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Comparison of Holladay equivalent keratometry readings and anterior corneal surface keratometry measurements in keratoconus

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Abstract

Purpose To compare the accuracy of the anterior corneal simulated keratometry (SimK) and the Holladay equivalent keratometry reading (EKR) provided by a Scheimpflug camera (Pentacam HR) with the keratometry (*K*) provided by a Placido system (T-Cone topography) in keratoconus and control eyes.

Methods This prospective study included 40 consecutive patients with keratoconus and 40 voluntary participants with no ocular complaints. Any patients with corneal scar, corneal trauma, history of corneal surgery or contact lens usage were excluded from the study. Mean SimK and Holladay EKR measurements were taken with Pentacam HR in the 2, 3, and 4.5 mm corneal zones, and these values were compared with the T-Cone mean *K* value with the Placido topography system attachment on the Lenstar LS 900. Statistical analysis was performed using the paired Student's *t* test and the Bland–Altman analysis.

Results A statistically significant difference was determined between the Placido *K* and the Scheimpflug EKR 2, 3, 4.5 mm and SimK values in the keratoconus group ($p < 0.05$). In the analyses which showed a difference between the SimK and Holladay EKR, it was observed that as the diameter of the corneal zone increased, the 95% LoA values were extended. No statistically significant difference was determined between the SimK and EKR 2 mm values ($p > 0.05$). In the control group, there was no statistically significant difference between any of the keratometric values.

Conclusion In diseases which affect the posterior corneal surface, such as keratoconus, it is thought that because of the asymmetrical peripheral placement of the corneal apex, as the corneal diameter increases there could be an error increase of 1–3 mm in keratometric systems evaluating the anterior surface.

Keywords Equivalent keratometry reading · Keratoconus · Placido · Scheimpflug

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Introduction

Various devices are available for the diagnosis of keratoconus, such as corneal topography, biomicroscopy, retinoscopy, and pachymetry [1]. Measurements of anterior corneal curvature and power have become easier due to current Placido ring-based topographers, manual keratometers, automated keratometers, and dual zone keratometers. Total corneal power is calculated with hypotheses related between the anterior and posterior surfaces [2]. Moreover, these

devices are usually used to measure the anterior corneal radius with a keratometric index for the calculation of the total corneal power. The keratometric index was developed from the anterior corneal surface measurements only, regardless of the posterior corneal surface measurement [3, 4].

Scheimpflug camera systems can measure Holladay equivalent keratometry reading (EKR), which are derived from corneal elevation values of the anterior and posterior surfaces in addition to local corneal thickness [5, 6]. There are several studies which have compared optic biometry with Scheimpflug camera. In the keratometric measurements of these studies, Scheimpflug camera, partial coherence interferometry (PCI) (IOLMaster 500), optical low-coherence reflectometry (OLCR) (Lenstar LS 900), and autokeratometer measurements are seen to have been widely used [7–12].

The aim of this study was to compare the mean anterior surface simulated keratometry (SimK) and Holladay EKR measurements in the 2, 3, and 4.5 mm corneal zones obtained by Pentacam HR (Oculus Optikgeräte GmbH) and the T-Cone Placido topography (Haag-Streit AG) system mean keratometry (K) measurements in keratoconus patients and control eyes.

Subjects and methods

Patients selection

This prospective study included consecutive patients with keratoconus and voluntary patients with no ocular complaints. Keratoconus diagnosis was based on the presence of slit-lamp biomicroscopy findings, such as Fleischer ring, Vogt striae, stromal thinning, and corneal topography findings such as asymmetric bow-tie pattern and the inferior–superior (I–S) asymmetry. The Amsler-Krumeich classification was used for the keratoconus grading [13]. According to the mean keratometry (K) readings obtained from corneal topography, eyes with keratoconus were subgrouped as mild ($K < 48$ D), moderate ($48 < K < 53$), or severe ($K > 53$).

The control was formed of voluntary participants with no ocular complaints. Eyes with corneal scar, corneal trauma, a history of corneal surgery and

contact lens wear in the previous 1 month were excluded from the study.

Approval for the study was granted by the Ethics Committee of the Faculty of Medicine at Harran University, Şanlıurfa, Turkey. This study was conducted in accordance with the tenets of the Declaration of Helsinki.

Devices

Once manifest refractions and visual acuity examinations were completed, the following devices were used: T-Cone topography and Pentacam HR (software version: 1.21r3). Examination quality specification graded by the instrument as "OK" was saved.

There has been recently widespread use of the T-Cone topography add on to the Lenstar LS 900 (which is based on partial coherence interferometry [OLCR]), and this provides Placido topography with 11 placido rings on the central 6 mm of anterior corneal surface. The T-Cone topography system evaluates keratometry measurements of the through the position of 32 projected light reflections in 2.3 mm (outer) and 1.65 mm (inner) rings. For each measuring point, the equivalent of an ideal sphere is calculated. Bench tests in addition to evaluation of real eye data showed that K-readings calculated from the topography image and the Lenstar's standard dual zone keratometry are equivalent [14, 15].

The Pentacam HR uses a rotating Scheimpflug camera which can evaluate anterior and posterior corneal surfaces. The Pentacam system includes pachymetry maps, anterior and posterior surface corneal elevation maps, biometric measurements of the anterior segment, and it calculates the total corneal power, SimK, and Holladay EKR values [16–18]. SimK is thus an estimation of the total corneal power by assuming that the cornea is a single refracting surface, based on the standard corneal refractive index and the anterior corneal curvature [16, 19]. The values were calculated using the following formula: $SimK = n - n_0/r_{anterior}$. The anterior central corneal curvature, within a certain diameter (in meter), was defined as $r_{anterior}$. The refractive index of air (n_0) is 1.000. The standard corneal refractive index (n) is 1.3375.

The Holladay EKR value was developed to calculate the total corneal power specifically for patients who have undergone corneal refractive surgery [5].

The "Holladay EKR Detail Report" which can be used in the Pentacam HR device takes measurements at 1-mm intervals in the central cornea from 1 mm up to 7 mm. The 4.5-mm corneal zone, as the actual zone, is also measured. Pentacam can consistently calculate EKR using a standard refractive index and the radius of the anterior and posterior corneal surfaces [5, 11]. The values were calculated using the following formula: EKR $(D) = 0.376/r_{anterior} - 0.03165/r_{posterior}$. The posterior central corneal curvature, within a certain diameter (in meter), was defined as $r_{posterior}$.

Statistical analyses

Statistical analyses were applied using SPSS for Windows version 22.0 software (IBM SPSS Inc, Chicago, IL, USA). The paired Student's t test was used to compare the mean values of the different methods. The limits of agreement (LoA) were calculated as 95% as described by Bland and Altman [20]. The 95% LOA were defined as mean $\pm$ 1.96 SD of the difference between the results given by the two measurement techniques. A value of $p < 0.05$ was accepted as statistically significant, $p < 0.01$ as statistically highly significant. According to the alpha error of 5%, the power analysis was determined 100% for all parameters.

Results

Keratoconus group

This prospective study included 40 eyes of 40 patients (20 males, 20 females) with keratoconus. The mean age of the patients was 20.15 ± 6.54 years (range 9–48 years). As the corneal measurement zone increased, the Holladay EKR value was determined to decrease (Table 1).

No statistically significant difference was found between the Scheimpflug SimK and Holladay EKR 2 mm values ($p = 0.898$). The Scheimpflug SimK value was significantly higher than the Holladay EKR (3, 4.5 mm) values. The Placido K value was statistically significantly higher than the Scheimpflug SimK and Holladay EKR values (2, 3, 4.5 mm) ($p < 0.001$) (Table 2). The comparison with the Placido K showed that 95% LoA was narrowest for the Scheimpflug SimK (6.32 D), and largest for the Holladay EKR 4.5 mm (9.26 D) values.

The analysis applied with the Bland–Altmann method of the Placido K and Holladay EKR values in the 4.5 mm corneal zone is shown in Fig. 1. The Bland–Altmann analysis of the Scheimpflug SimK and Placido K values is shown in Fig. 2.

25% (10) of eyes were mild keratoconus, 45% (18) of eyes were moderate keratoconus, and 30% (12) of eyes were severe keratoconus. There was statistically highly significant difference between the Placido K and EKR measurements in the moderate group (Table 3).

Control group

A total of 40 eyes of 40 healthy individuals (27 females, 13 males) were analyzed. The mean age of the control group subjects was 24 ± 9.43 years (range 8–57 years). No statistically significant difference was determined between any of the keratometric values (Table 4).

The comparison with the Placido K showed that 95% LoA was narrowest for the Scheimpflug SimK and Holladay EKR 4.5 mm (1.6 D), and largest for the Holladay EKR 2 mm (1.84 D) values (Table 5).

The Bland–Altmann analysis comparing the Placido K and Holladay EKR 4.5 mm zones values is shown in Fig. 3. The Bland–Altmann analysis of the

Table 1 Mean keratometry measurements in keratoconus group

|	Placido K	SimK	EKR 2 mm	EKR 3 mm	EKR 4.5 mm
Mean $(D) \pm$ SD	50.57 $\pm$ 4.57	49.35 $\pm$ 3.82	49.38 $\pm$ 4.57	48.62 $\pm$ 4.34	47.69 $\pm$ 4.35
Range (D)	44.41–64.79	44.1–59.6	42.99–61.31	42.28–59.89	41.54–58.39

EKR equivalent keratometry reading obtained by Pentacam HR; *Placido K* keratometry value obtained by T-Cone; *SimK* simulated keratometry obtained by Pentacam HR

Table 2 Mean keratometric difference measurements in keratoconus group

	Mean difference (D) ± SD	95% CI (D)	95% LOA (D)	p values
SimK–Placido K	− 1.23 ± 1.58	− 1.73 to − 0.72	− 4.39 to + 1.93	< 0.001
SimK–EKR 2 mm	− 0.03 ± 1.67	− 0.56 to + 0.50	− 3.37 to + 3.31	= 0.898
SimK–EKR 3 mm	+ 0.72 ± 1.74	+ 0.16 to + 1.28	− 2.76 to + 4.20	= 0.012
SimK–EKR 4.5 mm	+ 1.65 ± 1.92	+ 1.03 to + 2.26	− 2.19 to + 5.49	< 0.001
Placido K–EKR 2 mm	+ 1.19 ± 1.98	+ 0.56 to + 1.82	− 2.77 to + 5.15	< 0.001
Placido K–EKR 3 mm	+ 1.95 ± 2.05	+ 1.29 to + 2.60	− 2.15 to + 6.05	< 0.001
Placido K–EKR 4.5 mm	+ 2.87 ± 2.33	+ 2.13 to + 3.62	− 1.79 to + 7.53	< 0.001

EKR equivalent keratometry reading obtained by Pentacam HR; *Placido K*, keratometry value obtained by T-Cone; *SimK* simulated keratometry obtained by Pentacam HR; *CI* confidence interval; *LoA* limits of agreement

Fig. 1 Bland–Altmann analysis of Mean Placido K and Scheimpflug EKR 4.5 mm in keratoconus group. EKR, equivalent keratometry reading obtained by Pentacam HR; Placido K, keratometry value obtained by T-Cone topography; LoA, limits of agreement
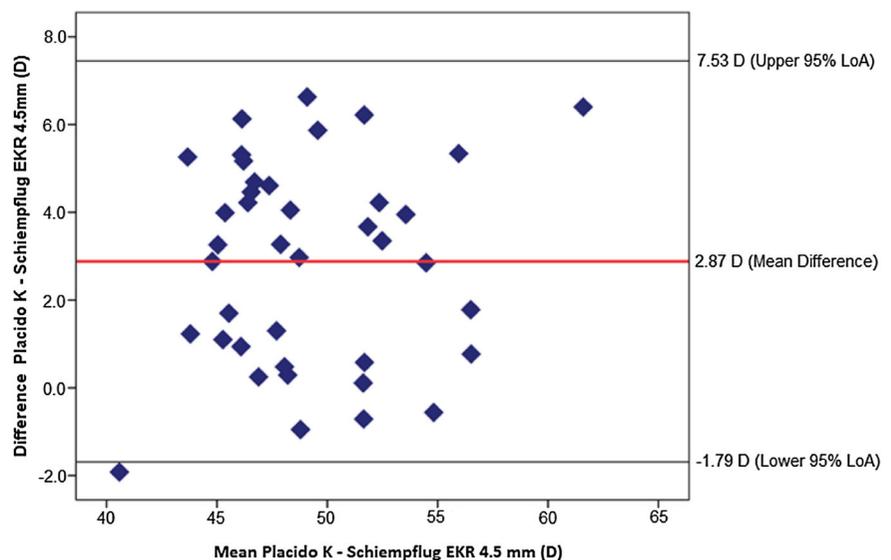
Scheimpflug SimK and Placido K values is shown in Fig. 4.

Discussion

The Holladay EKR value was developed specifically to calculate the intraocular lens (IOL) power after keratorefractive surgery, using the difference between the anterior and posterior central corneal surface measurements [5].

In addition, the high error rate of the keratometers in corneal asymmetric astigmatism such as keratoconus may affect the calculation of the corneal power measurement. Although several studies have been conducted on the subject of corneal topography

systems in keratoconus, the accuracy of these systems was slightly lower than that reported in normal corneas [21–24].

The current study differs from others in that a comparison was made of Holladay EKR and topography as an addition to optic biometry. Furthermore, in those studies which compared Holladay EKR with values obtained with other autokeratometers, PCI and the clinical history method, the study groups were formed of virgin cornea or patients who had undergone refractive surgery.

In some studies, Holladay EKR has been compared with PCI keratometry. However, Symes et al. [10] determined that the EKR at 4.5 mm was the closest match to conventional Keratometry (IOL Master) in virgin corneas, Karunaratne et al. [11] found a

Fig. 2 Bland–Altmann analysis of Mean Scheimpflug SimK and Placido *K* in keratoconus group. Placido *K*, keratometry value obtained by T-Cone topography; SimK, simulated keratometry obtained by Pentacam HR; LoA, limits of agreement
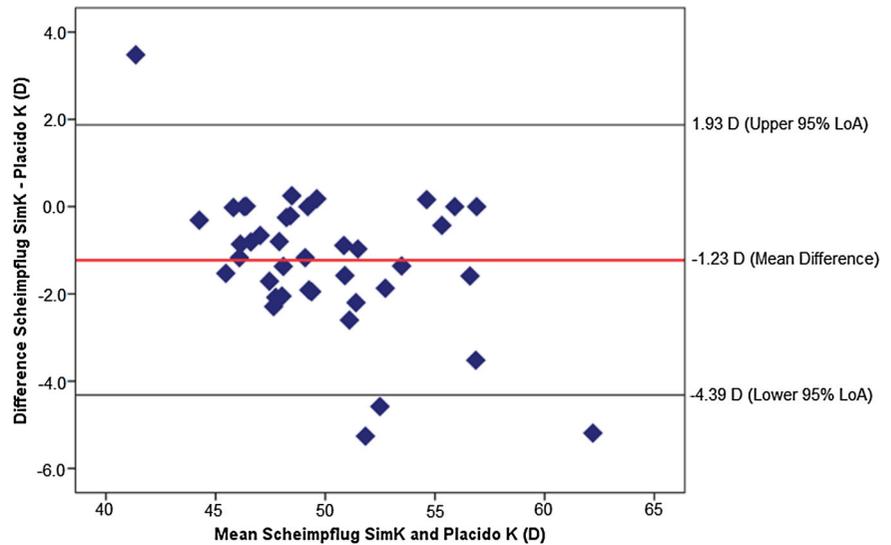

Table 3 Mean keratometric difference measurements in different keratoconus group

Groups of keratoconus	Mean difference (D)	SD	95% CI (D)	p values
Mild (n = 10)				
SimK—Placido K	2.61	4.32	− 0.48 to 5.70	= 0.089
SimK—EKR 2 mm	0.45	0.69	− 0.03 to 0.95	= 0.067
SimK—EKR 3 mm	1.06	1.19	0.21 to 1.91	= 0.020
SimK—EKR 4.5 mm	1.53	1.54	0.43 to 2.64	= 0.012
Placido K—EKR 2 mm	− 2.15	3.88	− 4.93 to 0.62	= 0.113
Placido K—EKR 3 mm	− 1.54	3.45	− 4.02 to 0.92	= 0.191
Placido K—EKR 4.5 mm	− 1.07	3.07	− 3.27 to 1.12	= 0.297
Moderate (n = 18)				
SimK—Placido K	1.78	2.43	0.57 to 2.99	= 0.006
SimK—EKR 2 mm	0.17	2.11	− 0.87 to 1.22	= 0.732
SimK—EKR 3 mm	0.78	2.33	− 0.37 to 1.94	= 0.173
SimK—EKR 4.5 mm	1.48	2.35	0.30 to 2.65	= 0.016
Placido K—EKR 2 mm	− 1.60	1.27	− 2.24 to − 0.97	< 0.001
Placido K—EKR 3 mm	− 0.99	0.77	− 1.38 to − 0.60	< 0.001
Placido K—EKR 4.5 mm	− 0.29	0.27	− 0.43 to − 0.16	< 0.001
Severe (n = 12)				
SimK—Placido K	1.41	1.34	0.55 to 2.27	= 0.004
SimK—EKR 2 mm	0.10	2.36	− 1.39 to 1.60	= 0.878
SimK—EKR 3 mm	0.33	1.05	− 0.33 to 1.00	= 0.295
SimK—EKR 4.5 mm	1.43	1.48	0.48 to 2.37	= 0.007
Placido K—EKR 2 mm	− 1.30	2.83	− 3.11 to 0.49	= 0.139
Placido K—EKR 3 mm	− 1.08	1.53	− 2.05 to − 0.10	= 0.032
Placido K—EKR 4.5 mm	− 0.01	1.60	− 1.00 to 1.04	= 0.969

EKR equivalent keratometry reading obtained by Pentacam HR; *Placido K* keratometry value obtained by T-Cone; *SimK* simulated keratometry obtained by Pentacam HR; *CI* confidence interval

significant difference between the EKR 2, 3, and 4.5 mm measurements and IOL Master K. Tang et al. [6] compared the Holladay EKR with a back-calculated value based on the actual surgical outcomes following cataract surgery prior to corneal refractive surgery. The Scheimpflug power measurements were

Table 4 Mean keratometry measurements in control group

|	Placido *K*	SimK	EKR 2 mm	EKR 3 mm	EKR 4.5 mm
Mean (*D*) ± SD	43.21 ± 1.59	43.17 ± 1.54	43.19 ± 1.45	43.15 ± 1.49	43.16 ± 1.52
Range (*D*)	40.09–46.59	40.0–46.7	40.12–46.39	40.11–46.49	40.04–46.34

EKR equivalent keratometry reading obtained by Pentacam HR; *Placido K* keratometry value obtained by T-Cone; *SimK* simulated keratometry obtained by Pentacam HR

Table 5 Mean keratometry difference measurements in control group

	Mean difference (*D*) ± SD	95% CI (*D*)	95% LOA (*D*)	*p* values
SimK—Placido *K*	− 0.09 ± 0.23	− 0.16 to − 0.01	− 0.55 to 0.37	= 0.533
SimK—EKR 2 mm	− 0.02 ± 0.2	− 0.08 to + 0.04	− 0.42 to + 0.38	= 0.467
SimK—EKR 3 mm	+ 0.01 ± 0.19	− 0.43 to + 0.07	− 0.37 to + 0.39	= 0.558
SimK—EKR 4.5 mm	+ 0.003 ± 0.18	− 0.06 to + 0.05	− 0.35 to + 0.36	= 0.925
Placido *K*—EKR 2 mm	+ 0.07 ± 0.32	− 0.03 to + 0.17	− 0.57 to + 0.71	= 0.817
Placido *K*—EKR 3 mm	+ 0.11 ± 0.29	0.01 to + 0.2	− 0.47 to + 0.69	= 0.416
Placido *K*—EKR 4.5 mm	+ 0.08 ± 0.32	− 0.01 to + 0.19	− 0.56 to 0.72	= 0.468

EKR equivalent keratometry reading obtained by Pentacam HR; *Placido K* keratometry value obtained by T-Cone; *SimK* simulated keratometry obtained by Pentacam HR; *CI* confidence interval; *LoA* limits of agreement

Fig. 3 Bland–Altmann analysis of Mean Placido *K* and Scheimpflug EKR 4.5 mm in control group. EKR, equivalent keratometry reading obtained by Pentacam HR; Placido *K*, keratometry value obtained by T-Cone topography; LoA, limits of agreement
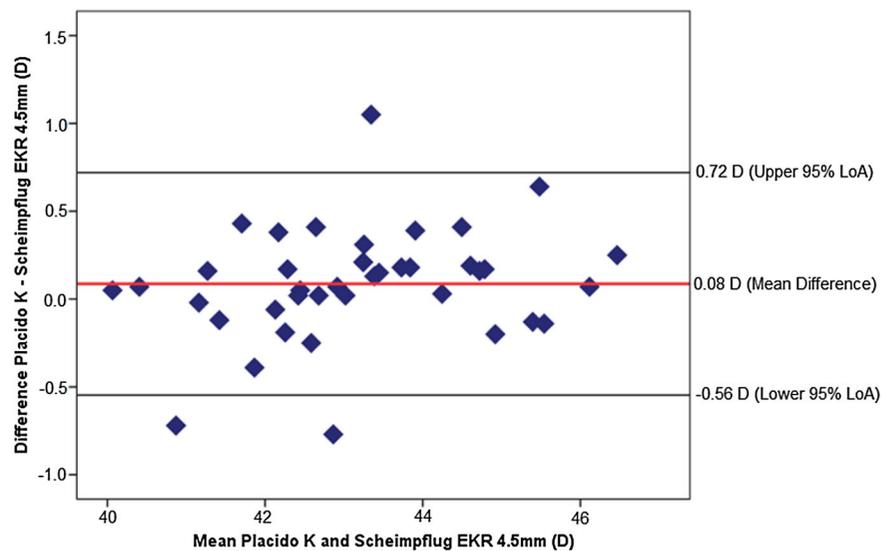
found to be consistently steeper than the back-calculated value, and an error of mean + 1.38 *D* was determined in the EKR 4.5 mm zone in virgin corneas. Furthermore, Shammas and Symes [25, 26] showed that the results of cataract patients, obtained with Scheimpflug camera, were determined to be not superior to those obtained from autokeratometer.

In the current study, the mean *K* value provided by the Placido topography was steeper than that of Scheimpflug topography in both patients groups. Although the mean Scheimpflug SimK and Holladay EKR values provided by the Pentacam HR were similar to the mean *K* value provided by T-Cone values in the control group, all the keratometric values obtained with Pentacam HR in keratoconus group

Fig. 4 Bland–Altmann analysis of Mean Scheimpflug SimK and Placido *K* in control group. Placido *K*, keratometry value obtained by T-Cone topography; SimK, simulated keratometry obtained by Pentacam HR; LoA, limits of agreement
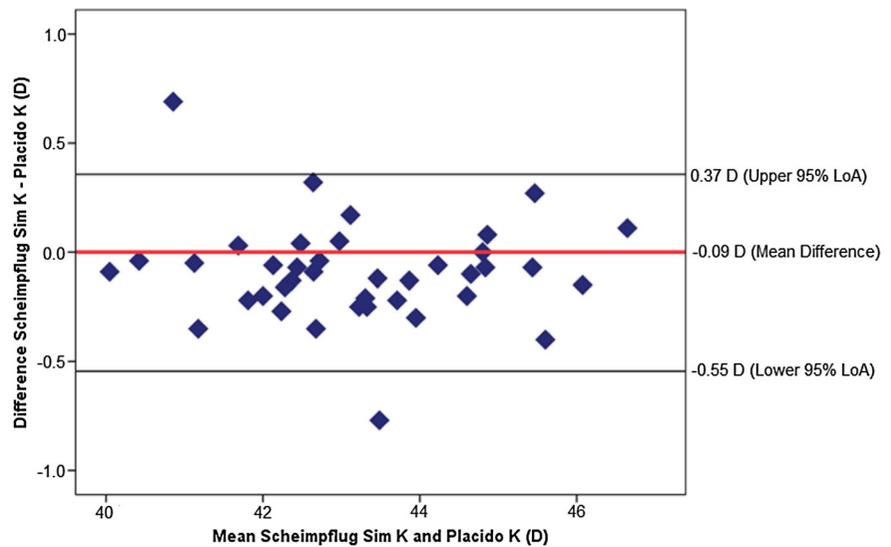
were statistically significantly different from the T-Cone values (Tables 2, 5).

In Fig. 2, 10% cases of the keratoconus group were not in the 95% LoA interval. This suggests that the Placido *K* and Scheimpflug SimK may increase the error margin in the keratoconus group. In contrast to the keratoconus patients, in the control group, no statistically significant difference was determined between the devices in any of the keratometric parameters. The additional variance seen when using the EKR values can be considered to result from direct measurement of the posterior curvature of the cornea. Therefore, this increased variance may be the result of measurements that are more precise than those calculated by the Placido system (Figs. 1, 2).

In the light of these data, it can be considered that in diseases which affect the posterior corneal surface, such as keratoconus, as the corneal evaluation zone increases, the margin of error of systems evaluating the anterior surface < 3 mm could increase due to the asymmetrical placement of the corneal apex. Similarly, Woodmass et al. [7] found that the mean anterior surface SimK value showed less inter-device variation than did the EKR when compared with the PCI keratometry. This was explained by the fact that the PCI keratometry and SimK values are both generated using a similar estimation of the posterior curvature. This result contrasts the data of the current study. These dissimilar results strongly prove that the Placido topography systems and other anterior surface

measurements may cause inaccurate keratometry power and IOL calculations in posterior corneal diseases.

In some studies, Pentacam HR measurements have been compared in patients who had not undergone corneal surgery, no statistically significant differences were found between any corneal power measurements in virgin corneas [12, 27]. However, unlike in other studies, Pentacam HR was used in that study. The new software of Pentacam HR was superior to older software in the biometric calculation, and therefore, it was claimed to be more reliable. The use of Pentacam HR with new software may affect the results in different patient groups.

There are several post-corneal refractive surgery studies in the literature that have compared Pentacam and PCI. The current study differs from previous research with the use of T-cone topography as an attachment to Lenstar LS 900 in the keratoconus patient group. Placido systems such as T-Cone which evaluate the corneal anterior surface and keratometers may provide different results in keratoconus in which the posterior corneal curvature is important.

In conclusion, although there was no significant difference between the any keratometric measurements in the control group, in the keratoconus group, in addition to the difference in the measurements, that the LoA values were broader, demonstrates that care must be taken in the evaluation of keratometric data in ectatic corneal diseases such as keratoconus.

Limitations of this study were that the patient group was small and there was no comparison of the IOL results. There is a need for further studies of more extensive keratoconus patient groups and evaluation of refractive results.

Compliance with ethical standards

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study. "Additional informed consent was obtained from all individual participants for whom identifying information is included in this article.

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