

Original research

Does astigmatism alter with cycloplegia?

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Abstract

Purpose: To determine the effect of the cyclopentolate 1% on the cylindrical and spherical components of the refraction.

Methods: Three hundred seventy-five eyes of 195 subjects, including 74 males and 121 females, aged from 3 to 59 years were refracted before and 30 min after cyclopentolate 1% eye drop instillation. To compare cylindrical data, power vector analysis (J_0 and J_{45} cross cylinder) was applied.

Results: A statistically significant difference between the J_0 values of the noncycloplegic and cycloplegic refraction was revealed ($P = 0.006$) while the J_{45} values did not significantly differ. 95% limit of agreement for dry and cycloplegic values of the J_0 and J_{45} were -0.22 to 0.25 and -0.19 to 0.20 , respectively. Astigmatism difference was separately analyzed in emmetropic, myopic and hyperopic eyes. The J_0 difference was significant ($P = 0.014$) only in hyperopic eyes. Spherical equivalent (SE) values in cycloplegic refraction were significantly more hyperopic than those yielded in dry refraction by mean difference of $+1.16 \pm 1.20$ diopters ($P < 0.0001$). Spherical equivalent difference (SED) values were negatively correlated with age.

Conclusions: Our findings indicated that cycloplegic drops caused a statistically significant shift in the “with the rule” and “against the rule” astigmatism, although the oblique astigmatism remained unaffected. Further research with larger sample sizes are needed to answer what mechanisms are involved in changing cylinder with cycloplegia.

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Keywords: Astigmatism; Cycloplegia; Noncycloplegia; Agreement

Introduction

Astigmatism is one of the most prevalent refractive errors encountered in ophthalmic practice. Uncorrected remaining of

the astigmatism can give rise to various kinds of visual and ocular symptoms, such as blurry vision, asthenopia (eye strain), glare, headache, and monocular diplopia.^{1,2} The axis orientation of astigmatism is an important factor dramatically influencing the frequency and severity of the subjective symptoms.^{2,3} As the axis orientation error in prescription becomes greater, the subjective complaints often become more. Exact determining of the cylinder axis is imperative to alleviate the astigmatism-induced asthenopia and prevent the meridional amblyopia.³

Various methods such as retinoscopy, autorefractometry, and photorefractometry can be used to evaluate the cylindrical

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component of the refraction. Ocular refraction procedures can be implemented in either non-cycloplegic (dry) or cycloplegic status. Seemingly, there is general consensus that the cycloplegic refraction is considered to be crucial in some situations such as idiopathic vision loss, high amount of anisometropia, latent hyperopia, accommodation anomalies, and esotropic eye squint.^{4,5}

So far, variegated types of the cycloplegic agents have been introduced. The well-known cycloplegics are atropine, homatropine, scopolamine, cyclopentolate, and tropicamide.^{6,7} Although much controversy still surrounds the choice of the better cycloplegic agents, the cyclopentolate 1% has been recommended by the majority of authors because of its adequate effectiveness and relatively fewer number of side effects.⁸

Almost all of the preceding studies have solely tended to focus on the spherical changes rather than the cylindrical modifications during the cycloplegic refraction. So far, there have not been a sufficient number of studies about the cylindrical component alterations with cycloplegic drop instillation.

With this study, we strived to find out whether or not cylindrical component of refraction alters with cycloplegia. It would be expected that both magnitude and axis values of the cylindrical refraction would be identical to those measured in dry status. However, in routine clinical practice, it has often been seen that the cylindrical properties of the refraction usually differ, though not always, in cycloplegic status compared with noncycloplegic one. Accordingly, a holistic comparison of the cylindrical component of refraction along with the spherical changes in non-cycloplegic with cycloplegic conditions was nicely addressed by this work. Addressing the cylindrical variations with cycloplegia was the main aspect of this survey.

Methods

A single center analytical prospective study was conducted on 375 eyes of 195 subjects aged from 3 to 59 (Mean \pm Standard Deviation = 17.89 \pm 9.56) years. Seventy-four (37.94%) subjects were male, and the remainder (62.06%) were female. The subjects of the present study were chosen from the patients who referred to the optometry clinic of Rehabilitation School of Iran University of Medical Sciences. We followed the tenets of the Declaration of Helsinki in obtaining and using the data in the present study. First, comprehensive information about the study's procedures and its possible side effects and complications were given to the volunteers. From all of the subjects a written informed consent was obtained before inception of the study. For individuals under age 15, parent approval was considered necessary to participate in this survey. The Ethics Committee of Iran University of Medical Sciences approved the study protocol. All participants signed a written informed consent.

Clarity of ocular media, lack of any active inflammatory or infectious corneal and intraocular disease, no history of contact lens wear at the time of enrollment, no history of undergoing refractive surgery, and having a wide anterior chamber

angle were considered as inclusion criteria. The individuals who had dry eye, ocular surface pathologies, neurological problems interfering refraction procedures (e.g. head nodding), and binocular vision disorders such as nystagmus and strabismus were excluded. Neither aphakic nor pseudo-phakic eyes were recruited in our research.

To check possessing of the inclusion criteria, a thorough visual and ocular examination, comprising unaided and corrected distance visual acuity, ophthalmoscopy, and biomicroscopy was implemented for all of the volunteers. All of the volunteers were questioned about dry eye symptom experience and recent contact lens wear history. The findings were recorded in a paper sheet designed for this purpose. The subjects who met the inclusion criteria during the preliminary examination participated.

To rule out the possibility of angle closure after the cycloplegic administration, anterior chamber angle estimation technique was carried out for all subjects. We applied Van Herick angle estimation method using the slit lamp to approximate and qualitatively evaluate the peripheral depth of the anterior chamber. We categorized the angle size with a five-point scale from grade 0 (closed angle) to grade 4 (wide open angle). Each individual whose angle was equal and narrower than 2 (grades 0, 1, 2) was excluded from the survey.⁹

Dry refraction

The refractive status was assessed quantitatively using autorefractometer (Autorefractor, TOPCON, KR-8900, Japan) by an optometrist. Before beginning, we explained the procedure to the subject and gave him or her the needed instructions. The subject was asked to sit comfortably on the exam chair. He or she was requested to locate and keep his or her chin in the chinrest cup and his or her forehead against the forehead bar. We monitored and controlled the position of the subject's head on the chinrest. The subject was instructed to fixate the fixation picture into the device. We chose a back vertex distance value of 12 mm in this device. After the precise centering and focusing of the semi-circular mires, we started to perform the refraction. Sphere, cylinder magnitude, and axis orientation in each subject were measured 5 times consecutively. The average value of these measurements was recorded. We performed retinoscopy for both eyes as a confirmatory and supplementary test after the autorefraction in all of the subjects.

Cycloplegic refraction

After completing the non-cycloplegic refraction, one drop cyclopentolate 1% (CICLOPLEGICO, ALCON CUSI, S.A., El Masnou-Barcelona) was instilled into the subject's eye. At this time, the subject was asked to close his or her eye immediately for 2 min and occlude the nasolacrimal passage by pressing his or her fingers on the lacrimal puncta to minimize systemic absorption of the eye drop.¹⁰ Thirty minutes was allowed to reach adequate cycloplegia.^{8,11} After

30 min had elapsed, cycloplegic refraction was performed by means of the same autorefractometer used in dry status. This refraction procedure was implemented by the same optometrist who had refracted the volunteers in non-cyclo condition. The procedure was carried out identically to the dry refraction. The final check for refraction was performed with a retinoscope.

Statistical data analysis

The data gathered in this study were analyzed by SPSS software version 22 (SPSS Inc., Chicago, IL). P values less than 0.05 were considered significant. Descriptive statistics, comprising central tendency indices (including mean, median, and mode), and dispersion indices (such as range, standard deviation, and variance) were calculated for all of the studied parameters. The paired samples *t*-test was used to compare sphere, cylinder, and overall blurring strength (OBS) data yielded in dry and cycloplegic refraction. To detect the relationship between variables, the Pearson bivariate correlation test was used.

The effect of age on the Spherical equivalent (SE) changes and astigmatic shifts by cycloplegia was tested. For this to occur, we classified our volunteers into 5 subgroups based on the age, including under 10 years (99 eyes), 11–20 years (144 eyes), 21–30 years (93 eyes), 31–40 years (33 eyes), and over 41 years (6 eyes). The significance of the differences between the cycloplegic and non-cycloplegic amounts of the SE values was separately analyzed by paired sample *t*-test in each of the age subgroups.

Spherical change calculations

We used both net spherical (S) and SE values to analyze the efficacy of the cyclopentolate eye drop. We used simple algebraical subtraction to calculate differences between the cycloplegic and dry refraction outcomes of both sphere and SE values. To reveal spherical difference (SD), we algebraically subtracted the spherical amounts of the pre-drop (S_{pre}) and post-drop (S_{post}) refraction. The following formula was used for this purpose:

$$SD = (S_{post}) - (S_{pre})$$

SE values of the refraction data were calculated easily by adding the spherical power (S) and one half of the cylindrical power (C).

$$SE = S + (C/2)$$

To compute the spherical equivalent difference (SED) values, we utilized the following equation:

$$SED = (SE_{post}) - (SE_{pre})$$

where (SE_{pre}) and (SE_{post}) denote the SE values of pre-drop (pre) and post-drop (post) conditions, respectively.

Cylinder vectorial calculations

Addressing the cylindrical changes and comparing cylindrical components of two spherocylindrical refractions is more challenging than spherical ones. Choosing the suitable way to subtract cylindrical values of two different measurements is dependent on the axis orientations. If the axes of two refractions are identical, we can algebraically subtract the cylinder amount of two refractions.¹² Indeed, by assuming C_{pre} for pre-drop and C_{post} for post-drop cylinder magnitude, the cylindrical difference (CD) can be accounted by

$$CD = (C_{post}) - (C_{pre})$$

It should be kept in mind that this equation will only be true in situations in which the axis orientations are identically similar.

If the two axes are not identical, we must use graphical and trigonometric analyses to mathematically add or subtract the cylindrical components. For this purpose, in fact, each cylinder magnitude with its axis orientation is considered a vector. The vectorial analyses of the cylindrical refraction of the eye have been previously explained.^{13–15}

First, we converted the refraction from conventional notation ($S, C \times \alpha$) to the vectorial coordinates. We expressed the conventional cylinder power and axis in terms of the two cross-cylinder powers, including J_0 (or J_{180}) and J_{45} . The J_0 cross cylinder encompasses two components with equal magnitude but opposite signs along the 180 and 90°. Similarly, the J_{45} cross cylinder comprises two components with equal magnitude but opposite signs along the 45 and 135°. The following formulas were used to calculate the J_0 and J_{45} components:

$$J_0 = (-C/2)\cos(2\alpha)$$

$$J_{45} = (-C/2)\sin(2\alpha)$$

The formulas can be used in either plus or minus cylinder forms. In this study, we entered minus cylinders in the formulas.

Overall blurring calculations

To judge Overall Blurring (OB) of both the dry and cycloplegic refractions, we used the following formula¹⁶:

$$OB = (SE^2 + J_0^2 + J_{45}^2)$$

Results

Of 220 volunteers who were initially enrolled, one child who had poorly cooperation, 2 elderly subjects who had narrow occludable anterior chamber angle, 3 children whose parents did not consent to enter them into the study, and 5 children who had pathologic dry eye and unhealthy ocular surfaces were excluded from the study. Moreover, 14 of the enrolled individuals abandoned the study after being informed

of the potential side effects of the cyclopentolate eye drop. The data obtained from 195 subjects were statistically analyzed.

Mean and standard deviation values of the dry and cycloplegic refraction outcomes are summarized in Table 1.

Sphere values of the cyclorefraction were significantly more hyperopic than those measured in dry (non-cycloplegic) refraction ($P < 0.0001$). Hyperopic shift of the spherical refraction after cycloplegia ranged from 0.00 to 10.00 diopters. A similar plus-ward shift was found also between the equivalent sphere values ($P < 0.0001$).

J_0 and J_{45} amounts of the dry and cycloplegic refraction were compared. The J_0 values yielded in cyclorefraction were significantly different than those measured in dry status ($P = 0.006$), whereas the J_{45} values did not differ significantly after drop instillation.

Overall blurring strength values of the dry refraction showed a significant discrepancy with those of cyclorefraction ($P = 0.001$).

Correspondence between the cycloplegic and non-cycloplegic values of both J_0 and J_{45} were analyzed by Pearson bivariate correlation test. It was seen that cycloplegic amounts of both the J_0 ($\rho = 0.981$, $P < 0.001$) and J_{45} ($\rho = 0.935$, $P < 0.001$) had significant high correlations with dry values. These correlations are best illustrated in Figs. 1 and 2.

The agreement of the cycloplegic and non-cycloplegic amounts of both the J_0 and J_{45} variables were depicted by Bland–Altman plots in Figs. 3 and 4, respectively.

As shown in Figs. 3 and 4, 95% limit of agreement of the pre-drop and post-drop J_0 values was -0.22 to 0.25 , while for J_{45} , it was -0.19 to 0.20 . In fact, the cycloplegic and non-cycloplegic values of the J_{45} agreed better than those values of J_0 .

To find out which type of refractive error was mostly affected by cycloplegia, we classified obtained refraction data into three subgroups based on the SE values. We categorized SE values lower than -0.51 D as myopia, -0.50 to $+0.50$ D as emmetropia, and higher than $+0.50$ D as hyperopia. The differences between the cycloplegic and noncycloplegic amounts of SE values were calculated in all three refractive error groups. The cycloplegic SE data in all of the three groups differed significantly with those of non-cycloplegic refraction (all $P < 0.0001$). The highest hyperopic shift was seen in hyperopic subjects and lowest in myopic subjects.

The J_0 and J_{45} alterations by cycloplegia were separately calculated in three groups of ametropia. A significant change in astigmatism was seen only in hyperopic subjects. Significant

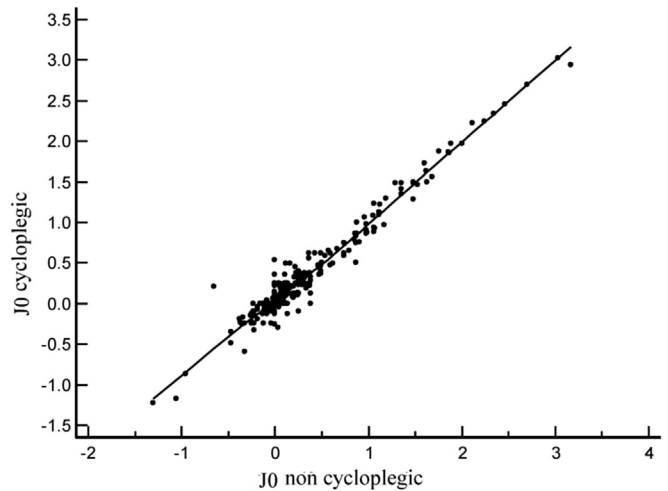


Fig. 1. The relationship between the cycloplegic and non-cycloplegic values of the J_0 vector (Pearson $r = 0.981$, $P < 0.001$).

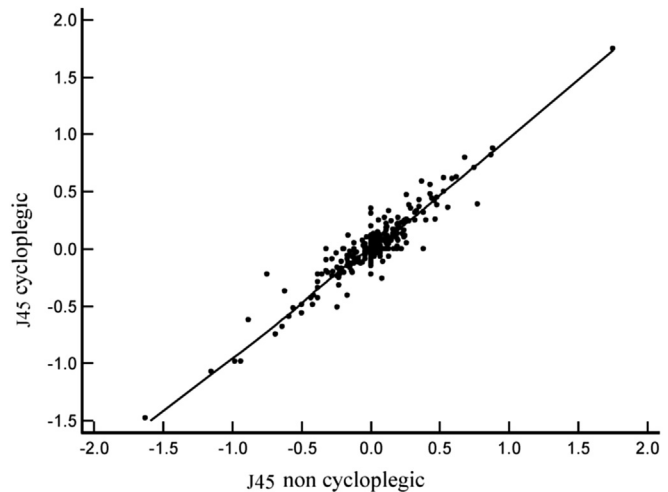


Fig. 2. The relationship between the cycloplegic and non-cycloplegic values of the J_{45} vector (Pearson $r = 0.935$, $P < 0.001$).

change occurred only in J_0 component but not in J_{45} dimension (J_0 : $P = 0.014$).

Mean difference values of the SE amounts reduced by increasing the age (from 1.52 D in individuals under the age of 10 to 0.45 D in those over 40 years of age). In all of the age groups, the differences were statistically significant even in persons over 40 years old ($P < 0.0001$). Correspondence between the age and SED data was investigated by Pearson correlation test (Pearson $r = -3.67$, $P = 0.001$).

Table 1
Mean and standard deviation (M \pm SD) values of the dry refraction, cyclorefraction, and their differences in astigmatism.

Refraction	S	SE	J_0	J_{45}	OB
	Mean (median) \pm SD	Mean (median) \pm SD	Mean (median) \pm SD	Mean (median) \pm SD	Mean \pm SD
Noncycloplegic	0.12 (0) \pm 2.33	-0.33 (-0.25) \pm 2.24	0.32 (0.12) \pm 0.61	0.01 (0) \pm 0.03	1.68 \pm 1.68
Cycloplegic	1.30 (1.25) \pm 2.26	0.84 (0.88) \pm 2.19	0.33 (0.13) \pm 0.59	0.01 (0) \pm 0.26	1.92 \pm 1.53
Diff	1.18 (1) \pm 1.17	1.16 (1) \pm 1.20	0.01 (0) \pm 0.12	0.00 (0) \pm 0.10	0.24 \pm 1.35
P value	<0.0001	<0.0001	0.006	0.682	0.001

S, sphere; SE, spherical equivalent; OB, overall blurring; Diff., difference; M, mean; SD, standard deviation.

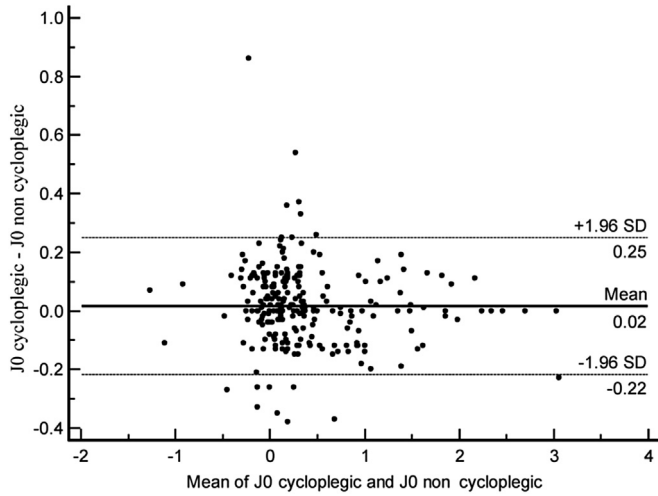


Fig. 3. Bland–Altman plots demonstrating 95% limits of agreement between cycloplegic and non-cycloplegic values of the J_0 vector.

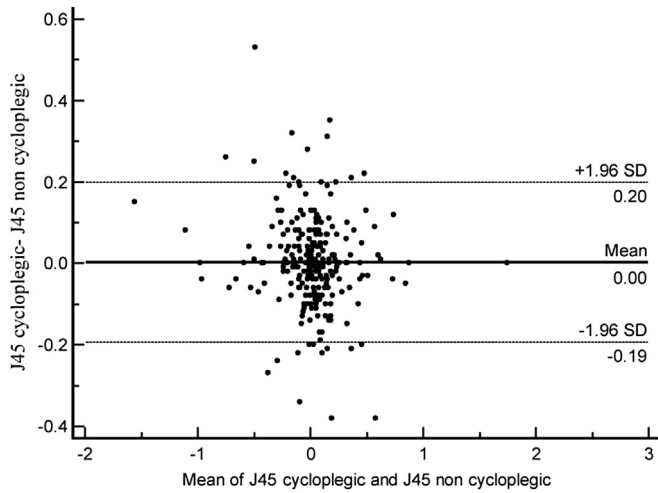


Fig. 4. Bland–Altman plots demonstrating 95% limits of agreement between cycloplegic and non-cycloplegic values of the J_{45} vector.

The significance level of the discrepancies between the cycloplegic and non-cycloplegic amounts of both J_0 and J_{45} values were calculated in each age subgroup. In all of them, the differences (for both J_0 and J_{45}) were not statistically significant.

Discussion

Our results surprisingly showed that cycloplegia caused statistically significant changes in vertical and horizontal components of the refractive astigmatism (J_0 power vector) while the oblique components (J_{45} power vector) remained uninfluenced. It can be said that just with the rule (WTR) and against the rule (ATR) astigmatism were affected by cyclopentolate-induced cycloplegia. These findings are consistent with the results of a similar study conducted by Jorge et al. in 2005.¹⁷ They reported a statistically significant change in J_0 but not in J_{45} .

Several factors can be responsible for cylindrical changing in refraction with cycloplegia, including accommodative astigmatism, subject's head positioning, and high order aberration increment in dilated pupil and different astigmatism vectors in different centrifugal rings in the visual axis during dilatation.

Astigmatic accommodation or accommodative astigmatism seems to be an important factor affecting the cylindrical refraction. Tilting of a spherical lens can create a cylindrical error named marginal astigmatism aberration. The induced cylinder by this way can be calculated with the following formula^{18,19}:

$$\begin{aligned} \text{Induced cylinder} &= F_t - F_s \\ &= F \left[\frac{(2n + \sin^2 \alpha)}{(2n \cos^2 \alpha)} \right] - F \left[1 + (\sin^2 \alpha / 2n) \right] \end{aligned}$$

F_t and F_s denote dioptric power of the tangential and sagittal meridian of the spherical lens, respectively. F and n denote dioptric power and refractive index of the spherical lens, respectively.

One of the possible sources for the cylindrical changes in cycloplegia may be the accommodation-induced oblique astigmatism. Recently, conducted studies have shown cylindrical and astigmatic changes during the accommodation process.^{20,21} Some studies reported that accommodation function causes a shift in WTR astigmatism because of lens tilt about the horizontal axis.^{21,22} Such a change may be attributed to the several factors such as sectorial differences in the ciliary body, lens, or zonula, external pressures from the lids or extraocular muscles, and crystalline lens tilt changes.^{21,23} During the dry autorefractometry procedure, the accommodation is active, whereas it is inactive in cycloplegic refraction. As the accommodation can be a source of astigmatism in the eye, the absence of it may affect cylindrical power of the eye proportional to non-cycloplegic status.

Another probable factor that seems to be important to rationalize the astigmatic changes is malposition of the subject's head during the cycloplegic or dry refraction procedure. To overcome this, we attempted to precisely adjust the forehead bar and chinrest for each subject in all refraction procedures. The position of the head was monitored carefully by keen observation throughout the testing time. Affection of the J_0 , unlike the J_{45} in this study, seems to suggest that head positioning factor had lesser importance.

It seems that mydriasis-induced high order aberration increase has also been implicated as playing a role in the change of astigmatism by cycloplegia. High order astigmatic aberrations such as rule 2nd astigmatism and oblique 2nd astigmatism may differ with dilatation of the pupil.^{24–26} These changes may cause a shift in the refractive astigmatism.

The change in astigmatism may be a result of different astigmatism vectors in different centrifugal rings in the visual axis during dilatation. In fact, the amount of astigmatism and its axis can be different in various diameters of the pupil. Our findings about cylindrical change may be related to this issue.²⁷

To address the main factor affecting the cylindrical changes, it seems that the accommodative astigmatism issue is more important than anything else. Two reasons exist for it. First is the fact that only J_0 component of astigmatism varied with cycloplegia. It is consistent with those studies reporting only WTR astigmatism change with accommodation. Second, the J_0 in this study was significant only in hyperopic subjects. Because of greater probability of accommodation during autorefractometry in hyperopic subjects compared with emmetropic and myopic ones, this issue could be very important in rationalizing the observed changes in astigmatism.

Along with the cylindrical findings, some important spherical results were found in this study. As stated in results, cycloplegia induced by a single drop of cyclopentolate 1% caused a hyperopic shift in the spherical refraction by mean value of 1.17 diopters. It should be noted that in the present study, all types of ametropia, including myopia, hyperopia, and astigmatism, were entered. Hence, the obtained results belong to a population comprising almost all kinds of refractive errors of the eye.

The cycloplegic effect of the cyclopentolate in all individuals was not identical. In fact, although the hyperopic shift was significant in all of the refractive error subgroups, amount of the shifts were not identical. Hyperopic subjects showed the highest shift, and myopic ones showed the lowest. It can be attributed to the accommodation functioning during autorefractometry.

As was shown in the results, an inverse significant correspondence was found between the SED values and age. A possible reason for the decrement of difference in older ages compared with lower ages may be decreased accommodation function. Owing to higher accommodative facility, amplitude, and reaction time, subjects with a lower age may accommodate more than older ones do. As a result, the difference of refraction in dry and cycloplegic conditions will become higher than older persons. As alluded above, the difference in all age subgroups were significant. In fact, in all subjects, even in those over 40 years, cycloplegia caused a significant shift in refraction.

To summarize, in this study, a significant alteration in J_0 , but not in J_{45} , component of the refractive astigmatism was seen. The J_0 vector shift was statistically significant only in hyperopic subjects. It seems that the accommodative astigmatism was the most important factor changing the cylindrical refraction by cycloplegia. Since in natural living conditions we deal with dry (and not cycloplegic) refractive state, in practice, the axis yielded from dry refraction is preferred. We found a significant hyperopic shift in the spherical component of refraction. This shift was highest in hyperopic volunteers. The age of the volunteers was not a factor affecting the J_0 shift. In contrast, the spherical shift in refraction had a significant negative correlation with age. Clinical utility of our study findings remains to be determined in future research. Further studies are needed to address the reasons of cylindrical changes during cycloplegia more completely.

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