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Reliability and agreement of apparent Chord mu measurements with Galilei G4 and Topolyzer Vario.

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Abstract:	Purpose: To assess the repeatability and agreement of Cartesian coordinates and length of apparent Chord mu and pupil diameter measurements during static (Galilei G4, Ziemer) and dynamic (Topolyzer Vario; Alcon Laboratories) evaluations. Setting: IOBA-Eye Institute, Valladolid, Spain. Design: Case series. Methods: Three consecutive measurements per scenario (Galilei G4 and Topolyzer Vario under low mesopic and photopic conditions) were performed by the same clinician in 37 right eyes of healthy participants. The intra-session repeatability was assessed using the within-subject standard deviation (Sw), the precision, the coefficient of variation and the intraclass correlation coefficient (ICC). The agreement was analyzed by repeated-measures ANOVA and the Bland-Altman method. Results: The Sw values for Chord mu parameters and pupil diameter ranged 0.01 to 0.03 and 0.08 to 0.21, respectively. The ICC was ≥0.89 for all parameters. Galilei G4, and Topolyzer Vario under low mesopic and photopic conditions provided significantly different measures of apparent Chord mu length (0.23±0.11mm, 0.30±0.10mm and 0.25±0.11mm, respectively,P≤.02), X-coordinate (-0.18±0.12mm,-0.27±0.11mm and -0.21±0.12mm, respectively,P<.001), and pupil diameter (3.38±0.50mm,6.29±0.60mm and 3.04±0.41mm, respectively,P<.001). Y-coordinate values obtained by Galilei G4 and Topolyzer Vario under low mesopic conditions were significantly different (0.06±0.13mm vs 0.03±0.11mm, respectively,P=.02), in contrast to Galilei G4 and Topolyzer Vario under photopic conditions (0.05±0.13mm,P=.82) and both illumination conditions of Topolyzer Vario (P≥.23). Conclusions: Galilei G4 and Topolyzer Vario provide consistent measurements of apparent Chord mu Cartesian coordinates and length, and pupil diameter, however, the measurements are not interchangeable. Ophthalmic surgeons should consider these findings when planning customized intraocular lens implantation and refractive surgery procedures.
Keywords:	Chord mu; Scheimpflug and Placido-disk technology; repeatability; Agreement.

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ABSTRACT

Purpose: To assess the repeatability and agreement of Cartesian coordinates and length of apparent Chord mu and pupil diameter measurements during static (Galilei G4, Ziemer) and dynamic (Topolyzer Vario; Alcon Laboratories) evaluations.

Setting: IOBA-Eye Institute, Valladolid, Spain.

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Methods: Three consecutive measurements per scenario (Galilei G4 and Topolyzer Vario under low mesopic and photopic conditions) were performed by the same clinician in 37 right eyes of healthy participants. The intra-session repeatability was assessed using the within-subject standard deviation (Sw), the precision, the coefficient of variation and the intraclass correlation coefficient (ICC). The agreement was analyzed by repeated-measures ANOVA and the Bland-Altman method.

Results: The Sw values for Chord mu parameters and pupil diameter ranged 0.01 to 0.03 and 0.08 to 0.21, respectively. The ICC was ≥0.89 for all parameters. Galilei G4, and Topolyzer Vario under low mesopic and photopic conditions provided significantly different measures of apparent Chord mu length (0.23±0.11mm, 0.30±0.10mm and 0.25±0.11mm, respectively, $P \leq .02$), X-coordinate (-0.18±0.12mm, -0.27±0.11mm and -0.21±0.12mm, respectively, $P < .001$), and pupil diameter (3.38±0.50mm, 6.29±0.60mm and 3.04±0.41mm, respectively, $P < .001$). Y-coordinate values obtained by Galilei G4 and Topolyzer Vario under low mesopic conditions were significantly different (0.06±0.13mm vs 0.03±0.11mm, respectively, $P = .02$), in contrast to Galilei G4 and Topolyzer Vario under photopic conditions (0.05±0.13mm, $P = .82$) and both illumination conditions of Topolyzer Vario ($P \geq .23$).

Conclusions: Galilei G4 and Topolyzer Vario provide consistent measurements of apparent Chord mu Cartesian coordinates and length, and pupil diameter, however, the measurements are not interchangeable. Ophthalmic surgeons should consider these findings when planning customized intraocular lens implantation and refractive surgery procedures.

INTRODUCTION

The visual axes and the angles formed between each other (kappa, lambda, alpha) have been deeply studied due to its importance in keratorefractive procedures or intraocular lens (IOL) implantations.[1,2] In the clinical practice, the angle kappa has been commonly used.[3,4] Specifically, in eyes with large angle kappa, centration of corneal refractive techniques over the coaxial corneal light reflex decreases higher order aberrations improving optical quality, in contrast to centering on the pupil.[5,6] Additionally, diffractive multifocal IOLs are usually designed to have the diffractive rings concentric with the aperture (pupil) and the center of the optic on the visual axis. However, these two requirements cannot be satisfied unless angle Kappa is zero. When angle Kappa (Chord Mu) becomes large, the diffractive images are degraded increasing postoperative dysphotopic phenomena, such as glare or halos.[7,8] Thus, different centration methods have been developed for refractive surgery procedures when angle kappa plays a key role.[9-11]

In clinical practice, angle kappa can be measured with the synoptophore, although this instrument is not commonly used for assessing refractive surgery candidates.[12] Anterior segment diagnostic devices, such as corneal topographers, which are frequently used during the preoperative refractive planning, capture a 2-dimensional image of the anterior segment while the subject fixates coaxially to the light source.[2,13,14] Based on this image, these devices estimate the distance between the vertex normal (Purkinje-Sanson image 1) and the pupillary center. Thus, the real angle kappa is not evaluated, instead a 2-dimensional displacement between vertex normal and the pupil center is provided. As both parameters have been commonly confused as previously reported,[14] Chang and Waring[2] introduced a new term, the Chord mu length, to designate this 2-dimensional displacement. Later, Holladay[15] described the difference between the apparent chord mu (distance between Purkinje image 1 and the pupil center viewed through the cornea) and the actual chord mu (whose distance is not affected by

corneal magnification). Chang and Waring's original description is therefore apparent chord mu.[2]

Galilei G4 (Ziemer Ophthalmic Systems AG, Switzerland), a combined Placido-disk and dual Scheimpflug imaging system, and Topolyzer Vario (Alcon Laboratories, Inc., Fort Worth, TX), a Placid-disk based system, are diagnostic devices commonly used for refractive surgery purposes. Both instruments automatically measured apparent Chord mu length and their Cartesian coordinates. Galilei G4 performs a static evaluation under a single lighting condition. In contrast, Topolyzer Vario performs a dynamic evaluation under two lighting conditions (low mesopic and photopic). Fluctuations in the lighting conditions induce changes in pupil size, which have an impact on Chord mu measurements.[16,17] Besides, the agreement of Chord mu measurements under static and dynamic pupil size evaluations have not been previously assessed. Thus, the purpose of the present study was first to assess the repeatability of Galilei G4 and Topolyzer Vario when measuring apparent Chord mu length and apparent Chord mu Cartesian coordinates as well as pupil diameter. Second, to analyze the agreement of apparent Chord mu measurements under two lighting conditions, mesopic and photopic ones, using the Topolyzer Vario. And third, to assess the agreement of these apparent Chord mu parameters obtained during a dynamic evaluation (Topolyzer Vario) and a static one (Galilei G4).

METHODS

An experimental study was performed in compliance with the tenets of the Declaration of Helsinki. The study was approved by the East Valladolid Health Area Ethics Committee (Valladolid, Spain) and conducted at Instituto of Oftalmobiología Aplicada (IOBA; University of Valladolid, Spain). Written informed consent was obtained from all participants.

Sample

The present study included 37 right eyes of 37 volunteers. Inclusion criteria were healthy subjects with an age between 18 and 40 years old. Exclusion criteria were the presence or history of any ocular anomaly or binocular alteration (tropia and high phoria). Cover test were done to exclude volunteers with tropia. In addition, subjects exceeding the normal ranges for distant phoria reported by Morgan[18] (1Δ exophoria ± 2) after undergoing both, the Maddox and Von Graefe tests, were also excluded.

Measurement procedures and study devices

Manifest refraction was performed, and corrected distance visual acuity (CDVA) was measured (logMAR units) using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart at 4 meters distance.

Galilei G4 and Topolyzer Vario were used to obtain the apparent Chord mu length and apparent Chord mu Cartesian coordinates as well as the pupil diameter. These evaluations were performed in the same closed dark room by the same experimented operator during one study visit. After 2 minutes of dark adaptation,[19] three consecutive Galilei G4 measurements per eye (right one) were recorded. Then, participants underwent another 2 minutes of dark adaptation and three Topolyzer Vario measurements were performed in the same eye. The measurement order between both systems was performed in a random fashion.

Galilei G4 and Topolyzer Vario devices consider the corneal light reflex as the center of the coordinate system for Chord mu measurements. Therefore, negative X values indicate that the pupil center is temporal to the corneal light reflex (Both instruments provide Chord mu measurements for right and left eyes in Cartesian coordinates, however, no further sign

transformations were needed because only right eyes were computed for analysis), and negative Y values indicate that the pupil is inferior.

Galilei G4

Galilei G4 (Ziemer Ophthalmic Systems AG, Switzerland) is a tomography system based on Dual-Scheimpflug imaging and Placido-disk technology. Before the examination, participants were convenient positioned on the head-chin rest and the height was adjusted. Then, subjects were asked to look at the fixation point, blink and open their eyes widely prior to each image acquisition. A manual alignment of the red cross-hair to the four Purkinje dots, which corresponds to the first Purkinje reflex in the cornea (Figure 1), was performed prior to image acquisition. Galilei G4 provides mesopic illumination (average of 5.5 lux) during acquisition. Pupil diameter, Chord mu length (mm) and their Cartesian coordinates (X, Y) were recorded from each measurement.

Topolyzer Vario

Topolyzer Vario (Alcon Laboratories, Inc., Fort Worth, TX) is a topographer based on Placido-disk technology that incorporates an infrared camera to accurately capture the pupil. After placing the patient´s head on the head-chin rest of the instrument and correctly centering the eye, an automatic dynamic pupil evaluation was performed. The dynamic pupil evaluation consists of 60 seconds recording pupil diameter, pupil center and the corneal light reflex. During the 60-seconds period, three consecutive cycles of low mesopic and photopic illumination are automatically performed, which provide an average illumination of 0.07 and 145 lux, respectively (Figure 1). Then, the average of pupil diameter, apparent Chord mu length and apparent Chord mu in Cartesian coordinates during the 60-seconds period are provided for both mesopic and photopic conditions.

Statistical analysis

The statistical analysis was performed with the R statistical package version 4.0.0. Sample size for the agreement analysis was calculated using the formula reported by McAlinden et al.[20] Standard deviation (SD) of the difference was estimated using the data from the first 10 volunteers enrolled, considering the three combinations of measurements (the difference between Galilei G4 and Topolyzer Vario, and between Topolyzer Vario under low mesopic and photopic conditions). SD of the difference for Chord mu length and their Cartesian coordinates was equal or less than 0.07 mm, then, this value was used for the sample size calculation. The desired confidence interval of the limits of agreement (LoA) was established as 0.04 mm. The calculated sample size was 37 subjects. The 10 first volunteers were included in the final analysis.[21,22]

The intrasubject repeatability was evaluated by calculating the within subject standard deviation (Sw) obtained from the square root of three consecutive measurements in a one-way analysis of variance (ANOVA).[23,24] The precision was calculated as the difference between a patient's measurement and the true value for 95% of observations (mean value that would be obtained over many measurements) and it was defined as 1.96×Sw.[24] The repeatability was the difference between two observed measurements with a probability of 95% and it was defined as 2.77×Sw.[23,24] The intrasubject variation was also calculated using the coefficient of variation (CVw), which was defined as the percentage of the ratio of the Sw and the overall mean;[24] CVw was not calculated for X and Y coordinates because these variables can obtain negative values. The intrasession reliability of the measurement method was also calculated by the intraclass correlation coefficient (ICC).[25]

To assess the agreement, the mean of the three measurements for each scenario was calculated and systematic differences were analyzed by repeated measures ANOVA, and post-

hoc multiple comparisons were performed with the Bonferroni correction. Normality was checked using the Shapiro-Wilk test. Agreement between the three combinations of measurements was evaluated by the Bland-Altman method.[26] The 95% LoA were determined as the mean difference of ±1.96SD. Two-sided p-values equal or less than 0.05 were considered statistically significant. A power analysis was also conducted to estimate the statistical power of ICC and ANOVA comparisons.

RESULTS

A total of 37 eyes of 37 subjects (31 females and 6 males) with a mean age of 19.9±2.8 years were evaluated. The mean spherical equivalent was -1.85±1.67 diopters and the mean CDVA was -0.03±0.09 logMAR.

Intrasubject repeatability

Table 1 shows the mean values of the repeated measures, the Sw, the precision, the repeatability, the CVw and the ICC for pupil diameter, X and Y coordinates and apparent Chord mu length obtained by Galilei G4 and Topolyzer Vario systems. Excellent (≥0.92) ICC values were obtained for all parameters measured with both diagnostic devices, except for the pupil diameter measured with Topolyzer Vario under low mesopic conditions (ICC=0.89). CVw values for pupil diameter and Chord mu length did not exceed 4.4% and 6.7%, respectively. The maximum repeatability (2.77×Sw) for X and Y coordinates was 0.05 and 0.08 mm, respectively.

Agreement between Galilei G4 and Topolyzer Vario

The Shapiro-Wilk confirmed the assumption of normality for the difference between instruments for the three scenarios: X-coordinate (P≥.57), Y-coordinate (P≥.41), apparent Chord mu length (P≥.38) and pupil diameter (P≥.12). Significant differences were obtained in

the ANOVA analysis for the four parameters (Table 2): X-coordinate (P<.001), Y-coordinate (P=.02) and length (P≤.02) of Chord mu, and pupil diameter (P<.001).

Figure 2 and table 2 show Bland-Altman plot and data, respectively, for the four parameters measured with Topolyzer Vario under low mesopic and photopic conditions. Topolyzer Vario under low mesopic conditions in comparison with photopic conditions, provided significant (P<.001) higher Chord mu length and pupil diameter values, and a significantly (P<.001) lower (more temporal) Chord mu X-coordinate. Y-coordinate of Chord mu did not significantly (P=.23) change between mesopic and photopic illumination.

Figure 3 and table 2 show Bland-Altman plot and data, respectively, for the four parameters measured with Galilei G4 and Topolyzer Vario under low mesopic conditions. The results obtained using the Galilei G4 were significantly (P<.001) lower for Chord mu length and pupil diameter. The Chord mu X- and Y-coordinates provided by Galilei G4 were significantly (P<.001 and P=.02, respectively) higher than the ones obtained by Topolyzer Vario under low mesopic conditions.

Figure 4 and table 2 show Bland-Altman plot and data, respectively, for the four parameters measured with Galilei G4 and Topolyzer Vario under photopic conditions. Galilei G4 compared with Topolyzer Vario under photopic conditions provided a significantly (P<.001) higher Chord mu X-coordinate and pupil diameter, and a significantly (P=.02) lower Chord mu length. Y-coordinate of Chord mu was not significantly (P=.82) different between both systems.

Power analysis

All ICC analyses reached a 100% power (higher than 99.99%). In regard to ANOVA, the power reached was the following: X-coordinate (96.92%), Y-coordinate (8.76%), Chord mu length (62.94%) and pupil diameter (99.98%).

DISCUSSION

Clinical references have been established as relevant landmarks in refractive surgery in an attempt to avoid an optical quality degradation originated by a decentration of corneal photoablation or IOL implantation.[27] Besides, the measurement reliability of any ophthalmic instrument commonly used in the daily clinic (i.e. aberrometers,[28] topographers,[29] etc) should be determined clinically to avoid misdiagnosis or erroneous treatment based on the data provided. This study assessed the repeatability and agreement of apparent Chord mu (X-coordinate, Y-coordinate and length) and pupil diameter measurements between two diagnostic devices frequently used in the clinical practice. Galilei G4 and Topolyzer Vario provide static and dynamic (mesopic and photopic conditions) measurements, respectively. We found that the repeatability of both instruments was very good, or even excellent, for most of the parameters evaluated (ICC≥0.89), whereas the agreement between the three measurement scenarios (Galilei G4 under mesopic conditions, Topolyzer Vario under low mesopic and photopic conditions) was low, especially between the low mesopic condition of Topolyzer Vario and the other two illumination scenarios (mesopic (Galilei G4) and photopic (Topolyzer Vario)).

In the present study, pupil diameter measured with Galilei G4 and Topolyzer Vario showed good repeatability. The CVw of Galilei and Topolyzer Vario was below 4.5% and 3.5%, respectively. Salah-Mabed et al.[30] have previously estimated the intra-session reliability of pupil size measurements with Topolyzer Vario. They have reported a repeatability (2.77xSw) of 0.19 mm and 0.36 mm for the photopic and mesopic conditions, respectively. These

repeatability values are similar to the ones of our study for the photopic conditions, and even better for the mesopic ones (Table 1). Nonetheless, the pupil diameter obtained with the Topolyzer Vario in the low mesopic condition might not be the maximum physiological dilation due to the design of the illumination cycle, which alternates photopic and mesopic conditions for one minute. In case of Galilei G4, as far as we know, the repeatability of pupil diameter measurements has not been previously estimated. Additionally, in our study we observed that the repeatability of Chord mu X-coordinate, Y-coordinate and length measurements for Galilei G4 and Topolyzer Vario was also good (Table 1). Salah-Mabed et al.[30] have reported the repeatability of these Chord mu parameters, and they observed that the maximum repeatability (2.77xSw) value was 0.11 mm, corresponding to the Y-coordinate in photopic conditions. In our study, the maximum repeatability value was 0.08 mm corresponding to the Y-coordinate under both illumination conditions. These values are rounding the theoretical limit of decentration not able to induce optical degradation for a 7.0-mm pupil, but widely covering it for 3.0- and 5.0-mm pupils.[31] Dominguez-Vicent et al.[32] have reported the repeatability of Chord mu length using Galilei G4. They also performed 3 consecutive measurements and calculated the 95% LoA following Bland-Altman statistics. They observed that the width of these LoA was 0.055 mm, a value which is close to the one obtained in our study, 0.04 mm, for the repeatability (2.77xSw) (Table 1). Therefore, it can be concluded that both Galilei G4 and Topolyzer Vario provide reliable intra-session measurements of pupil diameter as well as Chord mu X- and Y- coordinates and length.

The agreement observed in our study for pupil diameter measures among the three scenarios was low, as it was expected. The main reason for the differences found should be the specific illumination projected by each device during acquisition. A considerable disagreement was found between Topolyzer Vario under low mesopic conditions and the other two scenarios, being the mean differences in pupil diameter around 3 mm. Regarding the mean difference in

pupil diameter between Galilei G4 and the Topolyzer Vario under photopic conditions, it was much lower, specifically, 0.35 mm higher using Galilei G4 (Figure 4D); nonetheless, the difference was statistically significant (Table 2). In addition, the Bland-Altman plot (Figure 4D) did not show any tendency of the mean difference to change depending on the pupil diameter value, and the 95% LoA were reasonable from a clinical viewpoint.

The displacements observed in the three scenarios for Chord mu X- and Y-coordinates were temporal and superior, respectively, considering distances from the corneal vertex to the pupil center (Table 1). In concordance, this temporal displacement has been previously reported in the literature,[33] whereas the direction of vertical displacements, which are in general of lower magnitude, appears to be more unpredictable.[33] In our study, there were significant differences among the mean Chord mu X- and Y-coordiante and length parameters obtained for the three scenarios, except for the Y-coordinate measured by Topolyzer Vario under photopic conditions and the other two scenarios. Topolyzer Vario under mesopic conditions showed the most negative values for Chord mu X-coordinate and the highest for Chord mu length, whereas Galilei G4 obtained the lowest ones (Table 1). On the other hand, Galilei G4 obtained the highest Chord mu Y-coordinate values and Topolyzer Vario under mesopic conditions, the lowest ones. Given that the pupil center shifts depending on the illumination conditions,[17,34,35] our outcomes could be the result of the significantly different pupil diameters observed at each scenario (Table 1). Thus, our findings indicate that the illumination conditions, specially observed when comparing both Topolyzer Vario conditions (photopic and mesopic), have an effect on the Chord mu X-coordinate, Y-coordinate and length parameters.

To our knowledge, the agreement of Chord mu length or Cartesian coordinates measurements between Galilei G4 and Topolyzer Vario had not been studied before, despite they are very common devices used for refractive surgery purposes. Based on our outcomes,

Galilei G4 and Topolyzer Vario (static and dynamic assessment, respectively) devices provide Chord mu parameters that are not interchangeable, because the values obtained by both devices are significantly different, except for the Chord mu Y coordinate under photopic conditions (Table 2). Domínguez-Vicent et al.[32] has previously analyzed the agreement between Galilei G4 and Orbscan II when measuring Chord mu length, and they also concluded that the measures provided by these devices were not interchangeable either. Nonetheless, it is worth of mention that Chord mu length does not take into account the orientation, then, X- and Y-coordinates should be also considered for analyzing agreement among instruments.

Chord mu parameters and pupil diameter are frequently measured for refractive surgery purposes during preoperative examination. In the present study, measurements were taken in a dark room without any other illumination apart from the one provided by each device. These conditions are recommended by the manufacturers and they are the ones commonly used for the measurements in eye clinics (GALILEI™ G4 dual scheimpflug analyzer-Operator Manual, ALLEGRO Topolyzer VARIO-User Manual). It has been demonstrated that illumination conditions play a key role for these particular measurements. Then, a match between the lighting conditions during the preoperative examination and the surgery set up within the operating theatre is important to achieve accuracy and representative data. Given that the repeatability of the mesopic apparent chord mu is the lowest comparably, this measure could be disregarded in favor of the photopic condition of the Topolyzer Vario, or use the Galilei G4 alternatively, unless future studies demonstrate a superior clinical role of the apparent chord mu under mesopic illumination. In addition, the 95% confidence interval of the upper limit (mean + 2SD) for the apparent chord mu length may be used as a reference for detecting abnormal chord mu values,[15] which are more frequent in hyperopic eyes.[12] Then, patients with an apparent chord mu length higher than 0.45 mm when using the Galilei G4, and 0.50 mm and 0.47 mm when using the Topolyzer Vario in mesopic and photopic conditions,

respectively, should be treated with caution. However, considering the relatively small mean differences observed in this study for Chord mu X-coordinate, Y-coordinate and length among the three scenarios and the moderate width of the 95% LoA (Table 2), each surgeon should determine whether these differences are clinically acceptable or not depending on their clinical end points, using always the data of the same device to build their own nomogram.

The main limitation of the present study is that the illumination provided by the devices was different when the dynamic (Topolyzer Vario) and static (Galilei G4) evaluations were performed (Figure 1). However, these measurements were performed similarly to any other clinician during clinical practice worldwide, which assures the usefulness of the study outcomes for a clinical viewpoint. Additionally, when Chord mu parameters obtained by Galilei G4 and Topolyzer Vario under photopic conditions were compared, it was found significant differences only for X coordinate and length (Table 2), and these differences (mean: 0.02 mm for both parameters) could be considered clinically negligible. Second, the duration of the protocol was not likely to last longer than 10 minutes, however, it is possible that outcomes obtained from any patient might have been influenced by fatigue. Third, sample size was estimated using an internal pilot study, which involved the first 10 volunteers.[21,22] This method was used because of the lack of previous data to estimate the final sample size. This approach has the limitation of violating the independence premise. However, the negative effect has been estimated to be minimal in comparison with the benefits, and its use has been recommended.[21,22] Finally, this study only includes a young population group (mean age: 19.9±2.8 years), and it is well-known that there is an inverse relationship between mesopic pupil size and age, so that the pupil size substantially decreases in older subjects.[36] Thus, further studies should corroborate our outcomes, especially considering that the sample enrolled in the present study is not representative of cataract patients. However, they should not be expected

to vary greatly when assessing older population, because several participants showed pupil sizes between 2.5 and 3.5 mm under photopic conditions.

In conclusion, Galilei G4 and Topolyzer Vario have good repeatability for measuring pupil diameter, apparent Chord mu length and apparent Chord mu Cartesian coordinates. Illumination conditions when assessing patients, either photopic or mesopic, which have an impact on pupil diameter, should be considered to properly interpret the Chord mu length and Chord mu Cartesian coordinates because each condition provides different outcomes. Particularly, patients with an apparent chord mu length higher than 0.45 mm when using the Galilei G4, and 0.50 mm and 0.47 mm when using the Topolyzer Vario in mesopic and photopic conditions, respectively, should be treated with caution. Finally, Galilei G4 and Topolyzer Vario measurements of pupil diameter, X-coordinate, Y-coordinate and apparent Chord mu length parameters are not interchangeable. Future clinical studies should also assess the dependence of clinical outcomes on different chord mu values provided by different instruments for refractive surgery purposes.

VALUE STATEMENT

What Was Known:

- Chord mu centration and measurement are evaluated before keratorefractive procedures and intraocular lens implantations to maximize postoperative optical quality.
- Reliability and agreement of Chord mu measurements among commonly used diagnostic devices should be analyzed to provide clinically useful information for ophthalmic surgeons.

What This Paper Adds:

- Galilei G4 and Topolyzer Vario under mesopic and photopic conditions provide repeatable measurements of apparent Chord mu and pupil diameter.
- Measurements of apparent Chord mu X- and Y-coordinate and apparent Chord mu length obtained with Galilei G4 and Topolyzer Vario are not interchangeable. The illumination conditions provided by each device when imaging the cornea might be reason for the poor agreement.

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FIGURE LEGENDS.

Figure 1. Pupil diameter acquisitions and illumination from Galilei G4 and Topolyzer Vario devices.

Top: image of the illumination from Placido disk (left), capture of the 2-dimensional image (middle) and magnification of the pupil (right), when Galilei G4 is performing the measurement. Middle: illumination from the Topolyzer Vario under low mesopic conditions (left), capture of the 2-dimensional image (middle) and magnification of the pupil (right) when the device is performing the measurement. Bottom: illumination from the Topolyzer Vario under photopic conditions (left), capture of the 2-dimensional image (middle) and magnification of the pupil (right) when the device is performing the measurement.

Images are shown for the same eye. Each magnification image also includes the quantification of pupil diameter (P), Chord mu in Cartesian coordinates (X,Y) and Chord mu length (mu) for the representative case in each specific scenario.

Figure 2. Bland-Altman plot comparing Topolyzer Vario measurements under low mesopic and photopic conditions.

A: X-coordinate; B: Y-coordinate; C: Chord mu length; D: pupil diameter.

Black solid lines represent the mean difference between conditions, while dashed lines represent the 95% limits of agreement.

Figure 3. Bland-Altman plot comparing pupil diameter and Chord mu measurements between mesopic (Galilei G4) and low mesopic (Topolyzer Vario) conditions.

A: X-coordinate; B: Y-coordinate; C: Chord mu length; D: pupil diameter.

Black solid lines represent the mean difference between devices, while dashed lines represent the 95% limits of agreement.

Figure 4. Bland-Altman plot comparing pupil diameter and Chord mu measurements between mesopic (Galilei G4) and photopic (Topolyzer Vario) conditions.

A: X-coordinate; B: Y-coordinate; C: Chord mu length; D: pupil diameter.

Black solid lines represent the mean difference between devices, while dashed lines represent the 95% limits of agreement.

Synopsis:

Galilei G4 and Topolyzer Vario provide repeatable measurements of apparent Chord mu length and Cartesian coordinates, however, measurements are not interchangeable except for Y-coordinate values under photopic conditions.

Reliability and agreement of apparent Chord mu measurements with Galilei G4 and Topolyzer Vario

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Running head: Reliability and agreement of Chord mu measurements

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Figure 1

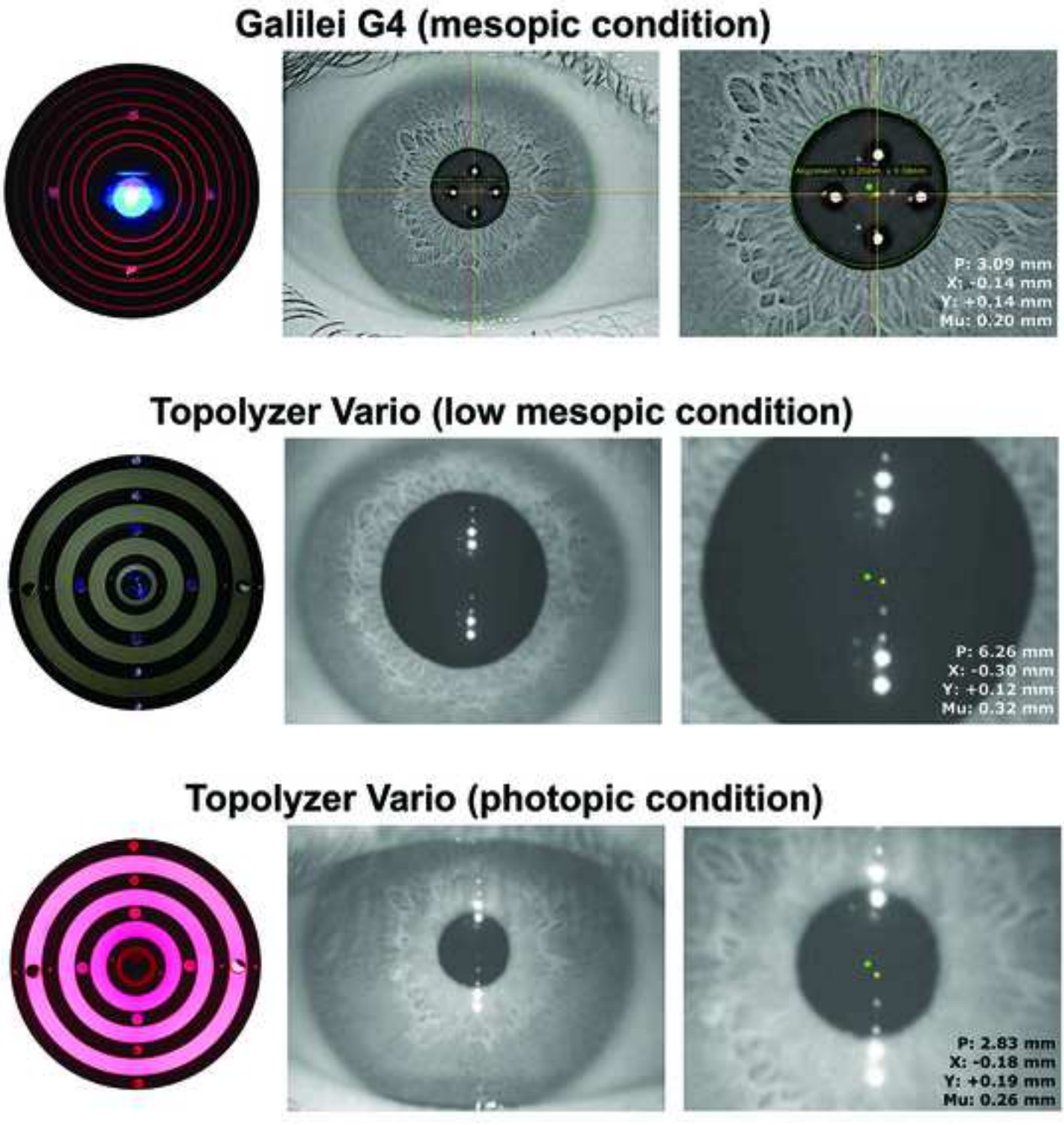

Figure 2

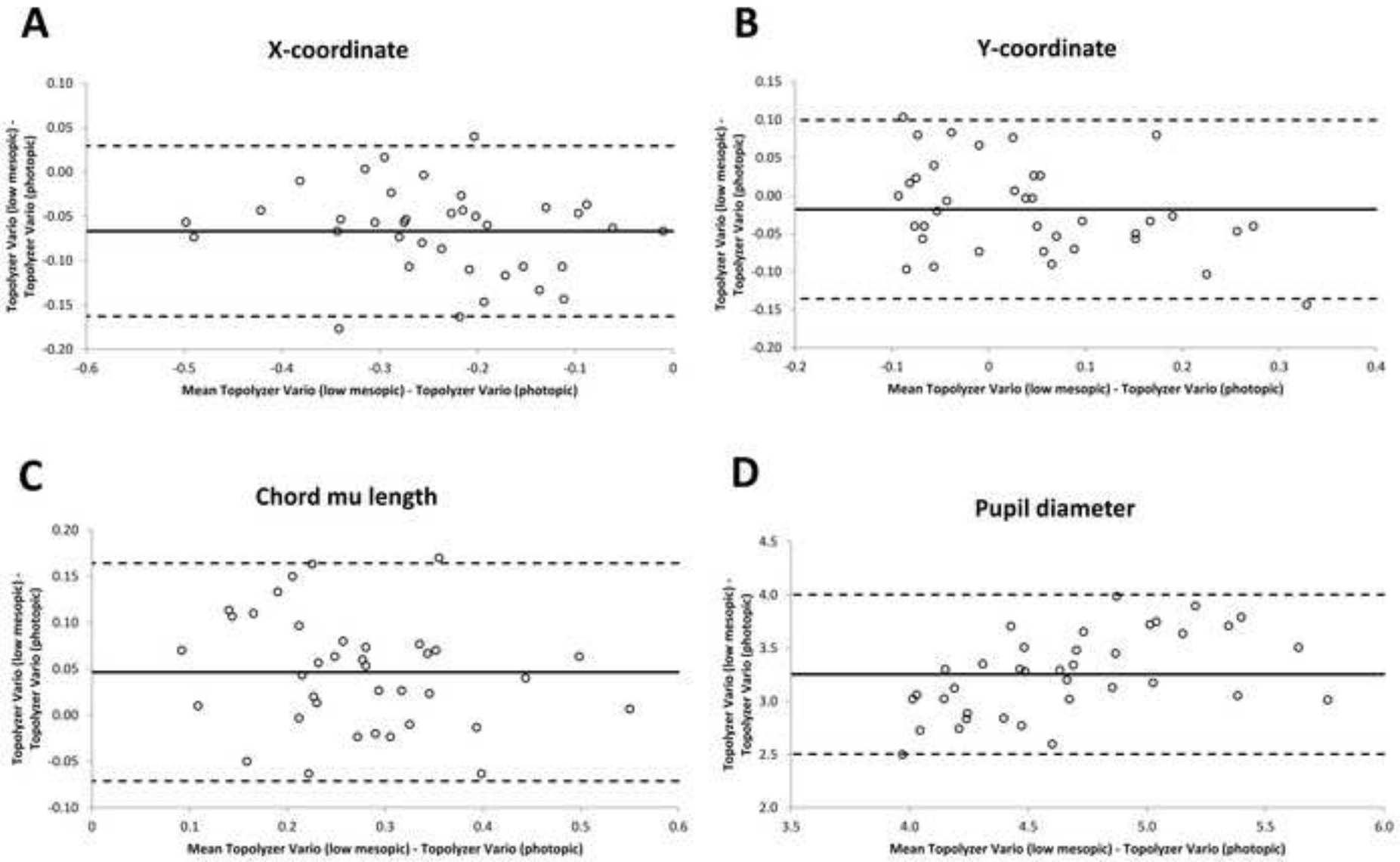

Figure 3

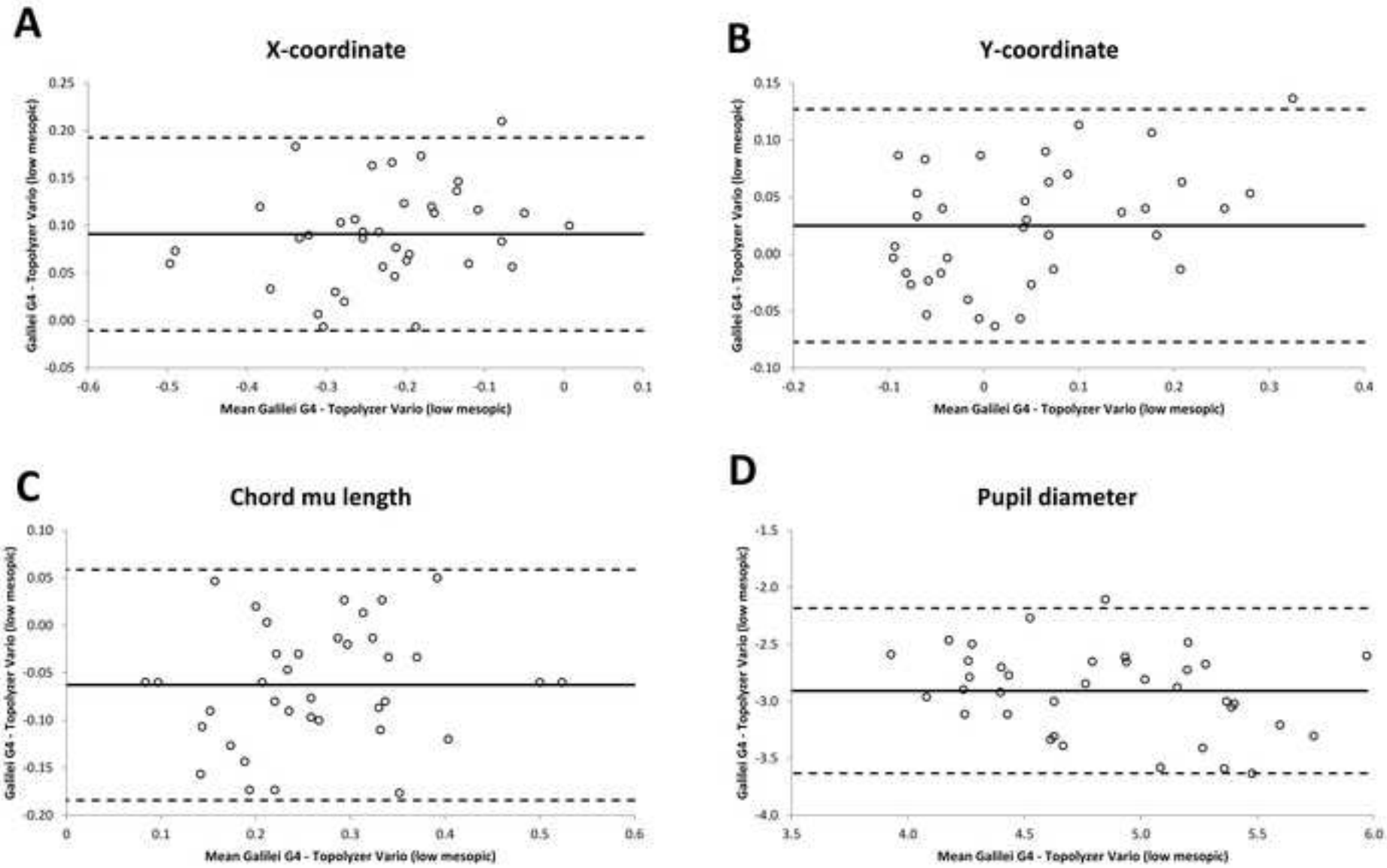

Figure 4

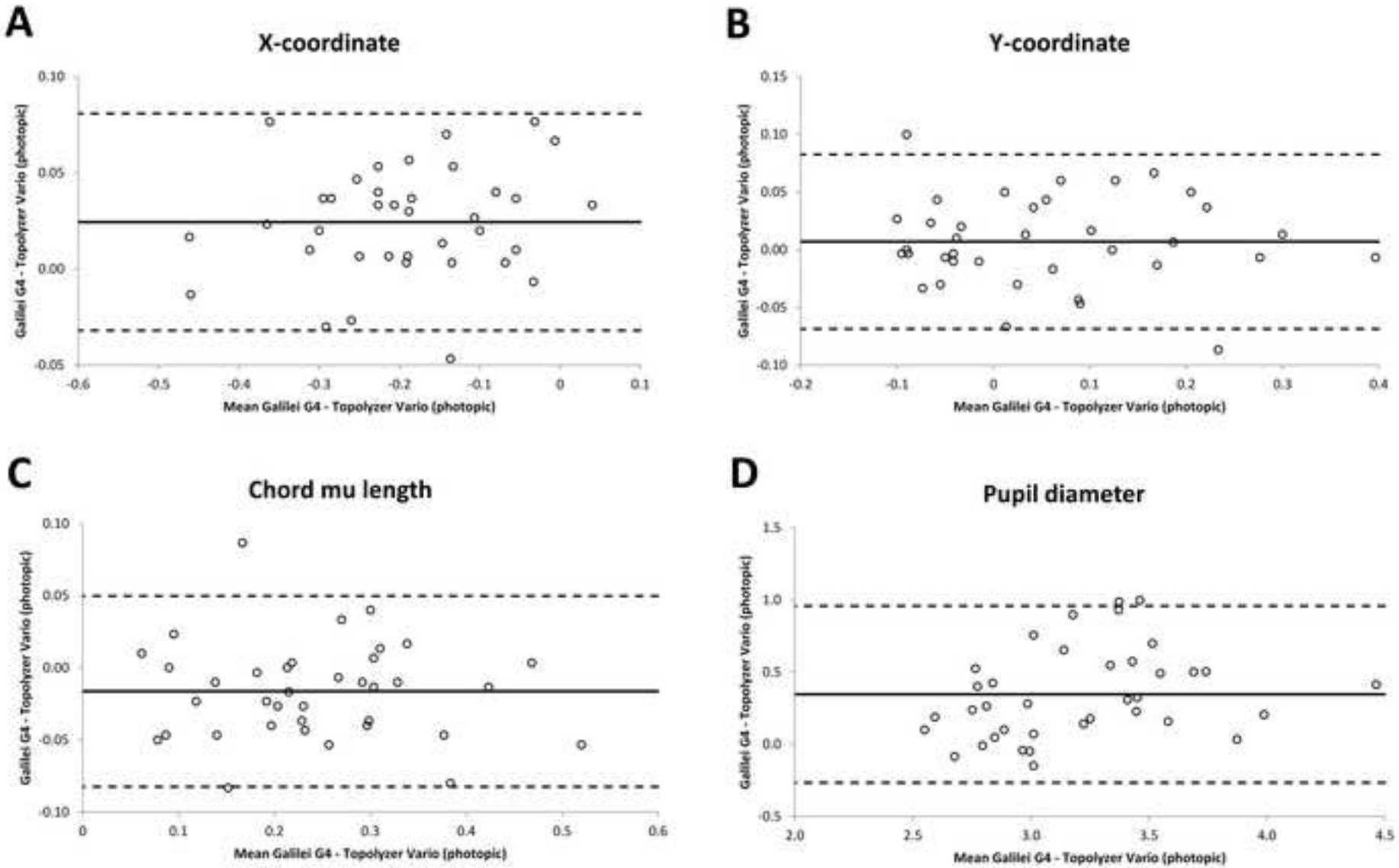

Table 1. Intrasubject repeatability data.

Situation	Parameter (mm)	Mean±SD	Sw (95% CI)	Precision (1.96xSw) (95% CI)	Repeatability (2.77xSw) (95% CI)	CVw % (95% CI)	ICC (95% CI)
Galilei G4. Mesopic conditions.	X-coordinate	-0.18±0.12	0.02 (0.02/0.02)	0.03 (0.03/0.04)	0.05 (0.04/0.05)	-	0.98 (0.97/0.99)
	Y-coordinate	0.06±0.13	0.01 (0.01/0.01)	0.03 (0.02/0.03)	0.04 (0.03/0.04)	-	0.99 (0.98/0.99)
	Chord mu length	0.23±0.11	0.01 (0.01/0.02)	0.03 (0.03/0.03)	0.04 (0.04/0.04)	5.87 (5.39/6.35)	0.98 (0.97/0.99)
	Pupil diameter	3.38±0.50	0.15 (0.14/0.16)	0.29 (0.27/0.32)	0.41 (0.38/0.45)	4.39 (4.03/4.76)	0.92 (0.83/0.96)
Topolyzer Vario. Low Mesopic conditions.	X-coordinate	-0.27±0.11	0.02 (0.01/0.02)	0.03 (0.03/0.03)	0.04 (0.04/0.046)	-	0.98 (0.97/0.99)
	Y-coordinate	0.03±0.11	0.03 (0.03/0.03)	0.06 (0.05/0.06)	0.08 (0.07/0.09)	-	0.93 (0.89/0.96)
	Chord mu length	0.30±0.10	0.02 (0.02/0.02)	0.04 (0.04/0.04)	0.05 (0.05/0.06)	6.62 (6.08/7.16)	0.96 (0.94/0.98)
	Pupil diameter	6.29±0.60	0.21 (0.19/0.23)	0.41 (0.38/0.45)	0.58 (0.53/0.63)	3.34 (3.06/3.61)	0.89 (0.78/0.94)

Topolyzer Vario. Photopic conditions.	X-coordinate	-0.21±0.12	0.01 (0.01/0.01)	0.02 (0.02/0.03)	0.03 (0.03/0.04)	-	0.99 (0.98/0.99)
	Y-coordinate	0.05±0.13	0.03 (0.03/0.03)	0.06 (0.05/0.06)	0.08 (0.07/0.09)	-	0.95 (0.92/0.97)
	Chord mu length	0.25±0.11	0.02 (0.01/0.02)	0.03 (0.03/0.03)	0.04 (0.04/0.05)	6.12 (5.62/6.62)	0.98 (0.97/0.99)
	Pupil diameter	3.04±0.41	0.08 (0.08/0.09)	0.17 (0.15/0.18)	0.23 (0.22/0.25)	2.78 (2.56/3.01)	0.96 (0.91/0.98)

CVw: coefficient of variation; CI: coefficient interval; ICC: intraclass correlation coefficient; SD: standard deviation; Sw: within subject standard deviation. For X-coordinate, negative values represent temporal displacement to the pupil center from the corneal vertex. For Y-coordinate, negative values represent inferior displacements to the pupil center from the corneal vertex.

Table 2. Agreement between Galilei G4 and Topolyzer Vario data.

Comparisons	Parameter (mm)	Mean±SD of the difference (95% CI)	p-value*	Lower LoA (95% CI)	Upper LoA (95% CI)
Topolyzer Vario low mesopic vs photopic conditions	X-coordinate	-0.07±0.05 (-0.08/-0.05)	<0.001	-0.16 (-0.19/-0.13)	0.03 (0.00/0.06)
	Y-coordinate	-0.02±0.06 (-0.04/0.00)	0.23	-0.14 (-0.17/-0.10)	0.10 (0.07/0.13)
	Chord mu length	0.05±0.06 (0.03/0.07)	<0.001	-0.07 (-0.11/-0.04)	0.16 (0.13/0.20)
	Pupil diameter	3.25±0.38 (3.13/3.38)	<0.001	2.50 (2.28/2.73)	4.00 (3.78/4.22)
Galilei G4 (mesopic conditions) vs Topolyzer Vario low mesopic conditions	X-coordinate	0.09±0.05 (0.07/0.11)	<0.001	-0.01 (-0.04/0.02)	0.19 (0.16/0.22)
	Y-coordinate	0.03±0.05 (0.01/0.04)	0.02	-0.08 (-0.11/-0.05)	0.13 (0.10/0.16)
	Chord mu length	-0.06±0.06 (-0.08/-0.04)	<0.001	-0.18 (-0.22/-0.15)	0.06 (0.02/0.10)
	Pupil diameter	-2.91±0.37 (-3.03/-2.79)	<0.001	-3.63 (-3.85/-3.42)	-2.18 (-2.40/-1.97)
Galilei G4 vs Topolyzer Vario photopic conditions	X-coordinate	0.02±0.03 (0.02/0.03)	<0.001	-0.03 (-0.05/-0.02)	0.08 (0.06/0.10)
	Y-coordinate	0.01±0.04 (-0.01/0.02)	0.82	-0.07 (-0.09/-0.05)	0.08 (0.06/0.11)
	Chord mu length	-0.02±0.03 (-0.03/-0.01)	0.02	-0.08 (-0.10/-0.06)	0.05 (0.03/0.07)
	Pupil diameter	0.35±0.31 (0.24/0.45)	<0.001	-0.27 (-0.45/-0.09)	0.96 (0.78/1.14)

CI: coefficient interval; LoA: limits of agreement; SD: standard deviation.

*Multiple comparisons ANOVA.