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Differences between Keratometry and Total Keratometry Measurements in a Large Dataset Obtained with a Modern Swept Source OCT Biometer

Short: Comparing Keratometry and Total Keratometry Values

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Abstract:

Purpose: This study aimed to explore the concept of total keratometry (TK) by analyzing extensive international datasets representing diverse ethnic backgrounds. The primary objective was to quantify the disparities between traditional keratometry (K) and TK values in normal eyes and assess their impact on intraocular lens (IOL) power calculations using various formulas.

Design: Retrospective multicenter inter-instrument reliability analysis

Methods: The study involved the analysis of biometry data collected from ten international centers across Europe, the United States, and Asia. Corneal power was expressed as equivalent power and astigmatic vector components for both K and TK values. The study assessed the influence of these differences on IOL power calculations using different formulas. The results were analyzed and plotted using Bland-Altman and double angle plots.

Results: The study encompassed a total of 116,982 measurements from 57,862 right eyes and 59,120 left eyes. The analysis revealed a high level of agreement between K and TK values, with 93.98% of eyes exhibiting an absolute difference of 0.25 D or less. Astigmatism vector differences exceeding 0.25 D and 0.50 D were observed in 39.43% and 1.08% of eyes, respectively.

Conclusions: This large-scale study underscores the similarity between mean K and TK values in healthy eyes, with rare clinical implications for IOL power calculation. Noteworthy differences were observed in astigmatism values between K and TK. Future investigations should delve into the practicality of TK values for astigmatism correction and their implications for surgical outcomes.

Introduction

For more than a century, the corneal power, displayed as keratometry (K) values, has been calculated based on measurements from the anterior corneal surface only, with assumptions made about the posterior corneal curvature and central corneal thickness. The anterior radius of curvature (in mm) is converted into the dioptric power of the whole cornea through a fictitious refractive index, usually defined as the keratometric refractive index (n_K), whose most commonly used value is 1.3375 (the Javal Index). The corneal power, obtained in this way, has been successfully used for many purposes, including intraocular lens (IOL) power calculations. Since most biometers and tomographers work with this value, the Javal Index is still used for reasons of compatibility with established IOL constants. However, since this index refers to the back vertex reference plane based on the classical Gullstrand model eye, it may slightly overestimate corneal power and adversely affect calculated IOL power.[1,2]

In recent years, devices based on Scheimpflug imaging or swept-source optical coherence tomography (SS-OCT), have enabled measurement of the posterior corneal curvature. One SS-OCT based biometry device, the IOLMaster 700 (IOLM700, Carl Zeiss Meditec AG, Jena, Germany), derives total corneal power using anterior, posterior corneal curvature and corneal thickness to generate total keratometry (TK) values. The IOLM700 anterior to posterior corneal curvature ratio (APR) closely resembles the Gullstrand ratio[3–5], thus enabling surgeons to utilize established IOL formula constants (e.g. ULIB or IOLCON) in combination with IOLM700 TK values without further adjustments. However, the IOLM700 posterior curvature radii differ from those of other SS-OCT devices, bringing into question the utility and interchangeability of these measurements. [3–5] For example, one source for further inquiry is corneal asphericity. As the cornea has asphericity on both the anterior and posterior surfaces, curvature measurements are dependent on the measurement zone. Thus, the studied biometer's ability to generate TK values must be further evaluated considering this potential limitation.

The concept of the IOLM700 TK value is to maintain the corneal power of normal eyes, but to meaningfully change corneal power in pathologic eyes (post refractive surgery, keratoconus, corneal scars, etc.), in order to produce more accurate results with established formula constants. Indeed, some authors have shown equivocal changes in outcomes in normal eyes, and improved results in post laser vision correction (LVC) eyes using TK values, which may support the concept of basing the posterior radius on the Gullstrand ratio.[3,6–8]

In the present study, we sought to further study the IOLM700 TK concept in normal eyes, studying multiple international large data sets with ethnic variation to better quantify relative and absolute differences between IOLM700 K and TK values, and report the impact of these differences on IOL power calculation in classical formulas.

Patients and Methods:

Study Design

This retrospective study conformed to ethics codes based on the tenets of the Declaration of Helsinki. Prior ethics approval was obtained (Ärztekammer des Saarlandes, 157/21). An Excel .CSV file (Microsoft Corporation) of exported biometry data collected using the IOLM700 SS-OCT biometry device (Software versions used included 1.70.14.53814 through 1.90.12.05) of patient exams from ten international centers acquired between 2018 and 2022 were included. Study centers from Europe, Asia, and North America are listed in supplementary table 1.

Every center had a recent software version for the SS-OCT biometer, as TK measurements were required to enter this study. All data acquisition was executed by experienced staff at the study centers.

The exported, anonymized biometric data were further studied using the following methods. Regarding corneal curvature measurements, we recorded the flat and steep anterior (R1 and R2), posterior (PR1 and PR2) and total corneal radii (TR1 and TR2), as well as their meridians. It is of note that while R and PR are real measurable radii, there is no real TR measurable in the human eye. Rather, TR is derived from an equivalent power (TK): First total corneal power is derived from a Gullstrand thick lens cornea model (R, PR, and CCT), then it is converted into a radius (TR) using one specific keratometric index that allows IOL calculation with most established IOL calculation formulas including Haigis. After this conversion to TR, TK can be calculated using the default or preferred keratometric index that is used for K values (e.g. 1.3375, or 1.332).

Corneal curvature data was converted from R and TR to anterior (K1, K2) and total (TK1, TK2) corneal power using a corneal refractive index of n_K=1.3375. Corneal power was expressed in 3 vector components including equivalent power (VEQ) and astigmatic vector considered in the 0/90° meridian (V0) and in the oblique 45°/135° meridian (V45)[4,9]:

$$K_{mean} = VEQ_K = 0.5 \cdot \left(\frac{nK-1}{R1} + \frac{nK-1}{R2}\right)$$

$$V0_K = \left(\frac{(nK-1)}{R1} - \frac{(nK-1)}{R2}\right) \cdot \cos(2 \cdot \mathrm{A1})$$

$$V45_K = \left(\frac{(nK-1)}{R1} - \frac{(nK-1)}{R2}\right) \cdot \sin(2 \cdot \mathrm{A1})$$

and

$$TK_{mean} = VEQ_{TK} = 0.5 \cdot \left(\frac{nK-1}{TR1} + \frac{nK-1}{TR2}\right)$$

$$V0_{TK} = \left(\frac{(nK-1)}{TR1} - \frac{(nK-1)}{TR2}\right) \cdot \cos\left(2 \cdot \mathrm{TA1}\right)$$

$$V45_{TK} = \left(\frac{(nK-1)}{TR1} - \frac{(nK-1)}{TR2}\right) \cdot \sin\left(2 \cdot \mathrm{TA1}\right)$$

Exclusion of questionable measurement quality

Prerequisite for inclusion was the fulfillment of all instrument-given quality indices (QI) during measurement. The instrument displays QI as “failed”, “warning”, or “successful”. A QI of “failed” or “warning” in any keratometric measurement led to the exclusion of the whole eye, allowing for a rough exclusion of eyes with malfixation, later stages of keratoconus, and corneal scarring. As identified by instrument settings, eyes with pseudophakia, phakic duophakia, vitrectomy, a history of previous laser vision correction, or any other history of ocular surgery were excluded. Duplicate measurements of eyes were omitted.

Statistical Analysis

Virgin eyes were then divided into eyes with steep corneal curvature (anterior radius < 7.337 mm (corresponding to ≥46 diopters (D) with n_K=1.3375)), normal corneal curvature (7.337 mm – 8.036 mm (corresponding to 42 D to 46 D with n_K=1.3375)), and flat corneal curvature (> 8.036 mm (corresponding to ≤42 D with n_K=1.3375)). For each subgroup descriptive statistics including mean and SD, median and IQR, 2.5% quantile, and 97.5% quantile were provided.

Differences between VEQ_K and VEQ_{TK} (using TK-K) and difference vectors between $V0_K$ and $V0_{TK}$, and $V45_K$ and $V45_{TK}$ were calculated and descriptive statistics were applied. Differences and absolute differences are provided. Differences for VEQ_K and VEQ_{TK} are shown with Bland-Altman plots. Differences for $V0_K$ and $V0_{TK}$, and $V45_K$

and $V45_{TK}$ are shown with double angle plots. Furthermore, the proportion of eyes with an absolute difference between VEQ_K and VEQ_{TK} of 0.25 and 0.50 D are reported.

The predicted postoperative spherical equivalent (SEQ) for the Haigis, Hoffer Q, Holladay, and SRK/T formulas were calculated using both K and TK values.[10–14] Differences and absolute differences are reported. Of note, the Haigis formula predicts effective lens position (ELP) without using corneal curvature, whereas the Hoffer Q, Holladay, and SRK/T do use it. For the sake of uniformity for comparisons, we chose the CT LUCIA 621P/PY IOL platform (Carl Zeiss Meditec AG) assuming an implanted IOL with a power of +21.0 D in all cases while using IOLCON optimized constants (optimized for best root mean squared prediction error) from IOLCON.org (Haigis a0/a1/a2 = -0.0527/0.2904/0.1989; Hoffer Q pACD = 6.082; Holladay SF = 2.298; SRK/T A-constant = 119.727). The proportion of eyes with an absolute difference in predicted SEQ of 0.25 and 0.50 D are reported. APR and the Cooke-Riaz-Wendelstein Index 1 (CRW1), an Index to detect eyes after myopic laser vision correction, were calculated for all eyes.[15]

Subgroups were tested for statistically significant differences using the Wilcoxon signed rank test. For bivariate analysis, bivariate normal distribution was tested using the Henze-Zirkler's Multivariate Normality Test. Normally distributed bivariate data were compared using a Hotelling T^2 test, nonparametric bivariate data was compared using a multivariate rank-sum test. The Bonferroni method was used for multiple comparisons adjustment.

Results

Demographic Data

A total of 116,982 measurements of 57,862 right and 59,120 left eyes met criteria for inclusion in our analysis dataset. **Supplementary Table 1** shows the descriptive data of the biometric measures of right eyes for the entire study population in terms of axial length (AL), central corneal thickness (CCT), anterior chamber depth (ACD, measured from the corneal epithelium to the anterior lens surface), lens thickness (LT), and the radii of curvature for the corneal front and back surfaces. The difference in mean keratometric power K / TK with the IOLM700 between right and left eyes was 0.05 D (43.75 ± 1.60 D / 43.81 ± 1.62 D in right eyes, and 43.80 ± 1.60 D / 43.86 ± 1.62 D in left eyes).

[insert supplementary Table 1]

Table 1 shows that in all datasets at least 91.13% and on average 93.98% of eyes were within an absolute difference of 0.25 D between K and TK values. Less than 0.40% of eyes showed an absolute difference of at least 0.50 D between K and TK measurement.

[insert Table 1]

The anterior/posterior corneal curvature ratio (APR) observed with the IOLM700 was 1.12±0.02 (95% CI: 1.08 – 1.17). The mean CRW1 Index was 3.37±2.70 with a 95%CI from 0.01 to 9.96 (**Table 2**).[15] The magnitude of the difference vector (DV) between astigmatism calculated with K and TK values was 0.23±0.10 D.

[insert Table 2]

Table 3 depicts TK-K in eyes with flat, normal, and steep corneal curvature, as well as normal and suspicious CRW1 Index. **Fig. 1 a-g** depict the correlations of TK-K with certain parameters and the difference between both keratometry modes calculated as TK-K is plotted against CCT, Kmean, astigmatism magnitude, APR and the CRW1 Index. A linear regression line displays correlations of both values. Besides the obvious correlation on APR, there were no relevant dependencies observed. For CCT vs. TK-K, R^2 was 0.0113, and vs. the absolute difference, R^2 was 0.0177. For Kmean vs. TK-K, R^2 was 0.082, and vs. the absolute difference, R^2 was 0.0057. For the magnitude of astigmatism vs. TK-K, R^2 was 0.0007, and vs. the absolute difference, R^2 was 0.0009. For the CRW1 Index vs. TK-K, R^2 was 0.0022, and vs. the absolute difference, R^2 was 0.0011. For APR vs. TK-K, R^2 is 0.9923, and vs. the absolute difference, R^2 is 0.0681.

[insert Figure 1]

[insert Table 3]

Fig. 2 displays the difference (TR-R and TK-K) over the mean value (Bland-Altmann plot) for the keratometry measurements in right eyes for corneal curvature (**Fig. 2a**) and corneal power (**Fig. 2b**).

[insert Figure 2]

Table 4 analyzes differences in predicted refraction of a +21.0 D Lucia 621P/PY IOL using either K or TK values for power calculation. **Fig. 3** shows the difference (in predicted SEQ using K or TK) over the mean value (Bland-Altmann plot) for the predicted SEQ calculated in right eyes.

[insert table 4]

[insert Figure 3]

Table 5 analyzes the magnitude of astigmatism (0.94 D for K, and 0.97 D for TK). The centroid for K values is 0.17 D @ 84° and the centroid for TK is 0.11 D @ 36°. According to K values, 48.35% of all eyes showed a vertical astigmatism configuration (WTR), whereas 33.0% showed a horizontal astigmatism configuration (ATR). Reflecting the centroids, according to TK values, 38.84% of those same eyes exhibited a vertical WTR astigmatism configuration, whereas 42.24% exhibited a horizontal ATR configuration. Cartesian coordinates are further analyzed and described in **Table 5**. The double angle plots display the centroids and 95% confidence ellipses of K and TK derived astigmatism measurements in **Fig. 4a**, and difference vectors between K and TK derived astigmatism including the centroid and a 95% confidence ellipse in **Fig. 4b**. Bivariate data of $V0_K$ and $V45_K$ and $V0_{TK}$ and $V45_{TK}$ did not have a normal distribution (both $p<0.1$). There were statistically significant bivariate differences between K and TK derived astigmatic vectors V0 and V45 ($p<0.01$). We found that 39.43 % of all eyes had a DV magnitude of more than 0.25 D, while only 1.08 % of all eyes had a DV magnitude of 0.50 D between K and TK derived astigmatism.

When considering eyes with DVs larger than 0.50D, around 22% exhibited a vertical WTR orientation of astigmatism (based on keratometry measurements), while nearly 60% displayed a horizontal ATR orientation ; only 18% were in the oblique (OBL) range. For eyes with DVs greater than 0.25D, approximately 39% showed a WTR orientation of astigmatism, and about 42% had an ATR orientation. Among eyes with DVs smaller than 0.25D, roughly 55% had a WTR orientation of astigmatism, while approximately 27% had a horizontal ATR orientation.

Analyzing eyes with DVs larger than 0.50D, it was found that the DV (from TK to K) was oriented as follows: ATR in 93.06% of eyes, WTR in 3.12% of eyes, and oblique (OBL) in 3.82% of eyes. In eyes with DVs larger than 0.25D, the orientations were ATR in 96.97% of eyes, WTR in 0.54% of eyes, and OBL in 2.49% of eyes. In eyes with DVs smaller than 0.25D but larger than 0.10D, the orientations were ATR in 88.49% of eyes, WTR in 1.76% of eyes, and OBL in 9.75% of eyes. **Supplementary Fig. 1** plots $V0_K$ against $V0_{DV}$ and $V45_K$ against $V45_{DV}$ to give a better understanding on how DVs (or rather vectors from posterior keratometry) change vectors from anterior keratometry.

[insert table 5]

[insert figure 4]

Discussion

Historically, biometers have measured anterior corneal power and empirically accounted for the power contribution from the posterior cornea through a fictitious keratometric index. When changing to directly measured posterior corneal power, two scenarios are possible. First, total corneal power from a device with an APR that resembles a modern model eye, for example the Liou & Brennan model eye, may be used, with the consequence that new IOL formula constants must be established for classical IOL formulas. Second, if APR resembles the Gullstrand model, current IOL power constants can be continued to be used. Both scenarios should lead to more accurate IOL calculation results in eyes with abnormal corneas, but the latter should not change the corneal power in eyes with normal corneas. The TK concept of the IOLM700 is based on the latter concept.

Our study confirms the results of several studies that have demonstrated that K and TK provide comparable values, with no significant differences in healthy, unoperated eyes.[6,7] **Table 6** reports the mean values of other studies and reveals that only a minority of eyes have a difference of 0.25 D or greater.

[insert table 6]

Interestingly, confirming the results of our previous studies, measurements obtained with the IOLMaster 700 are different compared to those obtained with other devices, as the IOLM700 APR is usually 1.12 rather than 1.20-1.22.[3,15] This suggests that, on average, the IOLMaster 700 measures a flatter posterior corneal radius. This was true for the several European, Asian and American eyes in our dataset. In our database, the APR observed with the IOLMaster 700 is 1.12 ±0.02 (95% CI: 1.08 – 1.17). Since anterior and posterior corneal surfaces are actually not spherical but rather aspherical, the reconstructed radii strongly depend on the measurement and reconstruction method, primarily the incorporated zone diameter. Previous studies carried out with Scheimpflug cameras or anterior segment optical coherence tomographers reported APR similar to the Liou Brennan model eye, nonetheless, standard deviation seems to be between 0.02 and 0.04 D, independent of the measurement device (**Table 2 and Table 7**).[3–5,16–21] In our dataset, there was no noticeable difference in APR for gender, location (USA, Europe, Asia), or laterality (OD, OS).

Wei et al. found that a larger difference between K and TK was associated with a thinner CCT.[22] This could not be reproduced in our dataset (**Fig. 1a and b**). Corneal thinning is typically associated with keratoconus, which should lead to differences in both values (K and TK), but Wei et al. performed preoperative Scheimpflug tomography and excluded eyes with keratoconus, hence, undetected preclinical keratoconus is not likely to explain the difference in both studies. We were able to show that the difference between K and TK can be used to detect eyes after LVC.[15,23] While the heteroscedasticity of **Fig.2** could not be explained by flat or steep corneal curvature (**Table 3**), nor by CCT or astigmatism magnitude (**Fig.1**), eyes with a conspicuous CRW1 index that showed a noticeably larger difference between TK and K values than all other eyes and most likely constitute outliers in flat corneas. Although the maximum attention was paid to exclude cases with prior corneal refractive surgery or keratoconus, it is possible that in such a large retrospectively multiple-site collected dataset a minority of eyes was mislabeled.

When it comes to the clinical impact on IOL power calculation, some studies investigated the differences in the refractive outcomes between K and TK, once these are entered into IOL formulas to calculate the spherical equivalent power. It needs to be noted, that some formulas also use K values only to calculate the vergence of paraxial rays, whereas other formulas use it also to predict the ELP. Hence, formulas are influenced by varying degrees when switching from K to TK values. To our knowledge, no study on normal eyes reports the use of TK values with a double K mode (using TK for the cornea model and K for the ELP calculation), which might be the “cleanest” way to incorporate TK values. The use of TK values is associated with favorable results in eyes with abnormal corneas, such as eyes after LVC[8,24,25], eyes with keratoconus[26], and eyes after DMEK surgery (Rangu N, et al.

currently in submission). Unsurprisingly, it shows less favorable results in eyes undergoing triple DMEK surgery.[27] In eyes with normal corneas, slightly contradictory findings were reported: Danjo et al. showed better outcomes in 225 eyes when K rather than TK was used.[28] No significant differences were found by Ryu et al. in a sample of 62 eyes, by Wei et al, in a sample of 103 highly myopic eyes (with no prior laser correction), by Jeon et al in a sample of 101 eyes and by Tsessler et al in a sample of 153 eyes.[7,22,29,30] The similar refractive outcomes obtained with TK in this study mirror the findings of a previous study where the total corneal power was calculated by Scheimpflug cameras.[16] On the contrary, Fabian et al. reported better results entering TK rather than K into the Barrett and Haigis formulas.[31] Similarly, Srivannaboon et al. observed a trend toward more accurate results with TK.[32] Of course, the results from the above-mentioned studies are influenced by the percentage of eyes with an unusual ratio between the anterior and posterior corneal radii and, as a consequence, a larger than expected difference between K and TK. In this regard, it should be noted that the prediction error of the Holladay 1 and SRK/T formulas has already been found to be correlated to the A/P ratio by Savini et al., whereas such correlation was not detected by Hasegawa et al.[16,20]

In order to realize how often a clinically significant difference can be observed between K and TK, it was necessary to collect a large sample of eyes and this was the primary aim of this study. Our data confirm that, on average, K and TK do not show a clinically relevant difference in healthy unoperated eyes. This was true for keratometric indices of 1.332 and 1.3375 for Kmean and SE /TSE values. Clinically relevant differences that impact IOL power (eyes that revealed a difference of target refraction of at least 0.50 D), were found in less than 0.5% of cases for all formulas. This further confirms the TK concept to work with established IOL constants in normal eyes.

Unlike corneal power, larger differences were noticed in K and TK derived astigmatism. We chose to display results using a keratometric index of 1.332, as any calculations with astigmatism values do not need to work with established formula constants and 1.332 seems to be closer to back calculations of the keratometric index.[1,2] Similar to an earlier study, we observed significant differences in K and TK derived astigmatism.[3] In nearly 40% of all cases, the DV between both modalities was more than 0.25D. Considering that DVs not only display differences in astigmatism magnitude, but also in astigmatism orientation, results of surgical astigmatism correction can be heavily influenced by the right modality to base the correction on. We have observed that the higher the difference vector, the more frequently an ATR astigmatism was present. Based on a small patient cohort, Sharma et al. observed that the best results were obtained when the intraocular lens (IOL) axis for the IOL rotation procedure was planned using postoperative TK values instead of relying on postoperative measurements with the Barrett Toric Calculator or the Berdahl and Hardten Astigmatism Fix Calculator website. This finding indicates that considering TK values for IOL rotation can lead to improved outcomes in eyes with misaligned toric IOLs.[33] Further studies should shed light on the applicability of TK values in astigmatism correction.

This study is not without limitations. First, although the maximum attention was paid to exclude cases with prior corneal refractive surgery or keratoconus, it is possible that in such a large retrospectively multiple-site collected dataset a minority of eyes was mislabeled. This may explain the presence of some eyes with extreme K and CCT values, and of some eyes with a conspicuous CRW1 index that showed a noticeably larger difference between TK and K values than all other eyes and most likely constitute outliers in flat corneas seen in **Fig. 2**. Second, due to their undisclosed nature, we were not able to compare predicted refraction of new generation IOL power formulae. Third, we were unable to report refractive results and analyze if K or TK led to more favorable surgery outcomes. Future studies should focus on this subject.

In conclusion, the posterior cornea has garnered increased attention in recent years, leading to a shift from using anterior corneal power (K) to total corneal power (TK) in IOL calculations. Comparisons between K and TK values have shown generally comparable results in healthy eyes, with only a minority exhibiting significant differences. While favorable outcomes have been observed in eyes with abnormal corneas, findings in eyes with normal corneas are somewhat equivocal. Nevertheless, this large-scale study affirms that K and TK values do not significantly differ in healthy eyes, and clinically relevant differences impacting IOL power calculation are rare. Further research is needed to explore the applicability of TK values in astigmatism correction and to assess their impact on surgical outcomes.

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Figure Legend:

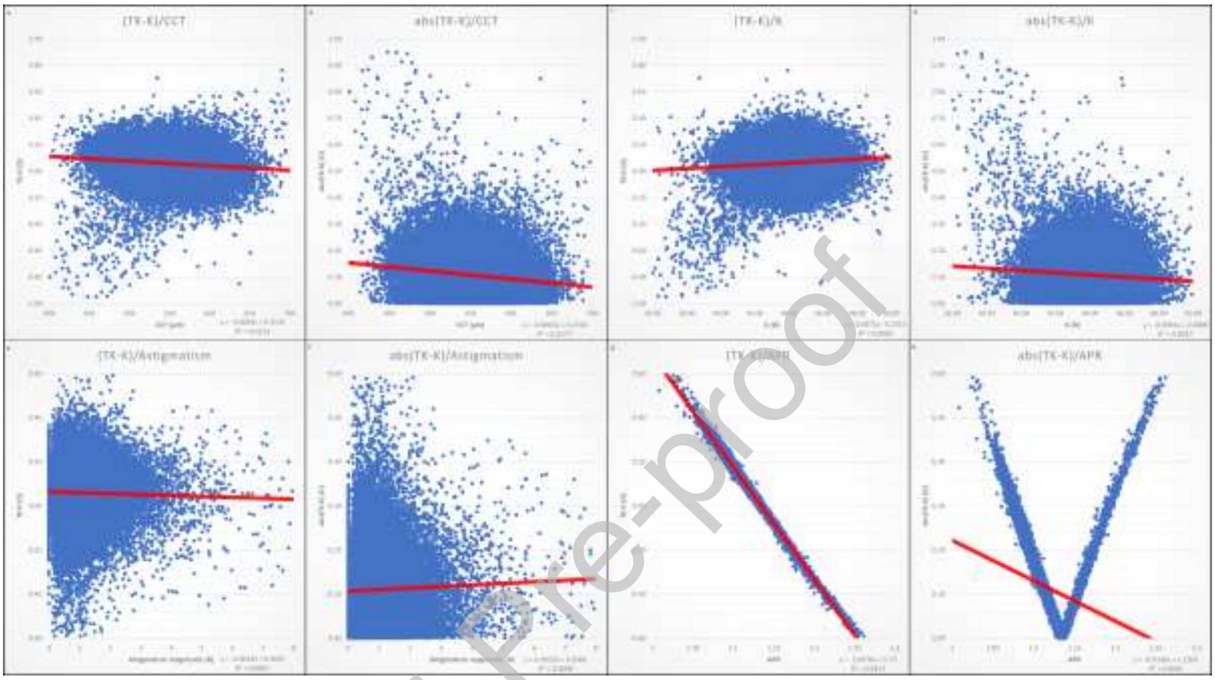

Figure 1: Figure 1 depicts the correlations of TK-K with certain parameters. For this purpose, the difference between both keratometry modes calculated as TK-K is plotted against CCT, Kmean, astigmatism magnitude, and APR. A linear regression line displays correlations of both values.

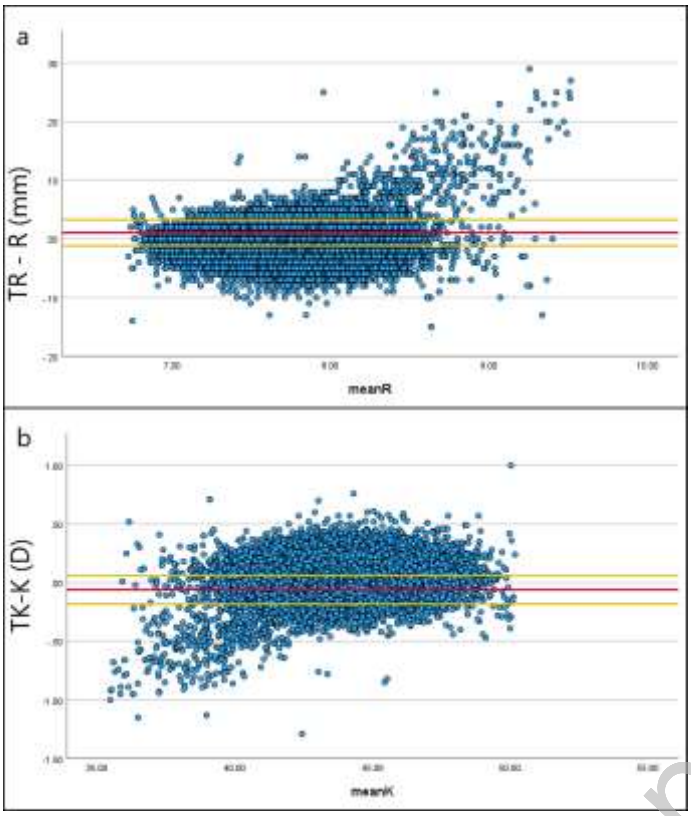

Figure 2: The Bland-Altmann plots show the differences between both display modes of keratometry measurement versus the mean difference value including the mean value (red line) and the 95% confidence intervals (yellow lines).

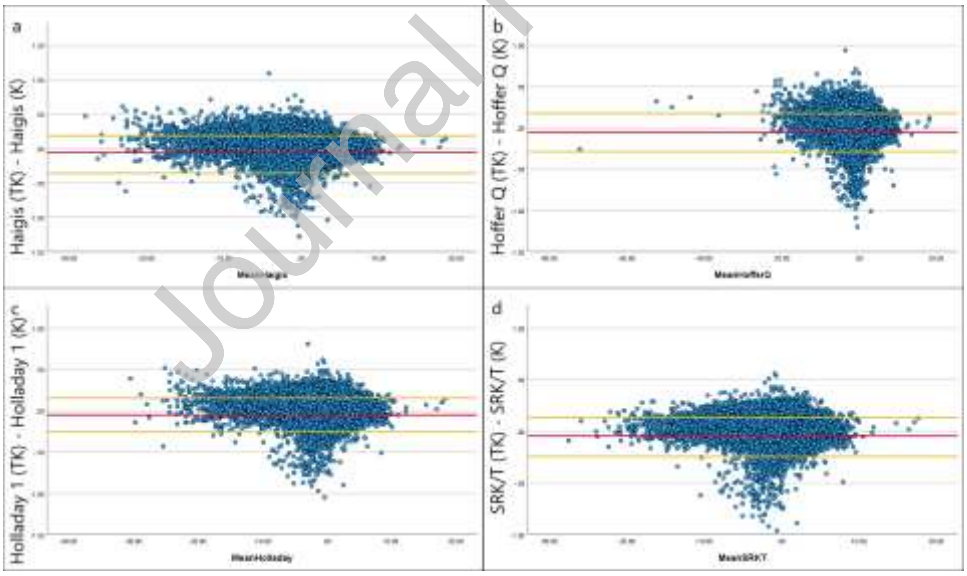

Figure 3: The Bland-Altmann plots show the differences between the predicted refraction calculated with keratometry or total keratometry measurement versus the mean difference value including the mean value (red line) and the 95% confidence intervals (yellow lines) using the Haigis formula (Figure 3a), the Hoffer Q formula (Figure 3b), the Holladay Formula (figure 3c), or the SRK/T formula (Figure 3d).

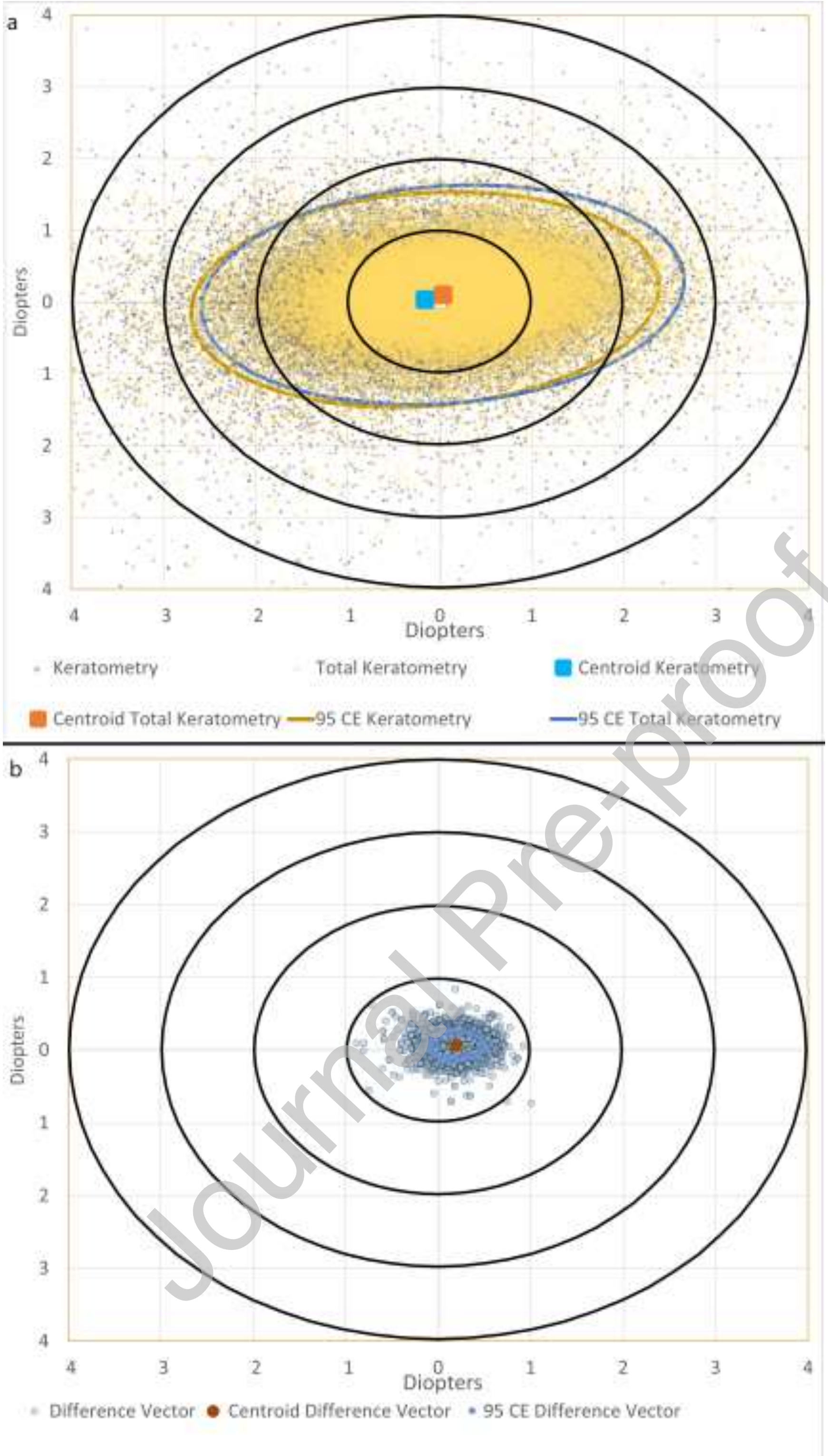

Figure 4: Double Angle plot of K and TK Astigmatism (figure 4a) and of DV between both (figure 4b). Each Ring is 1.0 D. Displayed is each eye, the centroid and the 95% confidence ellipse. The keratometric index chosen to display astigmatism is nk=1.332

Table 1

			Maximum absolute difference (mm/D)	Eyes with a difference <	
	R & K (mm/D)	TR & TK (mm/D)	mm/D	±0.25 D	±0.50 D
Bern OD (n=2,052)	7.71±0.28 43.84±1.59	7.70±0.28 43.91±1.59	0.14 0.72	92.40 %	99.71%
Castrop OD (n=3,865)	7.73±0.27 43.70±1.52	7.72±0.27 43.76±1.52	0.18 0.83	96.12%	99.90%
Linz OD (n=6,210)	7.70±0.27 43.90±1.51	7.69±0.27 43.97±1.52	0.16 1.01	94.89%	99.94%
Oklahoma City OD (n=4,993)	7.72±0.32 43.80±1.75	7.71±0.33 43.86±1.79	0.29 1.15	91.13%	99.12%
Paris OD (n=28,004)	7.74±0.29 43.67±1.63	7.73±0.30 43.73±1.65	0.27 1.29	93.55%	99.52%
Penn State OD (n=1,771)	7.69±0.28 43.93±1.57	7.68±0.28 44.02±1.58	0.09 0.58	92.59%	99.89%
Singapore OD (n=2,268)	7.66±0.26 44.09±1.47	7.66±0.26 44.13±1.48	0.16 0.64	95.55%	99.82%
St. Joseph OD (n=322)	7.67±0.27 44.06±1.60	7.67±0.28 44.09±1.60	0.13 0.65	96.27%	99.69%
Rome OD (n=1,107)	7.76±0.27 43.52±1.52	7.76±0.27 43.56±1.53	0.25 1.13	97.38%	99.91%
Vienna OD (n= 7,270)	7.72±0.27 43.75±1.50	7.71±0.27 43.82±1.50	0.20 0.88	95.27%	99.94%
Total VEQ OD (1.3375) (n=57,862)	7.73±0.28 43.75±1.60	7.72±0.29 43.81±1.62	0.29 1.29	93.98%	99.65%
Total SE/TSE OD (1.3375) (n=57,862)	7.73±0.28 43.74±1.60	7.72±0.29 43.80±1.62	0.29 1.29	93.98%	99.64%
Total VEQ OD (1.332) (n=57,862)	7.73±0.28 43.04±1.57	7.72±0.29 43.10±1.59	0.29 1.27	94.33%	99.66%
Total VEQ OS (1.3375) (n=59,120)	7.72±0.28 43.80±1.60	7.71±0.29 43.86±1.62	0.27 1.07	94.16%	99.60%

Table 1 displays keratometry data of right eyes (subsets for various locations and complete dataset) and left eyes (only complete dataset) using the equivalent power (VEQ). Data is shown using a keratometric index n_K=1.3375 and for reasons of comparison, the total cohort is also shown using a keratometric index nK = 1.332.
Furthermore, differences for a keratometric index nK = 1.3375 using the so called “SE (spherical equivalent)” and “TSE (total spherical equivalent)” instead of the VEQ are displayed. The difference is that VEQ is calculated by averaging the corneal power of each meridian, whereas SE is a direct conversion (by means of the keratometry index) of the mean corneal radius. The latter is displayed on the printouts of the study device.

Table 2

	Mean	SD	Median	Min	Quantiles (%)				Max
					2.5	5	95	97.5	
CRW1	3.37	2.70	5.05	-4.86	0.01	0.08	5.37	9.96	10.63
APR	1.12	0.02	1.12	0.96	1.08	1.09	1.16	1.17	1.39

Table 2: Analysis of anterior to posterior corneal curvature ratio (APR), and Cooke-Riaz-Wendelstein Index 1 (CRW1) in right eyes. The keratometric index used for this analysis is 1.3375.

Table 3

	MD (SD)	MedD (IQR)	D 95% CI	MAD (IQR)	AD 95% CI	AD 90% CI	% ±0.25D	% ±0.50D	N
	Difference in VEQ_K and VEQ_{TK}								
Flat curvature	*0.03 (0.17)*	*0 (0.19)*	*-0.48 to 0.28*	*0.13 (0.12)*	*0 to 0.48*	*0.01 to 0.35*	*90.21*	*97.76*	*7,399*
Normal curvature	*0 (0.13)*	*0 (0.19)*	*-0.25 to 0.25*	*0.11 (0.11)*	*0 to 0.29*	*0.01 to 0.25*	*94.75*	*99.93*	*46,007*
Steep curvature	*0 (0.14)*	*0.01 (0.20)*	*-0.28 to 0.28*	*0.11 (0.12)*	*0 to 0.32*	*0.01 to 0.28*	*92.28*	*99.89*	*4,456*
CRW1 Index less or equal than -0.22	*-0.45 (0.20)*	*-0.42 (0.24)*	*-0.89 to -0.15*	*0.45 (0.20)*	*0.15 to 0.89*	*0.17 to 0.80*	*15.69*	*66.80*	*497*
CRW1 Index higher than -0.22	*0.07 (0.12)*	*0.07 (0.15)*	*-0.18 to 0.28*	*0.11 (0.08)*	*0 to 0.29*	*0.01 to 0.25*	*94.66*	*99.93*	*57,365*

Table 3: Analysis of subsets with flat corneal curvature, normal corneal curvature and steep corneal curvature, as well as normal and suspicious CRW1 Index. Steep corneal curvature is defined as Rmean < 7.337 mm), normal corneal curvature is defined as Rmean >7.337 mm and < 8.036 mm), and flat corneal curvature is defined as Rmean > 8.036 mm.. A CRW1 Index lower or equal than -0.22 was considered as suspicious, higher than -0.22 was considered as normal.

MD = mean difference ; MedD = median difference ; MAD = mean absolute difference; AD X% CI = X% confidence interval of the absolute differences;

Table 4

	Difference			Absolute Difference					
	Mean (SD)	Median (IQR	95% CI	Mean	IQR	95% CI	90% CI	% ± 0.25 D	% ± 0.50 D
Haigis	-0.06 (0.13)	-0.07 (0.15)	-0.28 to 0.19	0.11	0.11	0 to 0.31	0.01 to 0.26	94.01	99.95
SRK/T	-0.04 (0.09)	-0.05 (0.11)	-0.20 to 0.14	0.08	0.08	0 to 0.22	0.01 to 0.19	98.58	99.81
Holladay	-0.05 (0.10)	-0.05 (0.12)	-0.23 to 0.16	0.09	0.09	0 to 0.25	0.01 to 0.21	97.50	99.77
Hoffer Q	-0.06 (0.12)	-0.06 (0.14)	-0.18 to 0.27	0.10	0.10	0 to 0.29	0.01 to 0.24	95.50	99.66

Table 4 analyzes differences in the predicted target refraction (TR) (or in other words, the predicted postoperative spherical equivalent) of a +21.0 D Lucia 621P/PY IOL using either K or TK values for power calculation. Differences are calculated as TR_{TK}-TR_{K}.

Table 5

	Mean (SD)	Median (IQR)	Min	Quantile 2.5	Quantile 5	Quantile 95	Quantile 97.5	Max
K - Magnitude	*0.94 (0.77)*	*0.76 (0.75)*	*0*	*0.12*	*0.18*	*2.32*	*2.88*	*18.37*
TK- Magnitude	*0.97 (0.77)*	*0.79 (0.78)*	*0*	*0.13*	*0.19*	*2.37*	*2.90*	*18.54*
DV-Magnitude	*0.23 (0.10)*	*0.22 (0.14)*	*0*	*0.05*	*0.07*	*0.41*	*0.45*	*1.24*
$V0_K$	*-0.16 (1.04)*	*-0.13 (1.13)*	*-10.45*	*-2.36*	*-1.81*	*1.38*	*1.77*	*17.51*
$V45_K$	*0.04 (0.61)*	*0.04 (0.60)*	*-7.19*	*-1.19*	*-0.86*	*0.91*	*1.16*	*11.33*
$V0_{TK}$	*0.03 (1.07)*	*0.06 (1.18)*	*-10.78*	*-2.24*	*-1.67*	*1.64*	*2.04*	*17.68*
$V45_{TK}$	*0.10 (0.62)*	*0.11 (0.62)*	*-7.32*	*-1.15*	*-0.82*	*1.0*	*1.26*	*11.68*

Table 5 analyzes astigmatic data, including the magnitude of astigmatism derived from anterior keratometry (K), and Total Keratometry (TK), and the magnitude of the difference vector between both (DV). Furthermore, Cartesian coordinates displaying the astigmatic vector considered in the 0/90° meridian (V0) and in the oblique 45°/135° meridian (V45) are analyzed for K and TK values. Displayed are results from 57,862 right eyes with a keratometric index of nk=1.332.

Table 6

	Keratometry (D)	Total Keratometry (D)	Eyes with a difference > ±0.25 D
Savini et al. (n = 69)	43.14 ±1.37	43.18 ±1.37	2 (2.9%)
Ryu et al. (n = 91)	44.20 ±1.46	44.24 ±1.48	N/A
Srivannaboon et al (n = 60)	44.56 ±1.18	44.59 ±1.22	N/A

Table 6 displays mean values of (anterior) Keratometry and Total Keratometry reported by previous studies.

Table 7

Study	N	Device	Average ± standard deviation	95%CI	Range
Debellemanière et al.	2,554	Pentacam	1.21 ± 0.04	n/a	0.83 – 1.41
Fam et al	2,429	Pentacam	1.22 ±0.03	n/a	1.10 - 1.35
Næser et al	951	Pentacam	1.21 ±0.02	n/a	1.13 – 1.32
Ho et al.	221	Pentacam	1.223 ±0.034	n/a	1.086 - 1.391
Savini'09 et al	71	Pentacam	1.22 ±0.02	n/a	1.14 - 1.31
Hasegawa et al	501	Casia SS-1000	1.19 ±0.02	n/a	1.11 - 1.26
Savini'17 et al	114	Sirius	1.20 ±0.03	n/a	1.10 - 1.30
Langenbucher et al.	854	Anterion	1.19 ± 002	1.06 – 1.09	n/a
Langenbucher et al.	854	IOLM700	1.12 ± 0.02	1.14 – 1.16	n/a
Wendelstein et al. Female short eyes	114	IOLM700	1.12 ± 0.02	n/a	1.08 – 1.18
Wendelstein et al. Female normal eyes	5470	IOLM700	1.12 ± 0.02	n/a	0.96 – 1.27
Wendelstein et al. Female long eyes	114	IOLM700	1.12 ± 0.02	n/a	1.06 – 1.18
Wendelstein et al. Male short eyes	93	IOLM700	1.13 ± 0.02	n/a	1.07 – 1.18
Wendelstein et al. Male normal eyes	4,415	IOLM700	1.12 ± 0.02	n/a	1.0 – 1.32
Wendelstein et al. Male long eyes	93	IOLM700	1.12 ± 0.03	n/a	1.06 – 1.18
Current dataset OD	57,862	IOLM700	1.12 ± 0.02	1.08 – 1.17	0.96 – 1.39

Table 7 displays anterior-to-posterior corneal radii ratio reported in previous studies. Measurement were performed with the Pentacam (Oculus), Casia SS-1000 (Tomey), Sirius (CSO), Anterion (Heidelberg engineering), and IOL Master 700 (Carl Zeiss Meditec AG). In the study by Wendelstein et al., long and short eyes were defined as longer and shorter than the 98th and 2nd percentile of the dataset (27.73 and 21.75 mm).

Table of Contents

Studying total keratometry (TK), this multicenter study analyzed 116,982 measurements from diverse international datasets. High agreement (93.98%) between traditional keratometry (K) and TK was found in 57,862 right eyes and 59,120 left eyes. Minimal impact on intraocular lens power calculations was observed. Astigmatism vector variations (>0.25 D) occurred in 39.43% of eyes. This study underscores TK's similarity to K in healthy eyes, urging exploration of its utility in astigmatism correction and surgical outcomes.