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Repeatability, Reproducibility and Inter-Device Agreement of Anterior and Posterior Corneal Parameters Measured with Visionix 130+ and Pentacam HR in Healthy Eyes

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Abstract

Assessing the validity and measurement performance of optical instrumentation is essential to ensure its clinical utility. Therefore, the study's aims were to analyze the repeatability and reproducibility of two multi-diagnostic platforms (Visionix 130+ and Pentacam HR) in the measurement of corneal characteristics, and to assess inter-device agreement. Anterior and posterior corneal curvature, eccentricity and central corneal thickness were measured using both devices in 31 healthy subjects. Each participant was subjected to six measurements per device, divided equally between two observers (three per observer). Both devices showed moderate-to-high reliability for anterior parameters and central corneal thickness (ICC > 79.89). For posterior parameters, Pentacam HR maintained moderate-to-high reliability (ICC: 78.28–99.34), whereas Visionix 130+ revealed decreased reliability (ICC: 5.16–77.77). Regarding eccentricity, high reliability was observed for Pentacam HR (ICC: 96.55), while Visionix 130+ exhibited low reliability (ICC: 68.81). No agreement was found between the results provided by the two devices for most of the parameters assessed. It is concluded that both devices demonstrate good repeatability and reproducibility when assessing anterior corneal surface and central corneal thickness, with the exception of eccentricity measured by Visionix 130+. For posterior surface measurements, Pentacam HR demonstrates moderate-to-high reliability, while Visionix 130+ exhibits low reliability for most parameters. Finally, the results of both devices are not interchangeable.

Keywords: Visionix 130+; Pentacam HR; cornea; diagnostic techniques; optical instrumentation

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1. Introduction

The anatomical and optical characterization of the cornea is fundamental for eye care clinical practice, as it provides key information for multiple clinical contexts, such as the fitting of contact lenses, the diagnosis of various ocular pathologies or the performance of refractive surgery procedures [1]. Although single-parameter devices were traditionally

employed to assess individual characteristics, such as corneal curvature or pachymetry, in recent years there has been a growing popularity and widespread adoption of multi-diagnostic platforms. This is due to their ability to perform rapid measurements of multiple corneal parameters within a single examination.

Currently, there are several multi-diagnostic devices that can perform an assessment of corneal characteristics. One such example is the Pentacam (Oculus Optikgerate GmbH, Wetzlar, Germany), which is widely used in the detection of ectasia [2]. In addition to the Pentacam base model, the company Oculus has developed the Pentacam HR device, which is the high-resolution version and, according to the manufacturer, offers enhanced accuracy. The device utilizes Scheimpflug imaging technology to perform anterior segment topography, encompassing the anterior and posterior surfaces of the cornea. Additionally, based on the distance between the two sides of the cornea, the pachymetry value is determined [3]. Another example of widely used multi-diagnostic devices that assess the characteristics of the anterior segment of the eye is the Visionix devices (Visionix Luneau Technologies, Pont-de-l'Arche, France). Specifically, the Visionix 120 device has been the subject of extensive research, with numerous reports on its repeatability and agreement with other devices [4–7]. However, as with the Pentacam, there are other more modern Visionix models with expanded functionality, although these have been less extensively studied. This is the case with the Visionix 130+. This device combines a Placido disc corneal topographer and a Scheimpflug image-based system for the measurement of corneal characteristics, which enables the acquisition of data from both the anterior and posterior surfaces of the cornea, in addition to the measurement of pachymetry [8].

Given the growing use of these devices, assessing the validity and measurement performance of these multi-diagnostic platforms is essential to ensure their clinical utility. Therefore, the aims of the present study were twofold: firstly, to analyze the repeatability and reproducibility of two multi-diagnostic platforms, the Visionix 130+ and Pentacam HR, in the measurement of corneal characteristics, and secondly, to compare the agreement between the measurements obtained by both devices.

2. Materials and Methods

2.1. Study Design

In this observational, prospective, cross-sectional study, volunteers who met the study's inclusion criteria were recruited among those attending the centre's Optometry Clinic. Participants were excluded if they had a history of corneal pathology, previous ocular surgery, and/or ocular or systemic conditions that could affect the measurements [9].

Each participant underwent an initial medical history review followed by a corneal assessment, measuring anterior and posterior corneal topography and pachymetry using both instruments, Visionix 130+ and Pentacam HR. The measurements were obtained from the right eye of each participant, and all procedures were conducted in accordance with the manufacturer's guidelines. For each device, six consecutive measurements were taken, with the first three performed by one observer and the subsequent three by a second independent observer. Both observers had comparable experience in handling the devices. For each participant, the order of device use and the order of observer measurements were randomized. Corneal surface analysis included flat keratometry (K1), steep keratometry (K2), corneal astigmatism, and axis for both anterior and posterior surfaces. Eccentricity was additionally evaluated for the anterior surface of the cornea. Regarding pachymetric assessment, this comprised central corneal thickness (CCT). All measurements were conducted between 10:00 and 18:00 h under scotopic conditions, with illumination provided exclusively by the measuring devices [10].

Informed consent was obtained from all participants included in the study. The study protocol was conducted in accordance with the principles set out in the Declaration of Helsinki, and was reviewed and approved by the institutional Ethics Committee of the University (Approval number: USC 04/2022).

2.2. Visionix 130+

The Visionix 130+ multi-diagnostic platform integrates Placido-disc corneal topography with Scheimpflug imaging, enabling comprehensive assessment of both anterior and posterior corneal surfaces, along with pachymetric measurements [8]. The Placido-disc system projects 24 concentric rings onto the corneal surface, allowing analysis over a corneal diameter of 0.75 to 10.00 mm and a keratometric range of 37.5–56.0 D. Pachymetric measurements are acquired using a continuous horizontal Scheimpflug scan, with a range of 150 to 1300 μm and a resolution of ±10 μm [6,8].

Once the measurement protocol had been configured and set, the device performed the measurements automatically. Potential misalignment during measurements is addressed by the device's XYZ mechanism, designed to automatically adjust the positioning of the device, ensuring precise alignment with the target area [6].

2.3. Pentacam HR

The Pentacam HR is an anterior segment tomograph featuring a high-resolution rotating Scheimpflug camera, which provides a detailed three-dimensional description of the cornea, including evaluation of the anterior and posterior surfaces of the cornea, as well as pachymetry, among other functions. The keratometry measurement range is between 9.0 and 99.0 D, with a resolution of ±0.1 D. With regard to pachymetry, its value is derived from the tomographic data by calculating the distance between both surfaces of the cornea, enabling point-by-point pachymetric mapping across the cornea without a predefined measurement range [3].

Once the measurement protocol had been configured and set, the device performed the measurements automatically. Potential misalignment during measurements is addressed by a second camera and corrected for in the process, ensuring precise alignment with the target area [11].

2.4. Statistical Analysis

Statistical analyses were conducted only on the right eye of each participant to avoid the presence of statistical dependence between the eyes of the same subject [12].

The analysis of astigmatic components involves the assessment of the power and axis of the astigmatism, as well as the calculation and subsequent evaluation of the Jackson cross-cylinder vectors at 0° (V0) and 45° (V45). The following equations were utilized for this purpose [13]:

$$J_0 vector = -(Cylinder\ power/2) \times \cos(2 \times Cylinder\ axis), \quad (1)$$

$$J_{45} vector = -(Cylinder\ power/2) \times \sin(2 \times Cylinder\ axis), \quad (2)$$

The statistical analysis was carried out using the free R-software version 4.5.2 (R Foundation for Statistical Computing, Vienna, Austria), a language and environment for statistical computing. First, a descriptive analysis of each parameter was made separately for each device, Visionix 130+ and Pentacam HR.

The repeatability and reproducibility of the two instruments were evaluated using a statistical model with random effects that is given by the following expression:

$$M_{ijk} = \mu + P_i + O_j + I_{ij} + \varepsilon_{ijk}, \quad (3)$$

where M_{ijk} is the measure obtained for the *i*-th patient by the *j*-th observer in the *k*-th repetition, μ is the general mean of the considered parameter that is being measured, P_i is the random effect from the *i*-th patient ($\mu + P_i$ is, in fact, the true value of the parameter for the *i*-th patient), $O_j + I_{ij}$ represents the random effect of the *j*-th observer that is decomposed in O_j, that is common to all patients, and I_{ij}, that is the interaction of the *j*-th observer with the *i*-th patient, and finally, ε_{ijk} contains a random error specific to the *k*-th repetition. The random variables P_i are assumed to have zero expectation and a standard deviation that accounts for the natural variability of the considered parameter. The random effects O_j and I_{ij} are also assumed to have zero expectation with standard deviations that represent the reproducibility of the procedure. The random variables ε_{ijk} have again zero expectation and their standard deviation is interpreted as the repeatability of the instrument when it is used under the same conditions by the same observer. All random variables are assumed to be independent, so this model provides a decomposition of variability in terms of patients' variability, repeatability and reproducibility. Patients' variability can also be called the intraclass correlation coefficient (ICC), as it is the correlation between two measurements on the same patient. The ICC was calculated using a two-way random-effects model, with values below 75% indicating a poor level of ICC; moderate levels, from 75% to 90%; and high, above 90%. Models of this type were adjusted for each ocular parameter and each instrument, Visionix 130+ and Pentacam HR, using the *lme4* R-package [14].

The standard deviation of measurement error, including repeatability and reproducibility effects, can be estimated under this model and then, according to the British Standards Institute and the International Organization for Standardization, the following parameters could be obtained: within-subject standard deviation (Sw), intra-subject precision (Pr) calculated as 1.96 × Sw, general repeatability (r), defined as 2.77 × Sw, accounting for the difference between two measurements on the same subject, and coefficient of variation (CV), defined as the ratio of Sw to the overall mean.

To evaluate the agreement between the two instruments, Visionix 130+ and Pentacam HR, the six measurements obtained on each patient by Visonix 130+ are averaged and then compared with the same average obtained by Pentacam HR. Bland–Altman plots are given, where each subject is represented by the difference between the two instruments versus the average of them. Limits of agreement (LoAs) at the 95% confidence level are drawn, so they lie at mean difference ± 1.96 × SD of the difference. Exact 95% confidence intervals for upper and lower LoAs considered as a pair (mean difference ± $c_{t_{0.025}}$ × SD of the difference, mean difference ± $c_{t_{0.975}}$ × SD of the difference) are given [15].

To assess a possible bias between the instruments, a Student's paired *t* test is applied to check the significance of the mean difference. Additionally, a binomial test is applied to obtain a nonparametric check of a possible bias consisting of one instrument providing higher measurements than the other.

3. Results

The statistical analysis was made with the measurements obtained for the right eyes of thirty-one patients with complete observations of the parameters under study. The mean age of the participants was 22.2 ± 2.1 years, ranging from 19 to 27 years. Regarding ocular refraction, the mean spherical equivalent of the right eyes was −1.09 ± 1.67 D, with a range from +2.88 to −4.75 D. When analysing the spherical and cylindrical components independently, the mean spherical power of the right eyes was −1.04 ± 1.66 D, ranging from +3.25 to −4.50, while the mean astigmatism was −0.10 ± 0.22, ranging from 0 to −0.75. Descriptive statistics of the ocular parameters studied are given in Table 1 for the Visionix 130+ multi-diagnostic platform and in Table 2 for the Pentacam HR multi-diagnostic platform. Results about the mean are similar for Visionix 130+ and Pentacam HR, although

Pentacam HR shows more variability than Visionix 130+ for all parameters except eccentricity and CCT, where Visionix 130+ has a larger standard deviation and a wider range.

Table 1. Descriptive statistics, percentages of repeatability, reproducibility and intraclass correlation coefficient, and other parameters of intraclass variation (Sw, Pr, r, CV) for the Visionix 130+ multi-diagnostic platform.

Parameter	Mean ± SD (Range)	Repeatability [1]	Reproducibility [1]	ICC [1]	Sw	Pr	r	CV [1]
K1 (D)	42.54 ± 1.36 (39.69 to 44.98)	2.14	0.00	97.86	0.201	0.395	0.558	0.47
K2 (D)	43.32 ± 1.38 (40.38 to 46.31)	2.54	0.00	97.46	0.222	0.436	0.617	0.51
Ast. (D)	−0.780 ± 0.369 (−1.664 to 0.000)	13.81	1.53	84.66	0.146	0.286	0.405	18.74
Axis (º)	173.4 ± 18.5 (100.0 to 218.0)	18.07	2.04	79.89	8.401	16.47	23.29	4.84
V0 (D)	0.305 ± 0.236 (−0.667 to 0.737)	8.13	0.98	90.89	0.072	0.142	0.200	23.72
V45 (D)	−0.058 ± 0.185 (−0.594 to 0.486)	11.92	1.42	86.66	0.068	0.134	0.189	118.44
Eccentricity	0.437 ± 0.121 (0.095 to 0.750)	29.59	1.60	68.81	0.068	0.134	0.190	15.68
Post. K1 (D)	−5.995 ± 0.260 (−6.517 to −5.122)	21.22	1.01	77.77	0.124	0.243	0.343	2.07
Post. K2 (D)	−6.340 ± 0.318 (−7.858 to −5.689)	28.42	0.00	71.58	0.171	0.336	0.475	2.70
Post. Ast. (D)	0.344 ± 0.234 (0.028 to 2.549)	90.84	3.11	6.04	0.227	0.445	0.629	65.93
Post. Axis (º)	183.0 ± 20.0 (99.0 to 269.0)	73.92	6.38	19.69	18.055	35.39	50.05	9.87
Post. V0 (D)	−0.136 ± 0.106 (−0.406 to 0.596)	69.75	1.61	28.64	0.090	0.177	0.250	66.15
Post. V45 (D)	−0.005 ± 0.116 (−0.363 to 1.247)	94.50	0.34	5.16	0.113	0.222	0.314	2463.85
CCT (µm)	547.8 ± 29.8 (485.0 to 652.0)	7.83	0.56	91.61	8.738	17.13	24.22	1.60

[1] Repeatability, reproducibility, ICC and CV are expressed as percentages. Ast. = Astigmatism; CCT = Central Corneal Thickness; CV = Coefficient of Variation; D = Diopters; ICC = Intraclass correlation coefficient; K1 = Flat Keratometry; K2 = Steep Keratometry; Post. = Posterior; Pr = Intra-subject precision; r = General repeatability; SD = Standard Deviation; Sw = Within-subject standard deviation; V0 = Vector J0; V45 = Vector J45.

Table 2. Descriptive statistics, percentages of repeatability, reproducibility and intraclass correlation coefficient, and other parameters of intraclass variation (Sw, Pr, r, CV) for the Pentacam HR multi-diagnostic platform.

Parameter	Mean ± SD (Range)	Repeatability [1]	Reproducibility [1]	ICC [1]	Sw	Pr	r	CV [1]
K1 (D)	42.69 ± 1.48 (39.89 to 45.18)	0.15	0.10	99.76	0.074	0.145	0.205	0.17
K2 (D)	43.60 ± 1.47 (41.01 to 46.55)	0.29	0.19	99.52	0.103	0.202	0.286	0.24
Ast. (D)	−0.910 ± 0.396 (−1.813 to 0.000)	5.81	3.98	90.22	0.125	0.246	0.347	13.77
Axis (º)	174.6 ± 24.3 (90.9 to 216.0)	4.84	1.13	94.03	6.005	11.77	16.64	3.44
V0 (D)	0.370 ± 0.261 (−0.678 to 0.807)	3.11	1.90	94.99	0.059	0.116	0.164	16.00
V45 (D)	0.005 ± 0.205 (−0.547 to 0.558)	11.89	7.18	80.93	0.090	0.177	0.251	1773.95
Eccentricity	0.567 ± 0.086 (0.210 to 0.730)	3.38	0.07	96.55	0.016	0.032	0.045	2.86
Post. K1 (D)	−6.126 ± 0.245 (−6.667 to −5.682)	0.54	0.12	99.34	0.020	0.040	0.056	0.33
Post. K2 (D)	−6.413 ± 0.251 (−6.838 to −5.961)	0.81	0.25	98.93	0.026	0.052	0.073	0.41
Post. Ast. (D)	0.287 ± 0.082 (0.038 to 0.429)	11.23	2.55	86.23	0.031	0.060	0.085	10.70
Post. Axis (º)	184.1 ± 10.7 (144.4 to 215.0)	19.25	2.48	78.28	5.036	9.872	13.96	2.74

Post. V0 (D)	−0.134 ± 0.042 (−0.213 to −0.006)	12.58	2.08	85.34	0.016	0.032	0.045	12.10
Post. V45 (D)	−0.024 ± 0.045 (−0.118 to 0.079)	11.57	2.59	85.84	0.017	0.034	0.048	71.47
CCT (µm)	548.6 ± 26.5 (497.0 to 627.0)	0.84	0.05	99.11	2.536	4.971	7.030	0.46

[1] Repeatability, reproducibility, ICC and CV are expressed as percentages. Ast. = Astigmatism; CCT = Central Corneal Thickness; CV = Coefficient of Variation; D = Diopters; ICC = Intraclass correlation coefficient; K1 = Flat Keratometry; K2 = Steep Keratometry; Post. = Posterior; Pr = Intra-subject precision; r = General repeatability; SD = Standard Deviation; Sw = Within-subject standard deviation; V0 = Vector J0; V45 = Vector J45.

3.1. Repeatability and Reproducibility

Tables 1 and 2 provide percentages of variability that can be assigned to repeatability, reproducibility and natural variability of each parameter for Visionix 130+ and Pentacam HR, respectively, where ICC represents the natural variability. Pentacam HR shows a high ICC (above 90%) for all parameters of the anterior corneal surface but V45. For the posterior corneal surface Pentacam HR shows lower ICC values, while they are still above 90% for K1 and K2 parameters. The values of ICC were lower for Visionix 130+, although still high for K1, K2, and V0 for the anterior corneal surface and CCT; moderate for Ast, Axis and V45 for the anterior surface; poor for eccentricity in the anterior surface; and very poor for astigmatism, V0 and V45 parameters for the posterior corneal surface. Repeatability was quite low with Pentacam HR, while reproducibility was low with Visionix 130+ for the anterior corneal surface.

3.2. Agreement Between Visionix 130+ and Pentacam HR

Figure 1 shows Bland–Altman plots for each of the ocular parameters. Each plot represents the difference between the two instruments, Visionix 130+ and Pentacam HR, versus their average. The central line is at the mean difference, the solid upper and lower lines are at the LoAs, while the dashed lines represent the 95% confidence intervals for the LoAs. Mean differences, standard deviations of the differences and LoAs are given in Table 3.

Table 3. Agreement between Visionix 130+ and Pentacam HR. The mean difference is computed with the differences, Visionix 130+—Pentacam HR, SD is the standard deviation of the differences, LoAs are derived from the mean difference and the standard deviation. Student's *p*-value and binomial test results are given for the comparison between Visionix 130+ and Pentacam HR. The binomial test counts the number of patients with a higher measurement of Visionix 130+ versus Pentacam HR, and *p* is the corresponding *p*-value.

					Binomial Test	
Parameter	**Mean Difference**	**SD**	**LoA**	**Student's *p***	**VX130+ vs. Pentacam HR**	***p***
K1 (D)	−0.1537	0.4711	−1.077 to 0.770	0.0793	3 vs. 28	<0.0001
K2 (D)	−0.2842	0.4919	−1.248 to 0.680	0.0031	3 vs. 28	<0.0001
Ast. (D)	0.1306	0.1464	−0.156 to 0.417	<0.0001	26 vs. 5	0.0002
Axis (º)	−1.1855	16.8166	−34.146 to 31.775	0.6975	7 vs. 24	0.0033
V0 (D)	−0.0650	0.0833	−0.228 to 0.098	0.0001	7 vs. 24	0.0033
V45 (D)	−0.0629	0.0818	−0.223 to 0.097	0.0002	7 vs. 24	0.0033
Eccentricity	−0.1304	0.1192	−0.364 to 0.103	<0.0001	3 vs. 28	<0.0001
Post. K1 (D)	0.1307	0.0571	0.019 to 0.243	<0.0001	31 vs. 0	<0.0001
Post. K2 (D)	0.0735	0.1172	−0.156 to 0.303	0.0015	22 vs. 9	0.0294
Post. Ast. (D)	0.0573	0.1112	−0.161 to 0.275	0.0075	22 vs. 9	0.0294
Post. Axis (º)	−1.0935	15.6292	−31.727 to 29.540	0.6996	9 vs. 22	0.0294

Post. V0 (D)	−0.0024	0.0604	−0.121 to 0.116	0.8289	15 vs. 16	1.0000
Post. V45 (D)	0.0195	0.0414	−0.062 to 0.101	0.0137	23 vs. 8	0.0107
CCT (µm)	−0.7634	10.1527	−20.663 to 19.136	0.6784	15 vs. 16	1.0000

Ast. = Astigmatism; CCT = Central Corneal Thickness; D = Diopters; K1 = Flat Keratometry; K2 = Steep Keratometry; LoA = Limits of Agreement; Post. = Posterior; SD = Standard Deviation; V0 = Vector J0; V45 = Vector J45; VX130+ = Visionix 130+.

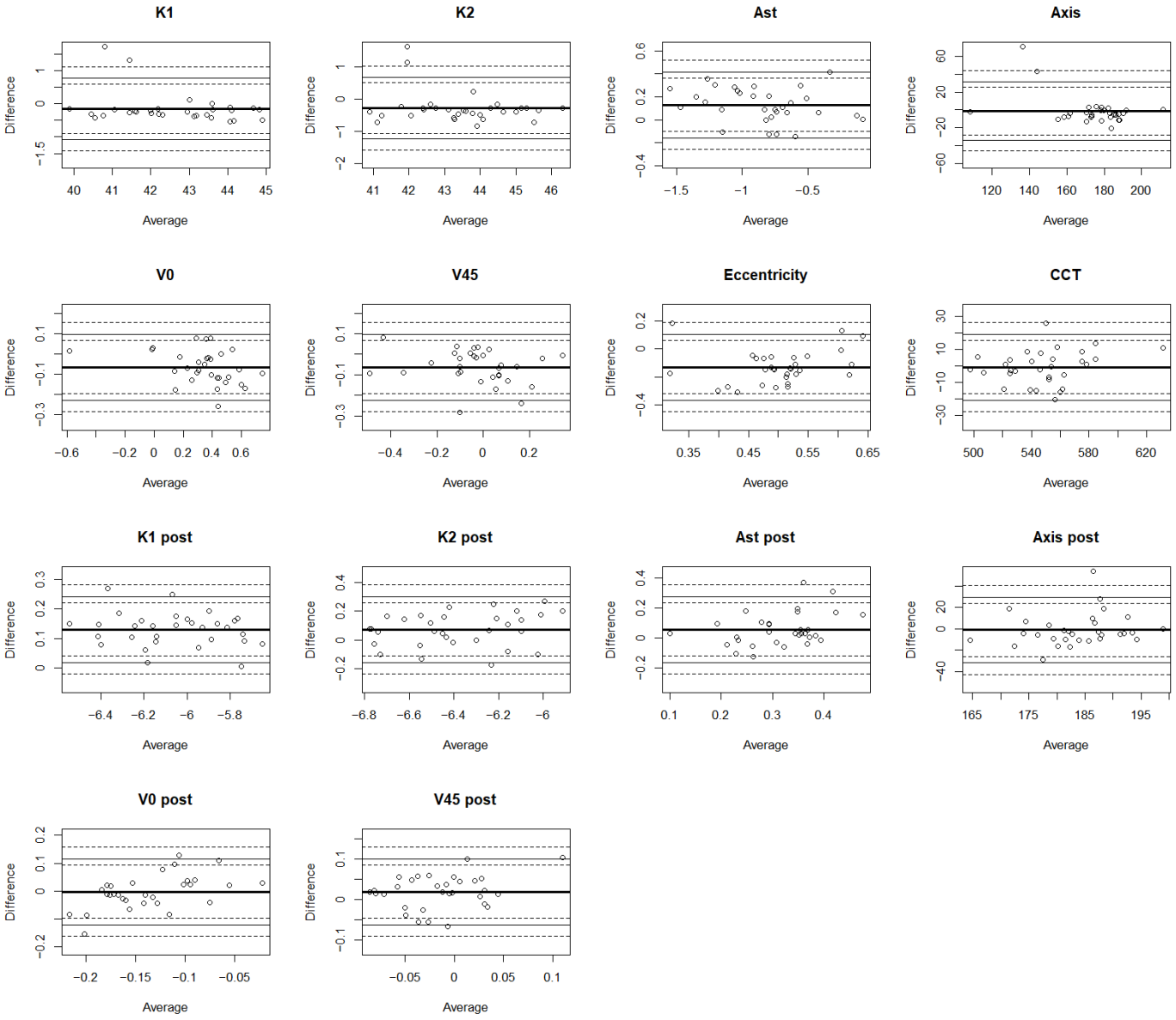


Figure 1. Bland–Altman plots for the comparison between Visionix 130+ and Pentacam HR measurements for each ocular parameter. The horizontal axis represents the average of the two measurements; the vertical axis contains the difference, Visionix 130+ minus Pentacam HR. The limits of agreement (LoAs) are computed as the mean difference plus or minus 1.96 × SD (Difference). The dashed lines indicate the 95% confidence intervals for the LoAs. Anterior and posterior keratometry (K1, K2), astigmatism (Ast), and astigmatism vector components (V0 and V45) are expressed in diopters (D). The axis of anterior and posterior astigmatism is expressed in degrees (°). Central corneal thickness (CCT) is expressed in micrometers (µm). Corneal eccentricity is a dimensionless shape factor.

As can be observed in Table 3, Visionix 130+ and Pentacam HR show a statistical bias in most of the parameters. Student's paired *t* test is significant, with a mean of Visionix 130+ measurements smaller than that of Pentacam HR, for K2, V0, V45 and eccentricity for the anterior corneal surface, and with a larger mean of Visionix 130+ for Ast for the anterior surface. The binomial test provides similar results to the Student's paired *t* test, except for the Axis for the anterior and posterior corneal surfaces, where only the binomial test is significant. LoAs are wide for most parameters.

4. Discussion

The present study evaluated the repeatability and reproducibility of two multi-diagnostic platforms, Visionix 130+ and Pentacam HR, in the characterization of anterior and posterior corneal parameters in a cohort of 31 healthy subjects. Regarding the anterior surface parameters, both devices demonstrated consistent performance, exhibiting high ICC values in the majority of variables. Specifically, keratometry (K1 and K2) yielded ICC values above 97% for the Visionix 130+ and over 99% for the Pentacam HR, with coefficients of variation below 0.51% in both cases. This finding aligns with the existing literature on both devices, which consistently reports the repeatability and reproducibility of anterior keratometry at ICC values close to 99% in healthy eyes [4,16]. Furthermore, ICC values of over 99% have been observed for anterior keratometry measurements taken by the Pentacam HR device in eyes with keratoconus [17]. However, these results are not replicated in the measurements of the posterior surface. While the Pentacam HR demonstrated still adequate reliability, with ICC values ranging from moderate to high for the posterior surface parameters (ICC between 78.28 and 99.34%), the ICC values for the Visionix 130+ exhibited a substantial decrease. In particular, it was observed that only K1 achieved an ICC value above the thresholds generally considered acceptable (ICC > 0.75); the remaining posterior surface parameters demonstrated values below this level (ICC between 5.16% and 71.58%). This difference is clinically significant, as the reliability of the posterior curvature is particularly important in the screening for ectasia, in the calculation of toric intraocular lenses and in the follow-up of refractive surgery [18–20]. Nevertheless, the Pentacam HR also demonstrated a slight reduction in ICC values for the posterior surface, which is consistent with the findings of the preceding study by Chen et al. [21]. As this author proposes, the variability in the reliability of the anterior and posterior measurements could be attributed to the difference in refractive index between the two media, given that the minor discrepancy between the cornea and the aqueous humor (approximately 0.040) could complicate the identification of the posterior corneal surface, in comparison to the difference in refractive index between air and the cornea (approximately 0.376), which would provide greater contrast. A significant finding of this study is that, while both devices demonstrate challenges in measuring the posterior surface, the Visionix 130+ exhibits a more pronounced decline in reliability compared to the Pentacam HR. This discrepancy could be attributed to variations in the reconstruction of the posterior surface between the Placido–Scheimpflug system of the Visionix 130+ and the pure Scheimpflug system of the Pentacam HR. An additional methodological consideration concerns the refractive index assumed by each device when computing posterior surface parameters. Neither the Pentacam HR nor the Visionix 130+ explicitly specifies, in its publicly available technical documentation, the refractive index employed by its internal software for posterior corneal calculations. Consequently, it cannot be definitively established whether both devices operate under identical optical assumptions. This limitation should be considered when interpreting the findings, although it does not materially affect the primary comparative conclusions of the study. Finally, with regard to reliability, the lowest ICC results were obtained for the variables reflecting astigmatism (for both power and axis, and, naturally, the vectors derived from these). Such findings must be interpreted

with caution, as the CV is highly responsive to mean values close to 0 [22], as is the case with corneas exhibiting low astigmatism. An important consideration when interpreting ICC values is their dependence on between-subject variability, as a relatively homogeneous study population may result in lower ICC estimates irrespective of the actual measurement error. In the present study, although posterior corneal parameters generally showed lower ICC values than anterior parameters, substantial differences were observed between devices for the posterior parameters. This observation occurred despite both devices being evaluated within the same cohort. This finding suggests that the low posterior ICC values obtained with the Visionix are unlikely to be attributable solely to limited between-subject variability and may instead reflect greater measurement variability associated with this device. Nevertheless, these results should be interpreted cautiously and confirmed in larger studies with more repeated measurements.

With regard to the agreement between platforms, the outcomes of this study demonstrate that only anterior K1, the astigmatic axis of both the anterior and posterior surfaces, the posterior vector 0 and the CCT exhibited no statistically significant differences between the Visionix 130+ and the Pentacam HR. The remaining parameters showed significant differences in both the Student's paired *t* test and the binomial test, indicating a systematic and consistent bias in the direction of the difference. Consequently, these devices yield non-interchangeable results. This observation is consistent with the findings of the previous study by Zhang et al. [23], which also described significant differences between the measurements obtained using a Visionix device and a Pentacam. Moreover, this finding is consistent with previous research comparing the Pentacam with other devices, which, despite their high individual reliability, do not produce comparable measurements for most of the parameters assessed [17]. The Bland–Altman plots further corroborate the absence of agreement between devices. In the case of anterior corneal keratometry, the data points on the plot demonstrate a clear mean difference line shifted away from zero, with a relatively narrow and constant range of variation. This finding corresponds to a systematic and predictable bias, in which one device (Visionix 130+) consistently yields lower measurements than the other (Pentacam HR). In this case, corrections for inter-device differences may be possible by applying an adjustment factor. Conversely, parameters such as K2 of the posterior surface of the cornea demonstrate a mean close to zero yet with unpredictable dispersion, exhibiting no systematic bias. Consequently, it is not feasible to predict, for an individual patient, in which direction and/or by what magnitude the devices will differ. Furthermore, the Bland–Altman plots suggest a potential proportional bias for eccentricity and posterior astigmatism, with the differences between devices tending to increase as the average measurement increases. This finding is consistent with the significant differences and directional predominance observed for both parameters. In contrast, although a similar visual pattern may be suggested for posterior V0, neither the mean differences nor their directional distribution reached statistical significance, providing no evidence of a systematic bias for this parameter. Regarding eccentricity specifically, it should be noted that all measurements were acquired using the manufacturer's default settings for each device. Under these conditions, the observed systematic bias may be partly related to differences in the corneal zones used by each device for the calculation of eccentricity. This is a plausible explanation that cannot be confirmed based on the present data, particularly given that the area sampled by an instrument should not necessarily be assumed to correspond to the area used by its internal algorithm to calculate eccentricity. Since corneal eccentricity is not a zone-independent parameter, but rather depends on the corneal profile and the area over which it is fitted, differences in the extent of the analysed zone or in the underlying computational approaches may contribute to systematic discrepancies between the reported values. In view of this methodological uncertainty, together with the statistically significant inter-device difference and the

directional predominance observed, eccentricity values obtained with the two devices should not be regarded as interchangeable. This limitation does not invalidate the comparative findings, but it qualifies the interpretation of eccentricity as a directly transferable parameter between platforms.

Taken together, these results, in conjunction with those of previous studies, support that multi-diagnostic devices such as the Visionix 130+ or the Pentacam offer acceptable intra-device reliability, particularly with regard to the anterior surface. However, it should be noted that their results should not be considered interchangeable.

The present study has certain limitations that require consideration when interpreting the results. Firstly, only healthy eyes were included in the sample; therefore, the results may not be generalizable to populations with corneal ectasia, post-surgical corneas or irregular corneas. Secondly, all measurements were systematically obtained in the same sequence rather than being randomized. Finally, the CV for the angular and vector parameters (astigmatic variables) is affected by the fact that the mean value of these variables is close to zero. As previously mentioned, this should be interpreted with caution, paying particular attention to the other statistical parameters.

5. Conclusions

The Visionix 130+ and Pentacam HR multi-diagnostic platforms demonstrate generally good repeatability and reproducibility in the assessment of the anterior surface of the cornea and the measurement of CCT, with the exception of anterior corneal eccentricity measured by Visionix 130+, which shows poor reliability. Measurements of the posterior surface yield poorer results for both devices. However, the Pentacam HR continues to demonstrate moderate-to-high reliability for the parameters assessed, whilst the Visionix 130+ shows low reliability for most parameters relating to the posterior surface of the cornea. Finally, with regard to inter-device agreement, it is concluded that their results are not interchangeable.

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Abbreviations

The following abbreviations are used in this manuscript:

CCT	Central corneal thickness
CV	Coefficient of variation
D	Diopters
ICC	Intraclass correlation coefficient
K1	Flat keratometry
K2	Steep keratometry
Pr	Intra-subject precision
r	General repeatability
SD	Standard deviation
Sw	Within-subject standard deviation
V0	Vector J0
V45	Vector J45

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