ABSTRACT

Background: Due to the increasing use of contact lenses (CL) and the interest in ocular and body size relationships, this study aimed to compare measurements from two biometers (contact ultrasonic EchoScan US-800 and non-contact optical Lenstar LS900) with and without CL and to explore the relationship between ocular and body biometric parameters.

Design and Methods: This cross-sectional study measured ocular biometry using two biometers along with their body height and right foot length in 50 participants. Differences between biometry data from the two devices were compared and correlations between ocular and body biometric values were analyzed.

Results: All parameters showed interbiometric differences ($p \leq 0.030$), except crystalline lens thickness during CL wear ($p=0.159$). Comparing measurements with and without CL, differences were observed in axial length ($p<0.001$), vitreous length measured by optical biometer ($p=0.016$), and anterior chamber depth by ultrasonic biometer ($p<0.016$). Lens thickness remained unaffected ($p \geq 0.190$). Body height and foot length were correlated with anterior chamber depth, vitreous length, and axial length ($p \leq 0.019$, $r \geq 0.330$). Most biometric parameters were correlated among them using both devices ($p \leq 0.037$, $r \geq 0.296$).

Conclusions: These biometers are not interchangeable and CL affects measurements. Body height and foot length correlate with ocular dimensions, and most ocular biometric values correlate positively.

Key words: Ocular biometry, Lenstar LS900, EchoScan US800, Contact Lenses, Human morphology.

HIGHLIGHTS

1. The present study analyzes the effect of CL wear during ocular biometry measurements.
2. CL should not be worn when performing biometry, both with optical and ultrasound biometry.
3. Results obtained by optical and ultrasonic biometry are not interchangeable.
4. Biometric parameters such as body height or foot length correlate positively with ocular dimensions.

1. INTRODUCTION

Ocular biometry enables clinicians to measure the dimensions of the components of the eye with specially designed biometers [1]. Biometric measurements can be performed based on different physical principles, with acoustic (ultrasound) and optical methods being two of the most commonly used [2,3]. Ultrasound biometry uses a high-frequency sound wave to measure the length of the internal structures of the eye, as well as its total length, by capturing the echoes as the sound bounces off the ocular structures [1,4]. There are two types of ultrasound biometry depending on the location of the probe: the direct contact and the immersion contact methods. In direct contact biometry, the probe is placed directly on the cornea after the instillation of topical anesthesia. In immersion biometry, a capsule filled with saline solution is placed between the patient's cornea and the probe. To avoid discomfort, the use of an anesthetic is also necessary [1,4]. Optical biometry allows non-contact biometric measurements, and there are also two techniques: partial coherence interferometry and optical low-coherence reflectometry, both based on laser interferometry. The partial coherence interferometry uses a multimode laser diode reflecting off the corneal surface and the retinal pigment epithelium to measure axial length; it can also be combined with other technologies such as a Scheimpflug camera device to obtain more ocular parameters [5]. The optical low-coherence reflectometry uses a super luminescent diode, which has stronger penetrating power and is capable of acquiring more parameters than partial coherence interferometry alone [1,6].

Since its inception in the 1970s, the main uses of ocular biometry have been for the calculation of the intraocular lens power in cataract or refractive surgery, or the assessment of pathological ocular disorders [1,7]. Additionally, its use has become increasingly widespread in monitoring the progression of myopia in the last decades due to the increase in availability of methods in the market for its control [8,9]. While non-contact devices are of great interest in the adult population, those devices have a particular interest in myopia control of the pediatric population as many children have difficulty with invasive testing; also myopia may be better studied if biometry can be performed while wearing myopia control soft contact lens (CL) in order to avoid as much as possible the manipulation of the eye during an examination [10]. Moreover, the ongoing increase in the prevalence of myopia has encouraged studies that relate ocular

parameters, such as lens thickness (LT), anterior chamber depth (ACD), vitreous length (VL) or axial length (AL), to other body parameters [11,12]; for example, a positive correlation has been observed between AL and body height, which means the taller the subject, the greater the AL [13], and between the relative value of foot length to body height and AL in men [14].

Regarding the devices studied here, the EchoScan US-800, A-scan ultrasound has been the standard technique for measuring ocular parameters for decades [15], although in recent years, optical devices have begun to gain relevance, especially for use in children [9]. Among these devices, the Lenstar LS900 has demonstrated excellent reproducibility and repeatability in previous studies [16,17]. The present study aimed: 1) to compare the values obtained between two biometers, the contact ultrasound EchoScan US-800 (Nidek Co., Tokyo, Japan) and the low coherence optical reflectometry Lenstar LS900 (Haag Streit AG, Köniz, Switzerland), with the naked eye and during CL wear, and 2) to assess the relationship between biometric parameters and other body parameters (body height and foot length).

2. METHODS

2.1 Participants

A total of 51 participants (13 men and 38 women) with a mean age of 22.2 ± 2.25 years (range from 18 to 28 years) were randomly recruited among university students. Participants were included if they had an auto-refracted sphere of - 10.00 to + 4.00D, astigmatism up to - 3.00D, anterior chamber angle ≥ 30º and a compensated intraocular pressure (IOP) ≤ 20.85 mmHg [2,18,19]. Patients were excluded if they had ever been diagnosed with an ocular infection, trauma disorders, diseases at the time of the study (glaucoma, scleral or corneal anomalies, dry eye disease, meibomian gland dysfunction, etc.), undergone ocular surgery, diagnosed with systemic disorders that could affect the measurements (diabetes mellitus, rheumatoid arthritis, etc.), or had a history of hypersensitivity or allergy to anesthesia [2,10,20]. No participant was under any type of topical, systemic treatment or used artificial tears at the time of the study. All participants gave their written informed consent to be included in the study. The study protocol followed

77 the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of the university
78 (Approval number: USC 04/2022).
79
80 **2.2 Experimental procedure**
81 In a single visit, participants underwent a battery of tests according to standard protocols always in the same
82 order based on the invasiveness of the test [10,21]: pachymetry, topography, anterior chamber angle, IOP,
83 objective refractive condition, biometry of the naked eye, body height, foot length, and ocular biometry
84 wearing CL.
85
86 2.2.1 Measurements of inclusion criteria parameters
87 Pachymetry, topography and anterior chamber angle were performed by the Visionix120 system (Visionix
88 Luneau Technologies, Chartres, France) [22]. The Visionix120 is a non-invasive optical diagnostic device
89 that uses a Scheimpflug image-based system and a Placido disk system projected on the cornea to assess
90 the anterior segment parameters of the eye.
91 IOP was measured by the Canon TX-10 non-contact tonometer (Canon Inc, Tokyo, Japan) in automatic
92 mode. The device automatically performs three measurements on each eye to avoid fluctuations due to the
93 cardiac pulse cycle [23]. The pachymetry values obtained by Visionix120 were used to calculate the
94 compensated IOP [24].
95 The objective refractive condition of the eye was determined using the Shin-Nippon NVISION-K5001
96 open-field window autorefractometer (Rexxam Co., Kagawa, Japan), which allows a binocular view of a
97 fixation target at a distance of 4 meters, minimizing instrumental myopia [25]. This device estimates the
98 refractive error by averaging three measurements.
99
100 2.2.2 Measurements of studied parameters
101 The participant's body height and the length of their right foot were both measured using measuring tapes
102 with 0.1 cm divisions. One tape was attached to the wall and another tape was attached to the floor [26].

The ocular biometry was measured exclusively in the right eye of each participant to avoid both the effects of overstating the precision of statistical estimates using two different devices, each twice: a non-contact biometer based on low coherence optical reflectometry as its measurement principle [27], and a contact ultrasound biometer [21]. The optical biometer was set to perform three automatically consecutive measurements once the operator manually starts the process to calculate the final value as the average of the values obtained. The ultrasound device was set at AUTO3 mode, which automatically performs a battery of measurements when the probe touches the cornea and chooses the closest three measures to obtain the average value. The first measurement was performed with the optical biometer and the second with the ultrasonic device, following instillation of one drop of anesthesia. This order was decided upon in order to follow a protocol from least to most invasive to avoid errors induced by corneal compression during contact biometry [21].

After performing ocular biometry measurements with the naked eye using both biometers, and allowing the anesthetic effect to wear off, a CL was fitted in the right eye of each participant, and the biometry was repeated with each device in the same order [10]. In all cases, a daily disposable silicone hydrogel CL of Delefilcon A (Alcon Laboratories, Inc, Fort Worth, USA) at - 3.00D of power was used [28].

2.3 Statistical analysis

Data analysis was performed using SPSS statistical software v.25.0 for Windows (SPSS Inc., Chicago, USA). The chosen level of statistical significance was $p \leq 0.05$. Prior to the analysis, the Shapiro-Wilk test was performed for all variables to detect deviations from the normal distribution [29]. Since the variables showed a non-normal distribution, non-parametric tests were performed in the data analysis. Differences between intra- and inter-biometers data with the naked eye and during CL wear were analyzed using the Wilcoxon paired-sample test. For graphical purposes, Bland-Altman procedures were used; this method describes the correlation or similarity between two variables, representing averages versus differences [29,30]. The 95% limits of agreement (95% LoAs) were calculated (Mean difference ± 1.96 x Standard Deviation (SD)), as well as the exact 95% Confidence Intervals (95% CI) for Upper and Lower LoAs

considered as a pair (Mean difference ± $ct_{0.025}$ x SD; Mean difference ± $ct_{0.975}$ x SD) [29,31]. The relationship between ocular biometry values and other body parameters (body height and foot length) was performed with Spearman's correlation test. Correlation between variables was described as weak (0.20 – 0.40), moderate (0.41 – 0.60), good (0.61 – 0.80) or strong (0.81 – 1.00) [32].

3. RESULTS

Based on the inclusion criteria, the final sample consisted of 50 participants (13 men and 37 women). One participant was excluded for having an intraocular lens. The descriptive data of the final sample are shown in Table 1.

3.1 Differences between biometers data with the naked eye

A statistically significant difference was found between all parameters when comparing the results obtained by the optical vs. the ultrasound device with the naked eye (Wilcoxon paired-sample test, all $p \leq 0.030$) (Table 2A). The Bland and Altman plot of means versus differences between the measurements with the naked eye by the devices studied is shown in Figure 1. In the ACD and AL plots (Figure 1A and 1D, respectively), no discernible trend is observed, indicating an absence of systematic bias in the measurements; however, the variability between devices is relatively high in both cases. On the other hand, the LT and VL plots (Figure 1B and 1C, respectively) exhibit two separate data sets: whereas the variability within each set is small, the between-set variability is large (around 4 mm in both plots), indicating the presence of an external factor that is affecting one of the sets.

3.2 Differences between biometers data wearing CL

Statistically significant differences between biometers were observed during CL wear in the ACD, VL and AL values (Wilcoxon paired-sample test, all $p \leq 0.001$), but not in LT (Wilcoxon paired-sample test, $p = 0.159$) (Table 2B). The Bland and Altman plot of means versus differences between the devices studied is shown in Figure 2. Similar to Figure 1, the plots for ACD and AL (Figure 2A and 2D) exhibit a no

discernible trend, and the variability is relatively smaller in these cases than in the previous analysis. Meanwhile, the plots for LT and VL (Figure 2B and 2C, respectively) still display two distinct data sets, suggesting that the factor affecting one of the sets in the naked eye measurements persists in the measurements taken with the CL on eye.

3.3 Differences between naked eye data and CL wear data measured by the optical biometer

A statistically significant difference between VL and AL measured by the optical biometer with the naked eye vs. during CL wear was found (Wilcoxon paired-sample test, all $p \leq 0.016$), while ACD and LT with the naked eye and during CL wear were not statistically different (Wilcoxon paired-sample test, all $p \geq 0.190$) (Table 2C). The Bland and Altman plot of means versus differences between the devices studied is shown in Figure 3. The plots for ACD, LT, and VL (Figure 3A, 3B, and 3C, respectively) show low variability in measurements with and without CL, indicating that any observed differences are not statistically significant or, if significant, are not clinically relevant. In contrast, the AL plot (Figure 3D) exhibits higher and more pronounced variability in comparison with the other parameters studied.

3.4 Differences between naked eye data and CL wear data measured by the ultrasound biometer

When comparing biometric data with the naked eye vs. during CL wear measured by the ultrasound biometer, statistically significant differences were observed in ACD and AL (Wilcoxon paired-sample test, all $p \leq 0.005$), while not in LT and VL (Wilcoxon paired-sample test, all $p \geq 0.395$) (Table 2D). The Bland and Altman plot of means versus differences between the devices studied is shown in Figure 4. The ACD plot (Figure 4A) displays a scatter of points with an increasing trend, from which can be inferred that the variability in the differences is greater at the extremes of the scale. For LT and VL plots (Figure 4B and 4C), most of the data points are close to zero, indicating small differences between values. However, the wide 95% LoAs suggest high variability. Finally, the AL plot (Figure 4D) exhibits a scatter of points with no discernible trend but high variability.

3.5 Correlation between body height, foot length and ocular biometry data measured by the optical biometer

The relationship between ocular biometric data measured by the optical biometer (naked eye) and body height was statistically significant with ACD, VL and AL values (Spearman's correlation, $r \geq 0.338$, all $p \leq 0.016$); similar results were obtained for the correlation between biometric data measured by this device and foot length, where ACD, VL and AL showed a statistically significant correlation (Spearman's correlation, $r \geq 0.330$, all $p \leq 0.019$) (Table 3). In all cases the correlation was weak.

Regarding the correlations of the optical biometric data with each other measured by the optical biometer, results showed a strong correlation between VL and AL (Spearman's correlation, $r = 0.986$, $p < 0.001$), a moderate correlation between ACD and LT (Spearman's correlation, $r = -0.568$, $p < 0.001$), and weak correlations between ACD and AL, and LT with VL and AL (Spearman's correlation, all $r \geq 0.344$, all $p \leq 0.015$) (Table 3). Nevertheless, no correlation was obtained among ACD with VL (Spearman's correlation, $p = 0.054$) (Table 3).

3.6 Correlation between body height, foot length and ocular biometry data measured by the ultrasound biometer

With the biometry data obtained by the ultrasound biometer, statistically significant correlations were only observed with AL. This was observed for both body height (Spearman's correlation, $r = 0.397$, $p = 0.004$) and foot length (Spearman's correlation, $r = 0.351$, $p = 0.012$), although with weak correlations in both cases (Table 3).

Regarding the correlations of the ultrasound biometric data with each other measured by that biometer, all parameters showed weak correlations with AL (Spearman's correlation, all $r \geq 0.344$, all $p \leq 0.015$), VL showed weak correlation with ACD and moderate correlation with LT (Spearman's correlation, both $r \geq -0.331$, both $p \leq 0.019$), and no relationship was found between ACD and LT (Spearman's correlation, $p = 0.095$) (Table 3).

4. DISCUSSION

Measuring ocular biometry is of high clinical relevance because of its application to some pathological conditions, such as the increasing prevalence of high myopia [9], and the intraocular lens calculations related to cataract or refractive surgery [1,7]. The technological development of biometers must ensure that accuracy is maintained. From the first ultrasonic biometers to the new optical biometers, numerous improvements have been achieved. Optical biometers have high resolution and, thanks to the possibility of incorporating other technologies, can quickly measure not only the AL, central corneal thickness (CCT), ACD, and LT, but also corneal curvature, white-to-white distance, and pupil diameter [6]. The main advantage of optical biometers over ultrasonic is that those devices do not require contact, avoiding the use of anesthetic and the possible transmission of infections [4]. In addition, a probe misalignment and corneal compression with ultrasonic biometers may contribute to inaccurate readings [1,4]. However, ultrasound biometry is still necessary, because optical methods cannot obtain readings in eyes with opacities (leukoma, dense cataract, hemorrhages…) or in the presence of inadequate foveal fixation (due to poor visual acuity, eccentric fixation, retinal pathologies or alterations…) [1].

In the present study, the results of two biometers (non-contact optical Lenstar LS900 and contact ultrasound EchoScan US-800) were compared both against each other and, as well as against their respective measurements obtained with the naked eye and taken during CL wear. When comparing the biometrics results between the optical and ultrasound biometers with the naked eye, significant differences were observed, which means that these devices could not be interchangeable. Similar results were obtained by Gursoy et al. [33] when comparing Lenstar vs. another ultrasound biometry device. Ultrasound biometry values were higher in ACD and LT, whereas optical biometry values were higher in VL and AL. When comparing both devices wearing CL, ultrasound biometry values were also higher in ACD and optical biometry values were also higher in VL and AL, but no significant differences were observed for the LT (Wilcoxon paired-sample test, $p = 0.159$). This variation in the LT may be due to accommodation. Figures 1B and 2B show that the LT results when biometers were compared are divided into two distinct groups. During the ultrasound biometer measurements, one group of participants likely maintained relaxed

accommodation, while the other group likely activated their accommodation, possibly due to the proximity of the probe. Previous studies in animals found that Lenstar underestimated ocular dimensions compared to an ultrasound biometer [34,35]. In humans the results have been equivocal: Buckhurst et al. [36] found that the total AL was significantly higher with an ultrasound biometer in an adult population, the mean difference being clinically relevant (0.14 mm), while a study in a pediatric population found the highest results in AL with Lenstar, the mean difference also being clinically relevant (- 0.72 mm) [33]. The results from the present study agree with those obtained in the latter study, a higher value of AL when measuring with the optical device.

When comparing the ultrasound biometry results against itself with the naked eye and during CL wear, significant differences in ACD and AL were observed (Wilcoxon paired-sample test, $p \leq 0.005$), with higher values while wearing CL. These differences may be due that the ACD measurement includes the CCT, therefore this parameter will be affected by the addition of the CL thickness. A similar hypothesis could be proposed for the higher values obtained in the AL measurements, where the total value may be affected by the CCT plus CL thickness value. Parallel results have been observed in studies by Ferrer-Blasco et al. [10] or Lewis et al. [37] who found that CCT, ACD, and AL values were affected during CL wear when measuring with IOLMaster. Values obtained during CL wear were higher and correlated with the thickness of each CL. LT was not affected. In the present study, the LT results were again divided into two groups (Figure 3B), which is probably due to the effect of accommodation.

On the other hand, there was found no statistical difference in ACD values with the naked eye and during CL wear by the optical biometer; this device measures the ACD from the corneal endothelium [1], thus the CL thickness will not affect this value. Nevertheless, significant and clinically relevant differences were found in VL and AL (Wilcoxon paired-sample test, $p \leq 0.016$). This could be due to the refraction or the refractive index of the CL material, which could affect the results as the biometer is based on optical principles.

The correlation between biometric data and other body parameters was also observed. Similar to previous research, taller individuals showed a larger AL and ACD [38,39], and even a positive correlation was found

with LT and VL, except for hyperopes, where the relationship between body height and AL or VL was negative [39]. In the present study, it was included a novel correlation, feet length with ocular biometry data, trying to assess if the correlation value was of equal power as between body height and ocular data. It was found that the correlation value between foot size and eye dimensions was similar to that of body height and eye dimensions, although in both cases the relationships were weak, being of poor predictive quality; these parameters could be determined by similar genetic and environmental factors. The correlations within the ocular biometry data were similar for both biometers when comparing ACD with AL and LT with VL. Also, between VL and AL a positive relationship was found with both biometers; the optical biometer showed a stronger correlation than the ultrasound one. As expected, an eye with greater AL was related to greater ACD and VL. On the other hand, between LT and AL the optical device showed a negative weak correlation and the ultrasound device showed a positive weak correlation; those differences are probably due to effects from accommodation.

There are several limitations to the present study. Firstly, no cycloplegic was used, hence the parameters involving the LT may have been affected by accommodation. It would have been better to have instilled cycloplegic or to have recruited participants who had undergone cataract surgery. Furthermore, the use of a CL with a power of -3.00 D for all participants may have impacted their accommodation. Secondly, the sample size employed was small, and all participants were healthy; therefore, the results cannot be extrapolated to pathological populations. Additionally, focusing solely on an adult population presents a limitation, as it would be beneficial to know the outcomes in children. However, due to the invasiveness of the test, it was decided to conduct an initial study in adults and replicate the research in children if the results had shown that it was possible to perform the measurements while wearing CL. Future studies should consider repeating the procedures with other devices using different technologies and evaluating the use of different CL thicknesses.

5. CONCLUSIONS

In conclusion, biometry findings obtained with an ultrasound biometer (EchoScan US-800) and with an optical biometer (Lenstar LS900) are not interchangeable and are less reliable when CL are worn for both instruments in healthy participants. Therefore, it is inferred that accurate biometric measurements cannot be obtained while the patient is wearing CL, and it is necessary to remove them before the examination (i.e., child being assessed for myopia control, or an adult being assessed for cataract/refractive surgery). Nearly all the ocular biometry values are correlated with each other (intra-biometer results). Regarding correlations to body height and foot length measurements, the various biometry data showed only weak correlations (ACD, VL and AL when measured with the optical device, and weak AL when measured with the ultrasound device) or no relationship (LT when measured with both biometers, and ACD and VL when measured with the ultrasound biometer).

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FIGURE LEGENDS

Figure 1. Mean versus differences (Bland-Altman plot) between biometers data with the naked eye in n = 50 participants. The thick solid horizontal line indicates the mean difference while the closely dashed horizontal lines indicate the 95% LoAs (Mean difference ± 1.96xSD). The widely dashed horizontal lines indicate the 95% Confidence Interval of the LoAs. A) ACD by Lenstar vs. ACD by EchoScan, B) LT by Lenstar vs. LT by EchoScan, C) VL by Lenstar vs. VL by EchoScan, D) AL by Lenstar vs. AL by EchoScan. 95% LoAs = 95% Limits of Agreement. 95% CI = 95% Confidence Interval. SD = Standard Deviation. ACD = Anterior Chamber Depth. LT = Lens Thickness. VL = Vitreous Length. AL = Axial Length.

Figure 2. Mean versus differences (Bland-Altman plot) between biometers data during CL wear in n = 50 participants. The thick solid horizontal line indicates the mean difference while the closely dashed horizontal lines indicate the 95% LoAs (Mean difference ± 1.96xSD). The widely dashed horizontal lines indicate the 95% Confidence Interval of the LoAs. A) ACD during CL wear by Lenstar vs. ACD during CL wear by EchoScan, B) LT during CL wear by Lenstar vs. LT during CL wear by EchoScan, C) VL during CL wear by Lenstar vs. VL during CL wear by EchoScan, D) AL during CL wear by Lenstar vs. AL during CL wear by EchoScan. 95% LoAs = 95% Limits of Agreement. 95% CI = 95% Confidence Interval. SD = Standard Deviation. ACD = Anterior Chamber Depth. LT = Lens Thickness. VL = Vitreous Length. AL = Axial Length. CL = Contact Lenses.

Figure 3. Mean versus differences (Bland-Altman plot) between ocular biometry with the naked eye and during CL wear measured by Lenstar in n = 50 participants. The thick solid horizontal line indicates the mean difference while the closely dashed horizontal lines indicate the 95% LoAs (Mean difference ± 1.96xSD). The widely dashed horizontal lines indicate the 95% Confidence Interval of the LoAs. A) ACD by Lenstar vs. ACD during CL wear by Lenstar, B) LT by Lenstar vs. LT during CL wear by Lenstar, C) VL by Lenstar vs. VL during CL wear by Lenstar, D) AL by Lenstar vs. AL during CL wear by Lenstar. 95% LoAs = 95% Limits of Agreement. 95% CI = 95% Confidence Interval. SD = Standard Deviation. ACD = Anterior Chamber Depth. LT = Lens Thickness. VL = Vitreous Length. AL = Axial Length. CL = Contact Lenses.

Figure 4. Mean versus differences (Bland-Altman plot) between ocular biometry with the naked eye and during CL wear measured by EchoScan in n = 50 participants. The thick solid horizontal line indicates the mean difference while the closely dashed horizontal lines indicate the 95% LoAs (Mean difference ± 1.96xSD). The widely dashed horizontal lines indicate the 95% Confidence Interval of the LoAs. A) ACD by EchoScan vs. ACD during CL wear by EchoScan, B) LT by EchoScan vs. LT during CL wear by EchoScan, C) VL by EchoScan vs. VL during CL wear by EchoScan, D) AL by EchoScan vs. AL during CL wear by EchoScan. 95% LoAs = 95% Limits of Agreement. 95% CI = 95% Confidence Interval. SD = Standard Deviation. ACD = Anterior Chamber Depth. LT = Lens Thickness. VL = Vitreous Length. AL = Axial Length. CL = Contact Lenses.