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ORIGINAL PAPER

Ocular biometric changes with different accommodative stimuli using swept-source optical coherence tomography

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Abstract

Purpose To evaluate ocular biometric changes with different accommodative stimuli using a new swept-source optical biometer.

Methods Only the right eye was analyzed. Each subject was measured six times with the IOLMaster 700 swept-source optical biometer (Carl Zeiss Meditec, Jena, Germany) with the subject looking at the stimulus shown by the instrument and with the subject looking at a target placed outside the instrument at 0D of vergence. Axial length (AL), anterior chamber depth (ACD), central corneal thickness (CCT), lens thickness (LT), white-to-white (WTW), and keratometry readings (K1 and K2) were evaluated in both cases. To assess if the changes found may affect the intraocular (IOL) power calculation for surgical applications, we have applied some formulae, using the software provided by the optical biometer manufacturer, to the ocular parameters found in both situations for three different types of IOLs.

Results No statistically significant differences were found for AL, CCT, WTW, K1 and K2 between the subject looking at the stimulus of the biometer and looking at the outside target at 0D of vergence ($p > 0.05$). However, the measurement of ACD revealed a statistically significant reduction of 20 microns ($p = 0.03$) and, on the contrary, LT increased significantly 30 microns ($p = 0.02$). ACD and LT changes were highly correlated ($R^2 = 0.91$). As for the IOL power calculation, in all cases, the mean change was lower than 0.25 D both for IOL power selection and residual refraction.

Conclusions Although ACD and LT change significantly with different accommodative stimuli measured by swept-source optical biometry, these changes are not clinically relevant.

Keywords Ocular biometry · Accommodation · Cataract · Optical biometer

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Introduction

Optical biometers have replaced ultrasound biometry due to the good and accurate outcomes reported [1]. Optical biometry employs infrared laser instead of ultrasound for acquisition of ocular distances. A recent commercial ocular optical biometric based on swept-source optical coherence tomography (SS-OCT) technology has been launched. This equipment generates

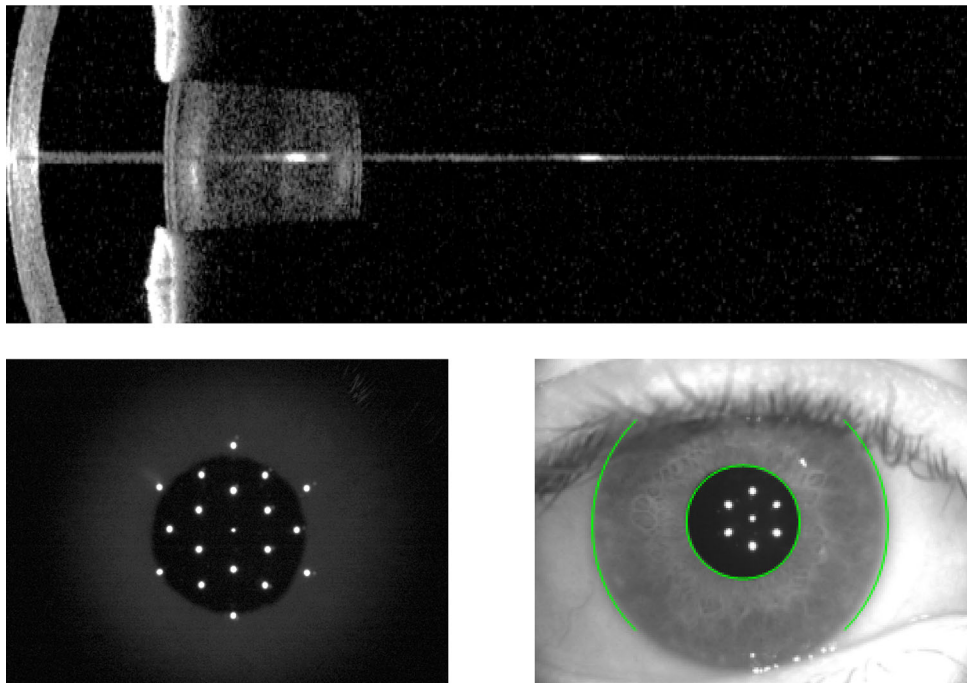

Fig. 1 Typical SS-OCT biometry optical B-scan for a subject participating in the study (top); keratometry spots on the cornea (bottom left) and anterior eye photograph for white-to-white measurements (bottom right)

optical B-scans to determine the biometric data of the eye providing cross-sectional visualization of the eye (in vivo imaging). This non-contact optical technology has been proved accurate and repeatable in cataract patients [2–4]. The equipment measures ocular parameters while the patient is looking at a point source inside the equipment. Some ophthalmic instruments in the market use a target to facilitate fixation and also to avoid accommodation when the patient is looking at the fixation target. In those patients with active accommodation, the type of target used to facilitate fixation may affect the accommodation state of the patient, affecting then the obtained measurements. This may be important, in the case of significant changes, for myopia progression control, intraocular lens (IOL) size calculation, or IOL power calculation with formulae that use different ocular parameters (specially fourth generation formulae).

Then, the aim of the present study was to assess the differences of ocular biometric parameters measured with the IOLMaster 700 using SS-OCT when the patient is looking at different visual stimuli. In our case, we have selected the own stimulus of the optical biometer (light point source) and compared the results obtained with it with those obtained using a standard visual acuity optotype located at infinity (outside the instrument and at 0D of vergence). A possible difference between the outcomes reported here may help clinicians when using these values for IOL power calculation, control of myopia progression, or any clinical evaluation/study that requires accurate measurement of ocular parameters. The present study will show evidences about if these changes should be taken into account during clinical practice.

Materials and methods

Subjects

Ten subjects with healthy and phakic eyes were included in this study. Only one eye per participant was included in order not to artificially reduce the confidence interval around the limits of agreement [5], and the patients had all their biometric measurements taken during the same session. Inclusion criteria were age between 25 and 40 years and non-pathological eye. All the subjects had a complete eye examination

1–2 days before taken the biometric measurements, which included refraction, screening for ocular and systemic diseases, slit-lamp biomicroscopy, and examination of the fundus. All the subjects were free of any ocular pathologic conditions, showed a photopic pupil diameter > 3.0 mm and had best-corrected monocular decimal visual acuity of 20/20 (0.0 logMAR). Exclusion criteria included tear film abnormality, amblyopia and/or strabismus, history of ocular surgery, or inflammation. The study followed the Declaration of Helsinki and was approved by the Ethics Committee of the University of Valencia. Informed consent was obtained from all the subjects after the nature and possible consequence of the study had been explained.

Optical biometer

The IOLMaster 700 is an optical biometry device for measuring different distances in the eye along the visual axis. It obtains measurements of the axial length (AL), anterior chamber depth (ACD), central corneal thickness (CCT), lens thickness (LT), white-to-white (WTW), and keratometry (K1 and K2) readings. Figure 1 shows an example of the ocular measurements obtained in one subject. The device acquires multiple measurements for each of the various eye parameters in measurement capture process and presents an average value per triggered measurement. The axial length measurement is based on SS-OCT enabling a 44 mm scan depth with 22 microns resolution in tissue. The speed of the length measurement system allows acquisition of full-eye length tomograms at 2000 A-scans/s.

Experimental procedure

One skilled operator was involved in the experimental procedure. Only the right eye of the subjects was used for the analysis. Measurements were taken for two conditions: (1) when the subject was looking at the punctual source of light located inside the instrument and (2) when the subject was looking at an optotype target located at infinity. Figure 2 shows the experimental setup for ocular measurements when the subject was looking at infinity. Measurements were taken on the right eye of the subject while the left eye was looking at the target located outside the instrument at 0D of vergence, through a mirror attached to the optical biometer. Six consecutive measurements were taken for each subject and each of the two conditions. Each measurement was taken 4 s after the subject's last blink to allow the tear film to spread over the cornea [6], and blinking was not permitted during the image acquisition. No other examinations or measurements of the eye involving contact were conducted on the same day prior to the start of measurements with the optical biometer.

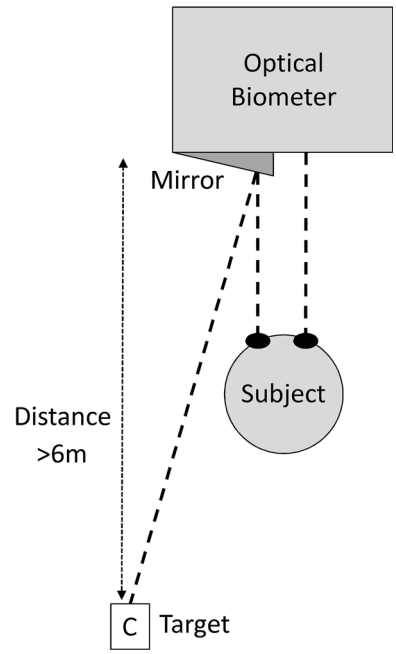

Fig. 2 Experimental setup. Ocular biometric measurements were taken on the right eye of the subject. When taking the measurements for the fixation target located at > 6 m of distance, left eye looked through a mirror attached to the optical biometer

Statistical analysis

The measurement results were evaluated using SPSS software (version 20, IBM). Baseline demographic observations were summarized by descriptive statistics. A *t* test was performed to analyze significant differences between measurements in both conditions. Statistical significance limit was set to $p < 0.05$.

Table 1 Mean values and ranges of the parameters evaluated for both conditions, difference between conditions, and *p* values

Parameter	Punctual source of light target	Optotype target at 0D	Difference	*p* value
AL (mm)				
Mean	23.86	23.87	− 0.01	0.14
SD	0.99	0.98	0.02	
Min	22.60	22.67	− 0.07	
Max	25.24	25.24	0.01	
ACD (mm)				
Mean	3.49	3.51	− 0.02	0.03*
SD	0.28	0.27	0.03	
Min	2.97	3.00	− 0.07	
Max	3.93	3.93	0.01	
CCT (μm)				
Mean	587.20	588.00	− 0.80	0.07
SD	72.74	72.19	1.55	
Min	478.00	481.00	− 3.00	
Max	729.00	730.00	2.00	
LT (mm)				
Mean	3.93	3.90	0.03	0.02*
SD	0.33	0.33	0.04	
Min	3.40	3.38	− 0.02	
Max	4.35	4.29	0.09	
WTW (mm)				
Mean	12.14	12.20	− 0.06	0.28
SD	0.45	0.56	0.31	
Min	11.40	11.30	− 0.90	
Max	12.90	13.00	0.20	
K1 (mm)				
Mean	7.96	7.96	0.00	0.17
SD	0.35	0.34	0.01	
Min	7.61	7.62	− 0.03	
Max	8.50	8.50	0.03	
K2 (mm)				
Mean	7.83	7.82	0.00	0.34
SD	0.34	0.35	0.02	
Min	7.49	7.45	− 0.03	
Max	8.45	8.50	0.03	

* represent statistically significant values

AL axial length, *ACD* anterior chamber depth, *CCT* central corneal thickness, *LT* lens thickness, *WTW* white-to-white, *K1–K2* keratometry

Results

A total of ten eyes of ten subjects (seven male and three female) were included, whose average age was 32.5±5.3 years (range 25–40 years). All subjects completed both experiments, and all ocular measurements were taken correctly.

Mean and standard deviation values and ranges (minimum and maximum) for all parameters measured in the study (AL, ACD, CCT, LT, WTW, K1 and K2) are summarized in Table 1. This table also shows the mean, standard deviation and ranges for the differences between both situations and the *p* value obtained.

No statistically significant differences were found for AL, CCT, WTW, K1 and K2 ($p > 0.05$). However, the difference in ACD and LT was statistically significant with *p* values of 0.03 and 0.02,

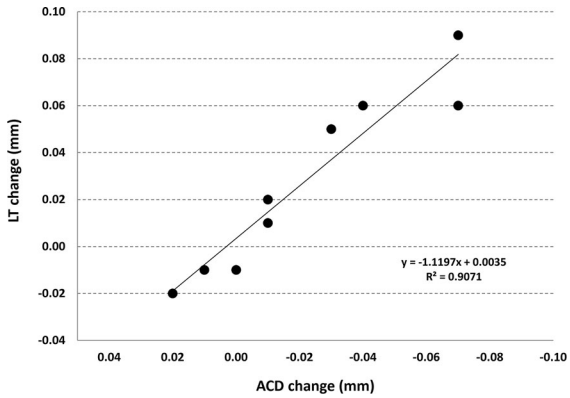

Fig. 3 Lens thickness (LT) change versus anterior chamber depth (ACD) change for the different subjects' evaluation. A simple linear regression model was used to adjust the values found ($y = -1.119x + 0.003$; $R^2 = 0.91$)

respectively. Mean ACD was reduced by 20 microns and mean LT increased by 30 microns when the subject was looking at the point source of the instrument compared to when the subject was looking at the outside optotype target located at 0D of vergence. The differences obtained for all the tested parameters were not dependent on the gender or the age of the subjects ($p > 0.05$; age groups: 25–30 and 31–40 years).

To correlate the significant changes obtained in both parameters, Fig. 3 shows the LT change versus the ACD change for the subjects participating in the study. A simple linear regression model was used to adjust the values found ($y = -1.119x + 0.003$; $R^2 = 0.91$).

Discussion

Our results revealed that there are no statistically significant differences for AL, CCT, WTW, K1 and K2 ($p > 0.05$) between both stimuli (experimental conditions). In the case of the cornea, this agrees with previous research that has found that different parameters in various zones of the cornea as well as corneal aberrations were stable during accommodation [7]. The crystalline lens is established to be the ocular structure that suffers the principal anatomical changes during accommodation; the cornea is known to be a very malleable entity whose changes while accommodating still remain unsure.

However, the difference in ACD and LT comparing both conditions was statistically significant ($p < 0.05$). Specifically, ACD decreased and LT increased when the subject was looking at the light point source of the optical biometer. The change in both parameters was highly correlated (see Fig. 3, $R^2 = 0.91$). Our findings agree with the consideration that when accommodation is active there is a decrease of ACD and an increase of LT [8–10]. The classic theory of Helmholtz and Fincham indicates that, during accommodation, the anterior surface of the lens became steeper and moved forward (increasing its thickness), causing a decrease of ACD. If there is a change in both parameters during our experiment, this indicates that accommodation is active when the subject is looking at the point source of the biometer and then produces the movement of the lens. Therefore, when the subject is looking at the light point source of the biometer, the accommodation may be active and the measurements of the ocular parameters taken may be affected. However, the most important thing is to evaluate if these changes have a clinically significant impact or not. The changes we have found in our study are quite small, 20 and 30 microns in absolute value for ACD and LT, respectively. In addition, there was no difference when comparing both conditions for the distance between the posterior corneal surface and the posterior lens surface ($p > 0.05$; mean value for the punctual source of light target 6.83 mm; mean value for the optotype target 6.82 mm). These changes seem not to have a clinically significant impact on current ocular parameters measurement for refractive surgery (i.e., phakic IOL implantation that requires certain degree of "safe" space for the surgery).

However, in the case of IOL power calculation, some additional calculations are necessary to be

Table 2 Variables required for IOL power calculation formulae

	Haigis	Holladay 2	SRK/T	HofferQ
Keratometry	X	X	X	X
AL	X	X	X	X
ACD	X	X		
LT		X		
WTW		X		

AL axial length, *ACD* anterior chamber depth, *LT* lens thickness, *WTW* white-to-white distance

Table 3 Mean intraocular lens power and refraction for different formulae and intraocular lenses

	Punctual source of light target				Optotype target at 0D			
	Haigis	Holladay 2	SRK/T	HofferQ	Haigis	Holladay 2	SRK/T	HofferQ
ACRI.SMART 36A								
IOL power (D)								
Mean ± SD	20.05 ± 1.12	19.70 ± 1.30	19.60 ± 1.22	19.75 ± 1.09	20.10 ± 1.07	19.70 ± 1.16	19.65 ± 1.20	19.75 ± 1.09
Range	[18.5, 22.0]	[18.0, 22.0]	[18.0, 21.5]	[18.5, 21.5]	[18.5, 22.0]	[18.0, 21.5]	[18.0, 21.5]	[18.5, 21.5]
Refraction (D)								
Mean ± SD	− 0.03 ± 0.11	− 0.01 ± 0.11	0.04 ± 0.09	0.04 ± 0.12	− 0.06 ± 0.09	0.00 ± 0.11	0.01 ± 0.10	0.04 ± 0.10
Range	[− 0.16, 0.18]	[− 0.17, 0.17]	[− 0.08, 0.15]	[− 0.15, 0.17]	[− 0.17, 0.09]	[− 0.16, 0.14]	[− 0.18, 0.11]	[− 0.10, 0.15]
ACRI.LISA 376D								
IOL power (D)								
Mean ± SD	20.30 ± 1.18	19.90 ± 1.35	19.90 ± 1.26	20.05 ± 1.23	20.20 ± 1018	19.90 ± 1.20	19.90 ± 1.26	20.05 ± 1.12
Range	[19.0, 22.5]	[18.0, 22.0]	[18.0, 22.0]	[18.5, 22.0]	[19.0, 22.0]	[18.5, 22.0]	[18.0, 22.0]	[18.5, 22.0]
Refraction (D)								
Mean ± SD	− 0.03 ± 0.10	0.03 ± 0.12	− 0.02 ± 0.11	0.03 ± 0.09	0.05 ± 0.09	0.05 ± 0.10	− 0.01 ± 0.11	0.03 ± 0.10
Range	[− 0.18, 0.09]	[− 0.15, 0.18]	[− 0.17, 0.14]	[− 0.13, 0.16]	[− 0.11, 0.18]	[− 0.14, 0.18]	[− 0.17, 0.16]	[− 0.13, 0.17]
AT LISA tri839MP								
IOL power (D)								
Mean ± SD	20.85 ± 1.23	20.70 ± 1.30	20.70 ± 1.36	20.70 ± 1.25	20.90 ± 1.22	20.70 ± 1.30	20.70 ± 1.36	20.70 ± 1.16
Range	[19.5, 23.0]	[19.0, 23.0]	[19.0, 23.0]	[19.0, 23.0]	[19.5, 23.0]	[19.0, 23.0]	[19.0, 23.0]	[19.0, 22.5]
Refraction (D)								
Mean ± SD	0.05 ± 0.09	− 0.03 ± 0.10	− 0.01 ± 0.11	0.01 ± 0.12	0.01 ± 0.12	− 0.01 ± 0.11	− 0.01 ± 0.11	0.01 ± 0.10
Range	[− 0.12, 0.15]	[− 0.14, 0.16]	[− 0.16, 0.13]	[− 0.16, 0.17]	[− 0.18, 0.14]	[− 0.14, 0.16]	[− 0.17, 0.14]	[− 0.14, 0.15]

properly sure, as complex designs have produced the development of different methods of controlling the optical power of the pseudophakic eye. Basically, all formulae require AL and corneal power, and some require additional variables such as ACD (before surgery) and/or LT. In our study, the variables measured and required in some of the current formulae used clinically are shown in Table 2. Then, to properly assess if the changes we have found in our experiment may affect the IOL power needed, we have applied these four formulae to the ocular parameters we have found in both situations. The application was done using the software that the manufacturer provides in the IOLMaster 700. Three types of IOLs were selected for the calculations, one monofocal (Acri.Smart 36A), one bifocal (Acri-LISA 376D), and one trifocal (AT LISA tri839 MP). The outcomes obtained are shown in Table 3. We may observe that the changes both in IOL power and residual refraction between the two conditions are small. In all cases, the mean change was lower than 0.25D both for IOL power selection and residual refraction. Differences between lenses are related to the constants of the lenses used by the different formulae. This reveals that the changes we have found in ACD and LT do not produce any significant change for IOL power selection in this type of IOLs, and hence a significant change in the residual refraction of patients implanted with these IOLs (note that the steps for available IOL power are of 0.50D). Then, surgeons may use this instrument with the subject looking at the light point source and obtain reliable outcomes for IOL power calculation.

The current study measured only healthy eyes, and therefore, this should not be applied to pathological eyes, or postoperatively altered corneas, and in addition in older patients with or without cataract. Further studies should assess this effect in those excluded eye groups.

All the ocular parameters measured by non-contact optical biometry might help researchers to know real values for the anatomical dimensions of the human eye on a defined sample. These values could be used to assess, for instance, some of the elastic properties of the eye structures, like Young's modulus and Poisson's ratio, by means of the definition and analysis of computational human eye models. These simulation models may help to estimate the eyeball properties during IOP measuring by non-contact tonometers [11, 12] or to model retinal behavior in vivo when forces are applied to detached retina [13]. These elastic material properties of the human eye might help quantify details of symptoms of the diseases in the near future.

In conclusion, our study confirmed, although ACD and LT change significantly with different accommodative stimuli measured by SS-OCT optical biometry, that these changes are not clinically relevant.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Montés-Micó R, Carones F, Buttacchio A, Ferrer-Blasco T, Madrid-Costa D (2011) Comparison of immersion ultrasound, partial coherence interferometry, and low coherence reflectometry for ocular biometry in cataract patients. J Refract Surg 27:665–671
2. Srivannaboon S, Chirapapaisan C, Chonpimai P, Loket S (2015) 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 41:2224–2232
3. Kunert KS, Peter M, Blum M, Haigis W, Sekundo W, Schütze J, Büehren T (2016) Repeatability and agreement in optical biometry of a new swept-source optical coherence tomography-based biometer versus partial coherence interferometry and optical low-coherence reflectometry. J Cataract Refract Surg 42:76–83
4. Akman A, Asena L, Güngör SG (2016) Evaluation and comparison of the new swept source OCT-based IOLMaster 700 with the IOLMaster 500. Br J Ophthalmol 100:1201–1205
5. McAlinden C, Khadka J, Pesudovs K (2011) Statistical methods for conducting agreement (comparison of clinical tests) and precision (repeatability or reproducibility) studies in optometry and ophthalmology. Ophthal Physiol Opt 31:330–338
6. Montés-Micó R, Alió J, Muñoz G, Charman W (2004) Temporal changes in optical quality of air-tear film interface

at anterior cornea after blink. Invest Ophthalmol Vis Sci 45:1752–1757
7. Sisó-Fuertes I, Domínguez-Vicent A, del Águila-Carrasco A, Ferrer-Blasco T, Montés-Micó R (2015) Corneal changes with accommodation using dual Scheimpflug photography. J Cataract Refract Surg 41:981–989
8. Ostrin L, Kasthurirangan S, Win-Hall D, Glasser A (2006) Simultaneous measurements of refraction and A-scan biometry during accommodation in humans. Optom Vis Sci 83:657–665
9. Bolz M, Prinz A, Drexler W, Findl O (2007) Linear relationship of refractive and biometric lenticular changes during accommodation in emmetropic and myopic eyes. Br J Ophthalmol 91:360–365
10. Richdale K, Bullimore MA, Zadnik K (2008) Lens thickness with age and accommodation by optical coherence tomography. Ophthalmic Physiol Opt 28:441–447
11. Cao HJ, Huang CJ, Shih PJ, Wang IJ, Yen JY. (2015) A method of measuring corneal Young's modulus. In: 7th WACBE world congress on bioengineering. IFMBE Proceedings, vol 52, pp 47–50
12. Hamilton KE, Pye DC (2008) Young's modulus in normal corneas and the effect on applanation tonometry. Optom Vis Sci 85:445–450
13. Jones IL, Warner M, Stevens JD (1992) Mathematical modelling of the elastic properties of retina: a determination of Young's modulus. Eye (London) 6:556–559