Anterior segment analysis with accommodation in young emmetropic subjects using Optical Coherence Tomography

Alberto Recchioni, MSc[1]; Daniel Monsálvez-Romín, MSc[1]; Teresa Ferrer-Blasco, PhD[1]; José J. Esteve-Taboada, PhD[1]; Robert Montés-Micó, PhD[1]

PURPOSE: To assess changes in the anterior segment with different accommodation stimuli by means of optical coherence tomography (OCT) in young emmetropic subjects.

SETTING: Optics and Optometry and Vision Sciences Department. University of Valencia. Spain.

METHODS: Five right eyes of five healthy adults (mean age 28.3 ± 2.9 years) were included. All measurements were taken using the Visante® Omni OCT system (Carl Zeiss AG, Oberkochen, Germany). The central corneal thickness (CCT), anterior chamber depth (ACD), central lens thickness (CLT) and anterior segment length (ASL) were assessed. The evaluated parameters were obtained for the unaccommodated eye (0.0 D vergence) and for −1.5 D and −3.0 D stimulus vergences.

RESULTS: The CCT remained unaltered with accommodation, whereas a significant reduction in ACD and a significant increase in CLT were observed. ASL changes were found to be significantly higher when comparing the unaccommodated eye parameters with −1.5 D and −3.0 D stimulus vergences, but not between −1.5 D and −3.0 D.

CONCLUSION: Analysis of anterior segment changes with accommodation is easily achieved using OCT technology in young emmetropic subjects.

J Emmetropia 2016; 3: 145-149

Accommodation is the capacity of the eye to focus at different distances from infinity to near targets. The crystalline lens adjusts its refractive power by changing its shape, which involves secondary anatomical variations in the anterior segment of the eye.

In recent years, researchers have been studying the changes produced by accommodation in the anterior segment, including changes in the crystalline lens thickness (CLT), crystalline lens anterior and posterior curvature, anterior chamber depth (ACD), anterior chamber angle and pupil diameter[1-4]. The crystalline lens is the major structure involved during the accommodation process, and is able to modify its shape in response to a near stimulus to focus a clear image on the retina.

Anterior segment optical coherence tomography (AS-OCT) evaluates all the relative changes during accommodation. Dubbelman et al.[5], using a Scheimpflug camera, found that the higher the stimulus vergence, the higher the increase in crystalline lens thickness; similar results have been obtained using AS-OCT technology[6].

The aim of this study was therefore to present a methodology to assess changes in the anterior segment using AS-OCT when an accommodative stimulus is presented to the eye at different vergences in young emmetropic subjects. This will enable the main changes in the anterior segment during accommodation to be observed in a non-invasive manner.

Submitted: 5/1/2016
Revised: 6/25/2016
Accepted: 9/26/2016

[1]Optometry Research Group (GIO), Optics and Optometry and Vision Sciences Department. University of Valencia. Spain.

Acknowledgements: Finantial support by the Ministerio de Economia y Competitivad (Research project *SAF2013-44510-R with FEDER Funds* from European Union). DMR has a "Formación de Profesorado Universitario" Grant (FPU13/05332, Ministerio de Educación, Cultura y Deporte) and AR a "Santiago Grisolía" research scholarship (Generalitat Valenciana).

Financial Disclosure: The authors report no conflicts of interest and have no proprietary interest in any of the materials mentioned in this article.

Corresponding Author: Alberto Recchioni
Departmento de Óptica, Universidad de Valencia.
c/ Dr. Moliner nº 50; 46100 Burjassot (Spain)
E-mail: alberto.recchioni@uv.es

© 2016 SECOIR
Sociedad Española de Cirugía Ocular Implanto-Refractiva

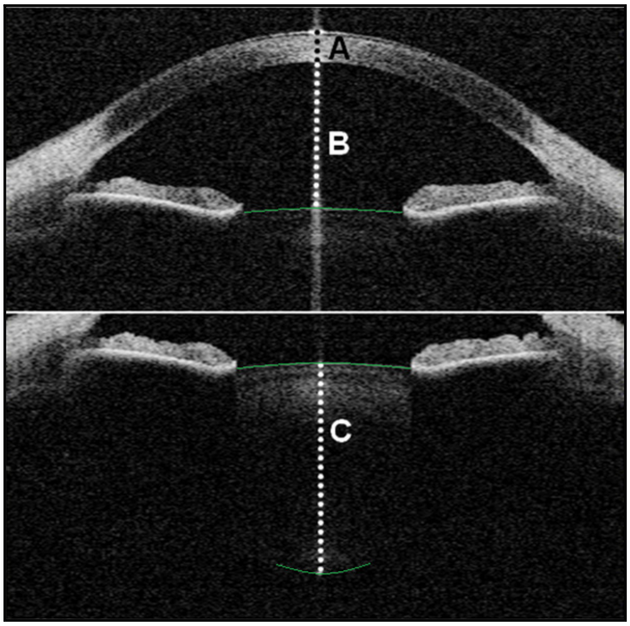


Figure 1. Visante AS-OCT measurements. A-Central corneal thickness. B-Anterior chamber depth. C-Crystalline lens thickness. The ASL was calculated as the sum of parameters B and C.

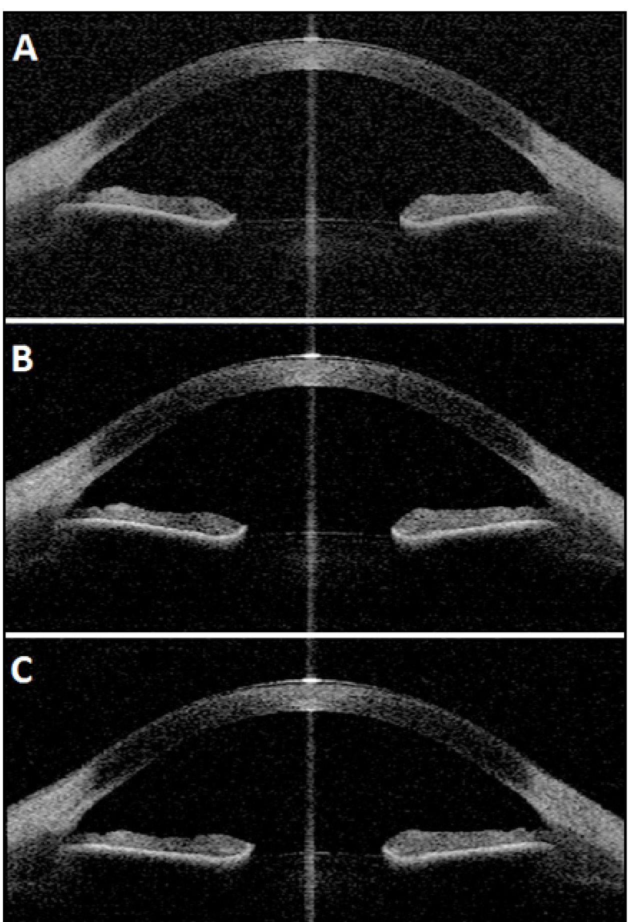


Figure 2. Anterior segment capture set at all measurement conditions for a given subject. A) 0 D; B) −1.5 D; C) −3.0 D.

METHODS

Subjects

Five right eyes of 5 healthy adults aged from 20 to 30 years (28.3 ± 2.9 years) were included in this study. All eyes were emmetropic with functional accommodation. The study subjects had no ocular abnormalities or systemic conditions, and no history of ocular surgery. Furthermore, they all presented clear intraocular media. Their best-corrected visual acuity was 20/20 or better. The subjects were informed about the details of the study, and formal consent was obtained after written and verbal explanation of the implications.

Measurement device and parameters

Measurements were taken with the Visante Omni OCT system (Carl Zeiss AG, Oberkochen, Germany), which uses OCT technology to perform advanced corneal and anterior segment evaluation. It is a non-contact diagnostic device, which acquires and analyses detailed cross-sectional tomograms and anterior segment measurements. OCT makes use of low-coherence interferometry in order to produce the images, in which light (1310 nm) is sent along an optical path that reaches the eye, together with another reference path of the interferometer. Both paths are then combined at the photodetector, so it can determine the axial depth of the tissue by means of the reflectivity signal.

The Visante OCT software has a set of different scan types; the scan used in this study was the "Raw image mode". Each single captured image is composed of 256 A-Scan primitive lines, which represent a total area of 16 mm in width and 6 mm in depth, but each primitive line is only obtained once. The image is not processed after capture via "Raw image mode", since it is conceived to capture images as a merely qualitative evaluation of the anterior eye segment.

Based on the protocol we designed, the captured images were exported to an external software program. We utilised ImageJ, a public domain software for image processing and analysis developed by Wayne Rasband (National Institute of Health, USA). The raw image mode was used in order to capture images of the central ACD; full lens thickness can also be evaluated with this mode, as it can obtain images deeper into the eye. More specifically, the central corneal thickness (CCT) was obtained from the epithelium to the posterior surface or endothelium. The ACD was measured from the posterior corneal endothelium at the centre of the cornea to the anterior lens surface at the centre of the pupil, while the CLT was calculated from the central posterior surface to the central anterior surface of the same. Since the raw image mode cannot correct the image for the refractive indices of the ocular media, the measurements were taken in pixels and then converted to millimetres, taking into account the depth of the image capture together with the group refractive indices of the cornea (1.388), as well as that of the aqueous humour for the ACD (1.343) and that of the crystalline lens (1.39) at 1310 nm[1]. The anterior segment length (ASL) is usually defined as the distance from the central anterior corneal surface to the posterior surface of the lens. Although this measurement was included in our study, it was considered from the posterior surface of the cornea (endothelium) to the posterior surface of the lens, in order to evaluate the change in position of the posterior pole of the crystalline lens without adding extra variability due to the corneal measurements. All these measurements were taken with and without the lenses at 0 dioptres (D) (unaccommodated state) and at −1.5 D and −3.0 D stimulus vergences. Figure 1 shows the parameters measured, while Figure 2 shows a set of captured images of the anterior segment variations with different stimuli for a given subject.

Experimental procedure

Each anterior segment parameter was captured three times per eye. Subjects were requested to keep their fixation on the instrument visual target and the camera live image of the eye was centred on the pupil before capturing. To avoid affecting the measurement during the acquisition process, subjects were also requested to blink before starting the examination and to open wide until the measurements were finished. All the measurements for each study participant were obtained during a single session.

Statistical analysis

Statistical analysis was performed with SPSS software (version 15.0, SPSS Inc., Chicago, IL, USA). Each measurement was obtained from three different captured images, from which a mean value was calculated. The Wilcoxon non-parametric test for paired samples was used to compare groups, with statistical significance defined as $p < 0.05$. The measurements were compared between 0.0 D and −1.5 D, between 0.0 D and −3.0 D and between the −1.5 D and −3.0 D stimulus vergences.

RESULTS

The study included five right eyes of five young adult emmetropes. CCT measurements were not found to be statistically significant at any stimulus vergence among any pair comparison. Results are shown in Figure 3.

The ACD measurements for the unaccommodated eye (0.0 D of stimulus vergence) were respectively compared with the stimulus vergence of −1.5 D and −3.0 D. The differences among these conditions were statistically significant ($p < 0.05$). When the stimulus vergence of −1.5 D was compared to −3.0 D, the reduction in the ACD due to accommodation was also significant. Figure 4 shows the values of ACD variations for all instances.

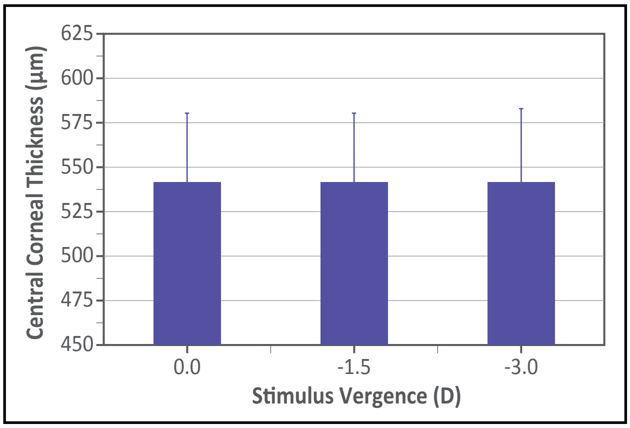


Figure 3. Corneal central thickness variations at 0 D, −1.5 D and −3.0 D stimulus vergences.

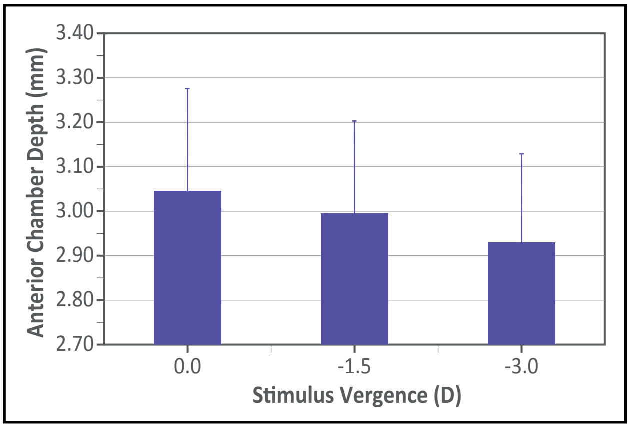


Figure 4. Anterior chamber depth variations at 0 D, −1.5 D and −3.0 D stimulus vergences.

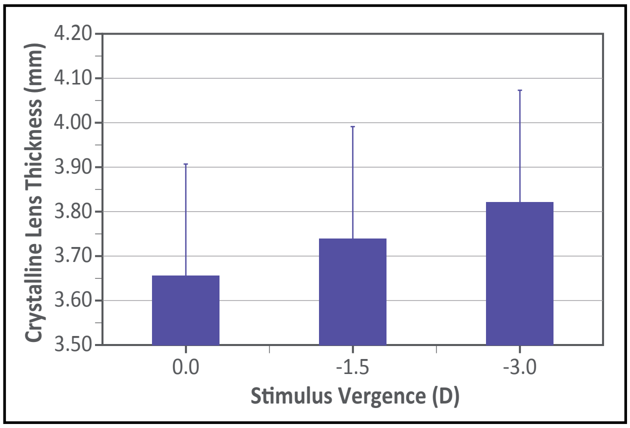


Figure 5. Crystalline lens thickness at 0 D, −1.5 D and −3.0 D stimulus vergences.

Considering the CLT at the 0.0 D stimulus vergence compared with −1.5 D and with −3.0 D, there were statistical differences among these pairs, as previously observed with the ACD. Additionally, when the −1.5 D stimulus vergence was correlated with −3.0 D, the comparison was found to be statistically significant ($p < 0.05$). A smaller increase in the crystalline lens thickness was observed. Figure 5 shows the changes in CLT.

Finally, the calculated ASL data showed statistically significant variations only when the unaccommodated eye (0.0 D) was related to the −1.5 D and −3.0 D stimulus vergences, respectively ($p > 0.05$). There was no significant variation when the −1.5 D stimulus was compared with the −3.0 D stimulus. Figure 6 shows the ASL differences with accommodation. Table 1 shows all the measurements previously mentioned in the Statistics section.

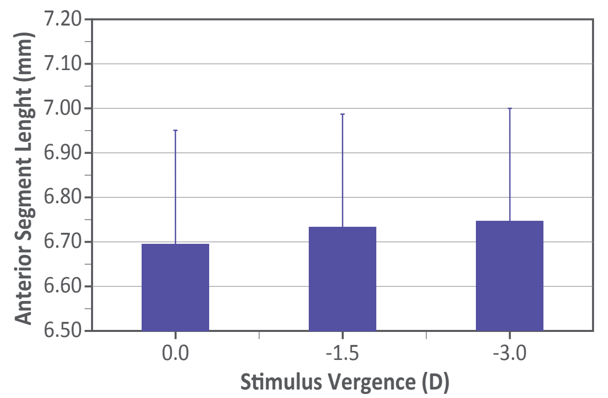


Figure 6. Anterior segment length variations at 0 D, −1.5 D and −3.0 D stimulus vergences.

Table 1. Measurements of all the variables considered and their comparison.

Values	MEAN	SD	*p*-value
CCT 0 D (μm)	542	39	0 D vs. 1.5 D 0.333
CCT 1.5 D (μm)	541	40	0 D vs. 3 D 0.927
CCT 3 D (μm)	541	42	1.5 D vs. 3 D 0.624
ACD 0 D (mm)	3.043	0.009	0 D vs. 1.5 D 0.003*
ACD 1.5 D (mm)	2.995	0.017	0 D vs. 3 D 0.001*
ACD 3 D (mm)	2.927	0.027	1.5 D vs. 3 D 0.001*
CLT 0 D (mm)	3.654	0.009	0 D vs. 1.5 D 0.001*
CLT 1.5 D (mm)	3.738	0.010	0 D vs. 3 D 0.001*
CLT 3 D (mm)	3.820	0.013	1.5 D vs. 3 D 0.001*
ASL 0 D (mm)	6.697	0.015	0 D vs 1.5 D 0.004*
ASL 1.5 D (mm)	6.734	0.019	0 D vs. 3 D 0.001*
ASL 3 D (mm)	6.748	0.009	1.5 D vs. 3 D 0.053

**p*-value <0.05; SD, standard deviation; D, dioptres; CCT, central corneal thickness; ACD, anterior chamber depth; CLT, central lens thickness; ASL, anterior segment length.

DISCUSSION

Nowadays, the anterior segment of the eye can be easily observed and described by means of OCT. Thanks to the non-invasive measurements, changes due to accommodation can be seen instantaneously without any contact with the eye surface of the subject. This, unlike ultrasonic biometry, avoids any interference (e.g. mechanical pressure) on the anterior segment[7].

AS-OCT technology is also useful in crystalline lens evaluation, but its light is blocked by the pigment of the iris structure. Due to the contraction of the ciliary muscles, the crystalline lens is able to modify its shape through the action of the zonular fibres during the accommodation process. This variation leads to an increase in the lens dioptric power (more convex), a forward movement towards the cornea and a reduction in the ACD[8].

Baikoff et al.[9] investigated this process using OCT in patients with intraocular lens implantation, assessing whether the anatomical modifications due to accommodation can respect the safety criteria of the surgery. Additionally, Radhakrishnan et al.[10] demonstrated that real-time visualization with a 1310 nm OCT can achieve a better morphological description of the anterior eye, also during accommodation.

In terms of repeatability, Doyle et al.[11] found that the AS-OCT Visante is able to measure the lens thickness during different accommodative demands over a wide range of ages and, moreover, can identify small changes proportional to its axial resolution. Farouk et al.[12] also evaluated the importance of OCT technology to study accommodation in children; their study argues the relevance of the Helmholtz capsular theory[13].

In this study, the CCT, ACD, CLT and ASL from the corneal endothelium to the posterior surface of the crystalline lens were evaluated at different stimulus vergences. It should be noted that the study group was fully able to focus those distances at which the stimuli were presented, due to the adequate amplitude of accommodation in their age range. The primary goal was to assess whether AS-OCT was useful when the accommodation was taking place, by observing the anatomical changes in the anterior segment.

Comparison of the ACD values for the 0.0 D vergence with the −1.5 D and −3.0 D stimuli showed a significant reduction. This is somewhat logical, because when the unaccommodated eye is stimulated to obtain a focused and clear image on the retina, the crystalline lens moves forward and reduces the ACD length. When the comparison was made between −1.5 D and −3.0 D, this reduction showed a statistically significant variation ($p < 0.05$).

The same significant tendency was observed in relation to the CLT. All the pair comparisons between the unaccommodated eye and at −1.5 D and −3.0 D stimuli vergences showed a statistically significant increase in the CLT.

As stated, ASL was considered from the corneal endothelium to the posterior surface of the lens in order to avoid additional variability coming from the corneal measurements. This parameter was considered in order to evaluate the change in position of the posterior pole of the crystalline lens. The longer this distance, the more it would have moved backwards. In the study, it was assumed that the position of the cornea does not change during accommodation, so the change in the anterior surface of the lens is directly related to the change in ACD.

The ASL values in our study showed a significant change only when the −1.5 D and −3.0 D stimuli were compared with the unaccommodated state of the eye (0.0 D). However, since the absolute variation of the ASL is smaller than that of the ACD values, this means that the posterior surface of the crystalline lens is not as altered as the anterior surface, which carries a more significant accommodative component.

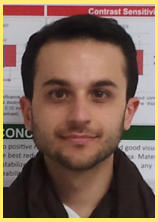
However, a slight modification is also produced when comparing the −1.5 D stimulus vergence with the −3.0 D stimulus vergence. Furthermore, it must be taken into account that the accommodation provided by the crystalline lens is not only due to the increasing thickness of its structure or to its displacement towards the cornea, but because a modification in shape also occurs, which increases the power of the lens by steepening its curvature radii.

Other eventualities such as the lag of accommodation, as well as crystalline lens microfluctuations or the instrumental component of accommodation, might also partly explain all these differences, and must be taken into account when analysing the measurements. Our study has limitations in that the sample size was relatively small, and only young emmetropic subjects were evaluated.

Our findings provide information on the anatomical changes in the anterior segment of the eye, and give a better understanding of the accommodation mechanism analysed through AS-OCT technology in young emmetropic subjects.

REFERENCES

1. Lehman BM, Berntsen DA, Bailey MD, Zadnik K. Validation of OCT-based Crystalline Lens Thickness Measurements in Children. Optom Vis Sci. 2009; 86:181.
2. Baikoff G, Lutun E, Ferraz C, Wei J. Static and dynamic analysis of the anterior segment with optical coherence tomography. J Cataract Refract Surg. 2004; 30:1843-50.
3. Tsorbatzoglou A, Nemeth G, Szell N, Biro Z, Berta A. Anterior segment changes with age and during accommodation measured with partial coherence interferometry. J Cataract Refract Surg. 2007; 33:1597-601.
4. Leng L, Yuan Y, Chen Q, et al. Biometry of anterior segment of human eye on both horizontal and vertical meridians during accommodation imaged with extended scan depth optical coherence tomography. PLoS One. 2014; 9:e104775.
5. Dubbelman M, Van der Heijde GL, Weeber HA. Change in shape of the aging human crystalline lens with accommodation. Vision Res. 2005; 45:117-32.
6. Richdale K, Bullimore MA, Zadnik K. Lens Thickness with Age and Accommodation by Optical Coherence Tomography. Ophthalmic Physiol Opt. 2008; 28:441-7.
7. Dada T, Sihota R, Gadia R, Aggarwal A, Mandal S, Gupta V. Comparison of anterior segment optical coherence tomography and ultrasound biomicroscopy for assessment of the anterior segment. J Cataract Refract Surg. 2007; 33:837-40.
8. Ciuffreda KJ. Chapter 4 – Accommodation, the Pupil, and Presbyopia. In: BenjaminConsultant WJ, Borish IM, editors. Borish's Clinical Refraction (Second Edition). Saint Louis: Butterworth-Heinemann; 2006; p.93-144.
9. Baikoff G, Lutun E, Wei J, Ferraz C. Contact between 3 phakic intraocular lens models and the crystalline lens: an anterior chamber optical coherence tomography study. J Cataract Refract Surg. 2004; 30:2007-12.
10. Radhakrishnan S, Rollins AM, Roth JE, et al. Real-time optical coherence tomography of the anterior segment at 1310 nm. Arch Ophthalmol. 2001; 119:1179-85.
11. Doyle L, Little JA, Saunders KJ. Repeatability of OCT lens thickness measures with age and accommodation. Optom Vis Sci. 2013; 90:1396-405.
12. Farouk MM, Naito T, Shinomiya K, et al. Optical Coherence Tomography Reveals New Insights into the Accommodation Mechanism. Journal of Ophthalmology. 2015; 2015:5.
13. Martin H, Guthoff R, Terwee T, Schmitz K-P. Comparison of the accommodation theories of Coleman and of Helmholtz by finite element simulations. Vision Research. 2005; 45:2910-5.



First author:

Alberto Recchioni, MSc

Optometry Research Group (GIO). University of Valencia, Spain.