Assessing Total Keratometry Astigmatism, Simulated Keratometry, and Total Corneal Topographic Astigmatism Against Manifest Refractive Cylinder

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Assessing Total Keratometry Astigmatism, Simulated Keratometry, and Total Corneal Topographic Astigmatism Against Manifest Refractive Cylinder

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ABSTRACT

PURPOSE: To evaluate how the Total Keratometry astigmatism measure from a swept-source optical biometer compares with simulated keratometry astigmatism from the same device, and total corneal topographic astigmatism (CorT Total) derived from a Scheimpflug tomographer.

METHODS: For normal virgin eyes, the ocular residual astigmatism (ORA) magnitudes were determined based on Total Keratometry, simulated keratometry from the same optical biometer ($SimK_{biom}$), and CorT Total and simulated keratometry ($SimK_{Scheim}$) from a Scheimpflug tomographer. The ORA magnitudes for each type of measure were summarized into the standard deviations (ORAsd) and means (ORAmean). The lower the ORAsd, the less variability there is between corneal astigmatism and manifest refractive cylinder. The ORAmean indicates the amount of vectorial difference between the total corneal astigmatism and manifest refractive cylinder.

RESULTS: The ORAsd for Total Keratometry was not significantly different from the ORAsd for CorT Total ($P = .06$) or $SimK_{biom}$ ($P = .41$). The ORAmean for Total Keratometry was not significantly different from the ORAmean for CorT Total ($P = .15$), but was significantly lower than the ORAmean for $SimK_{biom}$ ($P < .001$).

CONCLUSIONS: Total Keratometry astigmatism correlates as well with manifest refractive cylinder as simulated keratometry astigmatism from the same device and CorT Total from a Scheimpflug tomographer. The average difference (as quantified by the ORAmean) between Total Keratometry astigmatism and manifest refractive cylinder was comparable to that of CorT Total, and less than that of simulated keratometry. Both of these results support the use of Total Keratometry over simulated keratometry in the planning of astigmatism surgery when corneal values are required.

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A swept-source optical biometer (IOLMaster 700; Carl Zeiss Meditec) has recently added a new measure of total corneal power called Total Keratometry (TK). This measure appears to be able to replace standard keratometry in intraocular lens power calculation, with the potential for improving the prediction accuracy of the postoperative spherical equivalent[1-3] and cylinder.[1]

The problem with evaluating a new measure of corneal power by using refractive outcomes of toric implant surgery is that this method is rather indirect. There are multiple sources of noise in the evaluation, including those caused by a surgical intervention, such as the effect of the surgical incisions on corneal power or the inexact placement and tilt of the intraocular lens.

A more direct assessment of the astigmatic component of TK is possible by assessing its correlation with manifest refractive cylinder in healthy non-cataractous eyes prior to any surgery, in a way that has been performed for other measures of corneal power.[4-6] The concept is to

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analyze the variance of the ocular residual astigmatism (ORA),[7] which is the vectorial difference between the measured corneal astigmatism and the manifest refractive cylinder at the corneal plane, for a group of virgin eyes. If the variance is low, this indicates that the corneal astigmatism measure correlates well with manifest refractive cylinder, and thus that surgical planning using this measure of corneal power is expected to produce more accurate postoperative refractive outcomes.[4]

In this study, we used the same measure as in previous studies to quantify the variance of the ORA, namely the standard deviation of the ORA magnitudes (ORAsd).[4-6] The ORAsd derived from TK on the optical biometer is compared to the ORAsd derived from simulated keratometry from the same device ($SimK_{biom}$). It is also compared to the ORAsd derived from the corneal topographic astigmatism (CorT Total)[5] based on measurements by a previously studied Scheimpflug tomographer, because we know that this particular CorT Total correlates reliably with manifest refractive cylinder, as determined in a study of three tomographers.[4] The ORAsd derived from simulated keratometry from the Scheimpflug device ($SimK_{Scheim}$) is also calculated to allow parallel comparison of anterior and total corneal astigmatism measures on both devices.

We also calculated the mean of the ORA magnitudes (ORAmean) for each measure of corneal astigmatism. The ORAmean quantifies the vectorial difference between the measured corneal astigmatism and the manifest refractive cylinder at the corneal plane. The smaller the ORAmean, the fewer the number of cases with high ORA, which should then reduce the number of cases that require the Vector Planning method.[8]

The ORAsd comparisons allow us to assess how well TK measures corneal astigmatism, as compared with simulated keratometry and another measure of total corneal astigmatism (CorT Total) that has been previously benchmarked.[4] The ORAmean comparisons provide an insight into how often the ORA will be high enough (eg, > 0.75 diopters [D]) that a refractive surgeon may need to actively consider using the Vector Planning method[8] or think of the trade-off between postoperative refractive cylinder and postoperative corneal astigmatism, which can be thought of as the trade-off between visual acuity and visual quality.

PATIENTS AND METHODS

This prospective method-comparison study was performed in compliance with the tenets of the Declaration of Helsinki and was approved by the Melbourne Excimer Laser Group Protocol and Ethics Committee.

Measurements were conducted in Melbourne, Australia, between March 2019 and March 2020. All eyes included were healthy virgin eyes with no previous surgery and no cataract, amblyopia, keratoconus or keratoconic indications, or other preexisting ocular conditions. Eyes were measured with a swept-source optical biometer (IOLMaster 700) and a Scheimpflug tomographer (Sirius; Costruzione Strumenti Oftalmici), and manifest refraction was performed under controlled guidelines by optometrists. The standardized protocol included all patients being asked to take a full blink before each scan, green check indicators for all measures on the optical biometer, no tear film disruption or eyelid interference for the tomography acquisition, and all manifest refractions measured using a phoropter, pushing plus for sphere and preferring the least refractive cylinder.

TK and $SimK_{biom}$ data were manually transcribed from the screen of the optical biometer (IOLMaster 700 software; version 1.88.1.64861). CorT Total values were manually transcribed from software (iASSORT version 3.3.6; ASSORT Pty Ltd) that calculates such values from data exported by the Scheimpflug tomography software (CSO Phoenix software; version 3.4.0.73). $SimK_{Scheim}$ data were manually transcribed from the screen of the Scheimpflug device.

For each eye, the four ORAs (TK, $SimK_{biom}$, CorT Total, $SimK_{Scheim}$) were calculated with custom software using the R statistical environment.[9] Then, the distribution of ORA magnitudes for each corneal measure were summarized by the standard deviation (ORAsd) and the mean (ORAmean). ORAsd comparisons (including standard errors and *P* values) were performed by paired bootstrapping using the boot package[10,11] with 1,000 bootstrap estimates, and a Bonferroni correction was applied to the *P* values.

RESULTS

The study included 201 eyes from 104 patients (mean age: 38.4 ± 12.3 years; range: 19 to 70 years; 62% female). Basic statistics for the refractive and corneal power data are shown in **Table 1**.

Statistics for the ORAsd and ORAmean for all corneal measurement types are shown in **Table 2**. These are then compared with each other in **Table 3**. TK is equivalent to the other measures with respect to ORAsd, which implies that it correlates as well with manifest refractive cylinder as the other measures of corneal astigmatism. The measures of total corneal astigmatism (TK and CorT Total) have lower values of ORAmean than the measures of anterior corneal astigmatism ($SimK_{biom}$ and $SimK_{Scheim}$).

DISCUSSION

Based on the results in this study, TK astigmatism correlates as well with manifest refractive cylinder as

TABLE 1

Basic Summary Statistics (All at Corneal Plane in Diopters)

Device	Measurement Type	Min	Mean (SD)	Max
Phoropter	Refractive spherical equivalent	-7.67	-1.93 (2.52)	+7.53
	Refractive cylinder magnitude	0.00	0.86 (0.84)	5.05
Optical biometer	Mean simulated keratometry	39.67	44.00 (1.55)	48.84
	Simulated keratometry astigmatism	0.00	1.24 (0.79)	4.74
	Mean total keratometry	39.77	44.00 (1.56)	49.10
	Total keratometry astigmatism	0.00	1.11 (0.76)	4.53
Scheimpflug	Mean simulated keratometry	39.71	43.92 (1.56)	48.94
	Simulated keratometry astigmatism	0.03	1.16 (0.75)	4.38
	CorT Total astigmatism	0.10	1.07 (0.74)	4.32

SD = standard deviation; CorT total = total corneal topographic astigmatism

TABLE 2

ORAsd and ORAmean for Each Corneal Measurement Type[a]

Type	ORAsd (SE)	ORAmean (SE)
TK	0.453 (0.068)	0.674 (0.032)
$SimK_{biom}$	0.465 (0.065)	0.809 (0.032)
CorT Total	0.481 (0.076)	0.652 (0.033)
$SimK_{Scheim}$	0.494 (0.065)	0.759 (0.035)

ORAsd = ocular residual astigmatism standard deviation; SE = standard error; ORAmean = ocular residual astigmatism mean; TK = Total Keratometry; $SimK_{biom}$ = simulated keratometry from the optical biometer; CorT Total = total corneal topographic astigmatism; $SimK_{Scheim}$ = simulated keratometry from the Scheimpflug device

[a]Low values of ORAsd indicate good correlation between the measured corneal astigmatism and refractive cylinder. Low values of ORAmean facilitate surgical planning. All values including SE are in diopters.

other leading measures of corneal astigmatism.[4,5] In addition, TK is as easy to use for astigmatism surgery planning as other leading measures of total corneal astigmatism, and easier than measures of anterior corneal astigmatism because of the lower ORAmean and thus fewer cases where a refractive surgeon may have to trade off visual acuity against visual quality.

The CorT Total used in this study was not optimized on the current data set, but rather used because it is currently available through third party software on the Sirius device, which allows for a fair comparison. With this fair comparison, TK and CorT Total both perform equally well in representing total corneal astigmatism with respect to ORAsd and ORAmean. Naturally, if we had calculated an optimized CorT Total, which can be used as a benchmark, the corresponding ORAsd would have been a lower value.[4] Such a benchmark value is useful for determining whether other measures of corneal astigmatism might be improved on a specific data set. However, the fair comparison in this study is a more useful indication of how the studied measures are likely to perform in daily clinical practice.

It is interesting to note that Shajari et al[12] indicated that TK astigmatism meridia are variable, and that the TK astigmatism magnitudes are significantly and substantially different than total corneal astigmatism measurements made by a different Scheimpflug device than that used in this study. One would expect that such a difference should also show up in the ORAmeans when referenced to manifest refractive cylinder.

It would be interesting to generate a CorT Total on the same optical biometer that produces TK. Unfortunately, that is not currently possible because the biometer apparently does not calculate total corneal power measurements across the whole cornea; instead, it combines 18 anterior corneal curvature measurements in a hexagonal pattern at 1.5, 2.5, and 3.5 mm with posterior keratometry measurements derived from optical coherence tomography.

Results in this study are consistent with previous results[5] that show that total corneal astigmatism measures produce lower ORAmean values. Previous studies that compared TK to simulated keratometry indicated that TK, which quantifies total corneal power, could be used as a direct replacement for simulated keratometry during intraocular lens calculation, but that it may be possible to use a custom formula specific to total corneal power measures to improve prediction accuracy for postoperative spherical equivalent[1-3] and cylinder.[1] Our study supports the use of TK over simulated keratometry in the planning of astigmatism surgery when corneal values are required.

It is important to note that the TK should be used with care in toric intraocular lens calculators because some of these allow the user to account for the effect of the

TABLE 3
Pairwise Comparisons Between TK, CorT Total, and Their Corresponding Simulated Keratometries[a]

Measurement	ORAsd Difference (SE)	*P*	ORAmean Difference (SE)	*P*
TK compared with CorT Total	-0.029 (0.015)	.06	0.022 (0.014)	.15
TK compared with $SimK_{biom}$	-0.013 (0.011)	.41	-0.135[b] (0.008)	< .001
CorT Total compared with $SimK_{Scheim}$	-0.013 (0.013)	.37	-0.107[b] (0.010)	< .001

TK = Total Keratometry; CorT Total = total corneal topographic astigmatism; ORAsd = ocular residual astigmatism standard deviation; SE = standard error; ORAmean = ocular residual astigmatism mean; $SimK_{biom}$ = simulated keratometry from the optical biometer; $SimK_{Scheim}$ = simulated keratometry from the Scheimpflug device
[a]A Bonferroni correction has been applied to all P values.
[b]Statistically significant differences are marked with an asterisk. Differences and SEs are in diopters.

back corneal surface through nomograms or other approximate adjustments. The TK already incorporates the effect of the back corneal surface in its measurements, so further adjustments would result in incorrectly accounting for the back corneal surface twice. Ideally, the TK should be used in a calculator that specifically allows for the use of a total corneal power measurement.

In our clinical practice, we expect TK to show its greatest utility as an additional source of information about total corneal astigmatism for corneas that have had previous surgery, or that exhibit irregular astigmatism. In such corneas, it can be useful to have measures from several different devices, including devices that can report posterior corneal astigmatism in a visual way using the second Purkinje image.[13,14] If there is a broad consensus between measurements, a surgeon can proceed with some certainty, but if not, then a surgeon must proceed much more carefully, potentially discarding certain outlying measurements. Future work is needed to evaluate how TK and other measures of total corneal power perform for such non-standard corneas.

AUTHOR CONTRIBUTIONS

Study concept and design (NA); data collection (JKYO, GS); analysis and interpretation of data (NA, JKYO, GS); writing the manuscript (NA, JKYO); critical revision of the manuscript (NA, JKYO, GS); statistical expertise (JKYO); administrative, technical, or material support (NA, GS); supervision (NA, GS)

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