Intrasession repeatability of ocular anatomical measurements obtained with a multidiagnostic device in healthy eyes

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Abstract

Background: To evaluate the intrasession repeatability of anterior chamber depth (ACD), central (CCT) and peripheral corneal thickness (PCT), white-to-white diameter (WTW), and irido-corneal angle (IA) measurements obtained with a multidiagnostic device in healthy eyes.

Methods: A total of 107 eyes of 107 patients ranging in age from 23 to 65 years were examined with the VX120 system (Visionix-Luneau Technologies). Three consecutive measurements were obtained with this device to assess the intrasession repeatability of ACD, CCT, PCT at different nasal and temporal locations, WTW, and nasal and temporal IA. Data analysis included the calculation of within-subject standard deviation (Sw), intrasubject precision (1.96xSw), coefficient of variation (CV) and intraclass correlation coefficient (ICC).

Results: The Sw and CV for ACD was 0.03 mm and 1.16%, respectively, with an ICC of 0.992. The Sw values for central and peripheral pachymetric measurements were below 9 μm, with CV of less than 1.6% and ICC of 0.976 or higher. For IA measurements, Sw values of 0.84 or lower were found, with a CV between 1 and 2%, and an ICC of more than 0.970. The Sw for WTW was 0.24 mm and the CV was 1.95%. No statistically significant correlations were found between any anatomical parameter evaluated and their Sw and CV values associated (−0.220 ≤ r ≤ 0.204, p ≥ 0.125).

Conclusions: The VX120 system is able to provide repeatable measurements of anatomical parameters in healthy eyes. Inter-observer repeatability should be evaluated in future studies.

Keywords: Anterior chamber depth, Pachymetry, White-to-white, Irido-corneal angle, Scheimpflug imaging, VX120 system

Background

Accurate measurement of different anatomical dimensions of the anterior segment is crucial in the eye care clinical practice [1]. These accurate measurements allow the clinician to perform a precise planning of refractive and intraocular surgical procedures, to check the viability of a specific type of surgical technique, and to perform comprehensive monitoring of ocular diseases. Thus, clinical decisions based on unreliable or not consistent data are avoided. There are several studies evaluating the repeatability of anterior segment anatomical measurements provided by different types of instruments, most of them based on Scheimpflug imaging or partial coherence interferometry [2–19]. Specifically, good intrasession repeatability data have been reported with a variety of devices for anterior chamber depth (ACD), [2–19] central corneal thickness (CCT), [4, 6, 10, 13–18] peripheral corneal thickness (PCT) [21], white-to-white corneal diameter, [3, 5, 8–10, 14, 15, 20] and irido-corneal angle (IA) [6, 10, 19, 21]. All these studies confirm the good performance of currently available devices for measuring the anatomical dimensions of the anterior segment of the eye.

Recently, a new multidiagnostic platform has been developed that provides automatic measurements of corneal topography, corneal, internal and ocular aberrations, pachymetry, anterior chamber depth, irido-corneal

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angle, pupil diameter under different luminance conditions and intraocular pressure (IOP), which is the VX120 system (Visionix-Luneau Technologies, Chartres, France). To date, there are no scientific studies evaluating the reliability of this device. The aim of the current study was to evaluate the intrasession repeatability of anterior segment anatomical measurements obtained with the VX120 system in a sample of normal healthy eyes.

Methods

Patients
A total of 107 healthy eyes of 107 patients ranging in age from 23 to 65 years old were enrolled in this prospective study of evaluation of a technology. All subjects were selected randomly from patients attending to the Optometry Clinic of the University of Alicante, where this investigation was developed. One eye only from each subject was chosen randomly for the study using a random number sequence (dichotomic sequence, 0 and 1) in order to avoid the potential interference of the correlation that often exists between the two eyes of the same person. All patients were informed previously about the study and signed an informed consent in accordance with the tenets of the Helsinki Declaration. An approval for the performance of the study was obtained from the Ethics Committee of the University of Alicante (Spain).

The inclusion criteria were the following: eyes without active ocular pathology, age of more than 18 years, and the presence of a refractive error between +5.00 and −10.00 D. The following conditions were defined as exclusion criteria for the study: any systemic pathology at the moment of examination, previous ocular surgery, glaucoma, less than 18 complete consecutive Placido rings projected on the cornea and therefore considered for the corneal analysis, pseudophakia, corneal ectatic diseases, and any other type of pathological condition of the eye.

Examination protocol
A complete eye exam was performed in all cases that included measurement of uncorrected (UDVA) and corrected distance visual acuity (CDVA), manifest refraction, air tonometry (VX120 system, Visionix-Luneau Technologies, Chartres, France), and corneal topographic and anterior segment analysis with the VX120 system (Visionix-Luneau Technologies, Chartres, France). All measurements were performed by the same experienced examiner (ALN), taking three consecutive measurements in order to analyze the intrasession repeatability of some anatomical measurements. Specifically, the repeatability of the following parameters was evaluated: anterior chamber depth (ACD), peripheral corneal thickness at 1, 2 and 3 mm from vertex nasally (PCT_{N1}, PCT_{N2}, and PCT_{N3}), peripheral corneal thickness at 1, 2 and 3 mm from vertex temporally (PCT_{T1}, PCT_{T2}, and PCT_{T3}), central corneal thickness (CCT) (Fig. 1), nasal and temporal irido-corneal angles (IA_{N} and IA_{T}), and horizontal white-to-white corneal diameter (WTW).

The VX120 system
The VX120 system is a multidetector platform that combines several technologies in order to provide an integral exam of the anterior segment of the eye. Specifically, the system combines a Scheimpflug imaging-based system, a Placido disk corneal topographer, a Hartmann-Shack aberrometer, and an air tonometer. The information used to provide all corneal topographic information is provided by a Placido disk system that projects 24 rings on the corneal surface, measuring more than 100,000 points. Refractive and ocular aberrometric data are obtained with a Hartmann-Shack system that measures 1500 points in 0.2 s in an area ranging from 2.0 to 7.0 mm of diameter.
The Scheimpflug imaging-based system uses monochromatic blue light of 455 nm to obtain pachymetric measurements with a resolution of ±1 μm, and iridocorneal angle measurements with a resolution of ±1°. With the data obtained with all these technologies, the system also provides tangential and axial curvature data of the anterior corneal surface, internal wavefront aberrations, visual quality simulations, central and peripheral corneal pachymetry data, and IOP measurements.

**Statistical analysis**

The statistical analysis was performed using the software SPSS version 15.0 for Windows (SPSS, Chicago, Illinois, USA). Normality of all data distributions was confirmed by means of the Kolmogorov-Smirnov test. Then, parametric statistics was applied. Intrasession repeatability for anatomical parameters was assessed according to the following variables: the within-subject standard deviation (Sw) of the 3 consecutive measurements, intrasubject precision (1.96 x Sw), and the intraclass correlation coefficient (ICC). The within-subject standard deviation (Sw) is a simple way of estimating the size of the measurement error. The intraobserver precision was defined as (±1.96 x Sw) and this parameter indicates how large is the range of error of the repeated measurements for 95% of observations. Finally, the ICC is an ANOVA-based type of correlation that measures the relative homogeneity within groups (between the repeated measurements) in ratio to the total variation. The ICC will approach 1.0 when there is no variance within repeated measurements, indicating total variation in measurements is due solely to variability in the parameter being measured. Furthermore, Pearson correlation coefficients were used to assess the correlation between different parameters evaluated. All statistical tests were 2-tailed, and p-values less than 0.05 were considered statistically significant.

**Results**

Table 1 summarizes the main characteristics of the sample evaluated. The sample was comprised of 49 males (45.8%) and 58 females (54.2%), with a mean age of 47.8 years old. Table 2 summarizes the outcomes of the intrasession repeatability analysis for all anatomical parameters evaluated. The Sw and CV for ACD was 0.03 mm and 1.16%, respectively, with an ICC 0.992. The Sw values for central and peripheral pachymetric measurements were below 9 μm, with CV of less than 1.6% and ICC of 0.976 or higher. For IA measurements, Sw values of 0.84 or lower were found, with a CV between 1 and 2%, and ICC of more than 0.970. The Sw for WTW was 0.24 mm and the CV was 1.95%.

Table 3 displays the coefficients of correlation of the magnitude of different anatomical parameters and the Sw and CV values associated to each parameter. As shown, no statistically significant correlations were found (−0.220 ≤ r ≤ 0.204, p ≥ 0.125). Likewise, no significant correlations were found between mean keratometry, corneal eccentricity, corneal astigmatism or spherical equivalent and the Sw values obtained for each anatomical parameter evaluated (−0.253 ≤ r ≤ 0.275, p ≥ 0.125).

**Discussion**

The concept of integrating several clinical tests in one device in order to simplify the activity in clinical setting has been investigated extensively in the last years. Some multidagnostic platforms combining different technologies have been developed and commercially released [1, 21–23]. One of the potential concerns about these systems if they are able to provide consistent and reliable measurements that can be considered as interchangeable with those measurements provided by gold-standard or widely tested devices. The current study was aimed at confirming if one experienced operator was able to obtain repeatable measurements of different anatomical parameters of the anterior segment with the multidagnostic platform VX120. If this intrasession repeatability is confirmed, future studies will be conducted to analyze the inter-observer repeatability and the interchangeability of VX120 measurements with those obtained by other different currently available topography systems or tomographs.

In our study, the intrasession repeatability of ACD measurements was excellent, with Sw of 0.03 mm, CV of 1.16% and ICC of 0.992. This confirms that the multidagnostic device evaluated is able to provide repeatable consecutive measurements of the depth of the anterior chamber of the healthy eye. Our intrasession repeatability outcomes for ACD are consistent with those reported with other commercially available devices, including Scheimpflug-based topography systems, [3, 5, 6, 10–14, 16–19] biometers, [2–4, 8, 9, 15, 17] and optical coherence tomographers [3, 11] (Table 4). Kurian et al. [2] obtained in 100 eyes evaluated with the

### Table 1 Main characteristics of the sample evaluated

|                      | Mean (SD) | Median | Range       |
|----------------------|-----------|--------|-------------|
| Age (years)          | 47.8 (8.3)| 47.0   | 23.0 to 65.0|
| Mean central corneal | 7.92 (0.30)| 7.86   | 7.26 to 8.84|
| radius (mm)          | 0.82 (0.59)| 0.75   | 0.00 to 3.75|
| Mean central corneal | 0.40 (0.75)| 0.00   | 0.00 to 0.00|
| astigmatism (D)      | 0.63 (2.03)| 0.00   | 0.00 to 0.00|
| Manifest sphere (D)  | −0.43 (2.02)| 0.00   | −7.00 to 6.00|
| Manifest cylinder (D)| −0.40 (0.75)| 0.00   | −4.00 to 0.00|
| Manifest spherical   | −0.63 (2.03)| 0.00   | −7.33 to 5.50|
| equivalent (D)       | 0.34 (0.31)| 0.43   | −1.16 to 0.83|

**Abbreviations:** SD standard deviation, D diopter
IOL-Master (Carl Zeiss Meditec) and Lenstar 900 (Haag-Streit) optical biometry systems, \( S_w \) values for ACD of 0.04 and 0.06 mm, and CV of 1.22 and 1.99%, respectively. Kunert and coauthors [4] found a \( S_w \) value for ACD of 0.0098 mm with the optical biometry system IOL Master 700 (Carl Zeiss Meditec). Other authors have also reported \( S_w \) values below 0.06 mm for the same and other optical biometers [8, 9, 15, 17]. Likewise, several studies have evaluated the consistency of ACD measurements using Scheimpflug imaging-based topography systems, such as the Sirius (CSO), Galilei (Ziemer) and Pentacam.

Table 2

| Measurement   | Overall mean (SD) | Overall median (Range) | \( S_w \) | \( Pr \) | CV (%) | ICC (Range 95% CI) |
|---------------|-------------------|------------------------|----------|--------|-------|-------------------|
| ACD (mm)      | 2.86 (0.29)       | 2.83 (2.10 to 3.77)    | 0.03     | 0.06   | 1.16  | 0.992 (0.989 to 0.994) |
| PCTN3 (\( \mu \)m) | 592.04 (39.87)  | 601.00 (533.67 to 699.00) | 8.98     | 17.59  | 1.52  | 0.976 (0.957 to 0.987) |
| PCTN2 (\( \mu \)m) | 567.77 (37.83)  | 575.67 (506.33 to 675.33) | 7.05     | 13.81  | 1.25  | 0.984 (0.971 to 0.991) |
| PCTN1 (\( \mu \)m) | 574.89 (45.35)  | 549.67 (508.33 to 699.00) | 7.70     | 15.09  | 1.34  | 0.984 (0.972 to 0.992) |
| CCT (\( \mu \)m) | 545.88 (34.70)  | 544.67 (428.00 to 657.67) | 6.41     | 12.56  | 1.17  | 0.983 (0.977 to 0.988) |
| PCTT1 (\( \mu \)m) | 553.27 (37.44)  | 545.67 (492.00 to 664.33) | 5.91     | 11.59  | 1.08  | 0.987 (0.977 to 0.993) |
| PCTT2 (\( \mu \)m) | 568.70 (37.58)  | 573.33 (510.67 to 681.33) | 6.06     | 11.87  | 1.07  | 0.987 (0.977 to 0.993) |
| PCTT3 (\( \mu \)m) | 593.76 (38.58)  | 598.67 (529.00 to 708.00) | 8.33     | 16.33  | 1.41  | 0.979 (0.963 to 0.989) |
| IAN (°)       | 37.17 (4.35)     | 37.00 (28.33 to 46.00)  | 0.73     | 1.45   | 2.23  | 0.973 (0.946 to 0.984) |
| IAT (°)       | 39.63 (4.59)     | 39.67 (30.67 to 50.33)  | 0.92     | 1.84   | 3.12  | 0.995 (0.988 to 0.997) |
| WTW (mm)      | 12.21 (0.57)     | 12.17 (10.99 to 13.94)  | 0.24     | 0.46   | 1.95  | 0.873 (0.823 to 0.911) |

Abbreviations: SD standard deviation, CV coefficient of variation, \( S_w \) within-subject standard deviation, \( Pr \) intrasubject precision: \( 1.96 \times S_w \), ICC intraclass correlation coefficient, ACD anterior chamber depth, PCTN1, PCTN2, and PCTN3 peripheral corneal thickness at 1, 2 and 3 mm from vertex nasally, PCTT1, PCTT2, and PCTT3 peripheral corneal thickness at 1, 2 and 3 mm from vertex temporally, CCT central corneal thickness, IAN and IAT nasal and temporal irido-corneal angles, and WTW horizontal white-to-white corneal diameter.

Table 3

| Measurement   | Pearson correlation coefficient | \( p \)-value | Pearson correlation coefficient | \( p \)-value |
|---------------|---------------------------------|--------------|---------------------------------|--------------|
| ACD (mm)      | 0.033                           | 0.734        | -0.058                          | 0.550        |
| PCTN3 (\( \mu \)m) | 0.024                          | 0.893        | -0.082                          | 0.652        |
| PCTN2 (\( \mu \)m) | -0.125                         | 0.487        | -0.220                          | 0.218        |
| PCTN1 (\( \mu \)m) | 0.101                          | 0.577        | 0.000                           | 0.999        |
| CCT (\( \mu \)m) | 0.149                           | 0.127        | 0.056                           | 0.565        |
| PCTT1 (\( \mu \)m) | -0.069                         | 0.704        | -0.158                          | 0.381        |
| PCTT2 (\( \mu \)m) | -0.059                         | 0.746        | -0.142                          | 0.431        |
| PCTT3 (\( \mu \)m) | 0.000                           | 0.997        | -0.100                          | 0.580        |
| IAN (°)       | 0.204                           | 0.254        | 0.122                           | 0.498        |
| IAT (°)       | 0.039                           | 0.827        | -0.102                          | 0.572        |
| WTW (mm)      | -0.109                          | 0.282        | -0.154                          | 0.125        |

Abbreviations: SD standard deviation, CV coefficient of variation, \( S_w \) within-subject standard deviation, \( Pr \) intrasubject precision: \( 1.96 \times S_w \), ICC intraclass correlation coefficient, ACD anterior chamber depth, PCTN1, PCTN2, and PCTN3 peripheral corneal thickness at 1, 2 and 3 mm from vertex nasally, PCTT1, PCTT2, and PCTT3 peripheral corneal thickness at 1, 2 and 3 mm from vertex temporally, CCT central corneal thickness, IAN and IAT nasal and temporal irido-corneal angles, and WTW horizontal white-to-white corneal diameter.
(Oculus) systems. Shin et al. [5] reported an ICC > 0.980 for ACD measurements obtained with the Galilei G6 system in a sample of 140 eyes with cataract, and Savini et al. [19] obtained CV < 3.5% and ICC > 0.94 in 45 healthy eyes using the same system. With the Sirius system from CSO, Prakash et al. [6] obtained a mean value of 0.06 mm

### Table 4

Summary of the results of previous studies evaluating the consistency of anterior chamber depth (ACD), peripheral corneal thickness (PCT), central corneal thickness (CCT), iridocorneal angle (IA), and white-to-white corneal diameter (WTW)

| Authors          | Year | Number of eyes | Type of eyes | System                          | Parameter       | 1.96 Sw | Sw     | ICC   | CoV      |
|------------------|------|---------------|-------------|---------------------------------|-----------------|---------|--------|-------|----------|
| Kurian et al.    | 2016 | 100           | Healthy     | IOL Master 700                  | ACD             | –       | 0.04 mm| 0.06 mm| 1.22%    |
|                  |      |               |             | Lenstar 900                      |                 |         |        |       |          |
|                  |      |               |             |                                 |                 |         |        |       |          |
| Shajari et al.   | 2016 | 40            | Healthy     | Pentacam HR                      | WTW             | 0.5     | –      | –     | –        |
|                  |      |               |             | IOL Master 500                   | ACD             | 0.5     | –      | –     | –        |
|                  |      |               |             | Lenstar 900                      |                 | 0.6     | –      | –     | –        |
|                  |      |               |             | Visante OCT                      |                 | 0.3     | –      | –     | –        |
| Shin et al.      | 2016 | 140           | Cataract    | Galilei G6                       | WTW             | –       | –      | > 0.980| –        |
|                  |      |               |             |                                 | ACD             | –       | –      |       |          |
| Kunert et al.    | 2016 | 120           | Cataract    | IOL Master 700                   | CCT             | –       | 19.5 μm| 9.8 μm| –        |
|                  |      |               |             |                                 | ACD             | –       |        |       |          |
| Prakash et al.   | 2016 | 100           | Healthy     | Sirius                          | CCT             | 5 μm   | 0.06 mm| < 2°   | –        |
|                  |      |               |             |                                 | ACD             | –       | –      |       |          |
| Huang et al.     | 2015 | 52            | Healthy     | Aladdin                         | WTW             | –       | 0.80 mm| > 0.94 | 0.795    |
|                  |      | 46            | Cataract    |                                 | ACD             | –       | 0.93 to 1.00 | –        |< 0.89%  |
| Srivannaboon et  | 2015 | 100           | Cataract    | IOL Master 500/700               | WTW             | –       | –      |       |          |
| et al. [9]       |      |               |             |                                 | ACD             | –       | –      |       |          |
| Masoud et al.    | 2015 | 100           | Healthy     | Sirius                          | IA              | –       | –      |       | <2%      |
|                  |      |               |             |                                 | ACD             | –       | –      |       |          |
| Wang et al.      | 2015 | 71            | Healthy     | Galilei G2                       | ACD             | –       | 0.04 to 0.07 mm | –       |          |
|                  |      |               |             | Visante OCT                      |                 |         |        |       |          |
| Shetty et al.    | 2014 | 55            | Keratoconus | Pentacam                         | ACD             | –       | 0.03 mm| 0.05 mm| 1.1%     |
|                  |      |               |             | Galilei                          |                 |         | 0.03 mm| –      | 1.3%     |
|                  |      |               |             | Sirius                          |                 |         |        |       | 1.0%     |
| Hernandez-Camarena et al. [12] | 2014 | 84            | Healthy     | Galilei G2                       | CCT             | –       | –      | –     | <1%      |
|                  |      |               |             | Pentacam HR                      | ACD             | –       | –      |       |          |
| Zhao et al.      | 2013 | 56            | Healthy     | Lenstar 900                      | WTW             | –       | 0.274 mm| 0.052 mm| –        |
|                  |      |               |             |                                 | ACD             | –       | 14.24 μm| –      | –        |
| Montolban et al. | 2013 | 61            | Keratoconus | Sirius                          | WTW             | –       | 0.07 mm| 0.089 | 0.56%    |
|                  |      |               |             |                                 | CCT             | –       | 2.30 μm| 0.998 | 0.51%    |
|                  |      |               |             |                                 | ACD             | –       | 0.02 mm| 0.998 | 0.64%    |
| Chen et al.      | 2012 | 40            | Healthy     | Sirius                          | WTW             | –       | 0.04 mm| 0.05 mm| –        |
|                  |      |               |             |                                 | ACD             | –       | 0.02 mm| 3.10 μm| –        |
|                  |      |               |             |                                 | CCT             | –       | 3.32 μm| –      | –        |
| Montolban et al. | 2012 | 117           | Healthy     | Sirius                          | WTW             | –       | 0.06 mm| 0.974 | 0.48%    |
|                  |      |               |             |                                 | ACD             | –       | 0.02 mm| 0.997 | 0.54%    |
|                  |      |               |             |                                 | CCT             | –       | 2.80 μm| 0.997 | 0.52%    |
| Nasser et al.    | 2012 | 45            | Healthy     | Sirius                          | ACD             | –       | –      | –     | 0.56%    |
| Savini et al.    | 2011 | 45            | Healthy     | Galilei                          | CCT             | –       | –      | > 0.94| < 3.5%   |

**Abbreviations:** SD standard deviation, Sw within-subject standard deviation, ICC intraclass correlation coefficient, CoV coefficient of variation, D diopter
for 1.96xS_w corresponding to ACD measurements in a sample of 100 healthy subjects. Likewise, Masoud et al. [10] obtained a CV < 2% in 100 healthy eyes of 50 patients, Nasser et al. [16] a CV of 0.56% in 45 healthy eyes, and Montalbán et al. [18] S_w, CV and ICC of 0.02 mm, 0.54% and 0.999 in 117 healthy eyes, respectively. Hernández-Camarena and coauthors [12] performed a comparative study of the repeatability of ACD measurements obtained with the Galilei G2 (Ziemer), Pentacam HR (Oculus) and Sirius (CSO) systems in 84 healthy eyes and found CV values below 1% in all cases. Shetty and coauthors [13] performed a similar comparison but in 55 keratoconus eyes and obtained S_w values of 0.03, 0.05 and 0.03 mm with the Pentacam, Galilei and Sirius systems, respectively. Therefore, the VX120 platform that uses Scheimpflug imaging for measuring ACD provides repeatable measurements of this anatomical parameter, with levels of reliability that are consistent with those found for other systems also based on Scheimpflug imaging or optical biometry (Table 4).

The intrasession repeatability of central and peripheral pachymetric readings obtained with the VX120 system in our sample was also excellent, with S_w values below 9 μm, CV below 1.6% and ICC of more than 0.97. Specifically, S_w for central corneal thickness was 6.41 μm in our sample, a value which is consistent with those reported using the Sirius system in healthy (Prakash et al. [6] S_w: 5 μm; Montalbán et al. [18] S_w: 2.80 μm; Chen et al. [17] S_w: 3.10 μm) and keratoconus eyes (Montalbán et al. [14] S_w: 2.30 μm). However, VX120 pachymetric repeatability outcomes were better than those reported for optical biometry systems (Zhao et al. [15] S_w: 14.24 μm, healthy eyes; Kunert et al. [4] S_w: 19.5 μm) (Table 4). Concerning peripheral pachymetry, the readings obtained with the VX120 system were very repeatable, with S_w values ranging from 5.91 to 8.98 μm. Milla and coauthors [20] evaluated the intrasession consistency of peripheral pachymetry obtained with the Scheimpflug imaging-based topography system Sirius from CSO and obtained S_w values ranging from 3.1 to 5.8 μm. These values are consistent with those found in the current study. Likewise, other authors have reported similar S_w or even worse than those obtained in the current series for minimal corneal thickness (Shetty et al. [13] S_w: 9.33 μm Pentacam, S_w: 11.64 μm Galilei, S_w: 8.88 μm Sirius, Montalbán et al. [14] S_w: 3.18 μm) (Table 4).

Besides ACD and pachymetry, the intrasession repeatability of WTW and iridocorneal angle measurements was also evaluated. In our series, excellent intrasession repeatability was found for WTW, with values of 0.24 mm, 1.95% and 0.873 for S_w, CV and ICC, respectively. Shajari and coauthors [3] reported in a sample of 40 healthy subjects in which WTW was measured with the Pentacam HR, IOL-Master 500, Lenstar 900 and Visante systems, a value of approximately 0.5 μm for 1.96xS_w. Likewise, excellent intrasession repeatability for WTW has been also reported by other authors using a variety of devices: Galilei (Shin et al. [5] ICC > 0.980 for cataract eyes; Savini et al. [19] ICC > 0.94 for healthy eyes), Lenstar 900 (Zhao et al. [15] S_w: 0.274 μm for healthy eyes), Aladdin biomter (Huang et al. [8] ICC > 0.94 for healthy eyes, ICC: 0.795 for cataract eyes), Sirius (Montalbán et al. [14] S_w: 0.07 mm for keratoconus eyes, Montalbán et al. [18] S_w: 0.06 mm for healthy eyes), and IOL-Master system (Srivannaboon et al. [9] ICC > 0.93 for cataract eyes). Concerning iridocorneal angle, an excellent intrasession repeatability was also obtained for nasal and temporal angle measurements obtained with the same topography system in another sample of 100 healthy eyes.

Finally, the level of correlation between the magnitude of all anatomical variables evaluated and their S_w and CV values associated. Thus, we investigated if the level of repeatability of each anatomical parameter was dependent on its magnitude. This analysis revealed that this dependency was not present for any anatomical variable evaluated. Therefore, the VX120 system provides anatomical measurements of the anterior segment, with minimal repeatability errors that do not seem to increase in cases with extreme values within the normal range. More studies are needed to corroborate this finding in eyes with abnormal or pathological anterior segment, such as microcorneas and ectatic corneas.

The results of this study have only demonstrated that the VX120 system is able to provide repeatable measurements, which is crucial for being used as a diagnostic tool in clinical practice. However, future studies are necessary to evaluate the inter-observer repeatability and the interchangeability of the measurements provided by the VX120 platform with those obtained with other
commercially available systems. In any case, good interobserver repeatability is expected to be found considering that measurements are taken automatically by the VX120 system, with minimal intervention from the observer. Indeed, the observer does not have to focus or center because this is done automatically by the system.

**Conclusion**

The multidiagnostic system VX120 seems to be able to provide consistent repeated measurements of ACD, central and peripheral pachymetry, WTW and iridocorneal angle in healthy eyes. The level of repeatability of the measurement of these anatomical parameters with the VX120 system is not dependent on the magnitude of such parameters, with the same precision ability for short and long eyes, small and large corneas, and eyes with deep and shallow anterior chamber within the normal range. Future studies should be conducted to confirm if this level of intraassession repeatability for the anatomical parameters evaluated is also observed in pathological eyes or after specific types of eye surgery. Furthermore, although measurements are done automatically by the device with minimal intervention of the operator, future inter-observer repeatability studies should be also performed.

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**Availability of data and materials**

The datasets during and/or analysed during the current study are available from the corresponding author on reasonable request.

**Authors’ contributions**

Conception and design of the study: DPP, ALN, VJC. Acquisition of data: IC, ALN, DDF. Analysis and interpretation of data: DPP, IC, DDF, MTC. Drafting of the manuscript: DPP, IC. Critically revision of the manuscript: IC; ALN, DDF. Analysis and interpretation of data: DPP, IC, DDF, MTC. Drafting of the manuscript: DPP, IC. All authors read and approved the final version to be published.

**Ethics approval and consent to participate**

An approval for the performance of the study was obtained from the Ethics Committee of the University of Alicante (Spain). All patients were informed previously about the study and signed an informed consent in accordance with the tenets of the Helsinki Declaration.

**Consent for publication**

Not applicable

**Competing interests**

The authors declare that they have no competing interests.

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**References**

1. Piñero DP. Technologies for anatomical and geometric characterization of the corneal structure and anterior segment: a review. Semin Ophthalmol. 2015;30:161–70.
2. Kutan M, Negalur N, Das S, Puttiaah NK, Hari D, TS J, Thakkar MM. Biometry with a new swept-source optical coherence tomography biometer: repeatability and agreement agreement with an optical low-coherence reflectometry device. J Cataract Refract Surg. 2016;42:577–81.
3. Shajari M, Lehmann UC, Kohren T. Comparison of corneal diameter and anterior chamber depth measurements using 4 different devices. Cornea. 2016;35:838–42.
4. Kurert KS, Peter M, Blum M, Hajgis W, Sekundo W, Schütze J, Bühren T. Repeatability and agreement in optical biometry of a new swept-source optical coherence tomography-based biometer versus partial coherence interferometry and low-coherence reflectometry. J Cataract Refract Surg. 2016;42:76–83.
5. Shin MC, Chung SY, Hwang HS, Hán KE. Comparison of two optical biometers. Optom Vis Sci. 2016;93:259–65.
6. Prakash G, Srivastava D. Single session, intrauser repeatability of anterior chamber biometer and corneal pachy-volumetric parameters using a new Scheimpflug-Placido device. J Optom. 2016;9:85–92.
7. Cerviño A, Domínguez-Vicent A, Ferrer-Blasco T, García-Lázaro S, Albarrán-Diego C. Intraand inter operator repeatability of corneal power, thickness, and wavefront aberrations with a new version of a dual rotating Scheimpflug-Placido system. J Cataract Refract Surg. 2015;41:186–92.
8. Huang J, Savini G, Wu F, Yu X, Yang J, Yu A, Yu Y, Wang Q. Repeatability and reproducibility of ocular biometry using a new noncontact optical low-coherence interferometer. J Cataract Refract Surg. 2015;41:2233–41.
9. Srivannaboon S, Chirapaisana C, Chonpimai P, Loket S. Clinical comparison of a new swept-source optical coherence tomography-based optical biometer and a time-domain optical coherence tomography-based optical biometer. J Cataract Refract Surg. 2015;41:2224–32.
10. Maroud M, Livny E, Bahar I. Repeatability and intraassession reproducibility obtained by the Sirius anterior segment analysis system. Eye Contact Lens. 2015;41:107–10.
11. Wang Q, Ding X, Savini G, Chen H, Feng Y, Pan C, Hua Y, Huang J. Anterior chamber depth measurements using Scheimpflug imaging and optical tomography repeatability, reproducibility, and agreement. J Refract Surg. 2015;31:616–21.
12. Hernández-Camarena JC, Chinios-Saldaña P, Navas A, Ramirez-Miranda A, de la Mota A, Jimenez-Corona A, Graue-Hernández EO. Repeatability, reproducibility, and agreement between three different Scheimpflug imaging systems in measuring corneal and anterior segment biome. J Refract Surg. 2015;41:704–8.
13. Flom J, Allover J, Papke J, Lu Y. Comparison of corneal and anterior segment biometry using a new swept-source optical coherence tomography-based optical biometer: repeatability and agreement agreement with an optical low-coherence interferometer. J Refract Surg. 2015;41:2233–41.
14. Shetty R, Arora V, Jayadev C, Nujits RM, Kumar M, Puttaiah NK, Kummelil MK. Repeatability and agreement of three Scheimpflug-based imaging systems for measuring anterior segment parameters in keratoconus. Invest Ophthalmol Vis Sci. 2014;55:2636–8.
15. Muntalbán R, Alíol JL, Javaloy J, Piñero DP. Intraand intersubject repeatability of keratoconus-eye measurements obtained with a new Scheimpflug photography-based system. J Cataract Refract Surg. 2015;41:9211–8.
16. Zhao J, Chen Z, Zhou Z, Ding L, Zhou X. Evaluation of the repeatability of the Lenstar and comparison with two other non-contact biometric devices in myopes. Clin Exp Optom. 2013;96:92–9.
17. Nasser CR, Singer R, Barkana Y, Zadok D, Avni I, Goldich Y. Reproducibility of the Sirius imaging system and agreement with the Pentacam HR. J Refract Surg. 2012;28:493–7.
17. Chen W, McAllinden C, Pesudovs K, Wang Q, Lu F, Feng Y, Chen J, Huang J. Scheimpflug-Placido topographer and optical low-coherence reflectometry biometer: repeatability and agreement. J Cataract Refract Surg. 2012;38:1626–32.
18. Montalbán R, Piñero DP, Javaloy J, Alió JL. Intrasubject repeatability of corneal morphology measurements obtained with a new Scheimpflug photography-based system. J Cataract Refract Surg. 2012;38:971–7.
19. Savini G, Carbonelli M, Barboni P, Hoffer KJ. Repeatability of automatic measurements performed by a dual Scheimpflug analyzer in unoperated and post-refractive surgery eyes. J Cataract Refract Surg. 2011;37:302–9.
20. Milla M, Piñero DP, Amparo F, Alió JL. Pachymetric measurements with a new Scheimpflug photography-based system. Intraobserver repeatability and agreement with optical coherence tomography pachymetry. J Cataract Refract Surg. 2011;37:310–6.
21. Asgari S, Hashemi H, Jafarzadehpur E, Mohamadi A, Rezvan F, Fotouhi A. OPD-Scan III: a repeatability and inter-device agreement study of a multifunctional device in emmetropia, ametropia, and keratoconus. Int Ophthalmol. 2016; [Epub ahead of print]
22. Piñero DP, Juan JT, Alió JL. Intrasubject repeatability of internal aberrometry obtained with a new integrated aberrometer. J Refract Surg. 2011;27:509–17.
23. López-Miguel A, Martínez-Almeida L, González-García MJ, Coco-Martín MB, Sobrado-Calvo P, Maldonado MJ. Precision of higher-order aberration measurements with a new Placido-disk topographer and Hartmann-Shack wavefront sensor. J Cataract Refract Surg. 2013;39:242–9.