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Cross-Sectional Study of Ocular Optical Components Interactions in Emmetropes

Biljana Kuzmanović Elabjer[1], Jelena Petrinović-Dorešić[1], Manda Đurić[2], Mladen Bušić[1] and Esmat Elabjer[3]

[1] University Department of Ophthalmology, General Hospital »Sveti Duh«, Zagreb, Croatia
[2] Ophthalmology Outpatient Clinic »Dom zdravlja MUP-a«, Zagreb, Croatia
[3] Traumatology University Hospital, Zagreb, Croatia

ABSTRACT

Purpose of the paper was to evaluate ocular optical components (OOC) interactions in a large number of emmetropes. A cross-sectional study of 1,000 emmetropes, aged from 18–40 years, has been conducted. Complete ophthalmological examination, corneal radius (CR) measurement, keratometry and echobiometry of both eyes were performed. The highest correlation of OOC was that of axial length (Ax) with vitreal body (CV) on both eyes (r=0.79 for the right eye (RE); r=0.81 for the left eye (LE)). The axial length had a positive correlation with the anterior chamber depth (ACD) on both eyes as well, but the coefficient was very low (r=0.29 for the RE; r=0.32 for the LE). The only negative correlation Ax had on both eyes was with the lens (L) (r=–0.17 for the RE; r=–0.19 for the LE). Keratometry of the horizontal (K_1) and vertical meridian (K_2) showed a negative correlation with CV and Ax on both eyes (for K_1 r=–0.64 for CV, r=–0.54 for Ax; for K_2 r=–0.67 for CV, r=–0.68 for Ax). CR had a positive correlation with Ax (r=0.74) and CV (r=0.79). It showed a negative correlation with L (r=–0.58). CV had a high, positive correlation with Ax (r=0.72 for the RE; r=0.75 for the LE). The correlation with K_1 and K_2 was negative. Our study showed that the axial length, keratometry, corneal radius, lens thickness and vitreal body were the most important OOC that correlated with each other following a pattern in our group of emmetropes. They interacted in such a way that in the subjects with axial length above the average value, the vitreal body was longer but the lens was thinner and the cornea was of less power. This could explain at least one of the mechanisms of emmetropization.

Key words: *ocular optical components, emmetropia, emmetropization, echobiometry, axial length, keratometry*

Introduction

Emmetropization is a theorized process or mechanism thought to be responsible for the production of a greater frequency of emmetropia or near emmetropia than expected from random variation[1]. The number of emmetropes is three times higher than predicted in the normal Gauss distribution curve[2]. Ocular optical components, the most important of which are corneal and lens power as well as the axial length, interact in an individual way to create emmetropia[3]. Stenström has shown variations of axial length in emmetropes using radiological method in 1948[4]. Roger P. Harrie used echobiometry to prove the development of emmetropization in ammetropes[5].

The purpose of this study was to measure ocular optical components responsible for the refractive state of the eye in a large number of adult healthy emmetropes with clear lens as well as to evaluate their interactions. Our hypothesis was that physiologic variations in optical components are present in the emmetropic eye. These variations allow optical components to interact in such a way that emmetropia occurs. Documenting the range of variation for each optical component as well as the pattern of their interactions would help to explain the development of emmetropia.

Materials and Methods

A cross-sectional study of 1,000 healthy emmetropes, policemen by profession, aged from 18–40 years (yrs),

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seen in Ophthalmology Outpatient Clinic »Dom zdravlja MUP-a«, Zagreb, Croatia, was conducted. Out of total of 1,000 emmetropes, there were 129 female and 871 male subjects. The mean age was $\overline{X}$=20.96±8.14 yrs, Median (M)=18 yrs (18–36 yrs). Mean age of female was a bit higher, $\overline{X}$ =21.69±6.24 yrs, M=19 yrs than of males, $\overline{X}$ =20.86±6.13 yrs, M=18 yrs (24–40 yrs). The difference was not statistically significant. The subjects were divided into two groups: group I consisted of emmetropes younger than 25 yrs and group II of those between 25 and 40 yrs, unevenly distributed. Majority of subjects were in group I, 863/1,000, while only 137 were in group II.

Only emmetropes with visual acuity 1.0 without correction on both eyes were included in the evaluation. Noncycloplegic refraction was assessed with Nidek Autorefractokeratometer. Refractive error was converted to spherical equivalent (SE) (spherical diopteric power plus half of the cylindrical diopteric power). Emmetropes were defined as SE between –0,5 and +0,50 diopters (D). A detailed general and ocular history was taken and subjects with any disease, trauma or operation of the eyes were excluded. They all had given a written consent. The following examinations were performed on both eyes: far and near visual acuity tested with Snellen's and Jaeger's charts; biomicroscopy; aplanation tonometry; corneal radius measurement (CR) and keratometry: horizontal keratometry (K_1) reading and vertical keratometry (K_2) reading, performed with Nidek Autorefractokeratometer with index of refraction 1.3375); direct ophthalmoscopy and contact echobiometry in the supine position[6]. Anterior chamber depth (ACD), lens (L), vitreal body (CV) and axial length (Ax) were measured using the Alcon biometer, with 10 MHz probe. There were 10 echobiometric measurements performed for each eye. The machine saved numeric and graphic readings of each measurement. After the examination was completed, readings were reviewed and the one with the highest, symmetric echoes of all structures was recorded.

The axial length/corneal radius (Ax/CR) ratio was calculated for each eye.

Statistical analysis of measured and calculated parameters included descriptive statistics, Student's t-test by sex, eye and age, linear correlation of optical components and Spearman's rank correlation of all optical components between the right and the left eye.

Results

Descriptive statistics

Ocular optical components had a normal distribution. Descriptive statistics of optical components is given in Table 1 through 4. Corneal radius values were: for the right eye the mean CR was $\overline{X}$ =7.99±0.25 mm, M=7 mm (6.84 to 8.75 mm); for the left eye $\overline{X}$ =7.85±0.27 mm, M=7 mm (6.9 to 9.02 mm).

Student's t-test

By sex

CR value was higher in males on both eyes (t=5.63, p<0.001 for the right eye and t=5.59, p<0.001 for the left eye). Keratometry values (K_1 and K_2) were higher in female emmetropes. The difference was statistically significant for the K_1 and K_2 of both eyes (right eye: t=4.64, p<0.001 for K_1, t=5.64, p<0.001 for K_2; left eye: t=4.74, p<0.001 for K_1, t=5.62, p<0.001 for K_2). There was no statistically significant difference of the right eye corneal astigmatism between sexes. Left eye corneal astigmatism was higher in females with a statistically significant difference (t=3.15, p<0.005). There was no statistically significant difference of the right eye ACD between sexes (t=1.38). The left eye ACD value was higher in males. The difference was statistically significant (t=2.03, p<0.05). The lens was thicker in females. The difference was statistically significant for the right (t=3.25, p<0.001) and the left eye (t=3.4, p<0.001). The vitreal body was longer in males. The difference was statistically significant

TABLE 1
DESCRIPTIVE STATISTICS – KERATOMETRY OF HORIZONTAL AND VERTICAL MERIDIAN (IN DIOPTERS)

Keratometry	No of emmetropes	$\overline{X}$	Median	Minimum	Maximum	SD
right eye – K_1	1000	42.24	42.25	34.50	47.00	1.36
right eye – K_2	1000	43.02	43.00	39.00	48.00	1.44
left eye – K_1	1000	42.29	42.25	38.00	47.00	1.33
left eye – K_2	1000	43.07	43.00	39.25	48.25	1.43
right eye – f-K_1	129	42.75	42.75	39.25	45.75	1.23
right eye – f-K_2	129	43.68	44.00	39.75	46.75	1.34
left eye – f-K_1	129	42.81	42.79	39.50	45.50	1.22
left eye – f-K_2	129	43.73	44.00	40.25	46.50	1.33
right eye – m-K_1	871	42.16	42.25	34.50	47.00	1.36
right eye – m-K_2	871	42.92	43.00	39.00	49.25	1.43
left eye – m-K_1	871	42.21	42.25	38.00	47.00	1.33
left eye – m-K_2	871	42.98	43.00	39.25	48.25	1.42

K_1 – horizontal keratometry, K_2 – vertical keratometry, f – female, m – male

TABLE 2
DESCRIPTIVE STATISTICS – CORNEAL ASTIGMATISM (IN DIOPTERS)

Corneal astigmatism	No of emmetropes	$\overline{X}$	Median	Minimum	Maximum	SD
right eye	1000	–0.76	–0.75	–4.00	0.75	0.450
left eye	1000	–0.78	–0.75	–4.00	1.75	0.460
right eye – f	129	–0.92	–1.00	–2.75	–0.25	0.418
left eye – f	129	–0.91	–1.00	–2.25	1.75	0.477
right eye – m	871	–0.74	–0.75	–4.00	0.75	0.450
left eye – m	871	–0.76	–0.75	–4.00	0.75	0.450

f – female, m – male

TABLE 3
DESCRIPTIVE STATISTICS – BIOMETRIC VALUES OF OCULAR OPTICAL COMPONENTS (IN MM)

Ocular optical components	No of emmetropes	$\overline{X}$	Median	Minimum	Maximum	SD
ACD$_R$	1000	3.259	3,33	1.61	3.91	0.431
L$_R$	1000	3.958	3.94	2.71	6.94	0.429
CV$_R$	1000	16.26	16.20	13.01	19.88	0.747
AX$_R$	1000	23.45	23.46	21.04	26.4	0.747
ACD$_L$	1000	3.264	3.33	1.84	3.93	0.439
L$_L$	1000	3.962	3.94	2.64	5.05	0.398
CV$_L$	1000	16.25	16.20	14.02	19.42	0.713
AX$_L$	1000	23.48	23.48	21.11	28.46	0.703
ACD$_R$-f	129	3.210	3.33	2.07	3.91	0.446
L$_R$-f	129	4.072	4.00	3.07	6.94	0.459
CV$_R$-f	129	15.89	15.86	14.25	17.58	0.641
AX$_R$-f	129	23.18	23.23	21.27	24.96	0.668
ACD$_L$-f	129	3.190	3.33	2.11	3.91	0.450
L$_L$-f	129	4.074	3.94	2.95	4.92	0.420
CV$_L$-f	129	15.92	15.97	14.36	18.04	0.645
AX$_L$-f	129	23.17	23.23	21.20	24.94	0.648
ACD$_R$-m	871	3.266	3.33	1.61	3.91	0.428
L$_R$-m	871	3.940	3.94	2.71	6.94	0.422
CV$_R$-m	871	16.31	16.32	13.01	19.88	0.746
AX$_R$-m	871	23.49	23.49	21.04	26.40	0.751
ACD$_L$-m	871	3.275	3.33	1.84	3.93	0.438
L$_L$-m	871	3.946	3.94	2.64	5.05	0.393
CV$_L$-m	871	16.30	16.32	14.02	19.42	0.710
AX$_L$-m	871	23.52	23.54	21.11	28.46	0.700

ACD – anterior chamber depth, L – lens, CV – vitreal body, Ax – axial length, $_R$ – right eye, $_L$ – left eye, f – female, m – male

TABLE 4
AXIAL LENGTH/CORNEAL RADIUS RATIO (AX/CR) FOR THE RIGHT AND THE LEFT EYE OF ALL EMMETROPES AND WHEN DIVIDED IN GROUPS

AX /CR	No of emmetropes	$\overline{X}$	Median	Minimum	Maximum	SD
AX / CR$_R$	1000	2.96	2.90	2.58	3.44	0.08
AX / CR$_L$	1000	2.97	2.95	2.63	3.51	0.07
AX / CR$_R$ (I)	863	2.96	2.90	2.58	3.44	0.08
AX / CR$_L$ (I)	863	2.97	2.95	2.63	3.51	0.07
AX / CR$_R$ (II)	137	2.97	2.95	2.80	3.38	0.09
AX / CR$_L$ (II)	137	2.96	2.90	2.79	3.14	0.07

$_R$ – right eye, $_L$ – left eye, I – group of emmetropes younger than 25 years, II – group of emmetropes between 25 and 40 years for the right (t=6.12, p<0.001) and the left eye (t=5.72, p<0.001). The axial length value was higher in males. The difference was statistically significant for the right (t=2.03, p<0.05) and the left eye (t=5.42, p<0.001).

By eye

There was no statistically significant difference of ocular optical components between the fellow eyes in all subjects.

c) By age

Group I had a deeper ACD than group II in both eyes (t=6.22, p<0.001 for the right eye; t=6.17, p<0.001 for the left eye).The lens was thinner in group I than group II for both eyes (t=9.36; p<0.001 for the right eye; t=9.36; p<0.001 for the left eye).The vitreal body of both eyes was longer in group I than in group II (t=2.6, p<0.01 for the right eye; t=3.38, p<0.01 for the left eye). There was no statistically significant difference in the remaining ocular optical components between the groups.

Linear correlation of optical components

The highest correlation of Ax of both eyes was with CV (r=0.79 for the right eye, (Figure 1) and 0.81 for the left eye). Ax had a positive correlation with ACD on both eyes as well, but the coefficient was lower than for CV (r=0.29 for the right eye (Figure 2), r=0.32 for the left eye). The only negative correlation Ax had on both eyes was with L (r=–0.17 for the right eye (Figure 3) and r=–0.19 for the left eye).

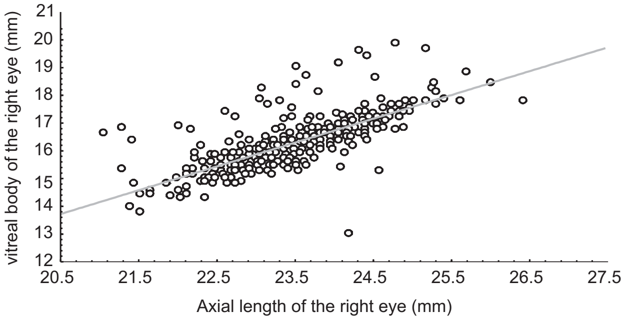

Fig. 1. The highest correlation of axial length of the right eye is with vitreal body. Ax – axial length, CV – vitreal body.

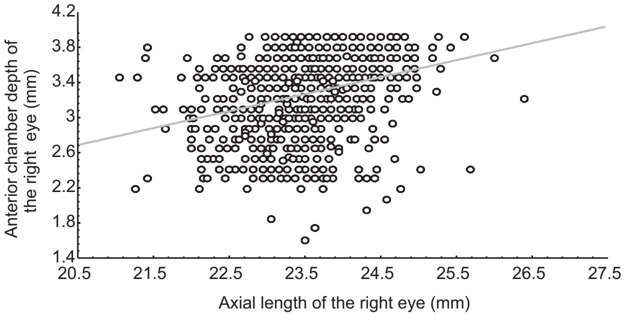

Fig. 2. The right eye axial length has a positive correlation with the anterior chamber depth. Ax – axial length, ACD – anterior chamber depth.

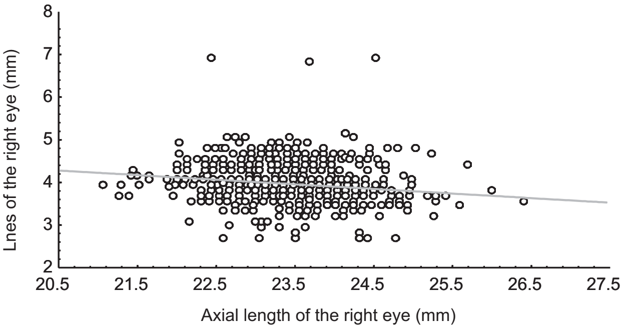

Fig. 3. The only negative correlation of the right eye axial length has is with the lens. Ax – axial length, L – lens.

CR had positive correlation with Ax (*r*=0.74, p< 0.001) and CV (*r*=0.79). It showed negative correlation with L (*r*=–0.58).

K_1 and K_2 had no correlation either with ACD or L. They showed a negative correlation with CV and Ax on both eyes (for K_1 r=–0.64 for CV, r=–0.54 for Ax; for K_2 r=–0.67 for CV, r=–0.68 for Ax).

ACD had a negative correlation with L on both eyes (r=–0.60 for the right eye; r=–0.47 for the left eye) and a small positive correlation with Ax (r=0.29 for the right eye; r=0.32 for the left eye). It had no correlation with CV.

CV had high, positive correlation with Ax (r=0.72 for the right eye; r=0.75 for the left eye). The correlation with K_1 and K_2 was negative.

The Ax/CR ratio had a correlation only with keratometry (r=0,38).

Spearman's rank correlation

The Spearman's rank correlation coefficient was calculated for all optical components between the right and the left eye. The highest was for K_1 and K_2 (R=0.97). Axial length had R of 0.92. Spearman's correlation coefficient for CR and CV was 0.89 and for ACD was a bit lower (R=0.64). The lowest was for L (R=0.56).

Disccussion

Ocular optical components interactions leading to emmetropic state of the eye have not yet been fully explained. According to the available literature, no paper has been published on echobiometric evaluation of a large number adult healthy emmetropes with clear lens. Two echobiometric studies performed on a large number of cataractous eyes were those of Shammas on 1,000[7] and Hoffer[8] on 7,500 eyes. Cataract increases the lens thickness and therefore changes the values of all optical components[9]. That is why optical components measured values found in those studies could not be considered as »standard« in clear lens emmetropic eyes nor can give an explanation of emmetropia. There have been numerous important papers documenting this process by following the eye growth in children[10–13] or on experimental animals[14], but the number of subjects involved was insufficient for conclusive results. Some of them investigated the same interactions of ocular optical components with comparable results to our study, such as those reported by Francois and Goes[15] and Barcsay et al[16]. However, the studied groups were much smaller.

Our prospective evaluation had been conducted mostly in policemen, which explains a high percentage of males (87.1%). Statistically significant differences in the ocular optical components between sexes were probably due to a much smaller female group combined with a very small real diversity in mean values of components. The reason for that was its leptokurtic distribution.

Echobiometry is widely used method of measuring ocular optical components[17,18]. A newer and seemingly 10 times more accurate method is Optical Coherence Tomography (OCT) [19,20]. However, it is still not accessible to us. We have used contact echobiometry. Although we were aware that immersion technique would have given more accurate results[21], it was not possible in our setting. One out of 10 readings for each eye, with equal, high echoes from all structures, was selected for the analysis. Although some authors recommend the application of several successive measurements[22], the use of a single high-quality axial length measurement has shown to be as accurate as the mean of three acceptable measurements[23].

In descriptive statistics (Table 1) there was an outlayer of keratometry reading of 34.5 D. Since it was measured in only one patient, this value had not influenced the main outcome. Also, ACD value of 1.61 mm (Table 3) was probably a measurement error since that eye was sine-morbo. This single mismeasurement had not influenced the main outcome. Table 2 shows a descriptive statistic of corneal astigmatism. Although, there is a range of corneal astigmatism from –4.0 D to +1.75 D, these patients still had 1.0 vision without correction.

Student's t-test showed no statistically significant difference in ocular optical components between the fellow eyes. Spearman's rank correlation test revealed extremely high and positive correlation of all ocular optical components between the fellow eyes. The highest correlation was noted for axial length and keratometry. Accordingly, in cases were we have documented emmetropic state of the eye prior to the pathology leading to keratoplasty, and where axial length or keratometry of one eye could not be measured, as for IOL calculation prior to triple procedure (perforative keratoplasty combined with extracapsulare extraction and intraocular lens implantation), its fellow eye values should be used instead of standard values. This is not in accordance with findings of Hoffer et al. [8] who found statistically significant difference between the eyes.

The Ax/CR ratio is very important parameter and the best predictor of the refractive state of the human eye[24,25]. It provides information on how best to determine the degree of emmetropization given by lens, decreasing its power and the ACD in concordance with Ax. A value of the ratio above 3.0 could be considered as a risk factor for the development of myopia in emmetropic eyes[25]. In our studied population Ax/CR ratio ranged from 2.58–3.51, mean value 2.96 for the right and 2.97 for the left eye. It is in concordance with work of Yebra-Pimentel et al[25]. They also found lower lens value as Ax/CR increased in all refractive groups. Our group I consisting of patients younger than 25 yrs, who had a thinner lens than group II, had lower minimal and higher maximal Ax/CR values than group II. The mean value and the median were the same for both groups. We did not present the linear correlation of Ax/CR with ACD, as Yebra-Pimentel et al[25] did in their paper. The only correlation of Ax/CR with ocular optical components we observed in our study was the one with keratometry, but the coefficient was very low.

The analysis showed that emmetropes younger than 25 yrs (group I) have a deeper anterior chamber, a thinner lens and a longer vitreal body than those 25–40 years old (group II). With all the other ocular optical components not being statistically different between the examined groups, the following conclusion imposes: the only ocular optical component changing with age after the eye has stopped growing is the lens. It gets thicker shalowing the anterior chamber and shortening the vitreal body. Might this lens thickening be a part of the beginning of cataract formation in 40 year-old persons? First, they had no history of any ocular or systemic disease that would cause cataract so early in life. All of them had 1.0 visual acuity. Finally, biomicroscopy showed no lens opacification.

The mean values of optical components in our work do not differ much from those reported in other papers with smaller groups of subjects[15,16,26–28]. However, its far wider range found the reason in 10 and more times higher number of emmetropes in our evaluation. The median was almost equal to mean value for all components and equal in the fellow eyes. By putting together median values of ocular optical components we have produced a model of a healthy emmetropic eye that, to some extent, could represent Croatian policemen and even age-matched population: CR=7 mm, K_1=42.25 D, K_2=43 D, Corneal astigmatism=–0.75 D, ACD=3.33 mm, L= 3.94 mm, CV=16.20 mm, Ax=23.4 mm (Figure 4.). However, the eye having such ocular optical values probably does not exist. In real life, axial length, corneal radius, keratometry, lens thickness and vitreal body are the most important ocular optical components responsible for emmetropia. This was shown through linear correlation coefficient. Ocular optical components correlated with each other following a pattern. This pattern is best represented by linear correlation coefficients of the axial length. It was the positive for CV and ACD, but more for CV. It was negative for K_1, K_2 and L. It means that in emmetropes with the axial length above the average value, the anterior chamber was deeper and the vitreal body longer, but the lens was thinner and cornea was of less power.

The following questions need to be answered: Which ocular optical component first starts to »stand out« of a normal eye growing process, that requires emmetro-

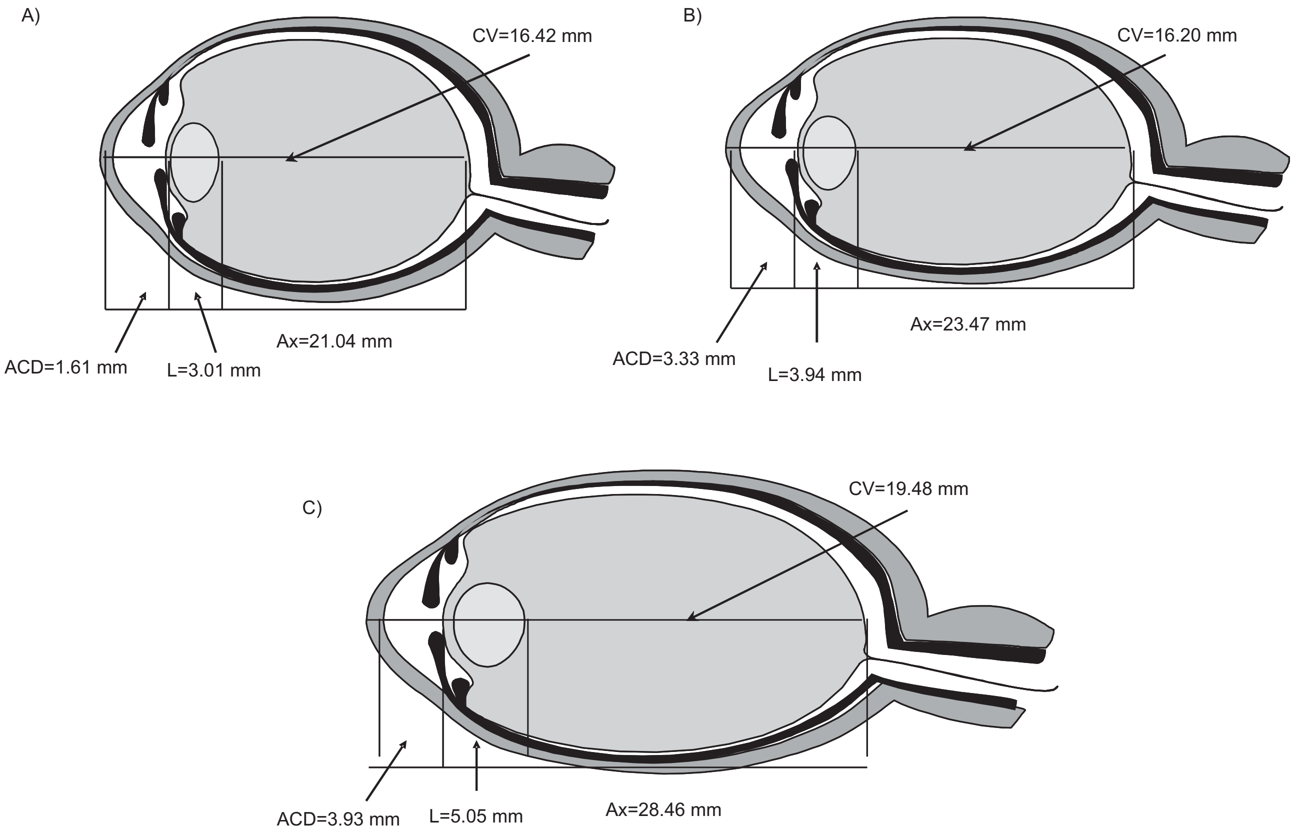

Fig. 4. Minimal, mean and maximal axial length of the eye. Eye A and C are real eyes, while B is model of the emmmetropic eye, made of median values of optical components. ACD – anterior chamber depth, L – lens, CV – vitreal body, Ax – axial length.

pization? How does emmetropization work? We do not know the answer to the former, but we think that wide range of ocular optical components values could be, at least to some extent, the answer to the latter question. For example, keratometry had a high variation of values. The »extreme« value of one component was combined with the »extreme« of other/s but in the opposite direction. For keratometry, axial length and vitreal body worked as a compensation mechanism in emmetropization. The proof for that was linear correlation of keratometry that was negative for CV and Ax and did not exist for others. It could be vice versa, that keratometry worked as compensatory mechanism to Ax and CV. But that would be the answer to the first question.

Conclusions

The most important ocular optical components in our studied population of emmetropes were axial length, corneal radius, keratometry, lens thickness and vitreal body. They interacted following a pattern in order to maintain emmetropia: when the axial length of emmetrope was above the average value, the vitreal body was longer, but the lens was thinner and the cornea was of less power. This could explain at least one of the mechanisms of emmetropization.

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B. Kuzmanović Elabjer

University Department of Ophthalmology, General Hospital »Sveti Duh«, Sveti Duh 64, 10000 Zagreb, Croatia
e-mail: ismat.elabjer@zg.htnet.hr

PRESJEČNA STUDIJA MEĐUSVEZE OČNIH OPTIČKIH ČIMBENIKA U EMETROPA

SAŽETAK

Rad je presječna studija međusveze očnih optičkih čimbenika (OOČ) u procesu emetropizacije Studija je provedena na 1000 zdravih emetropa, u dobi od 18–40 godina. Provedena su mjerenja rožničnog polumjera zakrivljenosti, keratometrija i ehobiometrija oba oka. Aksijalna duljina oka (Ax), rožnični polumjer zakrivljenosti (CR), keratometrija (K), debljina leće (L) i duljina staklastog tijela (CV) bili su najvažniji OOČ koji su međusvezom sudjelovali u nastanku emetropije. Ax je pokazala najvišu korelaciju s CV na oba oka ($r=0.79$ za desno oko (DO); $r=0.81$ za lijevo oko (LO)). Također je imala i pozitivnu korelaciju s dubinom prednje sobice (ACD) na oba oka, no koeficijent je vrlo nizak ($r=0.29$ za DO; $r=0.32$ za LO). Jedinu negativnu korelaciju Ax je imala s L na oba oka ($r=-0.17$ za DO; $r=-0.19$ za LO). Keratometrija horizontalnog meridijana (K_1) i vertikalnog meridijana (K_2) je negativno korelirala s CV i Ax na oba oka (za K_1 $r=-0.64$ za CV i $r=-0.54$ za Ax, za K_2 $r=-0.67$ za CV; $r=-0.68$ za Ax). CR je imala pozitivnu korelaciju s Ax ($r=0.74$) i CV ($r=0.79$). S L je dokazana negativna korelacija ($r=-0.58$). CV je imao visoku pozitivnu korelaciju s Ax ($r=0.72$ za DO; $r=0.75$ za LO). Korelacija s K1 i K2 je negativna. Najznačajniji OOČ u ispitivanoj populaciji emetropa su aksijalna duljina oka, rožnični polumjer zakrivljenosti, keratometrija, debljina leće i duljina staklastog tijela. Njihovom međusobnom korelacijom se održava emetropija: kod emetropa s aksijalnom duljinom oka većom od prosječne staklasto tijelo je također veće od prosjeka, no leća je tanja i rožnica je smanjene lomne jakosti. To bi mogao biti bar jedan od mehanizama koji sudjeluje u emetropizaciji.