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Original Article

Ophthalmology Section

Repeatability of Corneal Aberrations and Ocular Biometry Measurements using the Pentacam® AXL: A Cross-sectional Study

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ABSTRACT

Introduction: Accurate assessment of ocular biometry and corneal aberrations for diagnosis and therapy is crucial in many clinical settings. Devices to improve the measurements of these parameters are constantly being developed.

Aim: To evaluate the repeatability of ocular biometry and corneal aberrations obtained by the Pentacam® AXL in normal eyes.

Materials and Methods: This cross-sectional study was conducted in the Optometry Department of King Saud Universiy, Riyadh, Saudi Arabia from September 2021 to February 2022. The study included a total of 120 eyes from 60 normally sighted adult participants whose of ocular biometry and corneal aberrations were measured three times in a single session using the Pentacam® AXL. Biometric parameters include Axial Length (AL), mean K-reading (Km), Anterior Chamber Depth (ACD), Central Corneal Thickness (CCT), and Horizontal White-to-White Distance (HWTW). The aberrometry parameters include the most significant corneal higher-order aberrations (coma, trefoil, spherical aberration), and the Root Mean Square (RMS) of the higher-order aberrations. Repeatability was assessed using within-subject Standard Deviation (SD^w), the repeatability limit (r), and the Intraclass Correlation Coefficient (ICC).

Results: The current study included 120 eyes of 60 subjects with a mean age of 21±2.08 years (range: 18 to 28 years). The repeatability was good for all recorded biometric measurements, with the most repeatable being AL (r=0.028, SD=0.01). All values of ICC for biometric measurements revealed excellent repeatability, being over 0.994. In addition, coma and spherical aberrations had excellent repeatability with ICC ≥0.935, and RMS, trefoil, secondary astigmatism, and quadrafoil aberrations had good repeatability with ICC 0.938, 0.823, 0.898, and 0.827, respectively.

Conclusion: The Pentacam® AXL demonstrated good repeatability for ocular biometry and corneal aberrations in healthy eyes.

Keywords: Axial length, Non contact biometry, Ocular aberrations, Partial coherence interferometry

INTRODUCTION

Accurate and reliable measurements of ocular biometry parameters (such as corneal curvature, ACD, and AL) are essential in several clinical procedures and critical to surgical success and patient satisfaction. These parameters are essential for the Intraocular Lens (IOL) power calculation formula.

Ultrasound measurement has historically been the standard for calculating an IOL power [1,2]. However, technologies are constantly being developed in clinical practice to improve the precision measurement of these parameters for performing cataract and refractive surgery. These instruments have different measurement-based systems—for example, partial coherence interferometry (e.g., IOLMaster), optical low coherence reflectometry (e.g., Lenstar 900), and swept-source optical coherence tomography (e.g., IOLmaster 700) [3,4]. The Pentacam® AXL (Oculus, Wetzlar, Germany) has integrated non contact biometry using partial coherence interferometry and has an advantage over the widely used IOL Master by considering the posterior corneal curvature and reportings the total corneal refractive power [5-7].

In normal eyes, the cornea contributes 90% of total aberrations [8]. The measurement of corneal aberrations has long been of interest [9]. The Pentacam® AXL calculates the corneal aberrations based on corneal elevation data, fitting Zernike polynomials to the measured height data. A more accurate fitting will be achieved as more polynomial terms are used to define the aberration profile. Although several studies demonstrate the repeatability of this instrument in the measurement of ocular biometry [7,10], to author's knowledge, none have evaluated its capability to provide repeatable measurements of corneal aberrations.

Moreover, most studies on corneal aberrations focus only on the anterior corneal surface and ignore the posterior corneal surface [11-14]. However, the posterior corneal surface must be considered to describe corneal aberrations accurately [15]. Due to the lack of comprehensive assessment published to date, the present study aimed to evaluate the repeatability of corneal aberrations and ocular biometry measurements obtained by the Pentacam® AXL in normal eyes with a transparent lens.

MATERIALS AND METHODS

This cross-sectional study was conducted in the Optometry Department of King Saud University, Riyadh, Saudi Arabia from September 2021 to February 2022. The local Ethical Committee of King Saud University previously approved the study (Ref. No. 21/0460/IRB), and it adheres to the Declaration of Helsinki. Written informed consent was obtained from all subjects after they had been informed of the nature of the study.

Inclusion criteria: The study included normally sighted participants who had not used contact lensesin the two weeks before the examination.

Exclusion criteria: The study excluded subjects with a history of ocular surgery, trauma, or ocular pathology (example- no dry eye, corneal pathology, cataracts, or retinal disease).

Study Procedure

For present study, convenience sampling was used. The present study included 120 eyes of 60 normally sighted participants, all of whom underwent a standardised ophthalmic examination. Authors used the Pentacam® AXL (Oculus, Wetzlar, Germany) with integrated non contact biometry using partial coherence interferometry technology for AL measurements. In combination with a Scheimpflug rotating camera, this device provides analysis of the anterior segment parameters and calculates the IOL power required in cataract and refractive surgery. It uses a 475 nm blue Light-emitting Diode (LED) as a light source. The images of the cornea were captured with a 1.45-megapixel camera that records 138,000 data points within two seconds. In addition, Keratometry was calculated using a reference surface [7]. For the current study, authors used software version 1.22r05.

Authors calibrated the Pentacam® AXL as recommended by the manufacturer before use; all measurements were obtained after this calibration. A trained examiner took three measurements from both eyes of each subject under standardised conditions to minimise bias. These conditions included taking the measurements in the same dim room, a minute-long interval between each measurement in which patients were asked to stand up (the position of the joystick was changed), and having patients blink normally to avoid tear film disturbance before each measurement. The measures were considered acceptable according to the device manufacturer's quality criteria (they were marked as "OK" by an automatic quality check).

The ocular biometry and monochromatic corneal aberrations were measured without pupil dilation. A total of 25 images per scan were acquired to produce high-resolution corneal measurements. Two main groups of parameters, biometric and aberrometry, were measured. The biometric parameters included ACD, AL, CCT, HWTW, and Km. The aberrometry parameters included the most significant corneal higher-order aberrations (coma, trefoil, spherical aberration) [12] and the RMS of the higher-order aberrations. The higher-order aberrations were reported using the convention of the standards for reporting the optical aberrations [16].

STATISTICAL ANALYSIS

All data were exported into an Excel file (Microsoft Inc, Redmond, WA, USA) and transferred to Statistical Packages for Social Sciences (SPSS) 28.0 (SPSS Inc, Chicago, IL, USA) for statistical analysis. After the descriptive analysis was performed, the repeatability of the Pentacam® AXL with three consecutive measurements was evaluated using the following:

- **Mean of within-subjects Standard Deviation (SDw) [17]:** The SD of the three repeated measures of each parameter was calculated for each eye, and then the mean of these deviations was obtained to generate the SD. A lower SDw indicates higher repeatability.
- **The repeatability limit (r):** This is reported as ($r=\sqrt{2\times1.96\ SD^{w}}$), considering the 95% confidence interval [17]. A lower value indicates a more repeatable the parameter.
- **Intraclass Correlation Coefficient (ICC):** This is the ratio of the between-subject variance to the pooled within-subject variance and the between-subject variance. It was automatically calculated using SPSS software with the two-way mixed effects Model (absolute agreement definition). ICC ranges from 0 to 1 and is commonly classified as acceptable, good, and excellent with greater than 0.7, greater than 0.8, and greater than 0.9, respectively [7,18].
- **One-sample t-tests:** These were performed after calculating the differences between each eye's first and second, first and third, and second and third measurements. A p-value less than 0.05 was considered statistically significant.

RESULTS

The current study included 120 eyes of 60 subjects with a mean age of 21±2.08 years (range: 18 to 28 years). Their visual acuity was equal to or better than 20/20, with a mean spherical equivalent of 0.54±0.43D for the right eye and 0.65±0.56D for the left eye. [Table/Fig-1] describes the mean±SD values of all biometric parameters and corneal monochromatic aberrations for the three measurements and their comparisons.

Biometric parameters: The mean AL was 23.63±1.12 mm; the three measurements gave the same value, with a mean difference of –0.001±0.03 mm between them. This was not statistically significant (p=0.776; measurement 1 vs. 2; p=0.706; measurement 1 vs. 3; p=0.319; measurement 2 vs. 3). The mean for the K reading was 43.07±1.41, with the differences between measurements being -0.0004±0.097 D; these differences were not statistically significant (p=1; measurement 1 vs. 2, p=0.869; measurement 1 vs. 3 p=0.318; measurement 2 vs. 3). There was no statistical difference between mean ACD, CCT, and HWTW (p>0.05, [Table/Fig-2]).

Corneal aberrations: The mean of total aberrations (RMS) was 1.47±0.41 μm. Lower-order aberrations had the highest RMS of 1.41±0.41 μm, followed by higher-order aberrations (0.41±0.11 μm) and spherical aberrations (0.18±0.08 μm). There was no statistical difference between measurements in all values [Table/Fig-2].

Repeatability: The results of the SDw, the repeatability limit, and the intraclass correlation coefficient are reported in [Table/Fig-2]. The repeatability was good for all recorded measurements, with the most repeatable being AL (r=0.028, SDw=0.01). All ICC values for AL, Kmean, ACD, CCT, and HWTW measurements revealed excellent repeatability with an ICC over 0.994. Additionally, there was excellent repeatability of RMS, coma, and spherical aberrations, with ICC ≥0.935, and good repeatability of trefoil, secondary astigmatism,

Parameters	First measurement (m1)	Second measurement (m2)	Third measurement (m3)	Mean
Ocular biometry				
AL (mm)	23.63±1.13	23.63±1.12	23.63±1.12	23.63±1.12
Kmean (D)	43.07±1.4	43.07±1.41	43.06±1.41	43.07±1.41
ACD (mm)	3.49±0.31	3.49±0.32	3.49±0.31	3.49±0.31
CCT (μm)	554.24±27.16	554.36±27.21	554.67±27.39	554.42±27.25
HWTW (mm)	11.87±0.39	11.86±0.38	11.86±0.39	11.86±0.39
Corneal aberrations				
RMS (μm)	1.47±0.40	1.47±0.44	1.48±0.39	1.47±0.41
Higher-order aberrations RMS (μm)	0.41±0.11	0.41±0.10	0.41±0.11	0.41±0.11
Lower-order aberrations RMS (μm)	1.40±0.40	1.41±0.44	1.42±0.39	1.41±0.41
Coma aberrations (μm)	0.042±0.19	0.04±0.19	0.038±0.19	0.04±0.19
Trefoil aberrations (μm)	-0.057±0.1	-0.05±0.1	-0.05±0.1	-0.05±0.1
Spherical aberrations (μm)	0.18±0.08	0.18±0.08	0.18±0.08	0.18±0.08
Secondary astigmatism aberrations (μm)	-0.023±0.05	-0.023±0.05	-0.022±0.05	-0.023±0.05
Quadrafoil aberrations (μm)	-0.024±0.07	-0.024±0.06	-0.021±0.06	-0.023±0.07

[Table/Fig-1]: Mean±Standard Deviation (SD) values of all biometric parameters and corneal monochromatic aberrations.
AL: Axial length; Km: Mean keratometry; ACD: Anterior chamber depth; CCT; Central corneal thickness, HWTW: Horizontal white-to-white distance; RMS: Root mean square

Parameters	SDw	r	ICC	p-value (m1-m2)	p-value (m1-m3)	p-value (m2-m3)
Ocular biometry						
AL (mm)	0.01	0.028	1	0.776	0.706	0.319
Kmean (D)	0.05	0.149	0.999	1	0.869	0.318
ACD (mm]	0.02	0.047	0.999	0.976	0.927	0.328
CCT (µm)	1.8	5.00	0.998	0.634	0.118	0.314
HWTW (mm)	0.04	0.105	0.994	0.361	0.243	0.320
Corneal aberrations						
RMS (µm)	0.115	0.319	0.938	0.891	0.610	0.503
Higher-order aberrations RMS (µm)	0.034	0.094	0.936	0.890	0.886	0.484
Lower-order aberrations RMS (µm)	0.115	0.321	0.935	0.876	0.565	0.525
Coma aberrations (µm)	0.026	0.073	0.984	0.791	0.448	0.534
Trefoil aberrations (µm)	0.052	0.144	0.823	0.478	0.455	0.449
Spherical aberrations (µm)	0.020	0.056	0.960	0.433	0.336	0.351
Secondary astigmatism aberrations (µm)	0.020	0.056	0.898	0.532	0.312	0.181
Quadrafoil aberrations (µm)	0.034	0.093	0.827	0.572	0.509	0.318

[Table/Fig-2]: Repeatability analysis of the three consecutive measurements.
AL: Axial length; K_{mean}: Mean keratometry; ACD: Anterior champer depth; CCT: Central corneal thickness; HWTW: Horizontal white-to-white distance; SD^w: Within-subject standard deviation; r: the repeatability limit ($r=\sqrt{2}\times1.96\ SD^w$); ICC: Intraclass correlation coefficient. *p-values were calculated by one sample t test

and quadrafoil aberrations with an ICC of 0.823, 0.898, and 0.827, respectively.

According to the repeatability limits obtained when measuring each biometric parameter [Table/Fig-2], the repeatability was very good for all recorded measurements. The least repeatable parameter was CCT (5.00), while the most repeatable was AL (0.028). Additionally, based on the repeatability limits obtained when measuring corneal aberrations [Table/Fig-2], the repeatability was very good for all recorded aberration measurements. The least repeatable parameter was lower-order aberrations RMS (0.321), and the most repeatable were spherical aberrations and secondary astigmatism aberrations (0.056). These results indicate that the Pentacam® AXL measures these parameters with high repeatability.

DISCUSSION

The present study assessed the repeatability of ocular biometry and corneal aberrations measurements obtained by the Pentacam® AXL in normal eyes. Three repeated measures were collected from both eyes of each subject. The differences between the measurements were not statistically significant for any of the parameters studied.

The mean difference between AL measurements was 0.001±0.03 mm, which theoretically could have an insignificant influence on IOL power measurement and subsequent implantation. The Pentacam® AXL showed excellent repeatability, established by ICC values greater than 0.994 for all biometric parameters. These results are comparable to those found by Srivannaboon S et al., who reported an ICC higher than 0.974 in all measurements [1]. Similar to the current study, the lowest ICC value was for the measure of the HWTW distance.

A variability in ACD measurement of 0.02 mm would yield a movement of less than 0.10 mm in the IOL position, which could amount to approximately 0.20 D. As proved by Olsen T and Hoffmann P an error less than ±0.50 D is deemed optimal in phaco-refractive surgery [19]. In addition to IOL calculation, AL and ACD measurements may assist in assessing patients with narrow-angle glaucoma. Nongpiur ME et al., proved that the difference between healthy and angle-closure glaucoma patients was 0.30 mm, a much higher value than the variability presented by the Pentacam® AXL, which was 0.02 mm. The ACD measurement, ICC, and SDw values reported in present study were consistent with those revealed by Grulkowski I et al., employing long-range swept-source optical coherence tomography using a Vertical-cavity Surface-emitting Laser (VCSEL), achieving an ICC of 0.994 [20,21].

Keratometry repeatability data (mean keratometry 0.05 D) were not statistically significant; it could clinically yield a variation of 0.25 D in the IOL power. Test-retest repeatability confirmed that corneal power measurements were repeatable and expected to be less than a quarter of a diopter in 95% of paired observations, which would have little impact clinically.

This value has a low clinical impact on calculating IOL power [22]. The ICC and SDw values were in agreement with López de la Fuente C et al., who compared anterior segment measurements acquired from healthy subjects with three different devices, including the IOLMaster 500 [23].

The HWTW and ACD are two fundamental values for posterior chamber phakic IOLs (pIOL) calculation. In particular, the HWTW is utilised to compute the power of the pIOL to be implanted. This parameter is crucial because if a smaller pIOL than needed is implanted, it can be complicated by cataracts [24]; furthermore, if a larger pIOL is implanted, it can be complicated by angle-closure glaucoma [25]. Additionally, the difference between the HWTW and the power of the lens sets the vault [26]. The present measurements of white-to-white distance (11.86±0.39 mm) were slightly higher than those recorded by Martin R et al., (11.47±0.36 mm) in myopic patients with implanted pIOL; however, they used scanning-slit topography-based technology, which provides lower values than the Pentacam® AXL [27].

The CCT values (554.42±27.25 microns) were similar to those estimated in the healthy population in Mexico by de la Parra P et al., (542.333±3.446 microns) with Scheimpflug Sirius camera tomography [28].

Some studies have documented the repeatability of corneal aberrometric measurements [29-32], but none focused on internal aberrometry. The present study found no significant differences in higher-order aberrations, suggesting constant instrument repeatability over time. This was similar to the findings of Miranda MA et al., who interpreted aberration data over one week [30]. Similarly, they obtained repeatability values and found the highest variation in the total higher-order aberrations. Visser N et al., also revealed good repeatability values for two Hartmann-Shack aberrometers, the IRX-3 (Imagine Eyes, Paris, France), and the Keratron Onda (Optikon, Rome, Italy), with mean SD values below 0.1 µm for both aberrometers for all higher-order aberrations and slightly larger values (0.1 to 0.2 µm) for second-order aberrations [33]. In contrast, the SD was 0.034 µm in the current study.

The ICC values acquired in present study were homogeneous or slightly higher than those established by Piñero DP et al., who recorded ICC values above 0.75 for most aberrations analysed from three repeated consecutive automatic measurements recorded by the same examiner [34]. No pupillary dilation was performed for the measurements, and a 4-mm pupil was used for computation. Variability was noticed in repeated measurements of RMS values presented by primary coma, secondary astigmatism, and tetrafoil. These parameters had lower ICC values in the current study's repeatability analysis.

Limitation(s)

The present study had some limitations. Firstly, a power analysis was not performed to calculate the sample size, which could have affected the results. Additionally, the number of eyes examined and the inclusion of both eyes would have impacted the results due to their correlation. However, the main aim of the current study was to determine the repeatability of the Pentacam® AXL, which would be influenced by this correlation. Moreover, single-eye analysis demonstrated comparable results, and the one-eye process has the significant disadvantage of a loss of information; hence, many authors do not find it ideal [35,36]. It is recommended that repeated measurements of internal aberrations be done when the device is used clinically or for research to prevent variability in the measurement of some aberrometric errors.

CONCLUSION(S)

In conclusion, the present study confirmed that the Pentacam® AXL has high repeatability when used to measure biometric parameters and corneal aberrations in healthy eyes. The Pentacam® AXL seems suitable for use as an all-inclusive optical biometer and corneal tomographer, as it combines partial coherence interferometry for obtaining accurate AL measurements with Scheimpflug technology to obtain ACD and K measurements.

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