ORIGINAL RESEARCH

Cylinder Axis Agreement: Unexpected Scenarios

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Background: The purpose of this retrospective study was to evaluate cylinder axis agreement between manifest refraction (MR), cycloplegic refraction (CR), Allegro Oculyzer II and Allegro Topolyzer-Vario.

Methods: We included 82 patients (32 males and 50 females, 28.1 ± 8.7 years old), with 156 eyes scheduled for wavefront optimized laser refractive surgery, photorefractive keratectomy (PRK) in 50 eyes and laser-assisted in situ keratomileusis (LASIK) in 106 eyes, for correction of simple, myopic, hyperopic or mixed astigmatism. Cylinder axis was determined under manifest and cycloplegic refractions and using Allegro Occulyzer II and Allegro Topolyzer-Vario platforms. Cylinder axis agreement was assessed by intraclass correlation coefficient, Pearson correlation coefficient and by the method described by Bland and Altman.

Results: Intraclass correlation coefficient and Pearson correlation coefficient showed statistically significant cylinder axis agreement between manifest refraction, cycloplegic refraction, Allegro Oculyzer II and Allegro Topolyzer-Vario (p <0.001). Despite statistically significant cylinder axis agreement between the four measuring tools, 4 of 156 eyes (2.5%) showed unexpected discrepancy between Allegro Oculyzer II and Allegro Topolyzer-Vario cylinder axis.

Conclusion: Although cylinder axis shows statistically significant agreement between manifest refraction, cycloplegic refraction, Allegro Oculyzer II and Allegro Topolyzer-Vario, unexpected discrepancies occur.

Keywords: manifest refraction, cycloplegic refraction, Allegro Oculyzer II, Allegro Topolyzer-Vario, PRK, LASIK

Introduction

Laser refractive surgery, including photorefractive keratectomy (PRK) and laser-assisted in situ keratomileusis (LASIK), gained global establishment as a reliable and safe procedure for correction of refractive errors.[1,2]

Laser refractive surgery is undergoing great evolutions, including excimer laser current flying spot technology, enhanced intraoperative pupillary tracking mechanism and cyclorotation adjustment.[3–5] The WaveLight EX500 (Alcon Laboratories; Ft Worth, TX, USA), the recent excimer laser evolution, applies a 1050 Hertz (Hz) multidimensional active tracking system with estimated 2 milliseconds (ms) latency and pupillary size tracking ability ranging from 1.5 mm to 8 mm.[6]

The term "wavefront optimized" was introduced to describe aspherical ablation profiles attempting to eliminate or reduce spherical aberration associated with myopic laser refractive correction.[7]

The majority of refractive surgeons rely on clinical refraction, manifest or cycloplegic; however, this refractive data occasionally shows difference from topography, regarding cylinder axis. Some surgeons advocated clinical refractive

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data adjustment with topography, introducing the new term "topography-modified refraction".[8]

Cylinder axis significance is not solely related to laser refractive surgery; it represents a cornerstone in lenticular refractive surgery, phakic intraocular lens (IOL) implantation or refractive lens exchange, particularly toric IOL. Similarly, cylinder axis determination is a crucial step in contact lens fitting.

Multiple factors might influence the accurate measurements of corneal astigmatism such as tear film stability, xerophthalmia, ocular surface status and corneal epitheliopathy. In addition, soft or hard contact lens wear may alter the accuracy of corneal astigmatism measurements.

Currently, it is not clearly documented which instrument measures corneal astigmatism with the greatest reproducibility and repeatability, and whether available measuring modalities could be applied interchangeably. Therefore, multiple

Comparison studies were undertaken to determine reproducible and accurate methods for corneal astigmatism measurement.[9]

The aim of this study was to evaluate cylinder axis agreement between manifest refraction (MR), cycloplegic refraction (CR), Allegro Oculyzer II and Allegro Topolyzer-Vario.

Methods

All patients were recruited from the Department of Ophthalmology, Faculty of Medicine, Alexandria University (Alexandria, Egypt). Informed consent was obtained from all patients. This study was approved by the Ethics of Research Committee, Faculty of Medicine, University of Alexandria, Egypt.

Recruited patients were scheduled for wavefront optimized laser refractive surgery, PRK or LASIK, for correction of simple, myopic, hyperopic or mixed astigmatism. Exclusion criteria were coexisting ocular pathologies, uncontrolled diabetes mellitus, collagen vascular diseases, pregnancy or breastfeeding, severe xerophthalmia, corneal dystrophies, forme fruste keratoconus, and keratoconus.

Preoperative Examination

All patients underwent manifest and cycloplegic refractions by a TOPCON RM-8900 Auto Refractometer (Topcon Medical Systems, Tokyo, Japan), measurements of the uncorrected visual acuity (UCVA) and best spectacle-corrected visual acuity (BSCVA).

All eyes were subjected to corneal topography assessment by Allegro Topolyzer-Vario (WaveLight, Erlangen, Germany) and Scheimpflug tomography examination by Allegro Oculyzer II (WaveLight, Erlangen, Germany). The Oculyzer presents a Scheimpflug rotating camera, with a 360 degrees rotating light beam, scanning the cornea with a high density of points from the corneal centre. In contrast, the Topolyzer is a placido-disk-based system with a camera imaging reflections from the surface of the cornea. Since the Topolyzer camera is located at the centre of the topographer, a central scotoma is produced corresponding to the camera location, and hence a small area of central corneal data are extrapolated.[10]

Patients enrolled in the study had pre-operative pachymetry ≥460 microns (μm) for PRK and ≥500 μm for LASIK. PRK subjects were required to retain an average post-operative residual corneal bed ≥380 μm. LASIK subjects were required to retain an average post-operative residual corneal bed ≥300 μm.

Operative and Postoperative Data

All patients underwent wavefront optimized laser refractive surgery, PRK in 50 eyes and LASIK in 106 eyes, for correction of simple, myopic, hyperopic or mixed astigmatism, applying WaveLight EX500 (Alcon Laboratories; Ft Worth, TX, USA). All surgeries were performed by a single surgeon, the author. A superior hinge was applied in LASIK cases using Moria Evolution 3 Microkeratome (Moria, Antony, France) with a programmed planned flap thickness of 110 μm and a diameter of 8 mm. In PRK, the corneal epithelium was removed in a diameter of 8 mm in a centripetal fashion using a blunt hockey blade. UCVA and manifest refraction were evaluated at 1 month post-operatively. Postoperative refraction was assessed by a TOPCON RM-8900 Auto Refractometer (Topcon Medical Systems, Tokyo, Japan).

Statistical Analysis of the Data

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). Intraclass correlation coefficient (ICC) and Pearson correlation coefficient were used to assess agreement. A p value less than 0.05 was considered statistically significant. Cylinder axis agreement was also studied using the method described by Bland and Altman. This method also computed 95% limits of agreement (LoA=mean difference ± 1.96SD).

Results

The present study was conducted on 82 patients 32 (39%) males and 50 (61%) females and involved 156 eyes scheduled

for wavefront optimized laser refractive surgery, PRK in 50 eyes and LASIK in 106 eyes, for correction of simple, myopic, hyperopic or mixed astigmatism. The age of the studied patients ranged from 18 to 49 years (28.1 ± 8.7 years). (Table 1)

Intraclass correlation coefficient and Pearson correlation coefficient showed statistically significant cylinder axis agreement between manifest refraction (MR), cycloplegic refraction (CR), Allegro Oculyzer II and Allegro Topolyzer-Vario (p <0.001*). (Tables 2 and 3) (Figure 1).

Despite statistically significant cylinder axis agreement between the four measuring tools, 4 of 156 eyes (2.5%) (3 patients) showed unexpected discrepancy between Allegro Oculyzer II and Allegro Topolyzer-Vario cylinder axis (Figure 2). In these cases, the cylinder axis applied for laser treatment was the mean of the four measurements. One month postoperatively, these cases showed 0 cylinder with UCVA 1. In the first case, MR cylinder axis was 104, CR cylinder axis was 94, Allegro Oculyzer II cylinder axis was 136 and Allegro Topolyzer-Vario cylinder axis was 88. The cylinder axis applied for laser treatment was the mean of the four values 105. In the second case, MR cylinder axis was 52, CR cylinder axis was 15, Allegro Oculyzer II cylinder axis was 38 and Allegro Topolyzer-Vario cylinder axis was 5. The cylinder axis applied for laser treatment was the mean of the four values 28. In the third case, MR cylinder axis was 100, CR cylinder axis was 100, Allegro Oculyzer II cylinder axis was 49 and Allegro Topolyzer-Vario cylinder axis was 152. The cylinder axis applied for laser treatment was the mean of the four values 100. In the last case, MR cylinder axis was 97, CR cylinder axis was 95, Allegro Oculyzer II cylinder axis was 155 and Allegro Topolyzer-Vario cylinder axis was 134. The cylinder axis applied for laser treatment was the mean of the four values 120.

Discussion

The Alcon/WaveLight refractive surgery laser platform comprises the EX500 excimer laser, and a series of diagnostic networked devices that constitute the Refractive Suite® (including Allegro Placido Topolyzer-Vario and Allegro Scheimpflug Oculyzer II).[11]

This Refractive Suite applies ethernet networking, allowing diagnostic data import from networked screening devices into the laser planning software, including topography data from Allegro Placido Topolyzer-Vario and topometric data from Allegro Scheimpflug Oculyzer II.[12] Multiple studies reported the application of

Table 1 Distribution of the Studied Cases According to Different Parameters (n = 156)

	No. (%)
Age (Years)	
Mean ± SD	27.4 ± 7.7
Median (Min. – Max.)	26 (18–49)
Refractive Surgery	
PRK	50 (32.1%)
LASIK	106 (67.9%)
Pachymetry (µm)	
Mean ± SD	537.7 ± 34
Median (Min. – Max.)	533 (487–639)
Keratometric K1 (D)	
Mean ± SD	42.8 ± 1.4
Median (Min. – Max.)	42.8 (39.6–46.3)
Keratometric K2 (D)	
Mean ± SD	44.6 ± 1.6
Median (Min. – Max.)	44.6 (41.5–50.6)
Sphere (D)	
Mean ± SD	−2 ± 3
Median (Min. – Max.)	−1.5 (−8 – 5.5)
Cylinder (D)	
Mean ± SD	−1.9 ± 1
Median (Min. – Max.)	−1.5 (−4.5 - −0.5)
Manifest Refraction Cylinder Axis	
Mean ± SD	95 ± 66.4
Median (Min. – Max.)	101.5 (3–192)
Cycloplegic Refraction Cylinder Axis	
Mean ± SD	92.7 ± 66.1
Median (Min. – Max.)	98.5 (1–194)
Allegro Oculyzer II Cylinder Axis	
Mean ± SD	94.8 ± 68.5
Median (Min. – Max.)	107.5 (2–190)
Allegro Topolyzer-Vario Cylinder Axis	
Mean ± SD	94.5 ± 69.3
Median (Min. – Max.)	106 (0–185)
1 Month Sphere (D)	
Mean ± SD	0 ± 0.1
Median (Min. – Max.)	0 (−0.3–0.5)
1 Month Cylinder (D)	
Mean ± SD	0 ± 0.1
Median (Min. – Max.)	0 (−0.5–0)
1 Month UCVA	
Mean ± SD	1 ± 0.1
Median (Min. – Max.)	1 (0.8–1)

Abbreviations: SD, standard deviation; PRK, photorefractive keratectomy; LASIK, laser-assisted in situ keratomileusis; UCVA, uncorrected visual acuity.

Table 2 Intra Class Correlation Coefficient for Cylinder Axis Agreement

	ICC Coefficient	95% C.I	p
MR Axis vs.			
CR axis	0.996	0.995–0.997	<0.001*
Oculyzer axis	0.991	0.988–0.993	<0.001*
Topolyzer axis	0.989	0.985–0.992	<0.001*
CR Axis vs.			
Oculyzer axis	0.990	0.986–0.993	<0.001*
Topolyzer axis	0.991	0.987–0.993	<0.001*
Oculyzer Axis vs.			
Topolyzer axis	0.994	0.992–0.996	<0.001*

Note: *Statistically significant at p ≤ 0.05.
Abbreviations: ICC, intra class correlation coefficient; CI, confidence interval; MR, manifest refraction; CR, cycloplegic refraction.

Table 3 Pearson Correlation Coefficient for Cylinder Axis Agreement

	Mean Difference (SD)	95% Limits of Agreement	Pearson Correlation Coefficient (r)*	p-value
MR axis - CR axis	2.37(2.92)	14.0 to −9.2	0.996	<0.001*
MR axis - Oculyzer axis	0.25(9.02)	17.9 to −17.4	0.992	<0.001*
MR axis - Topolyzer axis	0.55(9.94)	20.0 to −18.9	0.990	<0.001*
CR axis - Oculyzer axis	−2.12(9.50)	16.5 to −20.7	0.991	<0.001*
CR axis - Topolyzer axis	−1.81(9.33)	16.5 to −20.1	0.992	<0.001*
Oculyzer axis - Topolyzer axis	0.30(7.53)	15.1 to −14.5	0.994	<0.001*

Note: *Statistically significant at p ≤ 0.05.
Abbreviations: SD, standard deviation; r, Pearson coefficient; MR, manifest refraction; CR, cycloplegic refraction.

topography-guided treatment with such platforms, whether in normal or irregular corneas.[13–20]

The Oculyzer presents a Scheimpflug rotating camera, with a 360 degrees rotating light beam, scanning the cornea with a high density of points from the corneal centre. Therefore, it should be the first choice when planning laser treatment in corneas with central irregularities or aberrations. However, it can be affected by ocular movement or corneal haze or cloudiness.[10]

In contrast, the Topolyzer is a placido-disk-based system with a camera imaging reflections from the surface of the cornea. Since the Topolyzer camera is located at the

centre of the topographer, a central scotoma is produced corresponding to the camera location, and hence a small area of central corneal data are extrapolated.

Therefore, it should be the first choice when planning laser treatment in corneas with more peripheral irregularities or aberrations. However, it lacks the provision of full surface information, with lower accuracy in cases of central corneal aberrations.[10]

A recent study by Cummings et al showed that both the Oculyzer and Topolyzer provide reliable and comparable results in pre-operative myopes and in subjects with mixed astigmatism.[10] This coincides with the present study, where statistically significant agreement between Allegro Oculyzer II and Allegro Topolyzer-Vario was detected.

In a recent study by Kanellopoulos, clinical refractive data were modified with topographic data, considering cylinder axis and amount, introducing the new term "topography-modified refraction". This provided superior visual function regarding UCVA, residual refractive error, total high-order aberrations, coma aberration, and contrast sensitivity. He hypothesized that "topography-modified refraction" allows to bypass the bias induced by lenticular astigmatism, particularly active in young myopic patients. Such hypothesized lenticular astigmatism seems to be responsible for the distortion of the objective cylinder axis and amount.[8]

Numerous comparative studies were undertaken to correlate between corneal measurements using variable techniques. Lee et al[21] reported that corneal astigmatism measurements obtained via partial coherence interferometry, automated keratometry, Orb scan slit topography, iTrace ray tracing, and Pentacam Scheimpflug imaging were comparable to manual keratometric measurements, concluding possible interchangeable application of these instruments for assessment of corneal astigmatism. Another study addressed the accuracy of preoperative astigmatism measurements in cases of toric IOL and concluded non-significant difference between manual keratometry, automated keratometry, Pentacam Scheimpflug imaging or partial coherence interferometry.[22] Similarly, Shirayama et al[23] reported comparable corneal astigmatism measurements obtained using manual keratometry, partial coherence interferometry, Atlas placido-based topographer, and Galilei Dual Scheimpflug analyzer. On the other hand, Visser et al[24] reported poor agreement considering the vector of corneal astigmatism between Pentacam Scheimpflug imaging, manual keratometer, partial coherence interferometer, placido-based corneal topographer, or
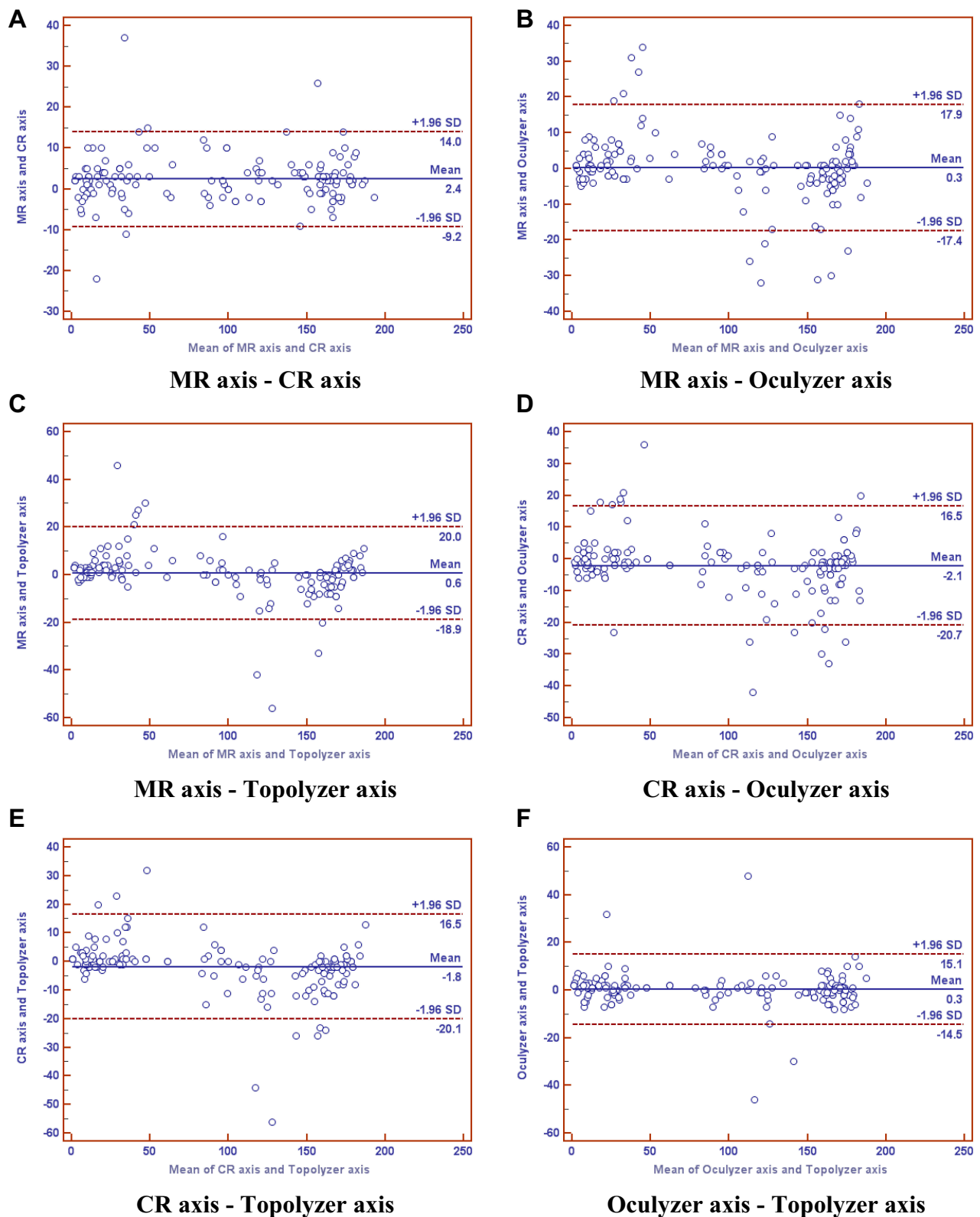
Figure 1 Bland–Altman plots of cylinder axis agreement between manifest refraction (MR), cycloplegic refraction (CR), Allegro Oculyzer II and Allegro Topolyzer-Vario. The bold horizontal line demonstrates the mean difference and the dotted lines above and below represent the 95% limits of agreement (LoA) interval. **A**: MR axis - CR axis. **B**: MR axis - Oculyzer axis. **C**: MR axis - Topolyzer axis. **D**: CR axis - Oculyzer axis. **E**: CR axis - Topolyzer axis. **F**: Oculyzer axis - Topolyzer axis.
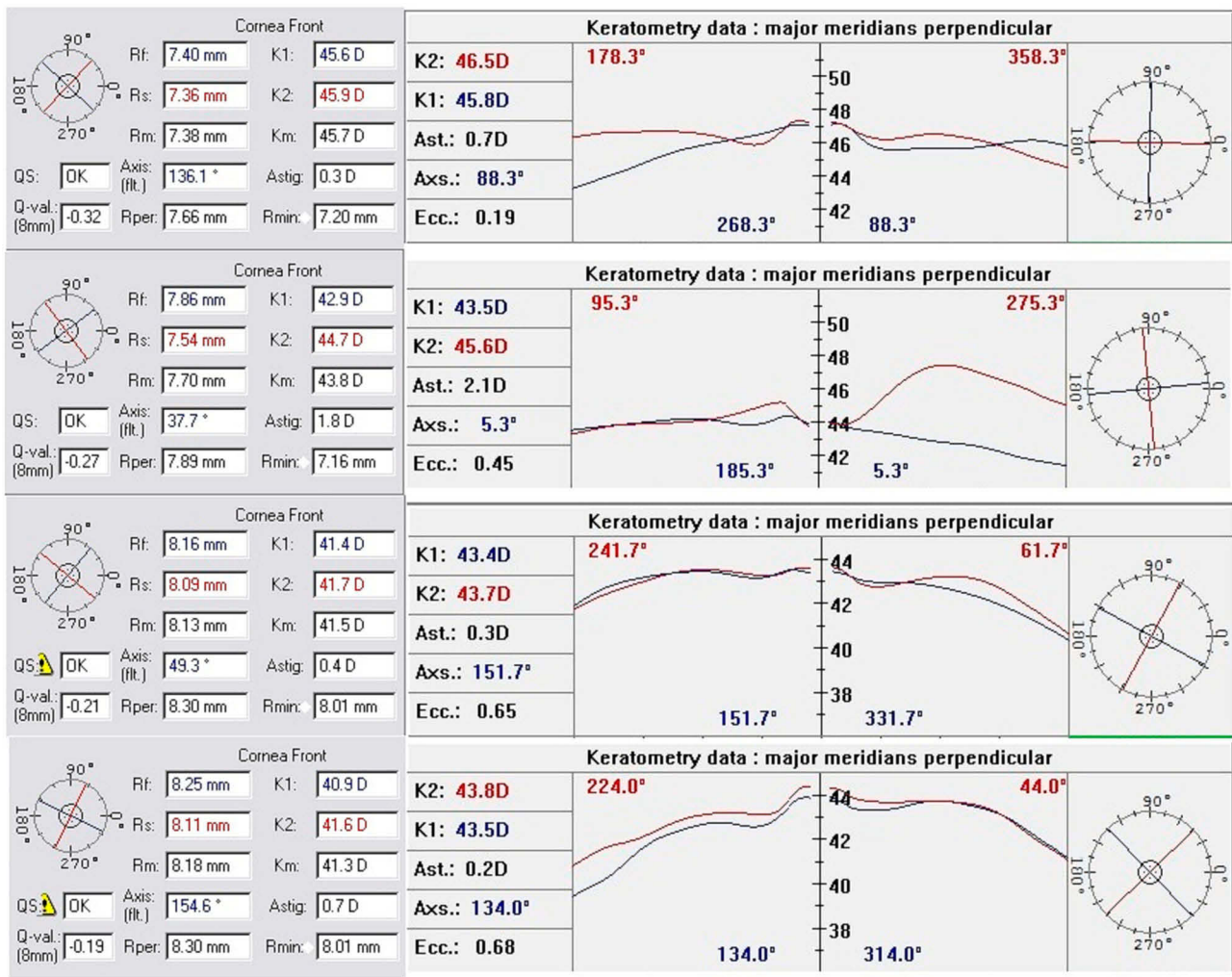
Figure 2 Allegro Oculyzer II and Allegro Topolyzer-Vario cylinder axis disagreement in four studied cases.

optical low coherence reflectometer. Similarly, Crawford et al[25] reported limited agreement between Orb scan slit topographer and Pentacam Scheimpflug imaging or Galilei Dual Scheimpflug analyzer in both steep and flat keratometric measurements.

Taking these comparative studies into consideration demonstrates considerable variability in corneal measurements obtained using various instruments. Behshad et al recommended the comparison of data from more than one measuring modality, looking for agreement, in order to confirm the magnitude and axis of corneal astigmatism in order to minimize errors, in cases of toric IOL implantation.[26]

Similarly, Browne et al[27] assessed absolute sphere, astigmatism amount, and steepest cylindrical axis in 87 eyes (54 patients) undergoing toric IOL implantation, using manual keratometry and four automated keratometers. The mean of the five measurements for sphere,

astigmatism amount, and steepest cylindrical axis were labeled meld sphere, meld astigmatism, and meld axis, respectively. Although Bland–Altman plots for statistical analysis yielded an insignificant difference from meld measurement for each parameter, the authors documented a disturbing number of outliers that might be overlooked if a single measurement modality was applied. Authors concluded that measurement errors can be dramatically reduced by averaging measurements from manual keratometry with any automated technology to make toric IOL selection more accurate.

This goes in agreement with the present study, where 4 of 156 eyes (2.5%) (3 patients) showed unexpected discrepancy between Allegro Oculyzer II and Allegro Topolyzer-Vario cylinder axis. In these cases, the cylinder axis applied for laser treatment was the mean of the four measurements. 1 month postoperatively, these cases

showed 0 cylinder with UCVA 1. In the first case, MR cylinder axis was 104, CR cylinder axis was 94, Allegro Oculyzer II cylinder axis was 136 and Allegro Topolyzer-Vario cylinder axis was 88. The cylinder axis applied for laser treatment was the mean of the four values 105. In the second case, MR cylinder axis was 52, CR cylinder axis was 15, Allegro Oculyzer II cylinder axis was 38 and Allegro Topolyzer-Vario cylinder axis was 5. The cylinder axis applied for laser treatment was the mean of the four values 28. In the third case, MR cylinder axis was 100, CR cylinder axis was 100, Allegro Oculyzer II cylinder axis was 49 and Allegro Topolyzer-Vario cylinder axis was 152. The cylinder axis applied for laser treatment was the mean of the four values 100. In the last case, MR cylinder axis was 97, CR cylinder axis was 95, Allegro Oculyzer II cylinder axis was 155 and Allegro Topolyzer-Vario cylinder axis was 134. The cylinder axis applied for laser treatment was the mean of the four values 120.

"These findings may change the current clinical paradigm of the optimal subjective refraction utilized in laser vision correction."[8]

Conclusions

Although cylinder axis shows statistically significant agreement between manifest refraction, cycloplegic refraction, Allegro Oculyzer II and Allegro Topolyzer-Vario, unexpected discrepancies occur.

Abbreviations

MR, manifest refraction; CR, cycloplegic refraction; PRK, photorefractive keratectomy; LASIK, laser-assisted in situ keratomileusis; Hz, Hertz; Ms, milliseconds; UCVA, uncorrected visual acuity; BSCVA, best spectacle-corrected visual acuity; μm, microns; ICC, intra class correlation coefficient; LoA, limits of agreement.

Data Sharing Statement

Datasets are available in additional supporting files by reasonable request to the author.

Ethics and Consent Statement

This study was approved by the Ethics of Research Committee (IRB 00007555, FWA 00015712), Faculty of Medicine, University of Alexandria, Egypt. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or

comparable ethical standards. Written informed consent to participate in the study was obtained from all individual participants included in the study.

Consent

Written informed consent to publish the results of the study and identifying images or other personal or clinical details of participants that compromise anonymity was obtained from all individual participants included in the study.

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Disclosure

The author reports no financial or proprietary interest in a product, method, or material and declares no conflicts of interest in this work.

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