Y components were calculated according to the method described by Holladay et al.15

**Comparability Analysis**

For each set of three repeated measurements, the scalar average of corneal power, cylinder magnitude, and cylinder steepest meridian, as well as the vector average of cylinder, was calculated.

**Repeatability Analysis**

For each participant on each device, repeatability of corneal power, cylinder magnitude, and cylinder steepest meridian measurements was calculated as the within-subject standard deviation ($s_w$).16 In addition, repeatability of corneal cylinder measurements was calculated as the vector difference between measurements 1 and 2, between measurements 1 and 3, and between measurements 2 and 3.17

**Statistical Analysis**

Statistical analysis was performed using Excel 2010 (Microsoft Corporation, Redmond, WA) and SPSS
version 21 (IBM, Armonk, NY) software. For each variable, normality of its distribution was visually inspected and tested using the Kolmogorov–Smirnov test. The distribution of corneal power was not statistically significantly different from a normal distribution ($P > .05$). The distribution of corneal cylinder magnitude and steepest meridian, as well as that of the $s_w$, of each variable, was statistically significantly different from a normal distribution ($P < .05$). Differences in corneal power measurements between the Cassini topographer and other devices were tested for statistical significance with the paired-samples $t$ test. Differences in cylinder magnitude measurements, cylinder steepest meridian measurements, and $s_w$ between the Cassini topographer and other devices were tested for statistical significance using the Wilcoxon signed rank test. Differences between vectors indicating cylinder measurements were tested for statistical significance using Hotelling trace multivariate analysis of variance. Differences between vector lengths indicating repeatability of cylinder measurements were tested for statistical significance using the Wilcoxon signed rank test. $P$ values less than .05 were considered statistically significant. However, because three comparisons were done (ie, Cassini topographer versus each of the three other devices), a Bonferroni correction was applied; the $\alpha$-threshold for statistical significance was adjusted to 0.016 (0.05 divided by three comparisons).

**SAMPLE SIZE CALCULATION**

The standard deviation of the differences in corneal power measurements between devices was estimated to be 0.25 diopters (D).\textsuperscript{17} The smallest difference that might be clinically relevant was defined to be 0.125 D. Setting $\alpha$ to 0.016 (0.05 divided by 3 comparisons) and power to 0.9, the minimum sample size was calculated to be 55 eyes.

**RESULTS**

### DEMOGRAPHICS

Twenty-two participants (35%) were patients with cataract and 41 participants (65%) were volunteers. Twenty-five participants (40%) were men and 38 participants (60%) were women. Thirty-eight eyes (60%) were right eyes and 25 eyes (40%) were left eyes. The median participants’ age was 45.7 years (range: 21.4 to 86.5 years).

### COMPARABILITY

The central tendency and spread of the measurements with all devices is shown in **Table 1**. Cassini measurements of corneal power were not statistically significantly different from those with Pentacam. However, they were statistically significantly lower than those with Keratron and Lenstar. There were no statistically significant differences in cylinder measurements with any of the devices.

### REPEATABILITY

The $s_w$ of the three repeated measurements with all devices is shown in **Table 2**. Median $s_w$ of corneal power measurements with the Cassini topographer was not statistically significantly different from the Keratron. However, repeatability with the Lenstar and Pentacam was statistically significantly higher ($P < .001$). For magnitude and steepest meridian measurements, repeatability was not statistically significantly different from the Lenstar, but was statistically significantly higher than the Keratron and Pentacam. There was no statistically significant correlation between the $s_w$ of cylinder magnitude measurements with the Cassini topographer and the cylinder magnitude (**Figure 1**, Spearman’s $\rho = 0.15$, $P = .24$). However, there was a statistically significant correlation between the $s_w$ of cylinder steepest meridian measurements and the

### TABLE 1

<table>
<thead>
<tr>
<th>Device</th>
<th>Corneal Power (D) Mean ± SD</th>
<th>$P$</th>
<th>Cylinder Magnitude (D) Median [IQR]</th>
<th>$P$</th>
<th>Cylinder Steepest Meridian (degrees) Median [IQR]</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassini</td>
<td>43.42 ± 1.37</td>
<td>–</td>
<td>0.70 [0.42 to 1.24]</td>
<td>–</td>
<td>89.7 [74.0 to 102.3]</td>
<td>–</td>
</tr>
<tr>
<td>Keratron</td>
<td>43.52 ± 1.42</td>
<td>.004b</td>
<td>0.74 [0.43 to 1.13]</td>
<td>.50</td>
<td>84.0 [68.3 to 105.3]</td>
<td>.28</td>
</tr>
<tr>
<td>Lenstar</td>
<td>43.54 ± 1.43</td>
<td>.002b</td>
<td>0.78 [0.41 to 1.24]</td>
<td>.64</td>
<td>89.3 [75.0 to 105.3]</td>
<td>.22</td>
</tr>
<tr>
<td>Pentacam</td>
<td>43.44 ± 1.46</td>
<td>.64</td>
<td>0.89 [0.50 to 1.18]</td>
<td>.04</td>
<td>92.3 [74.1 to 104.5]</td>
<td>–</td>
</tr>
</tbody>
</table>

\(D = \) diopters; IQR = interquartile range; SD = standard deviation

\(\alpha\)-threshold: 0.05 / 3 = 0.016.

\(b\)Statistically significant.

The Cassini topographer is manufactured by i-Optics, The Hague, The Netherlands, the Keratron by Optikon, Rome, Italy, the Lenstar by Haag-Streit, Koeniz, Switzerland, and the Pentacam by Oculus Optikgeräte, Wetzlar, Germany.
TABLE 2
Within-subject Standard Deviation of the Three Repeated Measurements of Corneal Power, Cylinder Magnitude, and Cylinder Steepest Meridian With the Studied Devices

<table>
<thead>
<tr>
<th>Device</th>
<th>Corneal Power (D) Median [IQR]</th>
<th>P</th>
<th>Cylinder Magnitude (D) Median [IQR]</th>
<th>P</th>
<th>Cylinder Steepest Meridian (degrees) Median [IQR]</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassini</td>
<td>0.14 [0.08 to 0.24]</td>
<td></td>
<td>0.08 [0.05 to 0.12]</td>
<td></td>
<td>2.9 [1.2 to 4.4]</td>
<td></td>
</tr>
<tr>
<td>Keratron</td>
<td>0.11 [0.08 to 0.14]</td>
<td>0.02</td>
<td>0.12 [0.06 to 0.17]</td>
<td>.009</td>
<td>8.7 [3.8 to 15.7]</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Lenstar</td>
<td>0.05 [0.03 to 0.09]</td>
<td></td>
<td>&lt; .001</td>
<td></td>
<td>2.5 [1.2 to 4.9]</td>
<td>.97</td>
</tr>
<tr>
<td>Pentacam</td>
<td>0.08 [0.04 to 0.11]</td>
<td></td>
<td>&lt; .001</td>
<td></td>
<td>6.5 [3.3 to 10.5]</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

D = diopters; IQR = interquartile range

P values indicate the statistical significance of the difference with the Cassini topographer. P values calculated with the Wilcoxon signed rank test. Bonferroni-corrected α-threshold: 0.05 / 3 = 0.016.

Statistically significant.

The Cassini topographer is manufactured by i-Optics, The Hague, The Netherlands, the Keratron by Optikon, Rome, Italy, the Lenstar by Haag-Streit, Koeniz, Switzerland, and the Pentacam by Oculus Optikgeräte, Wetzlar, Germany.

cylinder magnitude (Figure 2, Spearman’s rho = -0.39, P < .01). Table 3 shows the $s_w$ of cylinder steepest meridian measurements with the Cassini topographer, stratified by cylinder magnitude. Median $s_w$ of cylinder steepest meridian improved from 3.2° in participants with less than 0.5 D of astigmatism to 1.2° in participants with greater than 1.5 D of astigmatism.

Vector differences between repeated cylinder measurements are shown in Figure 3. For each of the three vector differences (ie, between measurements 1 and 2, between measurements 1 and 3, and between measurements 2 and 3), the median vector length of Cassini measurements was not statistically significantly different from that of measurements with the Lenstar (P > .05), but was statistically significantly lower (indicating higher repeatability) than that of measurements with the Keratron and Pentacam (P < .001).

DISCUSSION

This study investigated the performance of keratometry with color-LED corneal topography and compared it to that of three other commonly used devices. Color-LED corneal topography has been introduced recently and, to the best of our knowledge, no previously published literature exists about its performance in a clinical setting. In addition, the number of studies that have investigated the repeatability of cylinder
measurements, particularly cylinder steepest meridian measurements, is limited. However, knowledge about this is especially important in the planning of toric IOL implantation.

**Comparability**

Corneal power measurements with the Cassini topographer were not statistically significantly different from those with the Pentacam. However, they were statistically significantly lower than those with the Keratron and Lenstar. Compared to the latter devices, the Cassini topographer measured corneal powers that were on average 0.10 and 0.12 D lower, respectively. We believe that such differences are of negligible clinical relevance. The higher corneal power as measured with the Lenstar might be explained by the difference in measurement area. Measurements with the Lenstar are obtained at the central 2.3 mm of the cornea, whereas those with the Cassini topographer are obtained at the central 3.0 mm. The cornea is aspheric; its curvature becomes steeper toward the center. Thus, if a sphere is fitted to a smaller central area, it will be steeper. This explanation is supported by the findings of Elbaz et al., Savini et al., and Huang et al., who all found that a device that measures a larger central area (Pentacam) yields lower power values compared to a device that measures a smaller central area (Lenstar or IOLMaster; Carl Zeiss Meditec, Dublin, CA). We cannot explain the difference between the Cassini topographer and Keratron based on the principles behind both technologies. However, inspection of the topography images revealed that the Keratron often measured a steep rim, usually superiorly in participants who had difficulty keeping their eyes wide open during the measurement. In some cases, the algorithm extended these steep areas centrally into the simulated keratometry zone, causing the measured corneal power to be higher. After excluding these cases from the analysis, the difference between the Cassini topographer and Keratron was not statistically significant anymore. The Keratron appeared to be more sensitive to disturbances caused by the eyelids compared to the other studied devices, which often recognized the affected zones and excluded them from the analysis, as indicated on the maps by fogging or erasing these zones.

Corneal cylinder measurements with the Cassini topographer were not statistically significantly different from any of the other devices. This is in accordance with the findings of Visser et al., who found that astigmatism measurements of six different devices, including the Lenstar and Pentacam, yielded values that were not statistically significantly different. Statistically significantly lower values were measured only when measurements of the posterior corneal surface were included with the Pentacam’s equivalent keratometry values. Shirayama et al. also did not find statistically significant differences in cylinder measurement values among four different devices.

**Repeatability**

Repeatability of corneal power measurements of the Cassini topographer was statistically significantly lower than those of the Lenstar and Pentacam. This might be due to a high sensitivity to misalignment of the cornea with respect to the imaging system of the Cassini topographer. Repeatability of cylinder measurements was statistically significantly higher than those of the Keratron and Pentacam. This is visualized in Figure 3, in which the dots represent the heads of the difference vectors; the tails of all difference vectors are in the origin. Thus, the closer the dots are located to the origin of the plots, the shorter the difference vectors and the higher the repeatability. The average position of the dots is indicated by the centroid, which is analogous to the summated vector mean. As Alpins and Goggin point out, the summated vector mean can be used to identify a trend in aggregate data. The closer the summated vector mean or centroid is to zero, the more likely it is that the individual vectors indicate random events. This is clearly the case in Figure 3, which is not surprising because in repeated measurements of astigmatism the second measurement will randomly yield a

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**TABLE 3**

<table>
<thead>
<tr>
<th>Cylinder Magnitude (D)</th>
<th>No.</th>
<th>Median (degrees)</th>
<th>IQR (degrees)</th>
<th>Range (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.50</td>
<td>21</td>
<td>3.2</td>
<td>1.9 to 10.8</td>
<td>0.6 to 42.0</td>
</tr>
<tr>
<td>0.50 – 1.49</td>
<td>31</td>
<td>2.9</td>
<td>1.2 to 4.4</td>
<td>0.0 to 8.9</td>
</tr>
<tr>
<td>≥ 1.50</td>
<td>11</td>
<td>1.2</td>
<td>0.6 to 2.5</td>
<td>0.6 to 4.5</td>
</tr>
</tbody>
</table>

D = diopters; IQR = interquartile range

*Notice that within-subject standard deviation decreases with higher cylinder magnitude.

The Cassini topographer is manufactured by i-Optics, The Hague, The Netherlands.
higher or lower value, which is rotated either clockwise or counterclockwise relative to the first measurement. Thus, a different means of summarizing repeatability is necessary, such as the median vector length. Of note, vector length is in itself a scalar quantity.

As noted earlier, neglecting skew rays is a disadvantage inherent to all Placido systems, and it may partly explain the relatively low repeatability of the Keratron.\textsuperscript{6,8} In addition, we noticed that the issue mentioned in the previous paragraph caused a false local-

Figure 3. Vector differences between repeated cylinder measurements. Dots represent vector heads; all vector tails are in the origin. Notice that vectors representing the Cassini topographer (i-Optics, The Hague, The Netherlands) and Lenstar (Haag-Streit, Koeniz, Switzerland) measurements are shorter compared to those representing the Keratron (Optikon, Rome, Italy) and Pentacam (Pentacam; Oculus Optikgeräte, Wetzlar, Germany) measurements. D = diopters; MVL = median vector length in diopters
ization of the steepest meridian in some cases, leading to relatively low repeatability, whereas the internal quality check of the device indicated that repeatability was “good.” For the Pentacam, eye movements during acquisition time may limit its repeatability. It is not surprising that the difference between the Cassini topographer and Lenstar was not statistically significant, because the technologies are comparable. Both devices overcome the skew ray problem by the use of LED reflections, and both devices take instantaneous measurements, which reduces their sensitivity to eye movements. Scalar analysis of the repeatability of cylinder measurements (Table 2) revealed that in clinical practice, the high repeatability with the Cassini topographer and Lenstar was mainly observed as a high repeatability of cylinder steepest meridian measurements. There was a statistically significant inverse correlation between repeatability of cylinder steepest meridian measurements and actual cylinder magnitude. Measurements of cylinder steepest meridian were less precise in lower astigmatism, which may explain, at least partly, why many clinicians are cautious about implanting toric IOLs in eyes with low astigmatism. Future technical developments further improving the precision of cylinder steepest meridian measurements may allow toric IOL implantation to be successfully applied for the correction of lower astigmatism.

STUDY LIMITATIONS

Two operators performed all measurements. Although both operators adhered to the study protocol and were aware of the purpose of the measurements, subtle differences in their routines may in theory have increased measurement variation. However, in contrast to a manual keratometer, values measured by automated keratometers are mainly dependent on hardware, software, and the internal quality check. Moreover, a previous study using the Keratron and Pentacam did not find statistically significant differences between corneal power measurements by two different operators.23

CONCLUSIONS

Corneal power measurements with color-LED corneal topography may yield values that are statistically significantly lower compared to some other devices, but the differences are of negligible clinical relevance. The higher values of the Lenstar may be inherent to measuring a smaller central zone of the cornea. Cylinder measurements were not statistically significantly different compared to those of the other studied devices. Although the repeatability of corneal power measurements was relatively low, repeatability of cylinder measurements was higher than two of the three commonly used other devices that were studied. Color-LED corneal topography thus appears to be a potentially valuable tool in toric IOL implantation.

AUTHOR CONTRIBUTIONS

Study concept and design (SK, NJR, VADPS); data collection (SK, VADPS); analysis and interpretation of data (SK, NJR, VADPS); writing the manuscript (SK); critical revision of the manuscript (SK, NJR, VADPS); supervision (NJR, VADPS)

REFERENCES


