Optimized CorT Total to Compare Scheimpflug vs Dual Scheimpflug/Placido Imaging Devices

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ARTICLE

Optimized CorT Total to compare Scheimpflug vs dual Scheimpflug/Placido imaging devices

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Purpose: To compare the manufacturer-provided measures of total corneal power (TCP) generated by Scheimpflug and dual Scheimpflug/Placido imaging compared with corneal topographic astigmatism calculated on the basis of measured TCP data (CorT Total).

Setting: Emory University, Atlanta, Georgia, USA.

Design: Retrospective case series.

Methods: TCP values were exported from virgin 209 eyes that underwent imaging with both the Scheimpflug (Pentacam HR) and dual Scheimpflug–Placido (Galilei G4) imaging devices to compute an optimized CorT Total. The standard deviation of the ocular residual astigmatism (ORAsd), which serves as a value describing the vectoral difference between the corneal astigmatism measure and manifest refractive cylinder at the corneal plane, was evaluated for all eyes to compare manufacturer-provided measurements vs the optimized CorT Total.

Results: The Scheimpflug CorT Total had the lowest ORAsd (0.306 diopter [D]; spherical equivalent [SE] 0.018) of all the parameters evaluated, although the difference was not statistically significant (P = .22) from the dual Scheimpflug/Placido CorT Total (0.32 2 D; SE 0.017). For the Scheimpflug device, the CorT Total had a statistically significant lower (P < .05) ORAsd in comparison to the best measure on the device (total corneal refractive power apex zone 2 mm: 0.324 D; SE 0.021). For dual Scheimpflug/Placido measurements, the CorT Total had the lowest ORAsd (0.322 D; SE 0.017), but the difference was not statistically significant (P = .43) from the lowest manufacturer-provided measure (TCP 2).

Conclusions: CorT Total generated with the Scheimpflug device corresponded better with the manifest refractive cylinder than all measures of total corneal astigmatism calculated by the software from both the Scheimpflug and the dual Scheimpflug/Placido devices.

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Corneal tomography, based on Scheimpflug technology, permits 3D imaging of the cornea and provides critical information regarding the anterior and posterior surfaces of the cornea.[1] The ability to measure the curvature of both the anterior and posterior surface has enabled total corneal power (TCP) measurements. To calculate corneal power, corneal tomographers use ray-tracing technology to calculate corneal power, and local measures of corneal power can be calculated at specified distances from the pupillary center or corneal apex.[2] Depending on the device used to obtain the measurement, different terms are used to describe these values including TCP, or TCP (Galilei, Ziemer; Sirius, Costruzione Strumenti Oftalmici) and total corneal refractive power (TCRP) (Pentacam; OCULUS Optikgeräte GmbH).[3] These TCP values can be used in the surgical planning of astigmatism-correcting procedures such as toric intraocular lens implantation, limbal relaxing incisions, and topography-guided laser procedures. In addition, the TCP parameters can be used in vector planning approaches for refractive surgery.[4,5]

When planning for refractive surgery, the tomography-measured corneal astigmatism measurements often differ significantly in both magnitude and axis from what is measured with manifest refraction.[4,6,7] This difference is quantified by the ocular residual astigmatism (ORA).[4,8,9] This discrepancy in measurements poses a challenge for surgeons in refractive surgery planning, particularly when the difference is significant for both axis and magnitude.[8] Recent studies evaluating topography-guided laser in situ keratomileusis (LASIK) outcomes have highlighted the

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Table 1. Pentacam (Scheimpflug) ORA results.

Parameter	ORAsd, D (SE)	ORAmean, D (SE)
Optimized CorT Total: radius 0.1-1.8 mm	0.306 (0.018)	0.640 (0.021)
Optimized CorT Anterior: radius 0.6-2.4 mm	0.359 (0.015)	0.771 (0.024)
TCRP: apex zone 2.0 mm	0.324 (0.021)	0.649 (0.023)
SimK	0.370 (0.015)	0.770 (0.026)

ORAsd = standard deviation of the ocular residual astigmatism; SimK = simulated keratometry; TCRP = total corneal refractive power

challenge of cases with elevated ORA with mixed results depending on the approach to treatment.[6,10] A study by Wallerstein et al evaluating topography-guided LASIK outcomes demonstrated inferior outcomes in cases treated based on the measured corneal astigmatism axis when the axis difference exceeded 20 degrees.[6] An additional study by the same group, however, reported favorable outcomes overall in eyes with higher ORA with treatment plans based on the subjective refractive astigmatism.[10] In the latter study, however, with regard to accuracy of refractive astigmatism, more eyes in the higher ORA group had postoperative residual astigmatism ≥0.75 diopter (D) compared with eyes in the lower ORA group (6.1% vs 3.9%).[10]

A 2017 study by Arbelaez et al. demonstrated that in patients with a high magnitude of ORA presenting for LASIK, a vector planning approach provides visual outcomes comparable to treatments based on the manifest refraction.[5] In addition to providing similar visual outcomes, the vector planning method demonstrated superiority over manifest refraction planning in terms of accuracy and postoperative ORA. In addition, the vector planning group demonstrated a 41% reduction in resultant corneal astigmatism and no consequent increase in remaining refractive cylinder, supporting vector planning as a favorable approach in patients with high preoperative ORA to optimize outcomes.[5]

Within the last decade, a new method of quantifying total corneal astigmatism, also known as CorT Total, has been described and has been shown to closely match the manifest refractive cylinder in both regular and irregular corneas.[11,12] A recent study compared the ORA results of 3 different tomographers (Galilei, Pentacam, and Sirius) from different study populations to CorT Total and demonstrated that an optimized CorT Total corresponded to manifest refractive cylinder at least as well as the total corneal astigmatism data generated by the 3 tomographers.[13] In this aforementioned study, the CorT Total was optimized, and the results of this study indicated that the optimized CorT Total could serve as a cross-tomographer benchmark to evaluate and compare the total corneal astigmatism results generated by each tomographer. The different study populations, however, precluded direct comparisons of values obtained for different Scheimpflug devices.

The purpose of this study was to use the optimized CorT Total as a benchmark to directly compare the TCP and ORA measurements generated by the Scheimpflug and dual Scheimpflug/Placido imaging in the same eyes.

Table 2. Dual Scheimpflug/Placido ORA results.

Parameter	ORAsd, D (SE)	ORAmean, D (SE)
Optimized CorT Total: radius 0.1-2.4 mm	0.322 (0.017)	0.660 (0.022)
Optimized CorT Anterior: radius 0.1-3.7 mm	0.345 (0.019)	0.748 (0.024)
TCP 1	0.330 (0.018)	0.654 (0.024)
TCP 2	0.325 (0.017)	0.639 (0.023)
SimK	0.362 (0.018)	0.755 (0.025)

ORAsd = standard deviation of the ocular residual astigmatism; SimK = simulated keratometry; TCP = total corneal power

METHODS

This retrospective between-device comparative study was approved by the Institutional Review Board at Emory University (Atlanta, Georgia, USA). All patients in this study presented for refractive surgery evaluation at Emory Vision, Atlanta, Georgia, between the years 2015 and 2016. All eyes included in this study were healthy, virgin eyes without a history of prior ocular surgery. Patients included had no history of cataract, amblyopia, keratoconus, or other ocular conditions.

All patients included in the study population had measurements performed with both Scheimpflug imaging (Pentacam HR; OCULUS Optikgeräte GmbH) and dual Scheimpflug/Placido imaging (Galilei G4; Ziemer) on the same day at the same clinical visit with the same operator.

All Pentacam data were obtained and reprocessed by personnel at Oculus to ensure that all collected data were performed with uniform and the most updated software available (version 1.21r43 software). All Pentacam data were filtered to ensure that data were of adequate quality and machine calibration status was valid. Galilei data were exported with the latest available version of the software (6.1.4).

For every eye included in the chart review, the most recent tomographic measurement was used if multiple were available. TCP values across the entire cornea were exported from each measurement device. On the Pentacam, these values are known as total corneal refractive power or TCRP, and on the Galilei tomographer, they are called total corneal power or TCP. In both cases, the exported data were centered on the corneal vertex normal (also the position of Purkinje I). The corneal vertex normal has alternatively been referred to as the corneal apex. However, this can be a point of confusion as corneal apex has also been used to describe the point of maximum curvature or the most anterior point of the cornea. For purposes of this study, the corneal apex, which is often used with data produced by the Pentacam, refers to the corneal vertex normal.

For each device, the exported TCP values were used to compute an optimized CorT Total and optimized CorT Anterior following the previously described method by Alpins et al using iAssort software (ASSORT Pty. Ltd.).[11–13] For both the CorT Total and CorT Anterior, the process begins with calculating Ring.#.Ks (similar to keratometry readings for each ring with a steep meridian and flat/steep power) for each annular region to identify the ring range that minimizes the ORAsd across all eyes with the given tomographer. The ORAsd (standard deviation of the ocular residual astigmatism) is an important value because it describes the spread of the ORA; a low ORAsd indicates a low variability between the corneal astigmatism and manifest refractive cylinder.

Table 3. Paired ORAsd comparisons.

Parameter	ORAsd (1), D	ORAsd (2), D	*P* Value
Pentacam optimized CorT Total (1) vs Galilei optimized CorT Total (2)	0.306	0.322	.22
Pentacam optimized CorT Total (1) vs Pentacam TCRP apex zone 2 mm (2)	0.306	0.324	.02
Pentacam optimized CorT Total (1) vs Galilei TCP2 (2)	0.306	0.325	.08
Galilei optimized CorT Total (1) vs Pentacam TCRP apex zone 2 mm (2)	0.322	0.324	.46
Galilei optimized CorT Total (1) vs Galilei TCP2 (2)	0.322	0.325	.43
Pentacam TRCP apex zone 2 mm (1) vs Galilei TCP2 (2)	0.324	0.325	.47

ORAsd = standard deviation of the ocular residual astigmatism; TCP = total corneal power; TCRP = total corneal refractive power
(1) indicates corresponds to the ORAsd values in column 2, (2) corresponds to the ORAsd values in column 3.

After the optimal annular range/region is selected for each tomographer, this region was consistently used to collect data for all eyes in the study. Given that the ring ranges were optimized to minimize the ORAsd for both the CorT Total and CorT Anterior calculation, the ORAsd values for both the CorT Total and CorT Anterior parameters should be viewed as a benchmark measurement. In this present study, the optimized CorT Total and optimized CorT Anterior served as benchmark values to evaluate the manufacturer-provided TCP measurements from the Galilei and Pentacam.

For the total corneal astigmatism measurements, summary statistics for ORA were calculated including mean (ORAmean) and standard deviation (ORAsd). As mentioned, the ORAsd is a value that describes the variability, or correlation of measures, between the corneal astigmatism measure and the manifest refractive cylinder; a low ORAsd value indicates a low variability between the corneal astigmatism and refractive cylinder. The ORAmean is a measure that describes the magnitude of difference between the corneal astigmatism measure and the manifest refractive cylinder. The ORAmean is always expected to be a nonzero value because of noncorneal contributions to the manifest refractive cylinder, such as lens tilt and visual cortex processing. Despite this recognition, a low ORAmean is preferred because this indicates the most accurate TCP measurement and allows surgeons to choose a treatment plan close to the manifest refractive cylinder that minimizes residual astigmatism on the cornea.

Summary total corneal astigmatism values were exported on each device in addition to the raw TCP values obtained from each device. On the Pentacam, the TCRP apex zone was exported for a diameter of 2 mm (TCRP Apex Zone 2 mm). For the Galilei, the Total Corneal Power 1 and Total Corneal Power 2 were exported (based on data from the entire cornea). Simulated keratometry (SimK) measurements were also obtained from both the Pentacam and Galilei. To evaluate and compare the measurements from the 2 tomographers and how the exported total corneal astigmatism values correlated with the manifest refractive cylinder, ORAsd values were computed for each exported measure from both the Galilei and Pentacam.

All statistical analysis was performed by bootstrapping using the boot package with 1000 bootstrap estimates in the R statistical environment.[14–16] This includes standard errors of ORAsd estimates and *P* values of comparisons of ORAsd values.

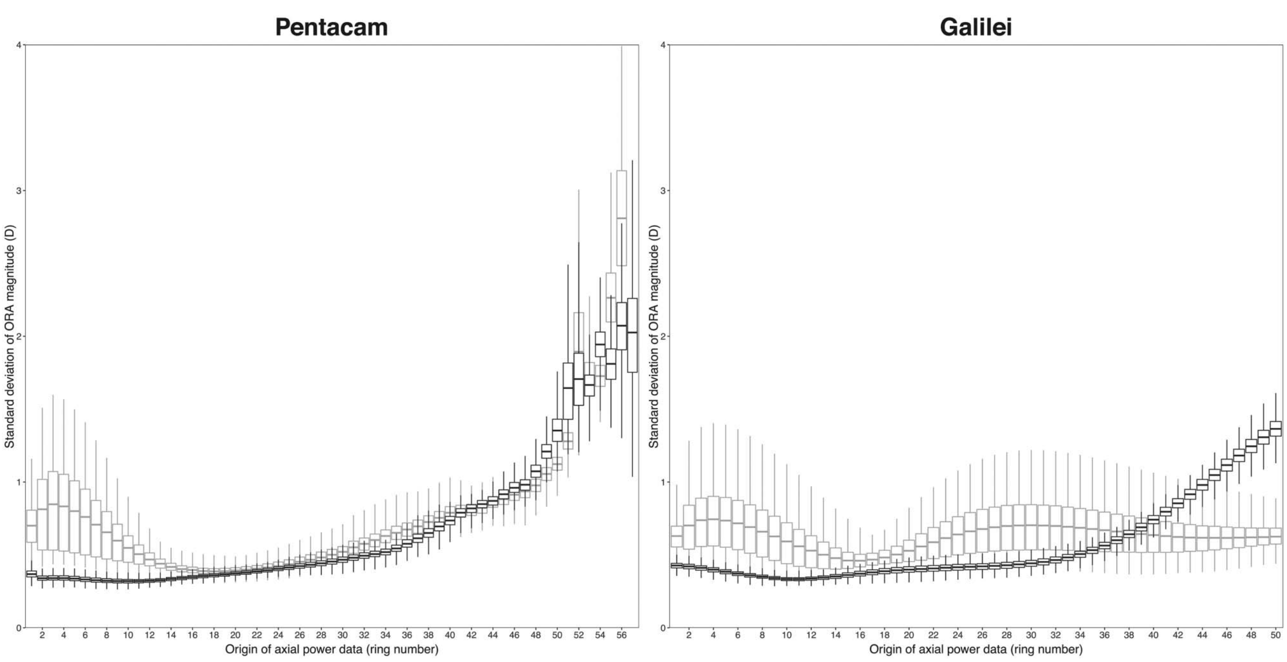

Figure 1. The standard deviation of ocular residual astigmatism magnitude (ORAsd) for each concentric ring (with annular width 0.1 mm) of corneal power data obtained from both the Scheimpflug (Pentacam HR) and dual Scheimpflug/Placido (Galilei G4) devices. The left figure is for corneal power data collected from the Scheimpflug imaging, and the right figure is for dual Scheimpflug/Placido. The data from the current study are superimposed on the data from the prior study for comparison.[12] The dark box plots depict the current data; the light box plots in the background represent the previous data.[12] The ORAsd for central rings is considerably lower in the current data than in the previous data.

RESULTS

The study included data from 209 eyes (193 right eyes and 16 left eyes) from 205 patients. Of the 205 patients, 110 were female, and 95 were male. Refractive data were as follows: mean spherical equivalent (SE) refractive error was −3.41 D, mean spherical error was −3.87 ± 2.41 D (−10.75 to +3.5 D), and mean cylinder was 0.92 ± 0.84 D (0 to 5 D). Each patient included in the study had both Scheimpflug and dual Scheimpflug/Placido measurements.

The ORA results for the Scheimpflug are shown in Table 1. The ORA results for the dual Scheimpflug/Placido are demonstrated in Table 2. The pairwise comparison between the ORAsd results of the dual Scheimpflug/Placido and Scheimpflug is shown in Table 3.

For the Scheimpflug, the optimized CorT Total (radius 0.1 to 1.8 mm) had a statistically significantly lower ORAsd in comparison to the Scheimpflug TCRP apex zone 2 mm ($P < .05$), which had the lowest ORAsd of the Scheimpflug manufacturer-generated measures available in this study. For the dual Scheimpflug/Placido values, the optimized CorT Total (radius 0.1 to 2.4 mm) did not demonstrate a statistically significantly lower ORAsd than the manufacturer-generated measure with the lowest ORAsd (TCP 1; $P = .43$). Although the difference was not statistically significant, the Scheimpflug optimized CorT Total ORAsd (0.306 D) was lower than the dual Scheimpflug/Placido optimized CorT Total (0.322 D) and all of the manufacturer-generated measures available from the dual Scheimpflug/Placido tomographer. Furthermore, optimized CorT Anterior values were also computed, and the Scheimpflug optimized CorT Anterior (radius 0.6 to 2.4 mm) ORAsd value was 0.359 D, slightly higher than the dual Scheimpflug/Placido CorT Anterior (radius 0.1 to 3.7 mm) ORAsd, 0.345 D.

Figure 1 demonstrates the ORAsd values for each concentric ring (with annular width 0.1 mm) in comparison to the results from the prior 3-tomographer study. As demonstrated in the figure, the ORAsd values for central rings were lower in this study than in the prior study.

DISCUSSION

The optimized CorT Total is calculated based on the optimal ring ranges of each tomographer to produce a resultant ORAsd that can serve as a benchmark value to assess how closely other measures of corneal astigmatism relate to the manifest refractive cylinder. In this study, the annular ring regions of the cornea to calculate the optimized CorT Total for the Scheimpflug and dual Scheimpflug/Placido were significantly different from a prior study investigating the optimized CorT Total measurement as a benchmark measure.[13] These differences indicate that notable software changes have been made to both the Pentacam (Scheimpflug) and Galilei (dual Scheimpflug/Placido) since our initial investigation.[13]

For the Scheimpflug device, the prior study identified that a corneal annulus with 0.15 to 2.65 mm radius should be used for optimizing the CorT.[13] In comparison, this present study identified the optimal zones more centrally, with a radius from 0.1 to 1.8 mm. Similarly, for the dual Scheimpflug/Placido device, the optimization for the CorT Total from the prior study determined that a corneal annulus with a radius from 1.0 to 2.6 mm should be used.[13] In this current study, the optimized CorT Total for the dual Scheimpflug/Placido selected a corneal annulus with radius 0.1 to 2.4 mm. As demonstrated in Figure 1, the ORAsd for both the Scheimpflug CorT Total and dual Scheimpflug/Placido CorT Total measures in this current study is improved (lower) compared with the prior study. These results suggest that measurements from the central corneal region have become more accurate; this reduces the need to use as large a measurement region when acquiring the scans. Of note, following the findings of this study, on direct inquiry, both manufacturers confirmed that their algorithms for calculating central corneal power had been modified: the Pentacam in 2018 (version 1.2.1r33) and Galilei in 2014 (version 6.1.4) (unpublished correspondence).

Based on the results of this study, it appears that the software change on the Scheimpflug tomographer has shifted the preferred, default measure of TCP from the TCRP apex zone 4 mm to the TCRP apex zone 2 mm. The prior report evaluating TCP measures from the 3 tomographers demonstrated that the TCRP apex zone 4 mm had the lowest ORAsd (0.337 D; SE 0.029) of the manufacturer-provided measures from the Scheimpflug. In this present study, the TCRP apex zone 2 mm performed the best among the manufacturer-provided measures obtained from the Scheimpflug. Of interest, the software change and shift to the TCRP apex zone 2 mm does not completely align with what we observed when calculating the optimized CorT Total, which would suggest that data from the central 3.6 mm (1.8 mm radius) zone should be used. The statistically significant difference in the ORAsd between the optimized CorT Total and the TCRP apex zone 2 mm suggests that altering the preferred acquisition zone on the Scheimpflug tomographer could improve the accuracy of the TCRP measure.

For the dual Scheimpflug/Placido, the results of this study suggest that the Galilei software modifications have led to notable performance improvements compared with the prior study evaluating 3 tomographers. In the prior study, there was a marked, albeit not statistically significant, discrepancy (13%) in the ORAsd between the CorT Total (0.472 D; SE 0.068) and the TCP2 (0.536 D; SE 0.124) measure from the device. In this present study, the discrepancy was minimal (1%) between the TCP2 (0.325 D; SE 0.017) and the CorT Total (0.322 D; SE 0.017). In addition, consistent with the results of the prior study, the ORAsd results of TCP1 and TCP2 values were very similar.

The results of this study indicate that the performance of the manufacturer-provided measures of TCP from the dual Scheimpflug/Placido and Scheimpflug has improved with software changes. This study highlights the value of the optimized CorT Total as a benchmark that can aid in comparing TCP measurements from tomographers as well as evaluate how software and algorithmic changes from each tomographer translate to performance.

WHAT WAS KNOWN

- The CorT Total is a corneal measure of astigmatism based on total corneal power (TCP) measurements that corresponds closely with the manifest refractive cylinder.
- The optimized CorT Total is a useful benchmark measure that can be used to evaluate how well other measures of total corneal astigmatism values correspond with the manifest refractive cylinder.

WHAT THIS PAPER ADDS

- The optimized CorT Total calculations indicated that measurements from the central corneal region from both Scheimpflug and dual Scheimpflug/Placido have become more accurate.
- The manufacturer-provided measures of TCP from both the Scheimpflug and dual Scheimpflug/Placido have improved with changes in software.

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