The Change in Ocular Refractive Components After Cycloplegia in Children

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Purpose: To study the change in ocular refractive components after cycloplegia in children.

Methods: Anterior chamber depth, lens thickness, vitreous chamber length, and ocular axial length were measured in 135 Chinese children (270 eyes) before and after cycloplegia. The corneal curvatures of 136 selected eyes were studied before and after cycloplegia with a computerized video keratoscope.

Results: Anterior chamber depth increased ($P < .001$) while both lens thickness and vitreous chamber length decreased ($P < .001$) significantly after cycloplegia regardless of the refractive state. However, axial length increased in hyperopic eyes ($P = .027$) but decreased in myopic eyes ($P = .008$) after cycloplegia. Mean corneal power of zones 3 mm (MD3, $P = .009$) and keratometer K1 readings increased ($P = .025$) in hyperopic eyes, while MD3 ($P = .033$), K1 ($P = .039$) and K2 ($P = .003$) readings decreased in myopic eyes significantly after cycloplegia. Similarly, mean corneal power of zones 5 mm and 7 mm in myopic eyes decreased dramatically ($P \leq .001$). In both hyperopic and myopic eyes, there was significant difference ($P < .001$) in the mean value of the upper and lower half of the vertical meridian, as well as the medial and lateral half of the horizontal meridian, respectively.

Conclusions: Cycloplegia has a great influence on various refractive components in children. There is asymmetry of the corneal surface within the same horizontal or vertical meridian. **Jpn J Ophthalmol 2002;46:293–298** © 2002 Japanese Ophthalmological Society

Key Words: Accommodation, corneal topography, cycloplegia, biologic measurement, refractive component

Introduction

It is now understood that several components contribute to refractive error, including corneal curvature, anterior chamber depth, lens power, and axial length.[1–3] Thus, the refractive state of one eye is determined by the magnitude of each refractive component and its interaction with the other components. We conducted the current study to determine the influence of cycloplegia on refractive components in children by means of modern measurement techniques, and then proceeded to investigate the role of accommodation in the development of ametropia.

Materials and Methods

Subjects

A total of 135 Chinese children (270 eyes) were examined. Informed consent was obtained from their parents. Ages ranged from 7 to 13 years (mean = 9.6 ± 2.30 years). Sixty-eight (50.37%) subjects (136 eyes) with a wide enough palpebral fissure were selected from the 135 subjects and enrolled in corneal topography analysis. All subjects satisfied the following criteria: (1) No subject had worn contact lenses; (2) Cornea topography was taken at least 12 hours after the last administration of atropine ointment but before the ultrasound examination, in order to mini-

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mize the influence on corneal topography; (3) Slit-lamp microscopy and fundus examinations were performed to rule out any ocular diseases.

Apparatus and Procedure

The cycloplegic regime was 1% atropine sulphate ointment twice a day for 5 days. All measurements were taken before and after cycloplegia. For the subjects with spectacles, the ocular components were measured after spectacles had been removed for about 3 minutes. All measurements were done by the same examiner (LG), except that cycloplegic refractive state (objective refraction) was recorded by another examiner (XYZ) with the Canon RK-5 automated refractor (Canon, Tokyo). Emmetropia was defined as spherical equivalent refraction from −0.5 diopter (D) to +0.75 D. Hypermetropia was defined as spherical equivalent refraction greater than +0.75 D. Myopia was defined as spherical equivalent refraction less than −0.5 D.

Anterior chamber depth, lens thickness, vitreous chamber length, and axial length were measured with A-scan of Sonomed 5500A/B ultrasound (Sonomed, Lake Success, NY, USA). System calibration was done prior to each measurement. All subjects were instructed to gaze at a fixation target 30 cm away with both eyes open at all times in order to stimulate and maintain accommodation in subjects as much as possible. Five reliable readings of each ocular component were taken from each subject and the mean value was recorded.

Corneal topography was obtained with a computerized video-keratoscope (Dicon CT 200, Software version 3.30; a division of Vismed, San Diego, CA, USA). The mean value of the upper half (UMD) and lower half (LMD) of the vertical meridian, as well as the medial half (MMD) and lateral half (LaMD) of the horizontal meridian were measured and calculated as shown in Figure 1.

Calibration and verification were performed weekly to ensure the reproducibility of readings. For each eye, measurements were repeated until a well-focused corneal image was captured. Both the focus and axial offset were within ±0.1 mm. Corneal images within at least 7.5 mm in diameter presented no distortion.

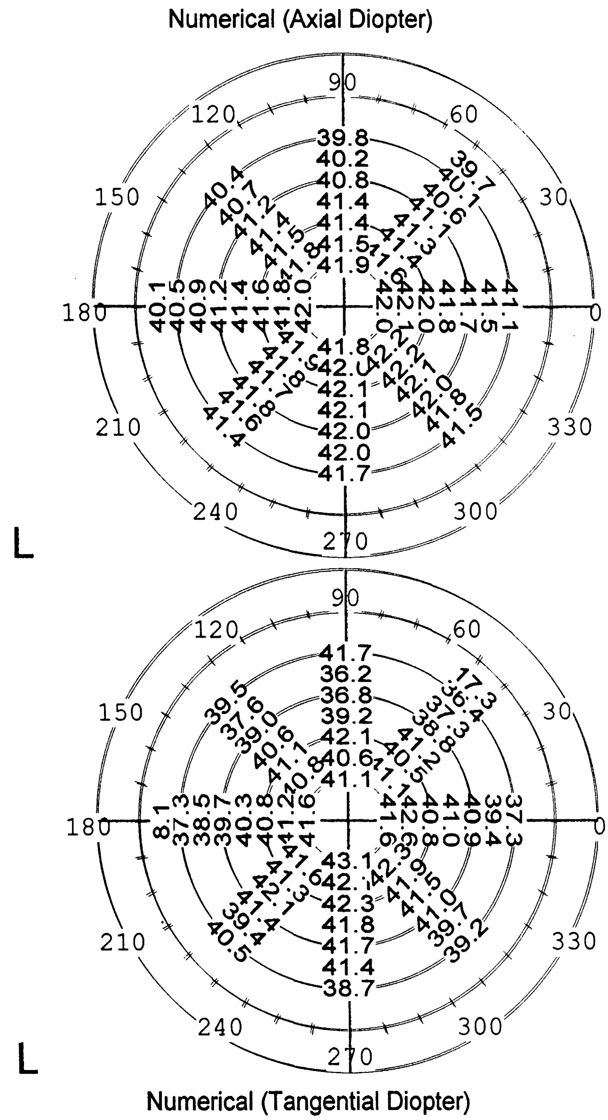

Figure 1. Numerical Corneal Topography of left eye of representative patient. The mean value of the upper half (UMD) and lower half (LMD) of the vertical meridian, as well as the medial half (MMD) and lateral half (LaMD) of the horizontal meridian were measured and calculated as: (1) LMD = (41.8 + 42 + 42.1 + 42.1 + 42 + 42) ÷ 6. (2) LaMD = (42 + 42.1 + 42 + 41.8 + 41.7 + 41.5) ÷ 6. (3) UMD = (41.9 + 41.5 + 41.4 + 41.440.8 + 40.2) ÷ 6; (4) MMD = (42 + 41.8 + 41.6 + 41.4 + 41.2 + 40.9) ÷ 6.

Statistical Analysis

The results of *t*-test and normal distribution analysis of paired samples were processed by means of SPSS 8.0 statistical software (SPSS; Cary, NC, USA) for all the variables. A *P*-value of $<.05$ was considered statistically significant.

Results

The results of a normality test showed that the distribution of all variables both before and after cycloplegia was normal ($-1 <$ Skewness < 1).

Table 1. Patient Demographics and Refractive Status of All Subjects (270 Eyes)

	Hyperopia	Emmetropia	Myopia
No. of eyes	118	38	114
Male/female (eyes)	44/74	24/14	58/56
Age (years)*	8.90 ± 1.18	8.50 ± 0.85	9.60 ± 1.12
Refractive state (diopter)*	4.57 ± 2.17	0.11 ± 0.47	−2.47 ± 1.80

*Values are mean ± SD.

One hundred and thirty-five children (270 eyes) were examined with A-scan of ultrasound. The patient demographics and refractive status are shown in Table 1. Data from A-scan ultrasonic measurements before and after cycloplegia are shown in Table 2, and pair sample *t*-test results of various ocular components are shown in Table 3. Anterior chamber depth increased ($P < .001$) while both lens thickness and vitreous chamber length decreased ($P < .001$) significantly after cycloplegia, regardless of the refractive state. However, axial length increased in hyperopic eyes ($P = .027$) but decreased in myopic eyes ($P = .008$) after cycloplegia. Based on the formula, the backward movement of the lens = (VL + 1/2 LT) − ($VL^‡$ + 1/2$LT^‡$), the backward movement of the lens was 0.20 mm, 0.14 mm, and 0.08 mm for hyperopic, emmetropic, and myopic eyes, respectively, under cycloplegia.

A total of 136 eyes were examined by corneal topography analysis. Eleven emmetropic eyes were excluded from the final analysis because of small sample size. The patient demographics and refractive status of the hyperopic and myopic groups (125 eyes) are shown in Table 4. Findings of the mean

Table 2. Descriptive Statistics of A-scan Findings of Various Ocular Components (270 Eyes)*

A-scan Variable† (mm)	Hyperopia (n = 118)	Emmetropia (n = 38)	Myopia (n = 114)
AD	3.31 ± 0.22	3.68 ± 0.29	3.76 ± 0.30
AD‡	3.66 ± 0.17	3.85 ± 0.27	3.88 ± 0.28
LT	3.72 ± 0.22	3.57 ± 0.19	3.49 ± 0.24
LT‡	3.46 ± 0.16	3.44 ± 0.15	3.40 ± 0.18
VL	14.62 ± 1.09	16.32 ± 0.79	17.18 ± 1.04
VL‡	14.54 ± 1.09	16.24 ± 0.79	17.14 ± 1.04
AL	21.64 ± 1.09	23.54 ± 0.88	24.44 ± 1.06
AL‡	21.66 ± 1.08	23.51 ± 0.90	24.42 ± 1.06

*Values are mean ± SD.

†AD: anterior chamber depth, LT: lens thickness, VL: vitreous chamber length, AL: axial length.

‡Data obtained after cycloplegia.

Table 3. Paired Sample *t*-Test of Corresponding A-scan Findings of Various Ocular Components Before and After Cycloplegia (270 Eyes)

A-scan Variable* (mm)	Hyperopia (n = 118)	Emmetropia (n = 38)	Myopia (n = 114)
AD	$P < .001$	$P < .001$	$P < .001$
LT	$P < .001$	$P < .001$	$P < .001$
VL	$P < .001$	$P = .006$	$P < .001$
AL	$P = .027$	$P = .281$	$P = .008$

*AD: anterior chamber depth, LT: lens thickness, VL: vitreous chamber length, AL: axial length.

corneal power of zones 3 mm (MD3), 5 mm (MD5), and 7 mm (MD7) in diameter as well as the major keratometer K1 and minor keratometer K2 readings with their corresponding paired sample *t*-test results are presented in Table 5. They show that MD3 ($P = .009$) and K1 increased ($P = .025$) in hyperopic eyes, while MD3 ($P = .033$), K1 ($P = .039$) and K2 ($P = .003$) decreased significantly in myopic eyes after cycloplegia. Similarly, MD5 and MD7 in myopic eyes decreased dramatically ($P \leq .001$). For hyperopic eyes, there was an increase of K2, MD5, and MD7, which was not statistically significant. Additionally, similar data and statistics of the mean value of the UMD and LMD of the vertical meridian, as well as the MMD and LaMD of the horizontal meridian are shown in Table 6.

Discussion

Refractive error has been chosen by The World Health Organization as one of the five priority areas in the "Vision 2020" program.[4] Within the ophthalmic community, there has been extensive discussion of the influence of hereditary and environmental factors in the development and progression of myopia. Epidemiological studies indicate that myopia represents a growing public health problem. It has been shown that the average prevalence of myopia among different age groups of school children in

Table 4. Patient Demographics and Refractive Status of the Corneal Topographic Group (125 Eyes)

	Hyperopia	Myopia
No. of eyes	46	79
Male/female (eyes)	20/26	38/41
Age (years)*	9.80 ± 1.18	9.60 ± 1.38
Refractive state (diopter)*	5.47 ± 2.50	−2.63 ± 1.79

*Values are mean ± SD.

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Table 5. Statistical Findings by Corneal Topography (125 Eyes)

Variable* (D)	Hyperopia (n = 46)	Myopia (n = 79)
MD3	42.64 ± 1.50	43.23 ± 1.41
MD3†	42.85 ± 1.58	43.18 ± 1.42
t-Test (MD3-MD3†)	*P* = .009	*P* = .033
MD5	42.43 ± 1.61	42.91 ± 1.42
MD5†	42.54 ± 1.63	42.85 ± 1.40
t-Test (MD5-MD5†)	*P* = .072	*P* = .001
MD7	41.81 ± 1.69	42.27 ± 1.35
MD7†	41.87 ± 1.53	42.18 ± 1.35
t-Test (MD7-MD7†)	*P* = .431	*P* < .001
K1	43.52 ± 1.55	43.65 ± 1.61
K1†	43.69 ± 1.73	43.59 ± 1.61
t-Test (K1-K1†)	*P* = .025	*P* = .039
K2	41.82 ± 1.65	42.66 ± 1.39
K2†	41.88 ± 1.59	42.58 ± 1.37
t-Test (K2-K2†)	*P* = .164	*P* = .003

*values are mean ± SD.

D: diopter, MD3: mean corneal power of zone 3 mm, MD5: mean corneal power of zone 5 mm, MD7: mean corneal power of zone 7 mm, K1 = keratometer K1, K2 = keratometer K2, *t*-Test: paired sample *t*-test.

†Data obtained after cycloplegia.

the Wenzhou area of south China has reached 53.8%.[5] It is double the average of 15 years ago. In Singapore there has been a similar trend of increase over the last decade.[6] These reported increases in myopia over the last generation may be attributed to the changes in the accommodative environment for eyes. During the last decade in Chinese societies, the environment has changed as primary and secondary school children spend more time coping with the increasing demand for near reading and watching, especially during their periods of rapid body growth.

Table 6. Statistical Findings of Partial Corneal Meridian Power Without Cycloplegia (125 Eyes)

Variable* (D)	Hyperopia (n = 46)	Myopia (n = 79)
UMD	42.92 ± 1.55	42.94 ± 1.60
LMD	43.42 ± 1.74	43.54 ± 1.56
t-Test (UMD-LMD)	*P* < .001	*P* < .001
MMD	41.42 ± 1.69	42.24 ± 1.35
LaMD	42.12 ± 1.67	42.66 ± 1.34
t-Test (MMD-LaMD)	*P* < .001	*P* < .001

*Values are mean ± SD.

D: diopter, UMD: mean value of the upper half of the vertical meridian. LMD: mean value of the lower half of the vertical meridian, MMD: mean value of the medial half of the horizontal meridian, LaMD: mean value of the lateral half of the horizontal meridian. *t*-Test: paired sample *t*-test.

Numerous theories have been presented in the last 100 years to account for the axial elongation associated with myopia. Many of the early theories involved various mechanical influences on the sclera.[1] The more recent theories suggest scleral growth regulated by feedback signals from retinal images. Experimental evidence has revealed that in the absence of a clear retinal image, eye growth is disturbed, which results in deprivation myopia.[7,8] As the quality of the retinal image is dependent on the refraction of the eye, viewing distance, and the state of ocular accommodation, the interaction between viewing distance and accommodation should be given high priority.

As long as 4 centuries ago, in 1619, Scheiner proved that accommodation occurs. However, accommodation is a research field in which agreement has not been reached.[9] From the viewpoint of human evolution, accommodation is the most original and essential element, compared to convergence and mydriasis.[1] In human eyes, the lens suffers dramatic changes in its dimension and surface during accommodation.

Atropine is the most powerful medicinal cycloplegic agent. It is known to all of us that the accommodation stimulated before cycloplegia will definitely be much more than that stimulated under cycloplegia, regardless of the refractive state. This may be confirmed by the measurement of the antero-posterior dimensions of the lens. As the accommodation state we worked with was a 30-cm distance to the fixation target with both eyes open in A-scan measurement and topography examination pre- and post-cycloplegia, the data we obtained before cycloplegia represented the state of one eye in near viewing condition, whereas the data under cycloplegia represented that of one eye in far viewing condition. So it would be reasonable for us to learn the effect of "enlarged accommodation" —the amplitude of accommodation was enlarged by the application of atropine—on refractive components before and after cycloplegia. However, this "enlarged accommodation" would have an influence on ocular components similar to that of physiological or real accommodation from the viewpoint of lens changes, because the accommodation of human eyes mainly relies on the change of the lens in shape. This was fully proven in our experiment by the significant decrease in lens thickness after cycloplegia for each group. From Table 2, the decrease in mean lens thickness was 0.26 mm, 0.13 mm, and 0.09 mm for hyperopic, emmetropic, and myopic eyes, respectively, after cycloplegia. So the data we recorded before cycloplegia could be regarded as that obtained during accommodation, while the data after cycloplegia could be regarded as that obtained with less or no accommodation.

In addition to the dramatic changes in lens thickness, the backward movement of the lens of 0.20 mm, 0.14 mm, and 0.08 mm for hyperopic, emmetropic, and myopic eyes, respectively, under cycloplegia were also confirmed. That means that there are both an increase in lens thickness and a forward movement of the lens itself during accommodation and that this will theoretically contribute to the increase in the refraction of an eye. Such changes are of the greatest magnitude in hyperopic eyes but smallest in myopic eyes. This finding agrees with the fact that myopic eyes have lower accommodative amplitudes.[1,10] Backward movement of the ciliary body after cycloplegia has also been observed with ultrasound biomicroscopy.[11] It may be helpful to better understand and study the apparent accommodation in pseudophakic eyes.[12]

Mechanical forces on the front of the eye have been shown to be capable of altering corneal curvature on a short-term basis.[3] It is not clear whether mechanical forces could be a significant factor in long-term refractive development. Corneal steeping has been observed in some cases of myopia progression.[13,14] It has been shown that the average corneal power of eyes with moderate and mild degrees of myopia was greater than that of normal eyes.[15,16] In our study, we found that both the corneal power (Table 5) and axial length (Table 2) decrease in hyperopic eyes with more accommodation (without cycloplegia). On the contrary, both increase in myopic eyes with more accommodation (without cycloplegia). This phenomenon may be due to a relative forward movement of the apex of the steep cornea in myopic eyes during accommodation, which in turn increases the axial length. The same argument may apply the other way around in hyperopic eyes. However, we have no clear explanation for the opposite direction of corneal shape alteration induced by accommodation between hyperopic and myopic eyes.

Moreover, we suspect that the changes in axial length and corneal shape with or without cycloplegia shown in our study may not be structural. It is hard to imagine such changes happened within only one week. Buphthalmos is the result of stretching of the coats of the eye with an increase in intraocular pressure. The human globe is subject to this stretching only until about 3 years of age.[17] The eyeball of children may still be regarded as an "elastic container" compared to that of adults. Only children were enrolled in the study based on the fact that the lens capsule becomes less elastic and its nucleus becomes harder and less compressible with aging, and flexibility of the outer coat of the eye in children may be better than that in adults.

We suspected from our study that whenever accommodation was stimulated, the eyeball of a myopic child would have the tendency to expand in its axial direction. However, the cumulative effects of accommodation induced by near work may ultimately cause the structural elongation of the eyeball in the myopic eye. Thus myopia may be considered as an adaptation to the new environment of a heavy near-vision burden. In other words, it should not be considered as a pathological process for early-onset myopia considering the fact of its prevalence of up to 60% in certain populations, with even higher prevalence expected in the future.

Our study reveals that the asymmetry of the corneal surface is not only limited to keratometer K1 and K2 readings, but also exists within the same horizontal or vertical meridian. In both hyperopic and myopic eyes, the mean value of the lower half of the vertical meridian is significantly greater than the same value of the upper half ($P < .001$); while the mean value of the lateral half of the horizontal meridian is significantly greater than the same value of the medial half ($P < .001$). Such differences may be related to the influence of human eyelids and extraocular muscles.

In conclusion, cycloplegia or ocular accommodation has a great influence on various refractive components in children. It may be one of the most important factors to study in relation to the increasing rate of myopia or the development of ametropia. It has been reported that bifocal or progressive lenses could reduce the progression of myopia in children, which might be attributable to the interaction of these lenses with the ocular accommodation system.[18,19]

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