Title:

Corneal topography with an aberrometry-topography system

Authors:

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ABSTRACT

Purpose: To investigate the agreement between the central corneal radii and corneal eccentricity measurements generated by the new Wave Analyzer 700 Medica (WAV) compared to the Keratograph 4 (KER) and to test the repeatability of the instruments.

Methods: 20 subjects (10 male, mean age 29.1 years, range 21-50 years) were recruited from the students and staff of the Cologne School of Optometry. Central corneal radii for the flat ($r_{c/fl}$) and steep ($r_{c/st}$) meridian as well as corneal eccentricity for the nasal (e_{nas}), temporal (e_{temp}), inferior (e_{inf}) and superior (e_{sup}) directions were measured using WAV and KER by one examiner in a randomized order.

Results: Central radii of the flat (rc/fl) and steep (rc/st) meridian measured with both instruments were statically significantly correlated (r=0.945 and r=0.951; p<0.001). Comparison between the WAV and KER showed that $r_{c/fl}$ and $r_{c/st}$ measured with WAV were significantly steeper than those measured with KER (p<0.001). Corneal eccentricities were statistically significantly correlated in all meridians (p<0.05). Compared to KER, e_{temp} and e_{sup} measured with WAV were greater (p<0.05), while there were no statistically significant differences for e_{nas} and e_{inf} (p=0.350 and p=0.083). For the central radii, repeated measurements were not significantly different for the KER or WAV (p>0.05). Limits of agreement (LoA) indicate a better repeatability for the KER compared to WAV.

Conclusions: Corneal topography measurements captured with the WAV were strongly correlated with the KER. However, due to the differences in measured corneal radii and eccentricities, the devices cannot be used interchangeably. For corneal topography the KER demonstrated better repeatability.

Key words: Corneal topography, placido-based, corneal radius, corneal eccentricity, aberrometry-topography.

The measurement of the shape, refractive power and thickness of the cornea is essential for the planning of corneal refractive surgery, for diagnosis of corneal diseases and for fitting contact lenses, in particular speciality lenses. Various diagnostic procedures have been developed for the analysis of the corneal surface. Corneal topographical measurements can be performed by classic Placido-based topographers as well as by tomography systems that produce three-dimensional corneal models from cross-sectional images [1].

Placido-based computerized videokeratoscopy, proposed first by Klyce in 1984 [2], are the most frequently used corneal topography systems in clinical practice [3]. This method of imaging of the anterior corneal surface analyses tear film reflected images of multiple concentric rings projected on the cornea. In contrast, corneal tomography provides an analysis of the shape of anterior and posterior corneal surfaces, as well as the thickness distribution of the cornea [4]. Corneal tomography can be performed by a scanned slit, rotating Scheimpflug cameras or by optical coherence tomography [5].

Recently, a new corneal topography with an integrated aberrometry-topography system named the Wave Analyzer 700 Medica (Essilor, Freiburg, Germany) has been introduced to the market. The Wave Analyzer is a multifunctional device for performing objective refraction, aberrometry, pupillometry, pachymetry, non-contact tonometry, measurement of anterior chamber depth and angle as well as corneal topography. The instrument combines a Hartmann-Shack aberrometer, an air tonometer, a Scheimpflug camera and a Placido-based topographer. However, the data for the corneal radii and corneal eccentricity is only generated from the Placido-disc measurement without any contribution of the Scheimpflug camera.

Consequently, the aims of this study were (i) to investigate the agreement in the measurement of central corneal radii and corneal eccentricity between the new Wave Analyzer 700 Medica (WAV) and the Placido-based Keratograph 4 (KER) (Oculus Optikgeräte GmbH, Wetzlar, Germany) and (ii) to test the repeatability of the instruments.

MATERIALS AND METHODS

Instruments

To measure central corneal radii as well as corneal eccentricity, two placido based corneal topographers were used in this study. The Keratograph 4 (Oculus Optikgeräte GmbH, Wetzlar, Germany) uses a placido cone consisting of 22 red illuminated rings (650nm) at 80mm from the eye to generate 22 000 measuring points. The Wave Analyzer 700 Medica (Essilor, Freiburg, Germany) is a diagnostic device that performs objective refraction, aberrometry, pupillometry, crystalline lens opacity, pachymetry, tonometry and topography. For corneal topography it uses a placido cone off 24 rings to generate 6144 measuring points. Instruments had been calibrated following the manufacturer’s recommendations. The room temperature was maintained at 18 to 22°C.

In Vitro Study

Four precision glass balls (radii: 6.00, 7.00, 8.00 and 9.00 mm; CA 100-Caldev, Topcon, Tokyo, Japan) were used as a model of the cornea. The mean of three consecutive measurements of the four glass balls was compared between the KER and the WAV at two different sessions at the same time of day (day 1 and day 2).

In Vivo Study

Twenty healthy subjects (mean age 29.1 $\pm$ 9.2 (SD) years, range 21 to 50 years, even male to female split) were recruited from the students and staff of the Höhere Fachschule für Augenoptik Köln (Cologne School of Optometry), Cologne, Germany.
All subjects underwent a medical history and a slit lamp examination. Subjects were excluded if: they had a current or previous condition known to affect the cornea, conjunctiva or the sclera such as pterygium and pinguecula; had a history of previous ocular surgery, including refractive or strabismus surgery, eyelid surgery, or corneal surgery; had any previous ocular trauma; were diabetic; were taking medication known to affect the ocular surface or sclera; and/or had worn rigid contact lenses or soft contact lenses during the preceding 24 hours prior to the study.

The study was approved by the Research Ethics Committee and all subjects gave written informed consent before participating in the study. The procedures were conducted in accordance with the requirements of the Declaration of Helsinki (1983) and patient data were used only in anonymized form.

Central corneal radii for the flat ($r_{c/fl}$) and steep ($r_{c/st}$) meridian as well as corneal eccentricity for the nasal (e_{nas}), temporal (e_{temp}), inferior (e_{inf}) and superior (e_{sup}) direction were measured by one examiner using the WAV and the KER in a randomized order. Corneal eccentricities were taken from the data given for an angle of 30°. The mean of three consecutive measurements of the right eye was recorded for both instruments at two different sessions at the same time of day (day 1 and day 2).

Statistical Analyses

Normal distribution of data was analyzed by Shapiro-Wilk test. As the data was normally distributed, differences between sessions (day 1 and day 2) and instruments were analyzed using Bland-Altman plots, coefficient of repeatability (CR), and paired t-tests. The relationship between the WAV and KER measurements was analyzed by Pearson product-moment correlation. Data were analyzed using SigmaPlot 12 (Systat Software Inc., Chicago, USA).

RESULTS

In Vitro Study

The measured radii of the four glass balls were 6.01, 6.97, 7.99, and 8.99 mm for the WAV and 6.02, 7.01, 8.00, and 9.00 mm for the KER. The mean difference between the measurements of the two devices was 0.018 mm (95% confidence interval [CI], -0.015 to + 0.050 mm; $p = 0.125$) (Figure 5). Repeated measurements from day 1 and day 2 were not significantly different for the KER (paired t-test: $p = 0.391$), but they were different for the WAV ($p = 0.034$). The mean difference and the limits of agreement (LoA) indicate a better in vitro repeatability for the KER (0.005 mm; LoA -0.013 to 0.008 mm) compared to the WAV (0.030 mm; LoA -0.003 to +0.118 mm).

In Vivo Study

Table 1 summarizes the mean values ± standard deviations of central corneal radii and corneal eccentricities, mean difference and limits of agreement (LoA) of the two measuring sessions (day 1 to day 2) and the mean differences and 95% confidence interval between the two instruments.

Central corneal radii of the flat ($r_{c/fl}$) and steep ($r_{c/st}$) meridian measured with both instruments were statically significantly correlated (r=0.945 and r=0.951; both $p<0.001$). On average the mean central radii measured with the WAV were significantly steeper than those measured with the KER (-0.05mm; CI -0.08 to -0.02; paired t-test; $p<0.001$) (Figure 6).

The measured corneal eccentricities were statistically significantly correlated in all meridians (e_{nas};r=0.747, e_{temp};r=0.541, e_{inf};r=0.783 and superior e_{sup};r=0.661; all $p<0.05$). On average the mean corneal eccentricities measured with the WAV were significantly greater than those measured with the KER (+0.06; CI 0.0126 to 0.105; paired t-test; $p=0.009$) (Figure 7). Compared to the KER, e_{temp} and e_{sup} measured with the WAV were greater ($p<0.05$), while there were no statistically significant differences for e_{nas} and e_{inf} ($p=0.350$ and $p=0.083$) (Table 1).

For the central radii, repeated measurements from day 1 to day 2 were not significantly different for the KER and WAV (paired t-test; rc/fl: $p=0.523$ and $p=0.860$; rc/st: $p=0.783$ and $p=0.154$). The mean difference and the limits of agreement (LoA) indicate a better repeatability for the KER compared to the WAV (Table 1).

For the overall corneal eccentricity, repeated measurements from day 1 to day 2 were not significantly different for the KER and the WAV (paired t-test; $p > 0.05$). The mean difference and the limits of agreement (LoA) indicate a better repeatability for the KER compared to the WAV (Table 1).

DISCUSSION

The Wave Analyzer is a multifunctional device for performing objective refraction, aberrometry, pupillometry, pachymetry, non-contact tonometry and corneal topography. Comparing the values obtained for corneal topography with those of a placido-based Keratograph 4 showed a high correlation. However, radii measured with the Wave Analyzer were, on average, 0.06 mm and 0.09 mm (flat or steep meridian) steeper than those of the Keratograph 4.

Shneor et al. [6] compared the L80 (Visionix Luneau, Chartes, France), a multi-function device similar to the Wave Analyzer, with a manual Bausch & Lomb ophthalmometer. As in the present study, they report statistically significantly steeper central radii measurements (by 0.05 mm and 0.07 mm in the flat or steep meridians respectively) compared to the manual ophthalmometer. For the Keratograph 4 (Oculus, Germany), Best et al. reported flatter central corneal radii compared to Tonoref II (Nidek, Japan) [7].

Likewise, a comparison of the Placido-based Allegro Topolyzer system (Alcon Research, Ltd., Fort Worth, TX, USA) with a Scheimpflug camera-based Galilei G4 system (Ziemer Ophthalmic Systems AG, Port, Switzerland) showed statistically significant differences in the central corneal radii [8]. The Scheimpflug camera-based system showed steeper radii than the Placido-based system; the differences in patients with keratoconus were even greater [8, 9]. Comparing the Orbscan II (Orbtek), a combination of a slit scanning technique and Placido disc image, with the Palcido-based EyeSys (Houston, TX, USA), Douthwaite and Mallen [10] found that the Orbscan appears to under-read slightly for both apical radius and p-value.

In contrast, Laursen et al. [11] reported no significant differences in the measurement of mean corneal power between different devices: Keratograph 4, Pentacam (Oculus, Germany), Tonoref II (Nidek, Japan), IOLMaster 500 and Lensstar LS 900 (Haag-Streit, Switzerland). A comparison of three Scheimpflug camera-based systems (Pentacam, Galilei G2 and Sirus 3D) in a study by Hernández-Camarena et al. [12] also did not show any statistically significant differences in the measurement of the central corneal radii.

For corneal eccentricities, significant differences (mean differences from 0.08 to 0.26) were found comparing four topographers (Humphrey, Atlas 991 (Zeiss), Dicon CT200 (Dicon, US), Orbscan II (Orbtek) and Medmont E300 (Medmont, Australia)) [13], which is in concordance to the mean differences of 0.07 and 0.08 reported for the temporal and superior eccentricities in the present study.

Furthermore, in the present study, a better in vivo repeatability of the measurements was obtained for the Keratograph 4 compared to the WaveAnalyzer. The values for the Keratograph 4 described in this study are in good agreement with repeatability described by Riede-Pult et al. [14] for the Keratograph 2. Device-specific differences in the repeatability of the measurement of central corneal radii as well as corneal eccentricities have already been reported in several studies [11-13, 15, 16].

For the differences in measurement and in repeatability described in the various studies, several causes can be considered: differences in the measuring principle (manual keratometry, Placido-based systems, Scheimpflug camera-based systems); differences in the measured area of the cornea (e.g. number of Placido-rings); different calculation algorithms of the devices; as well as differences between the subjects (eg. keratokonus or dry eye). Hamer et al. suggested, that the Placido-based systems seem to be more susceptible to changes in the tear film than the Scheimpflug camera-based systems [16]. Corneal topographers such as those utilising a Placido disc, analyse the pattern of light rays reflected off the cornea and tear film-air interface and therefore any disruption of the tear film may influence the measurement [16]. Since the reflection quality of the placido mires indicates the quality of the tear film over time, topographers can also be used to assess tear film stability [7].

A limitation of the present study results from the eye models used for the *in vitro* study. The glass balls had spherical surfaces which does not ideally reflects the aspherical shape of most corneas. Therefore, Douthwaite [17] proposed the use of conicoidal surface convex polymethylmethacrylate buttons to produce surfaces similar to the normal healthy human cornea. However, both instruments in the present study where calibrated using the manufactures spherical glass probes which corresponds to the normal procedure in clinical practice. Furthermore, it should be noted that *in vitro* models are never able to accurately reproduce the complexity of *in vivo* conditions [18, 19]. As a further limitation it should be noted, that in this study only healthy eyes were included. McMahon et al. [20, 21] reported a loss in repeatability and reliability of corneal topography measurements when corneal irregularity was present.

Although corneal topography has improved over time, it appears that even two devices, which are based on the same measuring principle as in this study, do not necessarily lead to the same measurement result and equivalent repeatability. Some devices have better repeatability than others, and therefore not all devices can be used interchangeable. It has been suggested that mathematicals models should be constructed to adjust the data of one instrument to be comparable to another [20], but this presumes instruments are repeatable and differences are systematic across all subjects.

Practitioners should be aware of the measuring accuracy and the repeatability of the topography instrument used. This is important for the appropriate selection of the first contact lens to be trialled, as well as for the diagnosis and monitoring of corneal changes, especially when different topography systems are in use.

CONCLUSIONS

Comparing the corneal topography determined by the Wave Analyzer with that of the Keratograph 4 showed a high correlation. However, due to the differences in measured corneal radii and eccentricities, the devices cannot be used interchangeably. For corneal topography the KER demonstrated better repeatability.

Conflict of interest

None

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Figures

Figure 1. Wave Analyzer 700 Medica (Essilor, Freiburg, Germany).

Figure 2. Keratograph 4 (Oculus GmbH, Wetzlar, Germany).

Figure 3. Output of the Wave Analyzer 700 (Essilor, Freiburg, Germany).

Figure 4. Output of the Keratograph 4 (Oculus GmbH, Wetzlar, Germany).

Figure 5. In vitro difference in mean radius (mm) between the Keratograph 4 and the Wave Analyzer.

Figure 6. In vivo difference in mean radius (mm) between the Keratograph 4 and the Wave Analyzer (solid line: mean; dashed line: 95% confidence interval).

Figure 7. In vivo difference in mean eccentricity between the Keratograph 4 and the Wave Analyzer (solid line: mean; dashed line: 95% confidence interval).

Tables

Table 1. Mean values ± standard deviations of three repeated measurements of central corneal radii and corneal eccentricities, mean difference and limits of agreement (LoA) of two measuring sessions (day 1 to day 2) and the mean differences and 95% confidence interval between both instruments (n=20 eyes). *Indicates statistically significant differences.

Table 1

	Wave Analyzer	Mean Difference (95% LoA) Day1 to Day 2	p value	Keratograph	Mean Difference (95% LoA) Day 1 to Day 2	p value	Mean Difference (95% CI) KER - WAV	p value
Central corneal radii								
Flat meridian ($r_{c/fl}$)	7.82 ± 0.26	-0.01 (-0.26 to 0.25)	p=0.860	7.88 ± 0.27	+0.01 (-0.08 to 0.09)	p=0.594	-0.06 (-0.10 to -0.02)	**p = 0.006***
Steep meridian ($r_{c/st}$)	7.62 ± 0.30	+0.02 (-0.15 to 0.20)	p=0.308	7.71 ± 0.26	0.00 (-0.06 to 0.06)	p=0.783	-0.09 (-0.17 to -0.01)	**p < 0.001***
Corneal eccentricity								
Nasal (e_{nas})	0.71 ± 0.24	+0.01 (-0.36 to 0.38)	p=0.810	0.68 ± 0.11	-0.02 (-0.11 to 0.14)	p=0.469	+0.04 (-0.04 to +0.12)	p = 0.350
Temporal (et_{emp})	0.50 ± 0.39	+0.01 (-0.78 to 0.79)	p=0.340	0.43 ± 0.08	-0.01 (-0.12 to 0.11)	p=0.615	+0.07 (-0.10 to +0.23)	**p = 0.014***
Inferior (e_{inf})	0.56 ± 0.19	-0.02 (-0.29 to 0.25)	p=0.496	0.51 ± 0.15	0.00 (-0.12 to 0.11)	p=0.823	+0.05 (-0.01 to +0.11)	p = 0.083
Superior (e_{sup})	0.61 ± 0.14	+0.03 (-0.77 to 0.82)	p=0.090	0.53 ± 0.13	+0.01 (-0.18 to 0.21)	p=0.402	+0.08 (+0.03 to +0.13)	**p = 0.004***
Overall	0.60 ± 0.26	+0.04 (-0.50 to 0.49)	p=0.592	0.53 ± 0.15	0.00 (-0.13 to 0.12)	p=0.780	+0.06 (+0.01 to +0.11)	**p = 0.009***

Figure 1

Figure 2

Figure 3

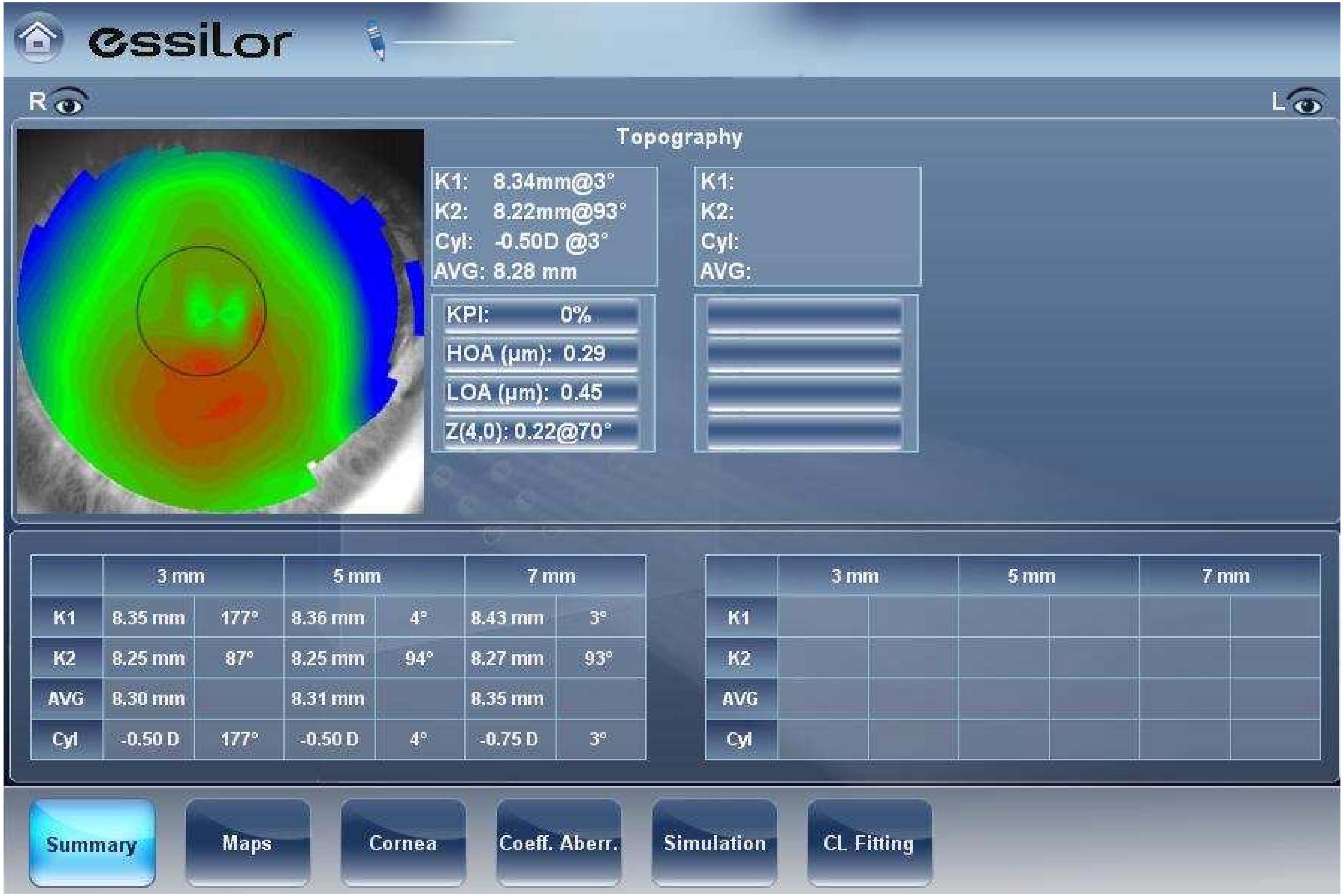
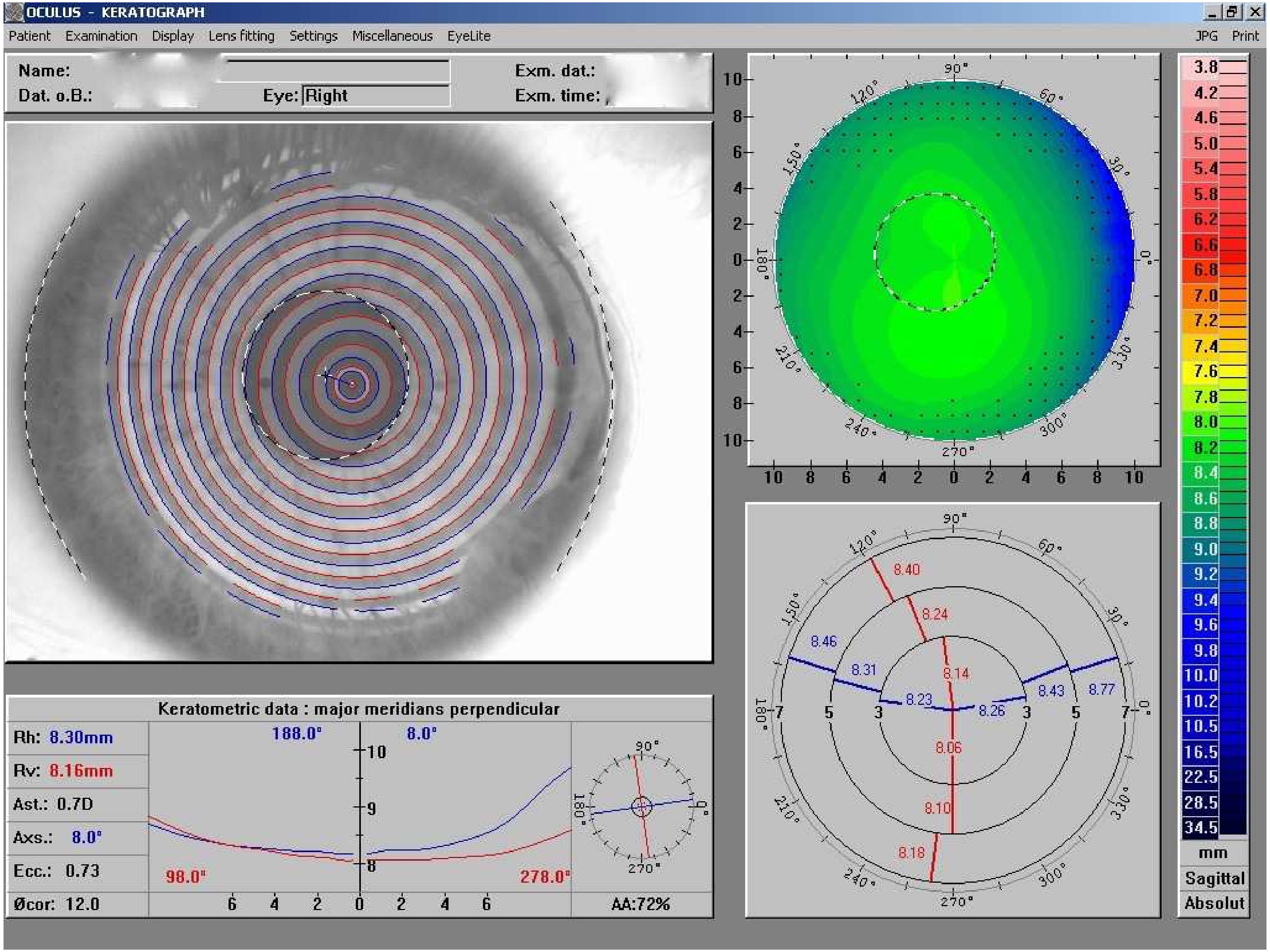
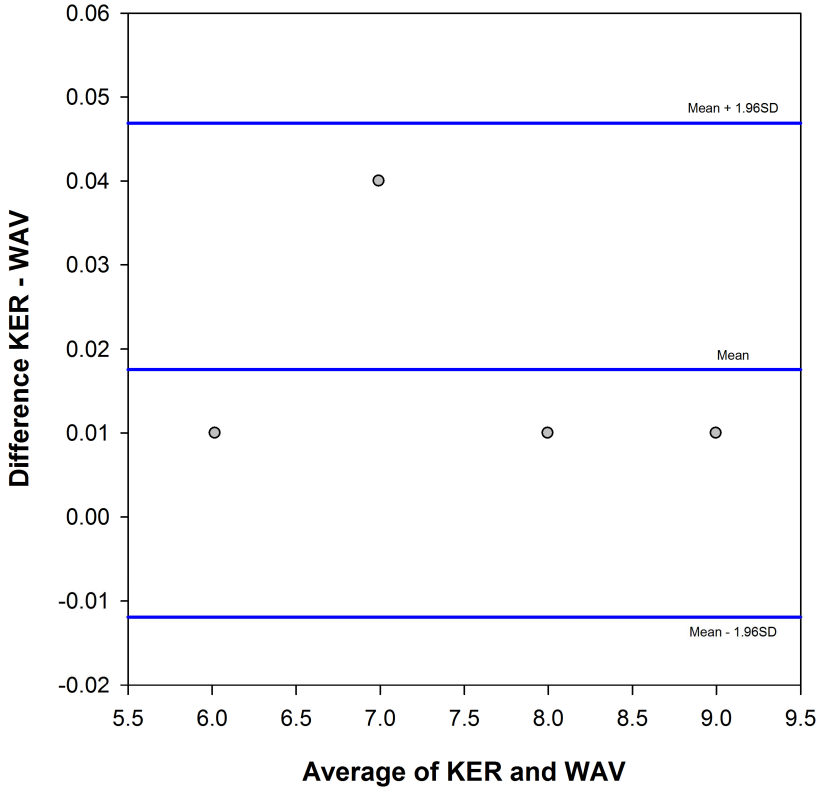

essilor
R
L
Topography
K1: 8.34mm@3°
K2: 8.22mm@93°
Cyl: -0.50D @3°
AVG: 8.28 mm
K1:
K2:
Cyl:
AVG:
KPI: 0%
HOA (µm): 0.29
LOA (µm): 0.45
Z(4,0): 0.22@70°
3 mm
5 mm
7 mm
K1
8.35 mm
177°
8.36 mm
4°
8.43 mm
3°
K2
8.25 mm
87°
8.25 mm
94°
8.27 mm
93°
AVG
8.30 mm
8.31 mm
8.35 mm
Cyl
-0.50 D
177°
-0.50 D
4°
-0.75 D
3°
3 mm
5 mm
7 mm
K1
K2
AVG
Cyl
Summary
Maps
Cornea
Coeff. Aberr.
Simulation
CL Fitting

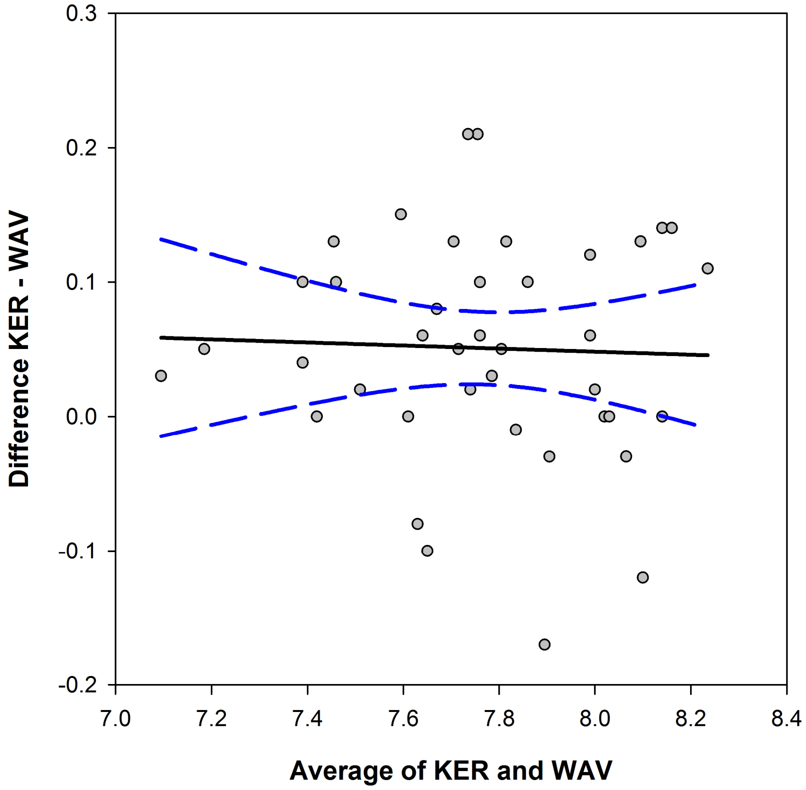
Figure 4


OCULUS - KERATOGRAPH
Patient Examination Display Lens fitting Settings Miscellaneous EyeLite
JPG Print
Name:
Dat. o.B.:
Eye: Right
Exm. dat.:
Exm. time:
Keratometric data : major meridians perpendicular
Rh: 8.30mm
Rv: 8.16mm
Ast.: 0.7D
Axs.: 8.0°
Ecc.: 0.73
Øcor: 12.0
188.0°
8.0°
98.0°
278.0°
AA:72%
8.40
8.24
8.14
8.46
8.31
8.23
8.26
8.43
8.77
8.06
8.10
8.18
mm
Sagittal
Absolut



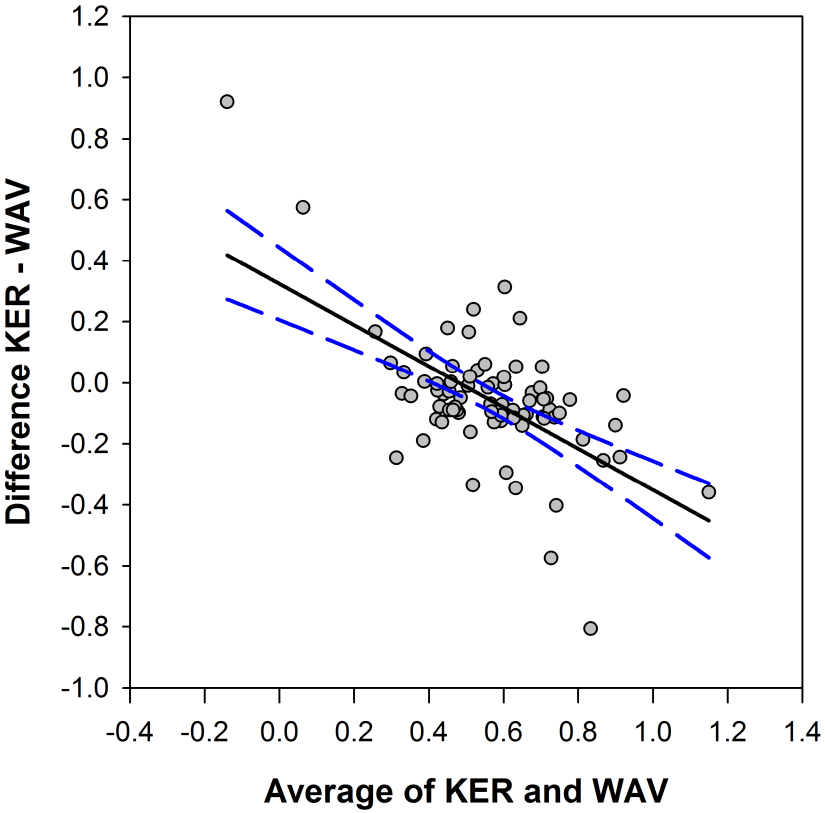
Mean + 1.96SD
Mean
Mean - 1.96SD
Difference KER - WAV
Average of KER and WAV
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5

Figure 6



0.3
0.2
0.1
0.0
-0.1
-0.2
Difference KER - WAV
7.0
7.2
7.4
7.6
7.8
8.0
8.2
8.4
Average of KER and WAV

Figure 7



1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
Difference KER - WAV
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Average of KER and WAV