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Scheimpflug Imaging of the Anterior Eye Segment during Standardized Accommodation Stimulation in Patients with Emmetropia, Myopia and Hypermetropia

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Abstract

Understanding of the biomechanics of the accommodative apparatus in the eyes with different refraction is important for solving the problems of theoretical and practical ophthalmology. **Purpose:** To determine the changes of anterior eye segment dimensions during accommodation response in normal eyes and in patients with myopia, hypermetropia. **Methods and Material:** 116 eyes (56 patients aged from 18 to 30 years, refraction from −2.0 to + 2.0 D) were examined. All the patients underwent a full ophthalmological examination. The ocular anterior segment was imaged using a rotational Scheimpflug camera Pentacam HR (Oculus, Wetzlar, Germany) under non- and 3.0 D of accommodative demands. The statistical data were represented as the mean value ± standard deviation (M ± SD). The Shapiro-Wilk test was used to assess the normality distribution. Wilcoxon test was used for comparison. **Results:** Results showed an increase in the optical density of the crystalline lens, a pupil diameter decrease and changing of the iris profile during accommodation in all patients. An increase in the total corneal aberrations and decrease in the corneal spherical aberration Z_4^0 were revealed only in emmetropic eyes. **Conclusions:** The accommodative response is a multicomponent process. Scheimpflug visualization revealed the differences in the accommodative response in normal and ametropic eyes.

Keywords

Eye Accommodation, Scheimpflug Imaging, Pupil Response

1. Introduction

Accommodation is the ability of the eye to change the refraction to focus on the objects at different distances. Among all the theories of accommodation, Helmholtz's theory is the most widely accepted [1]. To form a clear retinal focus on the retina on closely located objects, the ciliary muscle contracts, and the zonular fibers relax, causing a thickening of the lens and a change in its refractive power. The main links of the executive mechanism of accommodation are the lens, the ligamentous apparatus of the lens, the ciliary muscle and the choroid. However, almost all structures of the eyeball are involved somehow in providing the biomechanics of accommodation. Intraocular components of accommodation include a change in the curvature of the lens surface and in the refractive index inside the lens substance [2]-[8], the movement of the lens along the optical axis [9] [10] [11] [12], a change in the diameter of the pupil [13] [14]. There are also extralenticular components of accommodation—complex modification of ciliary muscle [8] [15] [16] [17], elongation of the axis of the eyeball due to its compression by the external muscles of the eye [18] [19] [20], the appearance of induced direct corneal astigmatism [21]-[29], etc.

Recently, several techniques have been developed for measuring the anterior segment of the eye *in vivo*, such as the ultrasound biomicroscopy (UBM), optical coherence tomography (OCT), optic aberrometry, magnetic resonance imaging (MRI), Scheimpflug imaging (SI). However, previously described SI registration of accommodation eye response [30]-[35] had some limitations: usually the eye refraction was emmetropic; the accommodation stimulation was on the fellow eye but not directly on the testing eye or not physiological obtained on pupil pharmacological reaction.

Assessment of the anterior eye segment during accommodation has clinically important applications in the study of eye diseases, such as glaucoma, refractive disorders, cataract and others. At the same time, the accommodative response in patients with different types of refraction has its own characteristics, which have not been practically studied. A better understanding of the biomechanics of the accommodative apparatus in the eyes with different refraction is necessary for solving the problems of theoretical and practical ophthalmology. The purpose of this study was to determine the changes of anterior eye segment dimensions during standardized accommodation stimulation in normal eyes and in patients with myopia, hypermetropia using the Scheimpflug visualization.

2. Subjects and Methods

This study adhered to the tenets of the Helsinki Declaration of Ethical Principles for Medical Research Involving Human Subjects and was approved by the Institution Research and Ethics Committee (protocol number 10/15 from 27/01/2020). All the patients were adequately informed and they signed a consent form.

Fifty-eight young patients (aged from 18 to 30 years, refraction from −2.0 to +2.0 D) were recruited into the study and both eyes were assessed: 20 patients with emmepropia (40 eyes), 20 patients with low myopia (40 eyes), 18 patients with low hypermetropia (36 eyes).

All the patients underwent a full ophthalmological examination, including the evaluation of the eye anatomy, refraction and accommodation. The refractive error was the average spherical equivalent (SE) of three cycloplegic measurements taken with an autorefractor/keratometer (KR8800, Topcon, Japan).

The distance visual acuity was measured with the Bailey-Lovie logical geometric scale (phoropter Topcon, Japan) and was converted into a decimal scale. The accommodation amplitude (AA) was measured with the help of the minus lens method. The subjects were asked to fixate on an N8 target at a distance of 40 cm, and then minus lenses were introduced in 0.25 D steps until the patient reported the first sustained blur that could not be cleared by further conscious effort. This procedure was done for each eye first monocularly and then binocularly. The total AA was estimated as the end-point value of the minus lens, with which it was possible to see the target at 40 cm under binocular conditions. The AA measurement in people with presbyopia was done with the near addition lens.

The habitual accommodation tone (HAT) was estimated as the difference between manifest and cycloplegic refraction. The assessment of the accommodation response was carried out 3 days after the initial examination. The ocular anterior segment of each subject was imaged using a rotational Scheimpflug camera Pentacam HR (Oculus, Wetzlar, Germany) and a screen data output of different refraction targets under non- and 3.0 diopters (D) of accommodative demands depending on eye refraction (**Table 1**).

All the images were analyzed to yield the following parameters: the pupil diameter (PD), the iris-cornea angle (ICA), the lens densitometry (LD), the root mean square (RMS) total of the cornea, the RMS of corneal spherical aberration Z40, the index of the corneal asphericity in the horizontal meridian (IAH), the asphericity index of the corneal peripheral part by a ring with a diameter of 10 mm (IAP). The densitometry average value was calculated in pre-defined 3D-zone centered around the pupil diameter. Two consecutive measurements were performed to assess the repeatability of Pentacam HR.

All the data were analysed with the help of a spreadsheet application (Statistica ver. 10.0; StatSoft Inc., USA). The statistical data were represented as the mean value ± standard deviation (M ± SD). The Shapiro-Wilk test was used assess the normality distribution. The comparison of the anterior segment dimensions

Table 1. Accommodative targets depending on refraction value.

Refraction, D	Non-accommodation target, D	3D accommodation target, D
−2.0	−2.0	−5.0
−1.0	−1.0	−4.0
0	0	−3.0
1.0	1.0	−2.0
2.0	2.0	−4.0

between non-accommodation and 3.0 D-accommodation status was made using Wilcoxon test. The critical level of significance (p) upon the examination of statistical hypotheses was 0.05. Intra-class Correlation Coefficient (ICC) was a measure of correlation for data of repeated measurements.

3. Results

Baseline characteristics of the study population were summarized in **Table 2**. Groups did not differ in age and gender, but differed in refraction, axial length and accommodation status.

Repeatability of anatomical and optical parameters was determined under non-accommodative and 3.0 D-accommodative conditions. There was no statistically significant difference between two repeated measurements under different accommodative status ($p > 0.05$). The ICC for all parameters ranged from 0.885 to 0.998.

Scheimpflug registration of accommodation response have revealed the 4% - 5% increase in the optical density of the anterior cortical layers of the lens ($p = 0.04$) and the changes in the perilenticular structures which were vary in different refractive groups.

The comparison of the anterior segment dimensions between non-accommodation and 3.0 D-accommodation status in normal patients with emmetropia (**Table 3**) showed statistically significant lenticular cortical density increase, irido-corneal angle increase, significant pupil constriction and changing of the iris profile. At the same time increase in RMS total value of the corneal wave front and asphericity indices were revealed. The mean value (M ± SD) of the corneal spherical aberration Z_4^0 decreased from 0.17 ± 0.01 to 0.12 ± 0.02 μm ($p < 0.01$). A decrease in the tangential curvature of the peripheral part of the cornea in the upper and lower segments was noted.

The mapping of the eye anterior segment images in non-accommodation and 3D-accommodation status according to the posterior surface of the cornea revealed an anterior displacement of not only the lens, but also the entire iris, a

Table 2. Baseline characteristics of the study population.

Characteristics	Emmetropia	Myopia	Hypermetropia
Age, years	22.3 ± 3.2	22.4 ± 2.2	22.6 ± 2.5
Female:Male	10:10	10:10	9:9
SE, D	0.25 ± 0.11	−1.95 ± 0.11	1.94 ± 0.12
Axial length, mm	23.5 ± 0.5	24.1 ± 0.5	22.8 ± 0.5
Lens thickness, mm	3.73 ± 0.23	3.61 ± 0.19	3.72 ± 0.30
AA, D	6.93 ± 1.12	6.18 ± 1.04	6.96 ± 1.07
HAT, D	0.04 ± 0.28	0.35 ± 0.13	1.48 ± 0.56

SE—spherical equivalent; AA—accommodation amplitude; HAT—habitual accommodation tone.

change in the pupil. The iris profile changed due to the narrowing of the pupil, as well as by increasing the tone and reducing the undulation in the pupillary zone, the appearance of dips in the ciliary zone in the upper segments.

Scheimpflug registration of the accommodation response revealed the significant differences in the accommodation system functional state in normal eyes and in patients with myopia and with hypermetropia (**Figure 1**).

In elongated eyes with myopic refraction, as well as in patients with emmetropic refraction, at the time of accommodative load there were: an increase in the light transmission of the cortical layers of the lens, a narrowing of the pupil, an increase in ICA, a decrease in spherical aberration of the 4th order and a change in the iris profile (**Table 4**).

In contrast to patients with emmetropia, no change in the corneal asphericity in the horizontal meridian was detected in patients with myopia at the time of accommodation. The pupil response in patients with myopia was less than in

Table 3. Results of comparative analysis of structural changes in the anterior eye segment dimensions during the 3D-accommodative response in patients with emmetropia (M ± SD).

Parameters	Non accommodation status	3D-accommodation status	Wilcoxon, p-level
LD, %	8.52 ± 0.58	8.81 ± 0.52*	0.04
PD, mm	3.61 ± 0.44	2.84 ± 0.41*	0.001
ICA, degree	37.5 ± 2.3	39.5 ± 2.1*	0.001
RMS total, μm	0.37 ± 0.17	0.42 ± 0.23*	0.008
IAH	0.25 ± 0.07	0.28 ± 0.07*	0.001
IAP	0.42 ± 0.14	0.78 ± 0.17*	0.001

LD—lens densitometry; PD—pupil diameter; ICA—iris-cornea angle; RMS—root mean square; IAH—index of the corneal asphericity in the horizontal meridian; IAP—index of the asphericity in the corneal peripheral part; *Wicoxon p-level < 0.05.

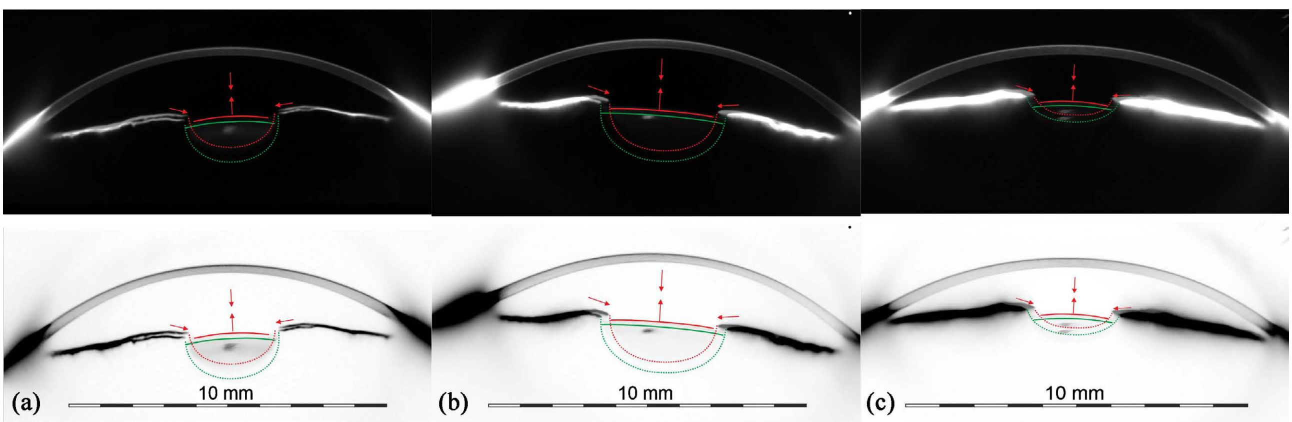

Figure 1. Comparison analysis of the Scheimpflug images of the anterior eye segment in non-accommodation and 3D-accommodation status in emmetropic (a), myopic (b) and hypermetropic (c) eyes according to the posterior corneal surface. Green lines show the contour of the crystalline lens and pupil in non-accommodation status, red lines during accommodation.

Table 4. Results of comparative analysis of structural changes in the anterior eye segment dimensions during the 3D-accommodative response in patients with different refraction (M ± SD).

Parameters	Emmetropia	Myopia	Hypermetropia
LD, %			
non accommodation	8.52 ± 0.58	8.42 ± 0.51	8.01 ± 0.17
3D-accommodation	8.81 ± 0.52*	8.69 ± 0.31*	8.17 ± 0.58*
p-level	0.03	0.04	0.04
PD, mm			
non accommodation	3.61 ± 0.44	4.09 ± 0.54	2.97 ± 0.43
3D-accommodation	2.84 ± 0.41*	3.63 ± 0.44*	2.22 ± 0.36*
p-level	0.001	0.001	0.001
ICA, degree			
non accommodation	37.5 ± 2.3	42.6 ± 5.3	35.7 ± 1.8
3D-accommodation	39.5 ± 2.1*	44.1 ± 4.1*	36.6 ± 2.5*
p-level	0.001	0.008	0.04
RMS total, µm			
non accommodation	0.37 ± 0.17	0.39 ± 0.17	0.43 ± 0.17
3D-accommodation	0.42 ± 0.23*	0.37 ± 0.15	0.43 ± 0.15
p-level	0.008	>0.05	>0.05
IAH			
non accommodation	0.25 ± 0.07	0.45 ± 0.11	0.16 ± 0.04
3D-accommodation	0.28 ± 0.07*	0.46 ± 0.12	0.16 ± 0.04
p-level	0.001	>0.05	>0.05
IAP			
non accommodation	0.42 ± 0.14	0.61 ± 0.14	0.38 ± 0.14
3D-accommodation	0.78 ± 0.17*	0.58 ± 0.14	0.40 ± 0.14
p-level	0.001	>0.05	>0.05

*Wicoxon p-level < 0.05.

emmetropes by 12-15% ($p < 0.001$), the transformations of the iris profile were moderate.

In shortened eyes with hypermetropic refraction, as well as in patients with emmetropia, an increase in the light transmission of the cortical layers of the lens was observed at the time of the 3D-accommodative response. Extremely interesting results were obtained when registering the pupillary response in a patient with hypermetropia. The initial PD in patients with hypermetropia was much smaller than in patients with emmetropia, and was consistent with the value of the HAT ($r = 0.23$; $p = 0.01$). At the time of the reflex accommodative response, an even more intense miosis was recorded—the pupil diameter decreased by 20% - 25%. Unlike emmetropic eyes, the accommodative response in hypermetropic eyes was not accompanied by significant changes in the optical parameters of the cornea. The profile of the iris has changed only due to the narrowing of the pupil.

4. Discussion

This study demonstrates the results of Scheimpflug registration of the anterior eye segment transformation during 3D accommodation response in 116 eyes, in three refractive groups. The study data show that SI can be considered as a reliable method of registering the accommodative response. The advantage of this technique is the possibility of presenting various refractive goals, which allows standardizing the accommodation load. Reconstruction of all anterior segment dimensions gives a complete picture of accommodation transformations.

Scheimpflug registration has revealed changes in all anatomical dimensions of the anterior segment of the eye-cornea, iris, pupil, lens. This study highlights the increase in the optical density of the anterior cortical layers of the crystalline lens at the time of accommodation, which clearly shows the transformation of the lens at the time of the accommodation response. Another finding of our study is the difference of the nature of the transformations of the iris and the other components of the anterior segment at the time of accommodation in patients with emmetropia, myopia and hypermetropia. It is established that the accommodative response in the emmetropic eye is characterized by the transformation of not only the lens, but also the entire optical apparatus, with active participation in the process of the cornea and iris, being the result of the inter-action of a number of biodynamic forces. The SI results in the corneal changes at the time of accommodation in patients with emmetropia are confirmed in the literature.

The results of this study show that at the time of the accommodative response, there is an increase in light scattering and an increase in the density of the anterior cortical layers of the lens. There was one limitation of the SI—the impossibility of a reliable densitometric assessment of the nucleus and posterior cortical layers of the lens in conditions of formed myosis. Despite this, the established densitometric changes in the anterior cortical layers of the lens at the time of accommodation significantly complement the general idea of the internal dynamics of the eye. However, the nature of the accommodative response in patients with myopia and hypermetropia differs somewhat from the nature of the response in patients with emmetropia, which indicates the existing differences in the initial structural and functional state of the accommodative apparatus. Common signs of an accommodative response in all patients, regardless of the type of refraction are: an increase in optical density and light scattering in the anterior cortical layers of the lens, a narrowing of the pupil and a change in the iris profile.

The study of the accommodation response using SI is a promising direction in the study of the pathological physiology of a number of diseases associated with the accommodation system. This study sample is enough to show the lens light scattering increase phenomenon and the general patterns of iris response during accommodation of the eye. But in order to full understanding the accommodation forces in the eyes with different refraction it is preferable to perform next study on a larger sample.

5. Conclusion

The accommodative response is a multicomponent process, in which all the structures of the anterior segment of the eye are involved. Scheimpflug visualization revealed differences in the accommodative response in patients with emmetropia, myopia and hypermetropia. An increase in optical density and an increase in light scattering in the anterior cortical layers of the lens, a narrowing of the pupil and a change in the iris profile were found in all patients, regardless of refraction and the usual tone of accommodation.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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