

Comparative analysis of anterior corneal surface characteristics measured by two topographers and two autokeratometers

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Background: Precise quantification of corneal parameters enhances the clinical of the anterior corneal surface for various clinical assessments, with ongoing research focusing on optimizing everyday practice through device comparison studies. The study aimed to compare the agreement on the anterior corneal surface characteristics values measured by four commercially available devices: EyeSys 2000, Oculus Easygraph, ARK700A and ARK510A.

Methods: Observational cross-sectional study involving 50 eyes from healthy volunteer recruited among subjects attending for an eye examination. Corneal radius minimum keratometry reading (min-K) and maximum keratometry reading (max-K), astigmatism axis and eccentricity were measured in all participants with EyeSys, Oculus Easygraph, ARK700A and ARK510A. Measurements were performed three times only in the right eye in random order by four optometrists who were unaware of the results of the other researchers.

Results: A statistically significant difference occurred for the measurements of the corneal radius (Greenhouse-Geisser and Huynh-Feldt: $P \leq 0.001$ for both max-K and min-K radius) and the axis of astigmatism (Friedman: $P < 0.001$), between the four devices. Pairwise comparisons revealed no radius differences between Oculus Easygraph and ARK510A (Sidak: min-K radius, $P = 0.231$; max-K radius, $P = 0.224$), and no axis differences in all pairwise analyses that have not imply the EyeSys (Wilcoxon: all $P \geq 0.130$). There was no statistical difference in the eccentricity value obtained by the topographers (paired t -test: $P = 0.507$).

Conclusions: The present study showed that EyeSys 2000 measurements differed from those of the other devices across all parameters. Alternatively, both topographers showed a perfect agreement concerning eccentricity measurements in everyday practice.

Keywords: Agreement corneal topographers; agreement autokeratometers; EyeSys; Easygraph; ARK

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Introduction

Precise quantification of corneal topography parameters provides a tool to define the optical characteristics of the anterior corneal surface to a proper contact lens fitting as well as a method for the early diagnosis and monitoring of corneal ectatic disorders, accurate intraocular lens power calculations, and preparation of corneal refractive surgery (1-3). Keratometry is a technique that measures the central area of the anterior cornea where two axes 90° apart are determined. These two axes are the steepest and the flattest meridians of the central area of the anterior cornea. The steepest meridian has the highest radius of curvature, which fits with the maximum keratometry reading (max-K). On the other hand, the flattest meridian is the smallest radius of curvature, that fits with the minimum keratometry reading (min-K) and is perpendicular to the max-K (4).

Keratometric measurements can be acquired using either conventional keratometry or corneal topography (2,5-8). These devices provide clinicians with the characteristics of the anterior surface of the cornea based on the two principal radii (min-K and max-K), the astigmatism axis and the shape factor (2). The anterior corneal curvature radius determines two-thirds of the optical refractive power of the eye and is thus a relevant parameter of the ocular optical system (9). The shape factor of the cornea can be described in terms of eccentricity based on the mathematical description of an ellipse from 0.00 (a circle with no flattening) to 1.00 (maximum flattening in the periphery) (10); this parameter

is usually only provided by the topographers, however, the problem with these instruments is that their sophistication inevitably induces a penalty in terms of cost and the induction of other errors because of the capture systems used, while an assessment of corneal topography using a simple instrument like keratometers provides the possibility of topographical assessment for the clinician with access only to basic instrumentation.

The differences of the precision and comparison between devices are still a relevant research topic for the optimization of the everyday practice (1,11-13). The present study aimed to compare the agreement of the anterior corneal surface characteristics values measured by four commercially available devices (two corneal topographers and two autokeratometers): the EyeSys 2000 (EyeSys Vision, United States), the Oculus Easygraph (Oculus Optikgeräte GmbH, Germany), the ARK700 (Nidek Technologies, Italy), and ARK510A (Nidek Technologies).

Methods

Study design

Measurements were performed in random order using four devices, two corneal topographers and two autokeratometers, following manufacturer's instructions: (I) EyeSys Corneal Analysis System 2000, (II) Easygraph, (III) ARK700, and (IV) ARK510A (5-8). Corneal radius (min-K and max-K) and astigmatism axis were measured by all the devices, while the eccentricity values were measured only with the Oculus Easygraph and the EyeSys 2000 topographers. All measurements were performed three times on each device only in the right eye of each subject to avoid overstating the precision of statistical estimates by four expert optometrists who were not aware of the results of the other researchers (14).

Sample

Fifty volunteer participants (mean age =22.9±5.85 years; range, 19–29 years) were recruited among students and patients attending the centre for an eye examination. Participants were excluded if they had a history of conjunctival, scleral, or corneal disease, prior eye surgery,

Highlight box

Key findings

- Agreement cross-sectional between devices on corneal surface measurements.

What is known and what is new?

- Differences in corneal radius and axis measurements between devices was found. Oculus Easygraph and ARK510A showed no difference in radius measurement.

What is the implication, and what should change now?

- EyeSys 2000 showed differences in axis measurements with the other devices. There was no difference in the eccentricity value obtained by the topographers.

dry eye disease, meibomian gland dysfunction, glaucoma, diabetes mellitus, a thyroid disorder, wore contact lenses, were pregnant or breast feeding (15,16). Participants were only included if their refractive spherical error was less than ± 6.00 D and/or astigmatism was less than 4.00 D (17). No one participant was under any type of topical or systemic medications or used artificial tears at the time of the study that could influence the measurements. To eliminate any diurnal variation in corneal curvature or tear physiology, all measurements were made in the morning at the same hour between 10:00 and 12:00 am (6,18).

Statistical analysis

SPSS statistical software v.23.0 for Windows (SPSS Inc., United States) was used for data analysis. Significance was set at a $P \leq 0.05$ for all statistical tests (19). Before analysis, the normal distribution of the data was checked using the Kolmogorov-Smirnov test.

Radius values showed a normal distribution (Kolmogorov-Smirnov test: $P \geq 0.074$ for all the examined values), therefore differences between measurements on devices were assessed using Greenhouse-Geisser or Huynh-Feldt correction based on Mauchly's W test of sphericity, while pairwise analysis was performed using the Sidak post-hoc test (20). Since the axis showed a non-continuous distribution (Kolmogorov-Smirnov test: $P \leq 0.001$ for all the examined values), differences in this parameter between devices were assessed using the Friedman test, while the Wilcoxon test was used to detect significant pairwise differences; to avoid type I errors arising from multiple comparisons in the axis values, statistical significance for the Wilcoxon test to be divided by the number of comparisons performed to give a $P \leq 0.0083$ (Bonferroni adjustment) (21).

Eccentricity values showed a normal distribution (Kolmogorov-Smirnov test: all $P \geq 0.194$). For eccentricity agreement between topographers, Bland-Altman's procedures were used. This method describes the correlation or similarity between two variables, representing averages versus differences (19,22). Thus, differences between the sets of measurements obtained in the two sessions were examined. Differences were assessed using a paired t -test for related samples and 95% limits of repeatability were also calculated [mean difference $\pm 1.96 \times$ standard deviation (SD) differences] (19); 95% limits of agreement (95% LoAs) were also calculated (mean difference $\pm 1.96 \times$ SD), as well as the exact 95% confidence intervals (95% CIs) for upper and lower LoAs considered as a pair

(mean difference $\pm c_{t_{0.025}} \times$ SD; mean difference $\pm c_{t_{0.975}} \times$ SD) (19,23).

Ethical consideration

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of Universidade de Santiago de Compostela (USC-40/2020) and informed consent was taken from all individual participants.

Results

There was a statistical difference in the measurements of both corneal radii, max-K [Mauchly's W test: $P=0.001$, epsilon (ϵ) =0.561; Huynh-Feldt correction: $P < 0.001$, Table 1] and min-K (Mauchly's W test: $P < 0.006$, ϵ =0.847; Greenhouse-Geisser correction: $P < 0.001$, Table 1), between the four devices. Pairwise comparisons showed that this difference was not true when comparing Oculus Easygraph topographer and ARK510A autokeratometers (Sidak test: min-K radius, $P=0.23$; max-K radius, $P=0.22$, Table 2), whereas there was a statistically significant difference for the remaining comparisons (Sidak test: all comparisons max-K or min-K radius, $P \leq 0.02$, Table 2).

There was a statistical difference in the measurements of the astigmatism axis between the four devices (Friedman test: $P < 0.001$). The pairwise analysis showed that the EyeSys 2000 results were statistically significantly different from the other devices (Wilcoxon test: all $P \leq 0.001$, Table 2), while all the other devices showed no paired differences between them (Wilcoxon test: all $P \geq 0.13$, Table 2).

There was no statistical difference in the eccentricity value obtained by the two topographers (paired t -test: $P=0.51$, Table 3 and Figure 1).

Discussion

In clinical practice, accurate corneal topography measurements are essential for contact lens fitting or the detecting of significant corneal shape alterations. The measurement of the anterior corneal curvature or keratometry could be performed with a variety of devices.

Considering the mean difference and the 95% LoAs for max-K or the min-K measurements, the worst agreement was obtained between the EyeSys 2000 against the other devices; this device overestimated the radius values of the other devices. Inter-device differences, although small (near

Table 1 Descriptive statistics and difference analysis between the flat or the steeper radius values obtained in each device

Parameter	Device	Mean/median	SD/IQR	P value
max-K (mm)	EyeSys 2000	7.81	0.26	<0.001 [†]
	Oculus Easygraph	7.72	0.26	
	ARK700	7.74	0.26	
	ARK510A	7.70	0.28	
min-K (mm)	EyeSys 2000	7.93	0.30	<0.001 [‡]
	Oculus Easygraph	7.87	0.29	
	ARK700	7.88	0.30	
	ARK510A	7.86	0.30	
Astigmatism axis (°)	EyeSys 2000	159	131–168	<0.001 [§]
	Oculus Easygraph	175	160–180	
	ARK700	176	144–1	
	ARK510A	176	147–180	

N=50. Mean and SD displayed for parametric variables while median and IQR for non-parametric variables. [†], Huynh-Feldt correction; [‡], Greenhouse-Geisser correction; [§], Friedman test. SD, standard deviation; IQR, interquartile range; max-K, maximum keratometry reading; min-K, minimum keratometry reading.

Table 2 Analysis of differences of radius and axis results obtained in each device

Parameter	Pair	Mean difference ± SD	P value	95% LoAs	
				Minimum (95% CI)	Maximum (95% CI)
max-K (mm)	EyeSys 2000-Oculus Easygraph	0.06±0.034	<0.001 [†]	-0.006 (-0.023, 0.004)	0.125 (0.115, 0.143)
	EyeSys 2000-ARK700	0.05±0.036	<0.001 [†]	-0.026 (-0.044, -0.015)	0.116 (0.105, 0.134)
	EyeSys 2000-ARK510A	0.06±0.032	<0.001 [†]	0.002 (-0.015, 0.012)	0.126 (0.116, 0.143)
	Oculus Easygraph-ARK700	-0.01±0.033	0.003 [‡]	-0.078 (-0.095, -0.068)	0.049 (0.039, 0.066)
	Oculus Easygraph-ARK510A	0.004±0.026	0.23 [‡]	-0.046 (-0.059, 0.038)	0.055 (0.047, 0.068)
	ARK700-ARK510A	0.02±0.023	<0.001 [†]	-0.026 (-0.038, -0.019)	0.064 (0.057, 0.076)
min-K (mm)	EyeSys 2000-Oculus Easygraph	0.09±0.047	<0.001 [†]	-0.003 (-0.027, 0.011)	0.182 (0.167, 0.206)
	EyeSys 2000-ARK700	0.08±0.040	<0.001 [†]	-0.002 (-0.022, 0.010)	0.154 (0.142, 0.174)
	EyeSys 2000-ARK510A	0.10±0.090	<0.001 [†]	-0.073 (-0.119, -0.045)	0.282 (0.254, 0.328)
	Oculus Easygraph-ARK700	-0.01±0.038	0.02 [‡]	-0.091 (-0.111, -0.079)	0.064 (0.052, 0.085)
	Oculus Easygraph-ARK510A	0.02±0.087	0.22 [‡]	-0.156 (-0.200, -0.129)	0.186 (0.159, 0.231)
	ARK700-ARK510A	0.03±0.085	0.02 [‡]	-0.138 (-0.181, -0.112)	0.195 (0.169, 0.239)
Astigmatism axis (°)	EyeSys 2000-Oculus Easygraph	-14.4±14.69	<0.001 [‡]	-43.16 (-50.66, -38.62)	14.42 (9.88, 21.92)
	EyeSys 2000-ARK700	-10.5±14.60	<0.001 [‡]	-39.11 (-46.56, -34.59)	18.11 (13.59, 25.55)
	EyeSys 2000-ARK510A	-11.7±1.68	<0.001 [‡]	-32.63 (-38.08, -29.33)	9.23 (5.93, 14.68)
	Oculus Easygraph-ARK700	3.9±2.25	0.61 [‡]	-35.81 (-46.15, -29.55)	43.55 (37.29, 53.89)
	Oculus Easygraph-ARK510A	2.7±11.93	0.13 [‡]	-2.71 (-26.80, -17.02)	26.05 (22.36, 32.14)
	ARK700-ARK510A	-1.2±12.50	0.26 [‡]	-25.71 (-32.09, -21.84)	23.31 (19.44, 29.69)

N=50. [†], Sidak test; [‡], Wilcoxon test. SD, standard deviation; LoAs, limits of agreement; CI, confidence interval; max-K, maximum keratometry reading; min-K, minimum keratometry reading.

Table 3 Descriptive statistics and paired *t*-test between the eccentricity results obtained in each topographer

Device	Mean ± SD	Mean difference ± SD	P value	95% LoAs	
				Minimum (95% CI)	Maximum (95% CI)
EyeSys 2000	0.458±0.083	-0.009±0.097	0.51	-0.200 (-0.250, -0.170)	0.182 (0.151, 0.231)
Oculus Easygraph	0.467±0.130				

N=50. SD, standard deviation; LoAs, limits of agreement; CI, confidence interval.

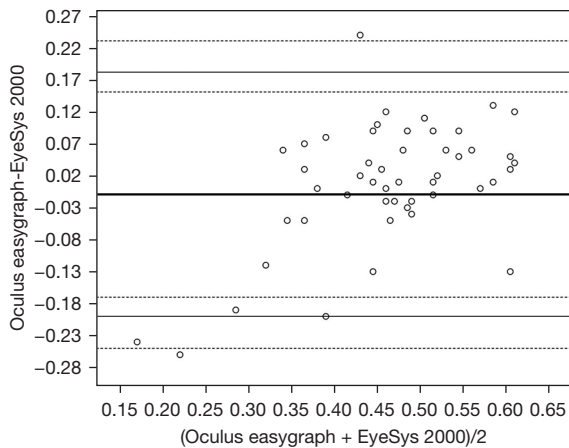


Figure 1 Mean versus differences (Bland-Altman plot) between the eccentricity values obtained by the two devices in 50 participants. The thick solid horizontal line indicates the mean difference while the thin solid horizontal lines the 95% LoAs (mean difference ± 1.96 × SD). The dashed horizontal lines indicate the 95% CI of the LoAs. LoAs, limits of agreement; SD, standard deviation; CI, confidence interval.

or over 0.10–0.20 mm), were suggested to be clinically significant for certain applications such as contact lens fitting and follow-up examinations. The same situation could be observed on the astigmatism axis measurement, where the EyeSys 2000 device may generate differences with the other devices higher than 10°, which could highly compromise a decision or evaluation of the initial contact lens chosen during a fitting procedure. From the studied devices here, the EyeSys 2000 is one of the most assessed for accuracy or repeatability in the literature (5,24–26). Previous studies of the EyeSys 2000 showed acceptable repeatability or agreement with other devices in the measurement of curvature parameters on human corneas or calibrated reference standards (5,25,27), while higher disparity was obtained on the astigmatism axis assessment than other devices or in the accuracy while the measured surface become more min-K flattening (5,26,27).

To the authors’ knowledge, whereas a statistically significant difference occurred with the Oculus Easygraph, this device was used in previous research on corneal optical quality and keratometry assessment (7,8). In the present study, a lower value of mean difference min-K, max-K, or the axis when the readings were compared to the autorefractometer results. However, while most of the 95% LoAs seem to be narrow, a few of them showed a bias that could compromise a clinical setting (e.g., min-K: Oculus Easygraph-ARK510A, 95% LoAs =-0.156, 0.186; axis: Oculus Easygraph-ARK700, 95% LoAs =-35.81, 43.55). It was previously stated those differences could be attributed to the measurement area of each device such as the normal prolate shape of the cornea is max-K in the centre and higher K-readings should be expected with smaller measurement areas (4).

Both studies autokeratometers studied showed a reliable agreement between them when min-K or axis was compared, whereas differences were found regarding the max-K measurements where ARK700 often overestimated the values in reference to ARK510A readings; nevertheless, the mean differences found could be considered non-clinically relevant (max-K: ARK700-ARK510A, mean difference ± SD =0.02±0.023 mm). Other autokeratometers models were also studied by other authors, showing good repeatability and agreement when compared with other automated devices and manual Javal keratometers (4). On the other hand, in concordance with present results other studies have proposed that EyeSys 2000 and the automated ARK700A keratometer lack interchangeability in their results (6).

Eccentricity could be defined as the flattening rate of the central curve radius of a surface and is a way to quantify aspheric changes across the diameter of that curve (10); the higher the value, the more quickly the surface flattens from the centre to the periphery (10). This variable has a relevant influence on the gas permeable fitting and evaluation process (e.g., irregular corneas or ortho-k fitting) (28). In the present study, EyeSys 2000 and Oculus Easygraph

showed a high concordance in the readings of this parameter (eccentricity: EyeSys 2000-Oculus Easygraph, mean difference \pm SD = -0.009 \pm 0.097). A few researchers have studied the agreement in the eccentricity values between different commercially available topographers, where significant differences among them were found (29).

It has been hypothesized that the differences in the readings of all those parameters between devices could be most likely due to the different imaging methods used by each device (29,30); topographers are based on an image capture of the Placido disc reflection from the anterior cornea while keratometry is based on the measurement and size measurement of an image in the cornea assumed as a convex mirror (29,30). In addition, it has been proposed that differences between keratometry assessments could emerge from not consistent use of an index of refraction or measurement area (the closer to the centre, the max-K the cornea will appear) by manufacturers (4). On the other hand, the differences could emerge from the capture times (30); topographers require a longer capture time to acquire multiple images or to focus the image than autokeratometers, therefore factors such as the fixation of the subject, compensatory saccadic movements, and ability to keep the eye open may influence on the measurements.

The present results are limited by the sample used, which despite the fact it was relatively larger (50 participants), was only composed of healthy participants. Future studies on those devices should include a second group composed of a well-designed group with a specific corneal topographic disruption condition (e.g., Keratoconus or post-Lasik patients) in order to enhance the applications of the finding.

Conclusions

As previously indicated, the findings of this study demonstrate that the EyeSys 2000 lacks agreement with the other devices under examination across any of the parameters investigated, while both the Oculus Easygraph and ARK510A display complete interchangeability. However, both examined topographers showed perfect agreement in eccentricity measurements for everyday practice.

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Footnote

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