ARTICLE

Effectiveness and agreement of 3 optical biometers in measuring axial length in the eyes of patients with mature cataracts

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Purpose: To evaluate the effectiveness and agreement of 3 optical biometers in measuring axial length (AL) and biometric parameters in the eyes of patients with mature cataracts.

Setting: Oftalmosalud Instituto de Ojos, Peru.

Design: Prospective, comparative study.

Methods: Eyes with mature cataracts were examined. Three consecutive scans were performed with each device: the IOLMaster 700, the Galilei G6, and the Pentacam AXL. The following parameters were recorded: AL, anterior flat keratometry (K1), steep K (K2), anterior astigmatism, mean K (Km), anterior chamber depth (ACD), central corneal thickness (CCT), and lens thickness. Agreement between devices was assessed using the coefficient of correlation of concordance (CCC).

Results: Forty-five eyes were included. After 3 attempts, the acquisition success rates in measuring mature cataracts were 84.4% (38/45), 42.2% (19/45), and 37.7% (17/45) for the IOLMaster, the Galilei, and the Pentacam, respectively. Significant differences were found between the Pentacam and the IOLMaster in terms of AL, K2, and CCT. Significant differences were found in terms of K1, K2, Km, ACD, and CCT between the Pentacam and the Galilei; and significant differences were found in AL, K1, Km, and ACD between the Galilei and the IOLMaster ($P < .05$ all). Good correlations were found between devices (>0.90) in terms of keratometries and AL.

Conclusions: The IOLMaster 700 had the highest AL acquisition success rate when compared with the Pentacam AXL and Galilei G6. Good agreement between devices was found in terms of AL and K readings.

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Cataracts are a major cause of blindness worldwide, affecting almost 18 million people. By 2050, 16.5% of the total population is expected to have this disease.[1,2] In developing countries, the incidence of blindness is higher because of brunescent and mature cataracts.[3]

Axial length (AL) measurement is a very important step of intraocular lens (IOL) calculation, and new devices allow the measurement of eye geometry that could not be measured previously, such as lens thickness, anterior and posterior surface depths of crystalline lenses, the crystalline lens equatorial plane, and the intracrystalline interphase point.[3–7] The acquisition rate has also improved.[8–13] One reason is that new devices use higher wavelengths, which allow for higher tissue penetration.[14] However, despite multiple improvements in biometers, measuring the AL in mature and brunescent cataracts is still a challenge because the signal from the retina becomes attenuated or blocked because of the light scattering inside the lens.[8,14] Usually in these cases, the device fails to identify the light that should be reflected in the retina by the obstruction of the cataract, resulting in an inexact measurement and a high percentage of variations.[9,10]

The purpose of this study was to evaluate the effectiveness and agreement of 3 optical biometers in measuring the AL in the eyes of patients with mature cataracts.

METHODS

This was a prospective cohort longitudinal study that included 45 eyes of 45 patients with mature cataracts who visited the Oftalmosalud Institute, Lima, Peru, between April 2018 and February 2019 for cataract surgery. The study complied with the tenets of the Declaration of Helsinki, and the Ethics Committee of

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Jose Chauca provided statistical analysis. Carmen Maldonado provided support for data collection.

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Oftalmosalud approved the study; written informed consent was obtained from all patients.

Inclusion criteria were an age-related cataract grade III or more, using Lens Opacities Classification System III (LOCS III) for nuclear color (NC) and nuclear opalescence (NO), posterior subcapsular cataract, and/or cortical cataract.[15] Exclusion criteria were age lesser than 45 years; previous ocular surgeries or laser treatments; macular degeneration without central fixation or sensorial disorders; retinal alterations; physical inability of the patient to be positioned at the device or insufficient mental ability to follow instructions; irregular corneal surface or corneal scarring; contact lens wearers; and history of diabetes, ocular trauma, and smoking.

All participants underwent the following same-day measurements in a random order: IOLMaster 700 (Carl Zeiss Meditec AG), Galilei G6 (Ziemer Ophthalmic Systems AG), and Scheimpflug imaging analysis (Pentacam AXL). For analysis of the density of the cataract, the pupil was dilated using tropicamide 1% (Midilar-T) 1 drop, after 5 minutes; a second drop was placed and then the patient waited 20 minutes for the medication to take effect. Lens density was assessed subjectively by using the LOCS III and objectively by using Scheimpflug imaging analysis with the built-in Pentacam Nucleus Staging (PNS) software.

Patients were seated in a dim room with the chin on the chinrest and the forehead against the forehead bar and instructed to focus on the fixation point. For each eye, 3 consecutive scans were performed by the same operator. Patients were instructed to blink completely just before each measurement. To ensure the independence of successive measurements, patients were asked to move their head away from the chinrest, and the scan unit was thoroughly retracted after each scan.

Table 1. Biometric parameters in the studied population measured with the 3 devices.

Parameter	Pentacam	Galilei	IOLMaster	*P* Value*
AL (mm)				
Mean ± SD	24.64 ± 1.16	24.47 ± 1.31	24.20 ± 1.28	
Median	24.32	24.40	24.15	<.001
IQR	24.00 to 24.81	23.74 to 25.08	23.31 to 24.77	
Range	23.02, 27.03	22.52, 27.08	22.58, 28.21	
K1 (D)				
Mean ± SD	42.66 ± 2.40	42.99 ± 2.41	42.74 ± 2.14	
Median	43.10	43.49	43.10	<.001
IQR	41.30 to 44.30	41.87 to 44.42	41.67 to 44.02	
Range	36, 46.90	35.74, 46.91	36.06, 46.44	
K2 (D)				
Mean ± SD	44.18 ± 2.40	44.25 ± 2.42	44.12 ± 2.35	
Median	44.40	44.42	44.55	.002
IQR	43.00 to 45.10	42.96 to 45.16	42.92 to 45.11	
Range	37, 50.70	37.03, 50.22	37.05, 50.92	
Km (D)				
Mean ± SD	43.38 ± 2.29	43.64 ± 2.35	43.41 ± 2.16	
Median	43.70	43.95	43.74	<.001
IQR	42.20 to 44.50	42.48 to 44.80	42.38 to 44.65	
Range	36.5, 48.60	36.37, 48.57	36.61, 47.99	
ACD (mm)				
Mean ± SD	3.20 ± 0.45	3.20 ± 0.41	3.32 ± 0.46	
Median	3.18	3.21	3.20	.011
IQR	2.90 to 3.44	2.92 to 3.46	2.89 to 3.42	
Range	2.05, 4.14	2.36, 4.05	2.47, 4.45	
CCT (mm)				
Mean ± SD	541.09 ± 33.21	535.30 ± 34.76	533.14 ± 35.56	
Median	543.00	537.00	536.5	<.001
IQR	524.00 to 563.00	524.00 to 555.50	518.50 to 557.25	
Range	458, 616	441, 617	445, 617	
Astig (D)				
Mean ± SD	1.48 ± 1.48	1.39 ± 1.16	1.40 to 1.23	
Median	0.90	1.07	1.05	.767
IQR	0.50 to 1.80	0.58 to 1.71	0.78 to 1.30	
Range	0.1, 6.10	0.2, 5.38	0.18, 5.53	
LT (mm)				
Mean ± SD	—	3.98 ± 0.82	4.27 ± 0.90	
Median	—	4.17	4.42	—
IQR	—	3.84 to 4.50	4.20 to 4.69	
Range	—	2.04, 5.00	1.00, 5.41	

ACD = anterior chamber depth; AL = axial length; Astig = astigmatism; CCT = central corneal thickness; D = diopters; IQR = interquartile range; K1 = flattest keratometry; K2 = steepest keratometry; Km = mean keratometry; LT = lens thickness

*Simultaneous comparison of measurements with the 3 devices using the nonparametric Quade test.

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Table 2. Absolute differences in measurements between devices.

Parameter	Mean Absolute Difference	IQR	Range	*P* Value*
Pentacam vs Galilei				
AL (mm)	0.04	0.02 to 0.06	0.00, 0.66	.104
K1 (D)	0.37	0.21 to 0.59	0.03, 2.21	<.001
K2 (D)	0.26	0.10 to 0.53	0.00, 1.71	<.001
Km (D)	0.26	0.13 to 0.48	0.01, 1.24	<.001
ACD (mm)	0.07	0.03 to 0.17	0.00, 0.61	.042
CCT (μm)	9.00	4.50 to 15.00	0.00, 47.00	<.001
Pentacam vs IOLMaster				
AL (mm)	0.05	0.02 to 0.13	0.00, 0.81	.012
K1 (D)	0.24	0.11 to 0.57	0.02, 2.12	.156
K2 (D)	0.33	0.17 to 0.52	0.02, 1.34	.034
Km (D)	0.22	0.11 to 0.46	0.02, 1.40	.270
ACD (mm)	0.03	0.02 to 0.12	0.00, 0.90	.356
CCT (μm)	12	5.75 to 16.00	0.00, 47.00	<.001
Galilei vs IOLMaster				
AL (mm)	0.07	0.05 to 0.11	0.00, 0.81	<.001
K1 (D)	0.25	0.14 to 0.47	0.00, 2.68	.001
K2 (D)	0.33	0.16 to 0.53	0.02, 1.83	.150
Km (D)	0.28	0.12 to 0.39	0.01, 2.14	<.001
ACD (mm)	0.05	0.03 to 0.12	0.00, 0.78	.003
CCT (μm)	7.50	4.00 to 12.00	0.00, 34.00	.540

ACD = anterior chamber depth; AL = axial length; CCT = central corneal thickness; D = diopters; IQR = interquartile range; K1 = flattest keratometry; K2 = steepest keratometry; Km = mean keratometry
*Pairwise post hoc test for the Quade test.

Lens Density

Lens density was assessed subjectively by using the LOCS III and objectively by using Scheimpflug imaging analysis with the built-in PNS software. For the LOCS III, 2 masked reviewers (R.Z.-I. and M.A.H.) independently assessed slitlamp and retroillumination images of the cataract; any disagreements were resolved by consensus or arbitration by a third party (L.I.). The scale ranged from 0.1 (clear or colorless) to 5.9 (very opaque in cases of cortical and subcapsular posterior) or 6.9 (very opaque and/or brunescent in cases of combined NO and NC). The following cataract parameter scores were obtained from the LOCS III: NO, NC, cortical cataract, and posterior subcapsular cataract. Only patients with cataract grade III or greater were included.

Objective analysis of cataract density was assessed with the PNS software. It has a grading system that is based on the pixel intensity measurement within the nucleus, which provides data on the mean density value, the standard deviation, and the maximum nuclear density, and is measured in a 3-dimensional template volume and optical density array that generate a nuclear cataract grade in 5 stages (PNS cataract grading score). Three parameters were obtained from each PNS recording: PNS mean (mean nuclear density), PNS maximum (maximum nuclear density), and PNS cataract grading score (from 0 to 4, with 4 indicating higher nuclear density).

IOL Power Calculation

All 3 biometric measurements were used for IOL power calculation with emmetropia (nearest negative number to zero) as a target for the AcrySof IQ IOL (Alcon Laboratories, Inc.). The SRK/T, Haigis, and Hoffer Q formulas were used for calculations.[16–18]

Statistical Analysis

The statistical analysis was performed using R version 3.6.2. To evaluate whether the data of each variable came from a normally distributed population, a graphical analysis (Q-Q plot) and the Shapiro-Wilks test were used. For the descriptive analysis, the central tendency and statistical dispersion of each parameter was reported as the mean and SD for normal data and as the median

Table 3. CCC on AL measurements between devices.

Parameter	Pentacam vs Galilei CCC (95% CI)	Pentacam vs IOLMaster CCC (95% CI)	Galilei vs IOLMaster CCC (95% CI)
AL (mm)	0.989 (0.887, 0.999)	0.981 (0.877, 0.997)	0.984 (0.844, 0.999)
K1 (D)	0.926 (0.878, 0.955)	0.925 (0.865, 0.959)	0.925 (0.868, 0.957)
K2 (D)	0.954 (0.917, 0.974)	0.966 (0.924, 0.985)	0.960 (0.925, 0.979)
Km (D)	0.948 (0.908, 0.972)	0.960 (0.932, 0.977)	0.957 (0.923, 0.976)
ACD (mm)	0.891 (0.806, 0.940)	0.881 (0.780, 0.938)	0.898 (0.811, 0.946)
CCT (μm)	0.779 (0.549, 0.900)	0.762 (0.559, 0.878)	0.900 (0.812, 0.948)
Astig	0.828 (0.740, 0.888)	0.851 (0.780, 0.900)	0.804 (0.693, 0.877)

ACD = anterior chamber depth; AL = axial length; Astig = astigmatism; CCT = central corneal thickness; CCC = coefficient of correlation of concordance of Lin; D = diopters; K1 = flattest keratometry; K2 = steepest keratometry; Km = mean keratometry

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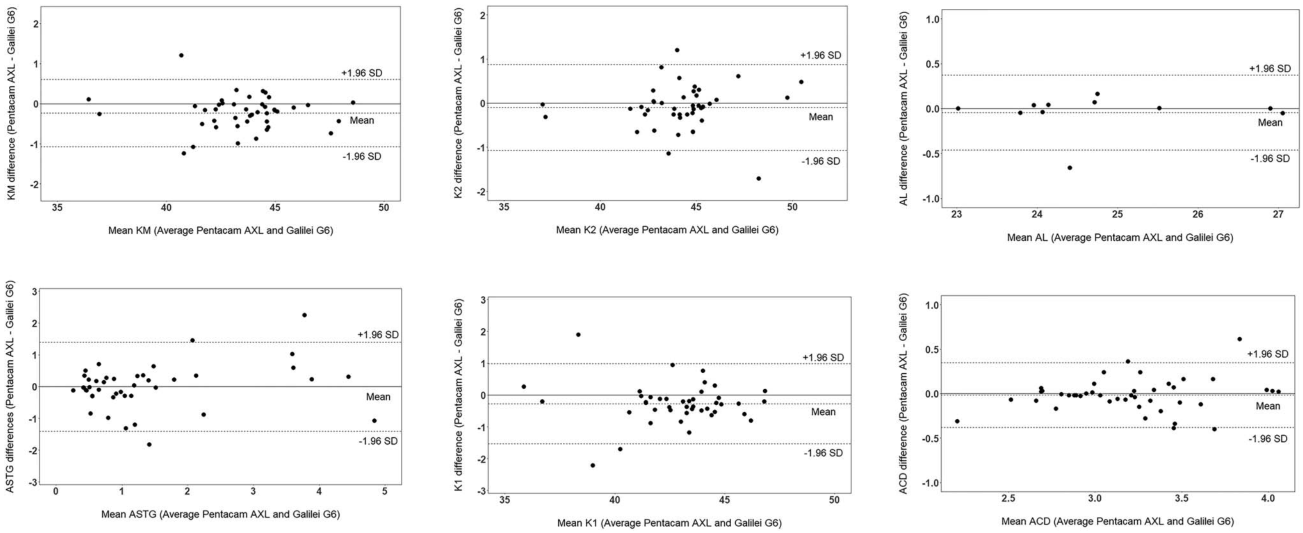

Figure 1. Bland-Altman plots of agreement between the Pentacam AXL and the Galilei G6 (ACD = anterior chamber depth; AL = axial length; ASTG = astigmatism; K1 = flattest keratometry; K2 = steepest keratometry; Km = mean keratometry).

and interquartile difference for nonparametric data. For simultaneous comparison of the measurements with the 3 devices, the nonparametric Quade test was used and the pairwise post hoc test for the Quade test. To evaluate the agreement between devices, Lin's concordance correlation coefficient (CCC) was used, with its corresponding 95% CI. All hypothesis tests were conducted considering a type I error equal to 0.05. A P value less than 0.05 was considered statistically significant.

The sample size was estimated using the G*Power software (http://www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3/). A sample size of 42 was established as the minimum to detect at least a small effect size (0.2) with a power of 0.8 and a type I error equal to 0.05.

RESULTS

Forty-five eyes of 45 patients (22 men and 23 women) with age-related cataracts were analyzed. The mean and SD of the nuclear density taken by the Scheimpflug device (PNS software) was 3.21 ± 1.33 pixels, the PNS mean was 13.60 ± 5.03, the PNS maximum was 43.61 ± 26.38, and the PNS score was 6.76 ± 5.75. The mean LOCS in the study population was 4.96 ± 1.03 for NO, 4.76 ± 1.18 for NC, 3.91 ± 1.81 for cortical cataract, and 3.22 ± 2.24 for posterior subcapsular cataract.

The mean and SD for each parameter in each device are shown in Table 1. There was a statistically significant difference between devices on AL, K1, K2, Km, anterior chamber depth (ACD), and central corneal thickness (CCT). Specifically, after pairwise comparisons as Table 2 shows, and using the post hoc Quade test with post hoc Quade test with t-students distribution approximation, significant differences were found between the Pentacam AXL and Galilei G6 in all variables except for AL; between the Pentacam and the IOLMaster 700 in

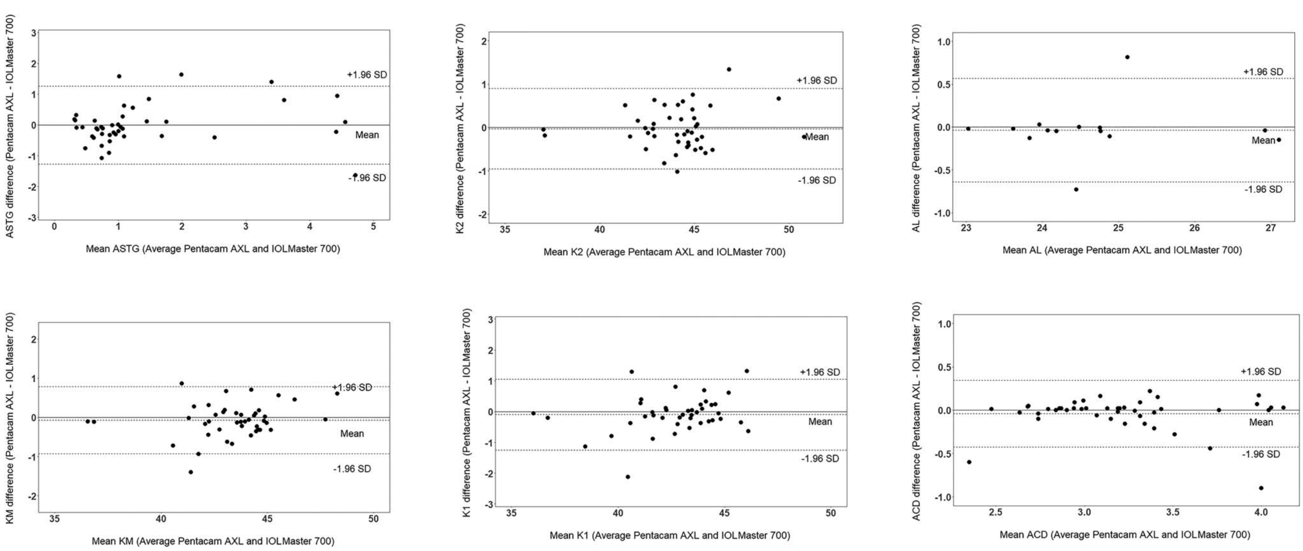

Figure 2. Bland-Altman plots of agreement between the Pentacam AXL and the IOLMaster 700 (ACD = anterior chamber depth; AL = axial length; ASTG = astigmatism; K1 = flattest keratometry; K2 = steepest keratometry; Km = mean keratometry).

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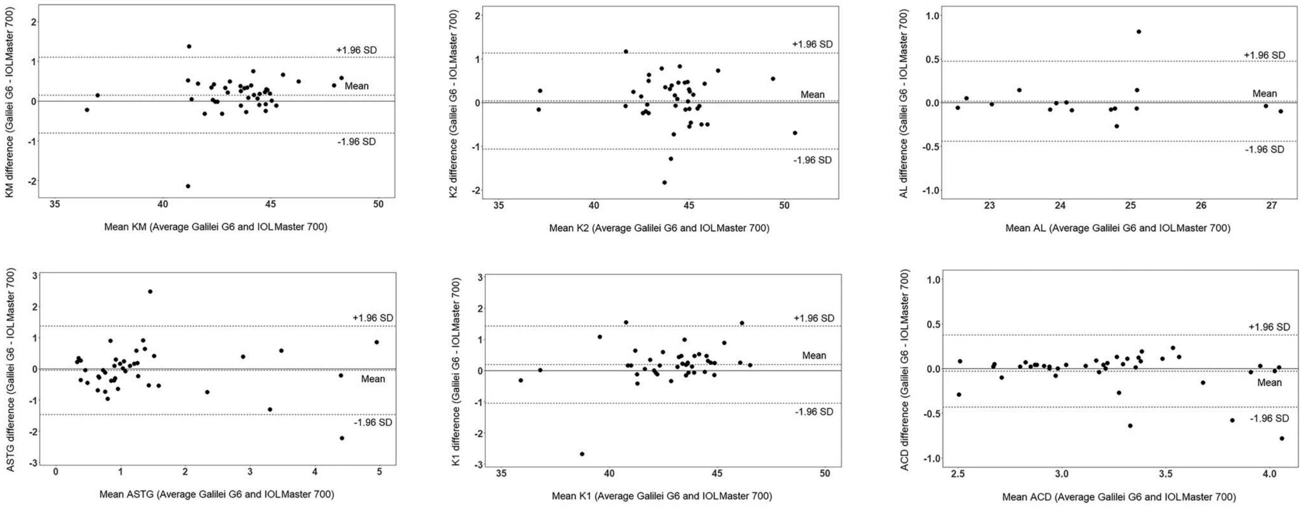

Figure 3. Bland-Altman plots of agreement between the Galilei G6 and the IOLMaster 700 (ACD = anterior chamber depth; AL = axial length; ASTG = astigmatism; K1 = flattest keratometry; K2 = steepest keratometry; Km = mean keratometry).

Table 4. Rate on axial length measurement acquisition success after 3 attempts.

	Pentacam AXL	Galilei G6	IOLMaster 700
First measurement (%)	31.1	34.7	80.0
Second measurement (%)	37.7	37.7	84.4
Third measurement (%)	37.7	42.2	84.4

AL, K2, and CCT; and between the Galilei G6 and the IOLMaster 700 in all variables except for K2 and CCT.

Agreement among devices, using the CCC, is shown in Table 3; all parameters reached a high CCC (>0.90) among all devices except for anterior astigmatism, ACD, and CCT. Also, Bland-Altman plots are provided in Figures 1 to 3 to display the differences between devices. The AL among the 3 devices had a high CCC, showing excellent agreement between devices (>0.90); however, the effectiveness in measuring the AL of mature cataracts differed among the devices. Table 4 shows the AL acquisition success rate in the first, second, and third attempts. After 3 attempts, the Pentacam AXL, the Galilei G6, and the IOLMaster 700 could measure AL in 17 (37.7%), 19 (42.2%), and 38 (84.4%) of the 45 eyes, respectively. According to the subjective analysis of cataract density, using LOCS III mean cataract density in eyes, in which the AL could not be measured after 3 attempts, is presented in Table 5. Finally, the effect of the difference between the devices on IOL power calculation is presented in Table 6; there were no statistically significant differences between the IOL power calculated between devices.

DISCUSSION

After comparing 3 optical biometers in measuring the AL in the eyes of patients with mature cataracts, the results show the superiority of the IOLMaster over the 2 Scheimpflug devices in measured mature cataracts. The success rate in the first attempt was 80.0%, 37.7%, and 37.7% for the IOLMaster, the Galilei, and the Pentacam, respectively. After a second attempt, the success rate increased to 84.4%, 37.7%, and 37.7% for the IOLMaster, the Galilei, and the Pentacam, respectively, and finally, after 3 attempts, the success rate increased to 84.4%, 42.2%, and 37.7% for the IOLMaster, the Galilei, and the Pentacam, respectively.

The IOLMaster 700 uses swept-source optical coherence tomography (SS-OCT), which uses a wavelength of 1055 nm. It has been shown to be superior to the IOLMaster 500 in measuring the AL of mature cataracts, because of the higher wavelength, which allows a better signal-to-noise ratio and improves tissue penetration and

Table 5. Mean cataract density that could not be measured with each device after 3 attempts.

LOCS III	NC (SD)	NO (SD)	C (SD)	P (SD)
Pentacam AXL	5.23 ± 1.00	5.14 ± 1.06	4.31 ± 1.83	3.71 ± 2.26
Galilei G6	5.40 ± 0.86	5.30 ± 0.95	4.57 ± 1.70	4.07 ± 2.20
IOLMaster 700	5.45 ± 1.04	5.27 ± 1.19	4.64 ± 1.96	4.27 ± 2.24

C = cortical; LOCS = Lens Opacities Classification System; NC = nuclear color; NO = nuclear opalescence; P = subcapsular posterior

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Table 6. IOL power calculated for emmetropia using each device.

	Pentacam			Galilei			IOLMaster			
Formula	Mean ± SD	Median	IQR	Mean ± SD	Median	IQR	Mean ± SD	Median	IQR	*P* Value*
SRK/T	18.73 ± 3.60	19.00	4.0	19.06 ± 3.69	20.3	4.3	19.75 ± 3.06	20.0	4.0	0.780
Haigis	19.00 ± 3.81	20.0	4.5	18.94 ± 3.67	20.5	4.0	19.80 ± 3.28	20.0	4.8	0.191
Hoffer Q	18.85 ± 3.91	20.0	4.0	18.97 ± 3.99	20.3	4.8	19.54 ± 3.47	20.0	4.4	0.485

IOL = intraocular lens; IQR = interquartile range
*Simultaneous comparison of the measurements with the 3 devices using the nonparametric Quade test.

image quality.[8–11] Higher success rates in eyes with posterior subcapsular and dense nuclear cataracts have been described.[10,11,19]

The Pentacam AXL is a single rotating Scheimpflug camera device that combines optical biometry based on partial coherence interferometry (similar to the IOLMaster 500); its light source is a blue LED with a wavelength of 475 nm.[12] The Galilei G6 is an optical biometer that combines a dual rotating Scheimpflug camera, Placido disk topography, and an OCT-based A scan. It performs axial biometry by using light of 880 nm wavelength and is based on low-coherence interferometry.[13]

Shammas et al. reported that the SS-OCT (IOLMaster 700) device correctly measured the AL in 96% of cases, compared with 77% for the partial coherence interferometry device (IOLMaster 500).[9] Jung et al. reported a failure acquisition rate of 0.9% for the IOLMaster 700 and 6.5% for the Galilei G6 and reported that all the failures were when measuring dense cataracts.[13] Kurian et al. reported a success rate of 96% among patients even with dense cataracts using SS-OCT.[20] Shin et al. reported a success rate of 99% (99/100) using the Galilei G6 in measuring the AL.[19]

The success rate of our results is lower than that in the previously reported literature; these differences could be related to the sample used in each study.[3,8,12,20] Our sample included only mature cataracts, and most studies do not specify their inclusion criteria, results, or which grade of cataracts was included.

Significant differences were found between the Pentacam AXL and the IOLMaster 700 in terms of AL, K2, or CCT, in agreement with the previous literature.[21] In addition, Shajari et al. reported a significant difference between the Pentacam AXL and the IOLMaster 700 on AL measurements.[11] These differences can be explained by the mechanism used in each device: The Pentacam AXL generates Scheimpflug images in 3 dimensions, so the entire cornea is analyzed in multiple ways; it considers the anterior and posterior corneal curvature, whereas the IOLMaster 700 uses telecentric keratometry for the assessment of keratometry.[11,13,22] In our study, significant differences were found in terms of K1, K2, Km, ACD, and CCT between the Pentacam and Galilei. Significant differences were found in AL, K1, Km, and ACD between the Galilei and the IOLMaster. In the Galilei G6, the anterior simulated keratometry values were calculated from the 0.5 to 2.0 mm annular zone and are represented in diopters, using a refractive index of 1.3375.[21] In conclusion, SS-OCT shows significant differences in AL measurements and higher success rates than optical biometers combined with the Scheimpflug camera.

WHAT WAS KNOWN

- There is good repeatability and reproducibility in the IOLMaster 700, the Pentacam AXL, and the Galilei G6.
- The IOLMaster 700 has the highest axial length (AL) acquisition success rate when compared with the IOLMaster 500.
- The IOLMaster 700, the Pentacam AXL, and the Galilei G6 have a high AL acquisition success rate in different grades of cataract but have limited information in terms of mature cataracts.

WHAT THIS PAPER ADDS

- The IOLMaster 700 had the highest AL acquisition success rate when compared with the Pentacam AXL and the Galilei G6 when measuring mature cataracts.
- When measuring mature cataracts, the IOLMaster 700 had a lower success rate of AL acquisition than that previously reported in the literature.

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