Anterior movement of the crystalline lens in the process of accommodation in children

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PURPOSE. *To investigate changes of crystalline lens position during accommodation in children with emmetropia, myopia, and hyperopia.*
METHODS. *A total of 188 children (372 eyes) from 4 to 19 years old (mean age 11.3±4.43) with cycloplegic refractive error within a range +9.00 D to -9.00 D were enrolled. After a general ophthalmic examination, ultrasound biometry was performed, with the eye at a maximal accommodative effort. Cycloplegia was induced by triple installation of 1% tropicamide drops and 30 minutes later the biometric examination was repeated.*
RESULTS. *In emmetropic eyes in the process of accommodation, the anterior pole of the crystalline lens moved forward by 0.144±0.14 mm (p≤ 0.001); the position of the posterior pole did not change. In myopic eyes, the anterior pole moved forward by 0.071±0.13 mm (p≤0.001) and the posterior pole moved backward by 0.039±0.10 mm (p=0.003). In hyperopic eyes, the whole lens translocated anteriorly: anterior pole moved forward by 0.242±0.16 mm (p≤ 0.001) and posterior pole moved forward by 0.036±0.09 mm (p≤0.001). Differences among emmetropia, myopia, and hyperopia were statistically significant. Forward movement of the posterior pole correlated with a low axial length of the eye, and also with plus refractive error and with a smaller accommodative increase of lens thickness.*
CONCLUSIONS. *In children, accommodative changes of the crystalline lens position depend on refractive status. (Eur J Ophthalmol 2007; 17: 515-20)*

KEY WORDS. *Accommodation, Crystalline lens, Refractive errors*

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INTRODUCTION

The increase in the optical power of the eye during accommodation is caused by several changes in the crystalline lens, including alterations in lens shape, thickness, and position (1). Previous studies found that accommodation caused a decrease in the radius of curvature of the central portions of the anterior and posterior surfaces of the lens (2, 3), an increase in the thickness of the lens by 170 mm (4) to 406 mm (5), and forward movement of the anterior pole by 120 mm (6) to 350 mm (2). However, reports on the accommodative changes of the posterior pole position are inconsistent: some studies showed that the posterior pole does not change position (7-9) while others revealed backward movement (2, 5, 6, 11, 12). Because all of the previous studies on accommodative changes of crystalline lens position were performed on emmetropic or myopic adults, we undertook a study of lens movement in children, whose accommodation range is much higher than that of adults.

METHODS

A total of 188 children (97 girls and 91 boys; 372 individual eyes) 4 to 19 years old (mean age 11.3±4.43) were enrolled. Eyes with a best-corrected visual acuity (BCVA) of 10/20 or better that also exhibited a cycloplegic refractive

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error within a range +9.00 D to –9.00 D (spherical equivalent) were included. The analysis was divided into three age groups (4–8, 9–13, and 14–19 years) and further subdivided with respect to refractive error (emmetropia –0.99 to +0.99 D, myopia –1.0 to –9.0 D, and hyperopia +1.0 to +9.0). The details are shown in Table I.

The examination included an interview, autokeratorefractometry (NRK-8000, Nikon), uncorrected visual acuity, refractive error determination, BCVA, an intraocular pressure check with a Goldmann tonometer, and slit-lamp biomicroscopy. After these tests were completed, ultrasound biometry during maximal accommodative effort was performed. To achieve maximal accommodation, the contralateral eye was fully corrected for distance vision and focused on the chart at the near point. Cycloplegia was induced by triple installation of 1% tropicamide (1% Tropicamidum, Polfa Warszawa, Poland). Thirty minutes later, ultrasound biometry, tonometry, autorefractometry, and a fundus examination were performed.

Contact biometric measurements were carried out with an ultrasound biometer (Ocuscan, Alcon) in semiautomatic mode. The instrument was calibrated for a velocity of 1532 m/s for the aqueous humor and vitreous, and 1641 m/s for the crystalline lens. The subjects were seated in an upright position, and corneas were anesthetized with one drop of 0.5% proparacaine hydrochloride (Alcaine, Alcon). Ten-MHz concave-ended probe in a spring-loaded hand-held assembly was applied with minimal compression to the center of the cornea perpendicular to the X-Z plane. A total of 10 measurements showing maximal peaks on an ultrasonogram and standard deviations of less then 0.1 mm were taken and subsequently averaged for anterior chamber depth, lens thickness, and vitreous chamber depth. Eyes for which the intraocular pressure (during accommodation and after cycloplegia) changed more then 3 mm Hg were excluded from the study. All procedures were performed by the same examiner (B.K.).

Statistical analysis of the accommodative changes was performed using a paired *t*-test after normal distribution was verified with the Shapiro-Wilk test. Analysis of variance and the Tukey test were used to determine whether differences among subgroups were statistically significant. Pearson correlation coefficient was used to examine the correlation of the posterior pole position change with other variables.

The study was approved by the ethics committee of the Collegium Medicum, Nicolaus Copernicus University, Bydgoszcz, Poland.

RESULTS

Anterior pole position

In ultrasound biometry analyses, the anterior chamber depth (ACD) is the distance from a probe tip on the surface of the central cornea to the anterior pole of the crystalline lens. Thus, ACD represents the position of the anterior pole of the lens (anterior pole position; APP). In emmetropic eyes in the process of accommodation, we

TABLE I - DEMOGRAPHICS AND CLINICAL PROFILES OF SUBGROUPS

Subgroup	Age range, yr	Mean ± SD age, yr	Refractive error range, D	Mean ± SD cycloplegic refractive error, D	Mean ± SD axial length after cycloplegia, mm	No. of eyes
4-8E	4-8	6.62 ± 1.06	–0.99 to +0.99	+0.60 ± 0.27	22.241 ± 0.71	42
9-13E	9-13	11.13 ± 1.64	–0.99 to +0.99	+0.31 ± 0.37	22.945 ± 0.62	32
14-19E	14-19	16.29 ± 1.29	–0.99 to +0.99	+0.03 ± 0.34	23.081 ± 0.84	55
4-19E	**4-19**	**11.90 ± 4.39**	**–0.99 to +0.99**	**+0.29 ± 0.41**	**22.773 ± 0.83**	**129**
4-8M	4-8	6.56 ± 1.59	–1.0 to –9.0	–2.69 ± 1.99	23.750 ± 1.08	32
9-13M	9-13	11.25 ± 1.57	–1.0 to –9.0	–2.51 ± 1.48	24.111 ± 0.77	32
14-19M	**14-19**	**16.63 ± 1.24**	**–1.0 to –9.0**	**–3.13 ± 2.07**	**24.741 ± 1.07**	**41**
4-19M	4-19	11.90 ± 4.45	–1.0 to –9.0	–2.80 ± 1.89	24.247 ± 1.07	105
4-8H	4-8	6.08 ± 1.41	+1.0 to +9.0	+4.22 ± 2.56	21.326 ± 1.04	53
9-13H	9-13	10.67 ± 1.37	+1.0 to +9.0	+3.88 ± 2.26	21.920 ± 1.08	54
14-19H	14-19	16.81 ± 1.28	+1.0 to +9.0	+2.58 ± 1.79	22.042 ± 1.01	31
4-19H	**4-19**	**10.30 ± 4.29**	**+1.0 to +9.0**	**+3.72 ± 2.36**	**21.719 ± 1.09**	**138**
All patients	**—**	**11.30 ± 4.43**	**—**	**+0.69 ± 3.17**	**22.798 ± 1.42**	**372**

E = Emmetropic; M = Myopic; H = Hyperopic found that the anterior pole moved forward by an average of 0.144±0.14 mm. In myopic eyes and hyperopic eyes, the anterior pole moved forward by an average of 0.071±0.13 mm and by 0.242±0.16 mm, respectively. Differences between those subgroups are statistically significant. See Table II for details.

Lens thickness

Lens thickness (LT) is the distance between the anterior and posterior poles of the lens. In emmetropic eyes during accommodation, the mean LT increased by 0.139±0.13 mm. In myopic eyes and in hyperopic eyes the mean LT increased by 0.110±0.14 mm and by 0.205±0.16 mm, respectively. Differences between these subgroups are statistically significant. The details are shown in Table III.

Posterior pole position

The position of the posterior pole (posterior pole position; PPP) of the lens may be determined as the distance between a probe tip on the surface of the central cornea and the posterior pole of the lens. Thus, it is equal to the

TABLE II - CHANGES OF MEAN ANTERIOR POLE POSITION (APP) DURING ACCOMMODATION IN SUBGROUPS

Subgroup	Mean ± SD APP after cycloplegia, mm	Mean ± SD APP at maximal accommodative effort, mm	Change ± SD, mm	p value
4–8E	3.489 ± 0.20	3.297 ± 0.24	–0.192 ± 0.15	≤0.001
9–13E	3.644 ± 0.16	3.527 ± 0.18	–0.117 ± 0.15	≤0.001
14–19E	3.612 ± 0.24	3.491 ± 0.28	–0.121 ± 0.10	≤0.001
4–19E	**3.580 ± 0.21**	**3.436 ± 0.26**	**–0.144 ± 0.14**	**≤0.001**
4–8M	3.594 ± 0.25	3.495 ± 0.23	–0.099 ± 0.12	≤0.001
9–13M	3.712 ± 0.14	3.637 ± 0.22	–0.075 ± 0.17	0.022
14–19M	3.744 ± 0.15	3.696 ± 0.17	–0.048± 0.11	0.022
4–19M	**3.688 ± 0.19**	**3.617 ± 0.22**	**–0.071 ± 0.13**	**≤0.001**
4–8H	3.357 ± 0.25	3.093 ± 0.29	–0.264 ± 0.17	≤0.001
9–13H	3.546 ± 0.22	3.332 ± 0.27	–0.214 ± 0.18	≤0.001
14–19H	3.463 ± 0.25	3.212 ± 0.29	–0.251 ± 0.11	≤0.001
4–19H	**3.455 ± 0.25**	**3.213 ± 0.30**	**–0.242 ± 0.16**	**≤0.001**
All patients	**3.564 ± 0.24**	**3.405 ± 0.31**	**–0.159 ± 0.16**	**≤0.001**

– Indicates forward movement.
E = Emmetropic; M = Myopic; H = Hyperopic

TABLE III - CHANGES IN MEAN LENS THICKNESS (LT) DURING ACCOMMODATION IN SUBGROUPS

Subgroup	Mean ± SD LT after cycloplegia, mm	Mean ± SD LT at maximal accommodative effort, mm	Change ± SD, mm	p value
4–8E	3.479 ± 0.16	3.679 ± 0.21	0.200 ± 0.13	≤0.001
9–13E	3.389 ± 0.18	3.516 ± 0.17	0.127 ± 0.09	≤0.001
14–19E	3.443 ± 0.19	3.542 ± 0.23	0.099 ± 0.13	≤0.001
4–19E	**3.441 ± 0.18**	**3.580 ± 0.22**	**0.139 ± 0.13**	**≤0.001**
4–8M	3.468 ± 0.22	3.604 ± 0.22	0.136 ± 0.17	≤0.001
9–13M	3.389 ± 0.14	3.511 ± 0.19	0.122 ± 0.14	≤0.001
14–19M	**3.439 ± 0.15**	**3.521 ± 0.18**	**0.082 ± 0.11**	**≤0.001**
4–19M	4.433 ± 0.18	4.543 ± 0.20	0.110 ± 0.14	≤0.001
4–8H	3.532 ± 0.23	3.770 ± 0.27	0.238 ± 0.19	≤0.001
9–13H	3.417 ± 0.18	3.596 ± 0.22	0.179 ± 0.16	≤0.001
14–19H	3.485 ± 0.22	3.681 ± 0.23	0.196 ± 0.11	≤0.001
4–19H	**3.477 ± 0.21**	**3.682 ± 0.26**	**0.205 ± 0.16**	**≤0.001**
All patients	**3.452 ± 0.19**	**3.608 ± 0.23**	**0.156 ± 0.15**	**≤0.001**

E = Eemmetropic; M = Myopic; H = Hyperopic sum (ACD + LT), where ACD is the anterior chamber depth, and LT is the lens thickness. In emmetropic eyes, the position of the posterior pole did not significantly change during accommodation. In myopic eyes, the posterior pole moved backward by an average of 0.039±0.10 mm while in hyperopic eyes, the posterior pole moved forward by an average of 0.036±0.09 mm. Differences among posterior pole movement in emmetropia, myopia, and hyperopia were statistically significant. Table IV shows the differences between subgroups in detail. I also observed significant correlations between changes in the PPP and refractive error (r=–0.202, p<0.001), between changes in the PPP and axial length (r=0.199, p<0.001), and between changes in the PPP and the accommodative increase of LT (r=0.300, p<0.001). I have noted a stronger tendency of the posterior pole to move forward during accommodation in more hyperopic eyes, with a correspondingly shorter axial length and a smaller accommodative increase of LT.

DISCUSSION

In the last several decades, there have been a number of studies on accommodative changes of the axial dimensions of the eye in emmetropic and myopic adults (4-6,

TABLE IV - CHANGES IN MEAN POSTERIOR POLE POSITION (PPP) DURING ACCOMMODATION IN SUBGROUPS

Subgroup	Mean ± SD PPP after cycloplegia, mm	Mean ± SD PPP at maximal accommodative effort, mm	Change ± SD, mm	p value
4–8E	6.968 ± 0.20	6.976 ± 0.18	+0.008 ± 0.11	0.312
9–13E	7.033 ± 0.18	7.043 ± 0.20	+0.010 ± 0.12	0.336
14–19E	**7.055 ± 0.21**	**7.033 ± 0.22**	**–0.022 ± 0.13**	**0.113**
4–19E	7.021 ± 0.20	7.017 ± 0.21	–0.004 ± 0.12	0.692
4–8M	7.062 ± 0.23	7.099 ± 0.24	+0.037 ± 0.12	0.178
9–13M	7.101 ± 0.18	7.147 ± 0.18	+0.046 ± 0.11	0.012
14–19M	7.183 ± 0.20	7.217 ± 0.20	+0.034 ± 0.12	0.043
4–19M	**7.121 ± 0.24**	**7.16 ± 0.21**	**+0.039 ± 0.10**	**0.003**
4–8H	6.889 ± 0.21	6.863 ± 0.21	–0.026 ± 0.10	0.033
9–13H	6.963 ± 0.25	6.928 ± 0.25	–0.035 ± 0.10	<0.015
14–19H	6.948 ± 0.23	6.892 ± 0.23	–0.056 ± 0.07	≤0.001
4–19H	**6.931 ± 0.23**	**6.895 ± 0.23**	**–0.036 ± 0.09**	**≤0.001**
All patients	**7.016 ± 0.23**	**7.012 ± 0.24**	**–0.004 ± 0.11**	**0.251**

– Indicates forward movement; + indicates backward movement.
E = Emmetropic; M = Myopic; H = Hyperopic

TABLE V - ACCOMMODATIVE CHANGES OF AXIAL DIMENSIONS IN RELEVANT STUDIES PUBLISHED TO DATE

Authors	Examination technique	No. of eyes	Age, yr	Refractive error, D	Mean ACD change, mm	Mean LT change, mm	Mean PPP change, mm
Coleman (5)	UB	50	22 to 29		–0.285	+0.406	+0.121
Shum Joi-Tsang et al (6)	UB	60	19.6 (mean)	–3.2 (mean)	–0.11	+0.19	+0.08
Garner and Yap (12)	UB	11	21.2 (mean)	–1.9 (mean)	–0.24	+0.28	+0.04
Drexler et al (11)	PCI	20	30 (mean)	0.0 to –5.0	–0.186	+0.258	+0.072
Drexler et al (4)	PCI	22	25.8 (mean)	–0.3 (mean)	–0.126	+0.17	+0.044
		24	25.0 (mean)	–3.5 (mean)	–0.135	+0.18	+0.045
Bayramlar et al (10)	UB	248	14 to 22	+0.4 (mean)	–0.12	+0.2	+0.08

+ Indicates an increase in a given value (in the case of PPP, + Indicates backward movement); – Indicates a decrease in a given value.
ACD = Anterior chamber depth; LT = Lens thickness; PPP = Posterior pole position; UB = Ultrasound biometry; PCI = Partially coherent interferometry

10-12). All of these studies noted that during accommodation, there was a decrease in ACD, indicating forward movement of the anterior pole of the lens, an increase of LT, and backward movement of the posterior pole. A summary of the results of these previous studies is shown in Table V.

In the present study of accommodative changes in children, I noted a decrease in ACD and an increase in LT in all subgroups likewise. However, I also observed a change in PPP dependent on refractive error. In emmetropic eyes, there was no significant change in the posterior pole position during accommodation. An increase in LT was associated only with forward movement of the anterior pole by an average of 0.114±0.14 mm. In myopia, the anterior pole moved forward by an average of 0.071±0.13 mm and the posterior pole moved backward by an average of 0.039±0.10 mm. Thus, in myopia, the geometric center of the lens changed its position by an average value of only 0.016 mm. In hyperopic eyes, where the highest accommodative increase of LT was noted, both anterior and posterior poles moved forward by an average of 0.242±0.16 mm and 0.036±0.09 mm, respectively. Forward movement of the posterior pole was correlated with a low axial length of the eye and plus refractive error. Surprisingly, a higher accommodative increase of LT was correlated with a stronger tendency of the posterior pole to move backward. This led to the conclusion that in hyperopic eyes, the forward movement of the whole lens (both anterior and posterior poles) is not a result of a higher accommodative effort of the lens.

In this study, we describe for the first time anterior movement of the whole crystalline lens in human eye. However, forward movement of the PMMA as well as foldable and accommodating IOLs have been previously reported (13, 14). A possible mechanism that may explain those observations is that increased pressure in the vitreous cavity is a driving a force on the posterior surface of the accommodating lens. The role of vitreous body in the process of accommodation was first proposed by Cramer in 1851 (15), and subsequently studied in more detail by Coleman (16-18). However, the Helmholtz theory of accommodation, which is still the most widely accepted, neglects the role of the vitreous body (19). Results of our study may support the theory that the vitreous body plays an active role in the process of accommodation. The discrepancy among emmetropic, myopic, and hyperopic eyes, as noted in the study, may be explained by the different volumes of the vitreous cavity and by differences in ocular rigidity (20) in these different types of eyes. These differences may collectively result in an unequal pressure increase during accommodation. It has also been proposed that anterior accommodative movement of the lens may be caused by forward movements of the ciliary processes (22). Several experimental and clinical studies of primates and humans showed that during accommodation, the apex of the ciliary processes moves forward and toward the center of the eye (19, 23-25). Thus, a contraction of ciliary muscle places a force along the zonules that may also result in anterior translocation of the crystalline lens.

How does anterior movement of the accommodating lens influence optical properties of the eye? According to Lin (21), forward movement of the lens by 1 mm results in an increase of optical power by 1.1 to1.5 D. Thus, from an optical point of view, the forward movement of the crystalline lens that I observed in children's eyes is not important. However, vitreous pressure, according to Coleman's theory of accommodation (16-18), may play a role in modeling of the lens shape.

In conclusion, in children in the process of accommodation a decrease in ACD and an increase in LT were found, while changes in PPP depended on refractive error. In emmetropic eyes, there was no significant change in the PPP during accommodation. In myopic eyes it moved backward whereas in hyperopic eyes it moved forward.

The study was approved by the Ethics Committee of the Collegium Medicum, Nicolaus Copernicus University, Bydgoszcz, Poland (December 20, 1999).

The author has no proprietary interest.

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