Tropicamide (1%): An Effective Cycloplegic Agent for Myopic Children

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PURPOSE. To evaluate the cycloplegic effect of 1% tropicamide in myopic children and to determine whether its efficacy is associated with age, gender, iris color, ethnicity, magnitude of the refractive error, or latent error.

METHODS. Four hundred sixty-nine children enrolled in the Correction of Myopia Evaluation Trial (COMET; a multicenter, randomized, double-masked clinical trial evaluating the rate of progression of juvenile-onset myopia in children wearing progressive-addition versus single-vision lenses) were given 1 drop of proparacaine in each eye followed 1 minute later by 1 drop of 1% tropicamide and then a second drop of 1% tropicamide 4 to 6 minutes later. Five accommodative responses to 20/100 letters located at 4 m and 33 cm were obtained in each eye with an autorefractor, 20 minutes after the second drop. Residual accommodation was calculated as the difference between the mean spherical equivalent responses obtained at the two distances. An examiner graded iris color, and ethnicity was reported by the children's parents or guardians.

RESULTS. The mean residual accommodation was small: 0.38 ± 0.41 diopters (D) in the right eye and 0.30 ± 0.41 D in the left eye. Small but statistically significant differences in residual accommodation were associated with ethnicity, but not with any of the other factors.

CONCLUSIONS. Tropicamide (1%) is an effective cycloplegic agent in myopic children. (*Invest Ophthalmol Vis Sci.* 2001;42: 1728–1735)

Cycloplegic agents are frequently used to control accommodation during the assessment of refractive error. By inhibiting accommodation pharmacologically with a topical anticholinergic agent, the cycloplegic refraction is reported to provide a more reliable estimate of the true refractive error,[1,2] particularly in hyperopia.[3,4] Cycloplegia also enhances the repeatability of the estimates of refractive error obtained objectively by autorefraction. In a group of 40 adults (spherical equivalent refractive error range: -10.00 to $+2.00$ diopters [D]), the 95% limits of agreement for repeatability for cycloplegic autorefraction were -0.27 D to 0.37 D compared with -0.72 to 0.71 D for noncycloplegic autorefraction.[5] Thus, cycloplegic autorefraction has been recommended for cross-sectional and longitudinal investigations of refractive error.[5]

Although the benefits of cycloplegia for refraction appear clear, the choice of the pharmaceutical agent is less apparent. Currently available topical ocular cycloplegic agents include atropine sulfate, homatropine hydrobromide, scopolamine hydrobromide, cyclopentolate, and tropicamide.[6] The primary differences in the action of these agents are the time course for the onset and recovery of cycloplegia and the depth of cycloplegia.[7] Although atropine provides the greatest amount of cycloplegia[7] and is considered the gold standard,[8] the delay in the onset of cycloplegia, the prolonged recovery required for the return of normal accommodative function,[7] and the potential for serious side effects[9,10] have led to more widespread acceptance of the shorter acting agents, cyclopentolate and tropicamide.[11-14]

Of the two shorter acting cycloplegics, tropicamide is reported to be less effective than cyclopentolate[11,15-17] and is considered by some to provide an unacceptable level of cycloplegia for refraction in children.[15] However, early reports[11,15,16] relied on a subjective assessment of the accommodation that remains during the peak action of the cycloplegic agent. Manny et al.[18] have demonstrated that subjective estimates of the amount of accommodation available after the application of cyclopentolate are much greater (0.64–3.16 D, depending on the sample and the time of measurement) than the magnitude of residual accommodation determined objectively. Others have replicated this result with cyclopentolate and tropicamide.[17,19]

The possibility that the accommodation remaining after the application of tropicamide has been overestimated, combined with its lower incidence of systemic side effects when compared with other cycloplegic agents[20,21] and its abbreviated time course, has led to renewed interest in tropicamide's potential as an acceptable cycloplegic agent for refraction.[17,22] In the present study, residual accommodation calculated from distance and near cycloplegic autorefraction was used to examine the depth of cycloplegia induced by tropicamide in 469 myopic children enrolled in the Correction of Myopia Evaluation Trial (COMET), a multicenter clinical trial. This large number of children permitted an investigation of previously reported factors associated with the effectiveness of various cycloplegic agents: iris color,[16,18,23] ethnicity,[24,25] age,[15,26] and magnitude of refractive error.[3,4,26,27] In addition, the association between residual accommodation and gender and the difference between cycloplegic and noncycloplegic autorefraction were examined. Tropicamide (1%) was found to be an effective cycloplegic agent in myopic children. The only factor found to be associated with residual accommodation was ethnicity.

METHODS

Subjects

Baseline data from the 469 children enrolled in COMET were used for this report. COMET is a multicenter clinical trial designed to investigate

myopic progression in children randomized to wear progressive-addition lenses (add power of +2.00 D) compared with children randomized to wear single-vision lenses. The COMET study and protocols conform to the tenets of the Declaration of Helsinki. Children, 6 to 11 years of age, living in or near Birmingham, Alabama; Boston, Massachusetts; Philadelphia, Pennsylvania; and Houston, Texas, were eligible for enrollment and recruited through the four colleges of optometry located in these cities. Before enrollment, children and parents were informed of the nature of the trial, and informed consent was obtained from the parent or guardian after the procedures were approved by each local institutional review board. Children also gave assent for their participation in the COMET study. Additional details about the COMET study design are described by Hyman et al.[28]

Eligibility for the study required that children have spherical equivalent refractive errors between −1.25 D and −4.50 D with no more than 1.50 D of astigmatism and no more than 1.00 D of anisometropia, as determined by cycloplegic (1% tropicamide) autorefraction (ARK-700A autorefractor; Nidek, Gamagori, Japan). Children with a history of contact lens wear and active ocular disease at the time of enrollment were excluded from enrollment.

The cohort was ethnically diverse with 36 (7.7%) Asian, 123 (26.2%) black, 68 (14.5%) Hispanic, 24 (5.1%) mixed/other, and 218 (46.5%) white children, as reported by their parents or guardians. Of these children, 246 (52%) were female. Iris color was assessed by using a standard protocol in each child before dilation during the biomicroscopy evaluation of the anterior segment. Under full illumination of the biomicroscope with the entire cornea illuminated, the iris color was graded 1 to 5, according to the classification system and standard photographs of Seddon et al.,[29] where 1 is a blue or gray iris and 5 is a dark brown iris.

Procedures

After noncycloplegic autorefraction, subjective refraction, assessment of ocular alignment, and anterior ocular health assessment, children received 1 drop of proparacaine HCl in the right and then the left eye. One minute after instillation of the anesthetic (actual mean time ± SD, 0.9 ± 0.86 minutes), 1 drop of 1% tropicamide, was instilled in each eye. A second drop of 1% tropicamide, was then instilled in each eye 4 to 6 minutes later (actual mean time ± SD, 4.6 ± 0.74 minutes). Twenty minutes after the second drop of tropicamide was instilled in each eye, residual accommodation was determined objectively using an autorefractor (model R1; Canon Europa NV, Amstelveen, The Netherlands). The design of the Canon R1 autorefractor allows real targets to be viewed at any distance through an infrared reflecting mirror. By positioning a target at a near distance, accommodation may be stimulated—an arrangement not possible with the Nidek ARK-700A or other closed-system autorefractors.

Residual accommodation was calculated by determining the eye's accommodative response to targets located 4 m and 33 cm from the child. The distant target was a back-illuminated, isolated line of letters on an Early Treatment Diabetic Retinopathy Study (ETDRS) chart (Precision Vision Chart 1; number 2121) with each letter subtending 25 minutes of arc at 4 m (20/100 or 6/30). Luminance of the background, averaged 15 candelas (cd)/m² across the four centers (range, 13.43–16.64 cd/m²) and was achieved by placing plastic semitranslucent diffusion sheets between the light source and the eye chart to reduce the luminance to a level that approximated the near target. The contrast of the letters averaged 98% across the four participating centers. The near target was also a line of letters, with each letter subtending 25 minutes of arc when positioned at the 33 cm viewing distance. This intermediate sized letter has been shown to be an effective stimulus for accommodation.[30,31] All measurements were made in a dark room with the spherical equivalent of the noncycloplegic subjective refraction positioned in a trial frame approximately 13 mm from the child's eye. No adjustment was made for vertex distance, because the accommodative demand at the corneal plane differed by no more than 0.27 D between the lowest (−0.75 D) and highest (−4.50 D) spherical equivalent correction.

With the child viewing the center letter of the distant target, five measurements in the right eye followed by five measurements in the left eye (excluding any measurements contaminated by blinks or extraneous eye movements) were taken with the Canon R1 autorefractor. Five measurements were then made on each eye (right eye first, left eye second) while the child viewed the center letter of the near target. The spherical equivalent for each measurement was determined and the mean spherical equivalent calculated for each eye, both at distance and near. The residual accommodation was determined for each child by subtracting the mean near response from the mean distance response.

The association between residual accommodation and the difference between the cycloplegic and noncycloplegic autorefraction were also examined. Because of the time required to first assess residual accommodation, the cycloplegic autorefraction was performed, on average, 33 ± 15.53 minutes (median, 29 minutes) after the instillation of the last drop of tropicamide. Five measurements were taken in each eye for both noncycloplegic and cycloplegic autorefraction, with the Nidek ARK-700A autorefractor. Each of the five measurements was expressed as a spherical equivalent and then averaged to obtain the cycloplegic and the noncycloplegic spherical equivalent refraction for each eye. These mean values were then used to compute the difference between the cycloplegic and noncycloplegic autorefraction results (also referred to as the latent error).[32]

Data Analysis

The statistical strategies used in the data analysis were based on a hierarchy that included data summaries, univariate analyses, and multivariate and modeling analyses. Data summaries were based on estimating distribution parameters such as the mean, median, quartiles, range, and SD for continuous measurements and the frequency and percentage of categorical variables.

Because normality assumptions were met, univariate analyses were based primarily on one or two independent sample(s) t distributions. For example, a one-sample t distribution was used to determine whether the difference in residual accommodation between the right and left eyes was 0 (based on reducing calculations to the one sample t-test by initially taking the difference between the right and left eyes). A two-sample t-test was used to detect a statistically significant difference in residual accommodation between light and dark irises. Another univariate analysis was the Pearson linear correlation.[33]

Multivariate and modeling analyses were based on linear multiple regression and ANOVA techniques,[34,35] to determine the magnitude and the significance of the effect of several covariates (e.g., ethnicity, iris color) on residual accommodation in each eye. Because of the degree and significance of the association in residual accommodation between right and left eyes, a regression model using the average residual accommodation for each child was also used to determine the effect of iris color, ethnicity, and average latent error on the averaged residual accommodation. Because interaction terms are the most appropriate method to detect a trend in residual accommodation within subgroups (different subgroups defined by ethnic and iris color groupings), these models allowed for a two-factor interaction between ethnicity and iris color for both the eye and the child analysis. Except for situations involving multiple comparisons, the significance levels for testing a statistically significant difference were preset at $\alpha = 0.05$. The power to detect a 0.12 D difference in residual accommodation between light and dark irises was 90%. Dunnett-Bonferroni adjustments[36] were applied when multiple comparisons were made.

RESULTS

The mean ± SD of the residual accommodation in the right eye after 2 drops of 1% tropicamide, was 0.38 ± 0.41 D (95% confidence interval [CI], 0.35–0.42 D), whereas the mean residual accommodation in the left eye was 0.30 ± 0.41 D (95% CI, 0.26–0.34 D). The median values were generally similar,

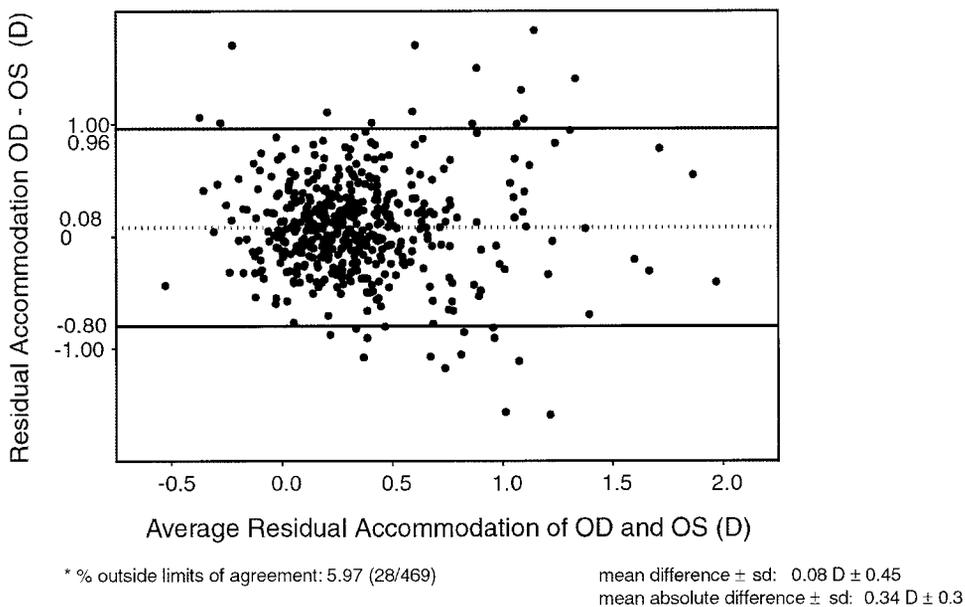Difference in Residual Accommodation Between OD and OS (N=469)

FIGURE 1. The difference in residual accommodation between the two eyes (right minus left) versus the average residual accommodation for the pair. The area between the *dark horizontal lines* positioned at −0.80 D and 0.96 D indicates the 95% limits of agreement, and the *dashed line* at 0.08 D depicts the slight bias for the right eye to retain more residual accommodation than the left eye.

* % outside limits of agreement: 5.97 (28/469)

mean difference ± sd: 0.08 D ± 0.45
mean absolute difference ± sd: 0.34 D ± 0.3

with 0.33 D of accommodation remaining in the right eye and 0.24 D in the left. The maximum amount of accommodation retained was 2.17 D in the left eye of one child. The maximum in the right eyes was 2.14 D. However, these larger amounts of residual accommodation rarely occurred. Only 7% of the right eyes and 6% of the left eyes retained more than 1 D of accommodation, whereas 71% of the right eyes and 77% of the left eyes had less than 0.50 D of residual accommodation.

Figure 1 illustrates the differences in residual accommodation between the right and left eyes with a difference-versus-mean plot. The dashed line positioned at 0.08 D represents the slight, but statistically significant ($P = 0.001$), bias for the right eye to retain more accommodation than the left eye when the sign of the difference is maintained. The area between the dark horizontal lines indicates the 95% limits of agreement (mean ± 1.96 SD). The number of points falling outside the 95% limits of agreement are equally distributed at each end, 14 above and 14 below, indicating no significant bias when larger amounts of accommodation remain—that is, they are just as likely to occur in the right eye as in the left eye.

Residual Accommodation, Age, and Gender

Because the effectiveness of some cycloplegic agents has been reported to be associated with age[15,26] the relationship between age and residual accommodation obtained with tropicamide was investigated over the range of ages (6–11 years) enrolled in the study. Although it has not been linked to the effectiveness of cycloplegia,[37] gender was included for completeness. When a simple linear multiple regression model was used that included residual accommodation, age, and gender, no significant association was found for either age or gender.

Residual Accommodation, Ethnicity, and Iris Color

The influence of ethnicity on the completeness of cycloplegia produced by tropicamide is shown for the right eyes in Figure 2A and for the left eyes in Figure 2B. For both the right and left eyes, the children of reported Hispanic descent retained the greatest amount of accommodation. A regression model assuming an unbalanced design (unequal number of children in the

various subclassifications defined by ethnicity and iris color) and controlling for iris color and interaction between ethnicity and iris color, indicated that the magnitude of residual accommodation was influenced by ethnicity for both the right and left eyes ($P \leq 0.001$). Subsequent multiple comparison analyses revealed a significant difference in residual accommodation between the white and Hispanic groups for both the right (mean difference, 0.21 D; 95% CI, 0.04–0.39 D) and left eyes (mean difference, 0.23 D; 95% CI, 0.05–0.40 D) with more accommodation retained by the Hispanic children. In the left eye, significant differences were also found between the Hispanic and black children (mean difference, 0.22 D; 95% CI, 0.03–0.40 D) and between the Hispanic and Asian children (mean difference, 0.28 D; 95% CI, 0.02–0.54 D), with the Hispanic children retaining more accommodation. Table 1 shows the mean ± SD, the median, the minimum and maximum, and the 95% CIs of residual accommodation for each eye, grouped by ethnicity and iris color.

The effect of iris color on accommodation after tropicamide was evaluated by dividing the five iris categories of Seddon et al.[29] into two groups: a light-iris group and a dark-iris group.[18] Categories 1, 2, and 3 were combined as the light-iris group and consisted of irises that were blue, gray, green, or light brown, with or without brown or yellow pigmentation (as illustrated in the standard photographs of Seddon et al.[29] Categories 4 and 5 were brown or dark brown with minimal yellow pigmentation (as illustrated in the standard photographs of Seddon et al.[29]) and were termed the dark-iris group. The pooling across categories provides a comparison with earlier work on iris color and cycloplegia in which iris color was typically classified as either light or dark, without the assistance of standard photographs. In addition, pooling across similar iris colors is expected to increase the sensitivity for detecting differences in residual accommodation associated with iris color, if true differences are present, by increasing the statistical power.

Figure 3 presents the residual accommodation remaining in the light- and dark-iris groups in the right (Fig. 3A) and left eyes (Fig. 3B). The format for Figure 3 is the same as that described for Figure 2. The mean residual accommodation in the light-iris
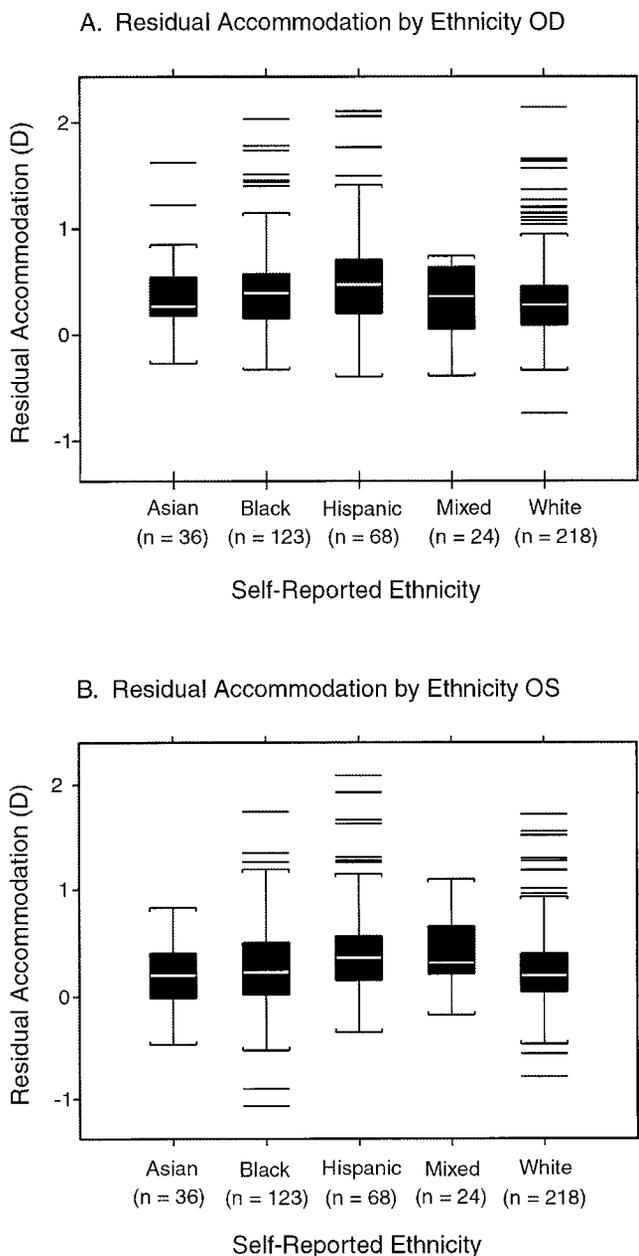
A. Residual Accommodation by Ethnicity OD

B. Residual Accommodation by Ethnicity OS

FIGURE 2.   Residual accommodation for Asian, black, Hispanic, mixed, and white children (ethnicity by parents' reports) after the application of 2 drops of 1% tropicamide in the (**A**) right and (**B**) left eyes. The *line* located within the box indicates the median residual accommodation in each ethnic group. *Filled box*: 25th (*bottom*) and 75th (*top*) quartiles; *vertical bar*: 1.5 times the interquartile range; *horizontal lines*: residual accommodations outside the interquartile range.

group was 0.35 ± 0.38 D in the right eye and 0.31 ± 0.38 D in the left eye. In the dark-iris group, the mean residual accommodation was 0.40 ± 0.42 D in the right eye and 0.30 ± 0.43 D in the left eye. No statistically significant association between the iris category and residual accommodation in either the right or left eye was found, when the regression model assuming an unbalanced design was used, adjusting for ethnicity and interaction between ethnicity and iris color.

Residual Accommodation and Cycloplegic Autorefraction

The refractive error may impact the amount of accommodation that remains after the application of tropicamide. For instance, children with smaller amounts of myopia could retain larger amounts of residual accommodation. Figure 4 displays the relationship between residual accommodation and the spherical equivalent cycloplegic autorefraction. Because similarity of measurements in the two eyes, only the data for the right eye are shown. Most residual accommodations fell between 0.00 and 0.50 D, and, by inspection of the figure, there was no apparent linear relationship between the magnitude of residual accommodation and the cycloplegic autorefraction. Negative values of residual accommodation occasionally result when the average distance autorefraction is greater than the average near autorefraction and represent small variability around 0 residual accommodation. Eyes with residual accommodation of 1.00 D or more appeared to be uniformly distributed throughout the range of refractive errors, suggesting that residual accommodation is not associated with refractive error. A regression model examining the influence of cycloplegic autorefraction on the amount of accommodation remaining after 1% tropicamide found no significant association in the right or left eye. Furthermore, when ethnicity, iris color, and their interaction were added to the model, only ethnicity showed a significant association with residual accommodation in both the right ($P = 0.002$) and left eyes ($P = 0.0003$).

Residual Accommodation and Latent Refractive Error

The latent refractive error is the difference between the refractive error found when a cycloplegic agent is used and that obtained without a pharmaceutical agent. Thus, the magnitude of accommodation remaining after the application of a cycloplegic agent may influence the determination of refractive error if those children with greater amounts of residual accommodation show a smaller latent refractive error. Figure 5 displays residual accommodation by latent error. Because of the similarity of the data in the two eyes, only the data for the right eye is shown. The differences between the cycloplegic and noncycloplegic autorefraction were small and the larger latent errors were not significantly associated with larger values of residual accommodation.

Further statistical analysis confirms what is apparent by inspection of the data in Figure 5. Ninety-two percent of children showed less than a 0.50 D difference between the two estimates of refractive error. A simple regression analysis model examining the relationship between residual accommodation and the difference between the cycloplegic and noncycloplegic autorefraction showed no statistically significant relationship for the right or left eye. An expanded regression analysis model expressing residual accommodation as a function of ethnicity, iris color, the difference between cycloplegic and noncycloplegic autorefraction results, and interaction between ethnicity and iris color showed a statistically significant influence of ethnicity only, in both the right ($P = 0.003$) and left eyes ($P = 0.0002$). Additional analysis of the latent error in this study population may be found in Marsh-Tootle et al.[38]

Child-Based Analyses of Residual Accommodation

Because of the highly significant correlation in residual accommodation between the right and left eyes ($P = 0.0001$) an analysis based on the child was also performed. A regression model using the mean residual accommodation in the right and left eyes as a function of ethnicity, iris color (dichotomous classification), and mean latent error (controlling for interactions between ethnicity and iris color) revealed a statistically significant association between mean residual accommodation and ethnicity ($P = 0.0001$), consistent with the eye-based analysis. In contrast to the eye-based analysis, a Pearson correlation analysis based on the child shows a small but statistically

TABLE 1. Residual Accommodation by Eye, Ethnicity, and Iris Color

Ethnicity	Iris Color	Right Eye		Left Eye	
		Accommodation	95% CI	Accommodation	95% CI
Asian	Dark ($n = 36$)	0.38 ± 0.35 0.27 (−0.27, 1.62)	0.26, 0.50	0.20 ± 0.33 0.21 (−0.47, 0.88)	0.09, 0.31
Black	Dark ($n = 123$)	0.43 ± 0.42 0.39 (−0.33, 2.03)	0.35, 0.50	0.27 ± 0.43 0.24 (−1.07, 1.82)	0.19, 0.35
Hispanic	Light ($n = 8$)	0.44 ± 0.41 0.41 (−0.27, 1.04)	0.10, 0.78	0.52 ± 0.49 0.34 (0.12, 1.38)	0.11, 0.93
	Dark ($n = 60$)	0.55 ± 0.50 0.47 (−0.40, 2.10)	0.42, 0.68	0.48 ± 0.51 0.39 (−0.35, 2.17)	0.35, 0.61
	All ($n = 68$)	0.54 ± 0.49 0.47 (−0.40, 2.10)	0.42, 0.65	0.49 ± 0.50 0.38 (−0.35, 2.17)	0.36, 0.61
Mixed	Light ($n = 4$)	0.43 ± 0.14 0.39 (0.32, 0.63)	0.21, 0.66	0.71 ± 0.49 0.73 (0.22, 1.16)	−0.08, 1.49
	Dark ($n = 20$)	0.27 ± 0.35 0.27 (−0.39, 0.74)	0.10, 0.43	0.43 ± 0.36 0.31 (−0.18, 1.14)	0.26, 0.60
	All ($n = 24$)	0.29 ± 0.33 0.36 (−0.39, 0.74)	0.16, 0.43	0.48 ± 0.39 0.33 (−0.18, 1.16)	0.31, 0.64
White	Light ($n = 168$)	0.35 ± 0.38 0.30 (−0.75, 2.14)	0.29, 0.41	0.29 ± 0.37 0.24 (−0.78, 1.80)	0.24, 0.35
	Dark ($n = 50$)	0.24 ± 0.35 0.19 (−0.34, 1.37)	0.14, 0.34	0.15 ± 0.32 0.10 (−0.56, 1.25)	0.05, 0.24
	All ($n = 218$)	0.32 ± 0.38 0.28 (−0.75, 2.14)	0.27, 0.37	0.26 ± 0.37 0.21 (−0.78, 1.80)	0.21, 0.31

Data are expressed as mean diopters ± SD followed by the median, with the minimum and maximum in parentheses.

significant association between the mean residual accommodation and mean latent error ($r = 0.11$; $P = 0.02$). Although statistically significant, this association is clinically negligible and consistent with the eye-based analysis, because a 1 SD change in average latent error (1.00 D) produces only an 11% change (0.18 D) in SD units of residual accommodation.

DISCUSSION

After 2 drops of 1% tropicamide, residual accommodation averaged 0.38 ± 0.41 D in the right eye and 0.30 ± 0.41 D in the left eye in this ethnically diverse group of myopic children. Recommendations for the maximum level of residual accommodation deemed acceptable for cycloplegic refraction based on subjective assessments of residual accommodation vary from less than 1 D,[39,40] to less than 2 D[15,41] to 2 to 3 D.[42] Although no comparable recommendations are available for objectively derived estimates of residual accommodation, the insignificant amount of residual accommodation found in this study for the majority of children indicated that 1% tropicamide is an effective cycloplegic agent for myopic children.

The significantly smaller magnitude of residual accommodation reported in this study compared with that reported by previous investigators after a single application of 1% tropicamide (1.33 D[11]; 2.23 ± 1.25 D[40]) or two applications of 1% tropicamide (3.27 D[17]) may be the result of the different methods used to determine residual accommodation (objective versus subjective). Differences between objective and subjective determinations of accommodation have been recognized for some time,[43,44] but direct comparisons after cycloplegia have been limited. Support for a smaller magnitude of residual accommodation when measured objectively rather than subjectively is provided by Mutti et al.,[17] who compared residual accommodation in 20 emmetropic to moderately hyperopic children aged 6 to 12 years after 2 drops of 1% tropicamide, when using both measurement methods. When residual accommodation was determined subjectively by near point of accommodation, they found a mean residual accommodation of 3.27 D. When determined objectively with an autorefractor

(R1; Canon) in response to a 6.00 D accommodative stimulus, residual accommodation averaged 0.71 D. Although the techniques used by Mutti et al. were similar to those used in this study, the refractive errors differed in the two studies, suggesting that direct comparisons between the two studies may not be prudent.

Although 1% tropicamide was an effective cycloplegic agent for the majority of myopic children reported herein, a small percentage of eyes (7% of the right eyes and 6% of the left eyes) retained more than 1 D of accommodation after application of the cycloplegic. Because residual accommodation was not found to be associated with age, gender, iris color, or refractive error, it did not appear helpful to use these parameters to predict which children might retain more accommodation. However, there was an association between residual accommodation and ethnicity when examined by eye and by child, and this association is reflected in the ethnic distribution of the children who retained more than 1 D of residual accommodation. Asian and white children were underrepresented in the group of children with more than 1 D of residual accommodation compared with the entire study population (Asians: 3.2% versus 7%; whites: 33.9% versus 46%), whereas Hispanics and those of mixed/other descent were overrepresented (Hispanics: 29% versus 14.5%; mixed descent 8% versus 5%).

The residual accommodation was very similar in the two eyes of each child with the mean difference between the right and left eyes equal to 0.08 ± 0.45 D. It is not clear what factors may be responsible for this small clinically insignificant, but statistically significant ($P < 0.001$) bias for the right eye to retain more residual accommodation. It is possible that the protocol that required the right eye to be measured first contributed to this small difference. However, because the measurement of the right eye preceded the left eye, on average, by approximately 3 minutes, this explanation seems unlikely.

Although most eyes retained similar amounts of residual accommodation, there were 28 children (Fig. 1) with a difference in residual accommodation between the two eyes that exceeded the 95% level of agreement. The most parsimonious explanation for the difference in residual accommodation be-
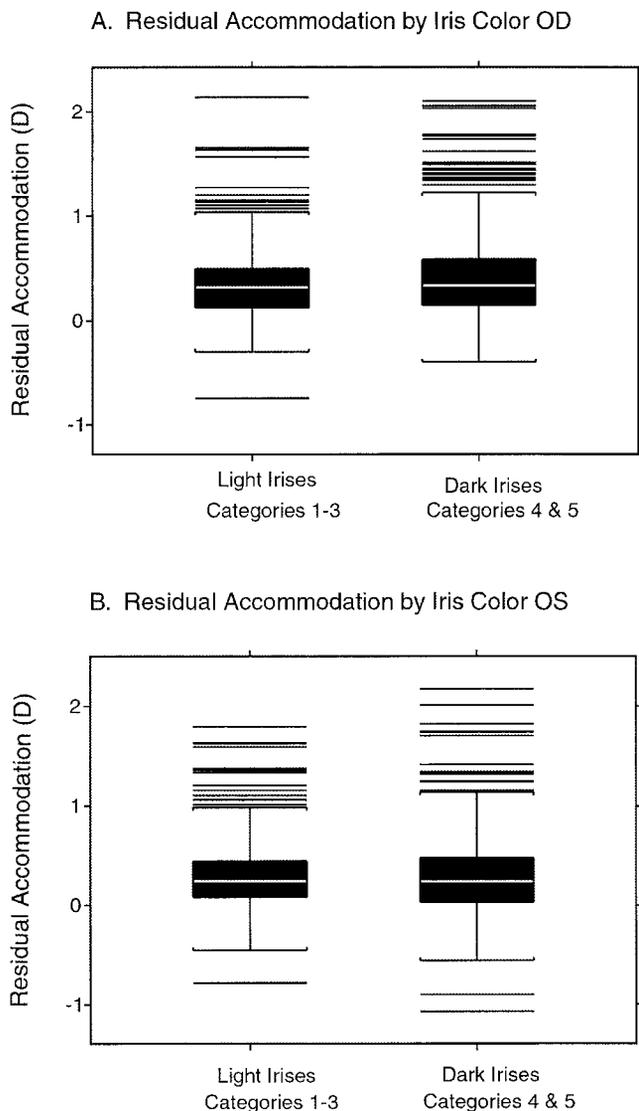
A. Residual Accommodation by Iris Color OD

B. Residual Accommodation by Iris Color OS

FIGURE 3.   Residual accommodation for children with light irises (categories 1–3) and dark irises (categories 4, 5) after the application of 2 drops of 1% tropicamide in the (A) right and (B) left eyes. See Figure 2 for description of data.

tween the two eyes is that despite the best efforts of the examiners, there was a difference in the amount of tropicamide that either entered or stayed in each eye. Although the residual accommodation was not equal in the two eyes of these children, the mean cycloplegic autorefraction for the 14 right eyes with measurements falling outside the 95% level of agreement (-2.27 ± 0.88 D) was similar to the corresponding left eyes (-2.38 ± 0.99 D). Likewise, the mean cycloplegic autorefraction for the 14 left eyes with measurements falling outside the 95% level of agreement (-2.53 ± 0.83 D) was similar to the corresponding right eyes (-2.57 ± 0.92 D) of these children. Thus, it seems unlikely that unequal residual accommodation influenced the cycloplegic refraction in these children.

Even though some eyes retained more residual accommodation than others, residual accommodation was not associated with latent error when analyzed by eye. However, there was a statistically significant but clinically negligible association between residual accommodation and latent error when analyzed by child. Although Mutti et al.[17] reported no correlation between objectively measured residual accommodation and latent error with 1% tropicamide, the study involved a small

number of hyperopic children. The significance of the present study is that it is the first study of a large group of ethnically diverse myopic children. That there was no meaningful association between residual accommodation and latent error shown in this study for myopic children and reported by Mutti et al. for hyperopic children should not be confused with a possible relationship between latent error and some types of refractive error. Although no association between latent error and myopic refractive errors has been reported,[4,22,26,27,45] some investigators have reported a relationship of hyperopic refractive errors[4,19,27,46] with a variety of cycloplegic agents. The previously reported relationship between latent error and hyperopic refractive errors may be responsible in part for the belief by some clinicians that strong cycloplegic agents are required for accurate refraction in myopic children.

Although investigators have reported an association between residual accommodation and iris color,[16,18,23] no such association was found (after controlling for interaction between ethnicity and iris color) in this ethnically diverse group of children with moderate amounts of myopia. Unlike iris color, a statistically significant association between residual accommodation and ethnicity was found after controlling for interactions between iris color and ethnicity. A significant difference in residual accommodation between the white and Hispanic groups was present in both the right and left eyes. In the left eye, significant differences were also noted between the Hispanic and black groups and between the Hispanic and Asian groups. Although this difference was statistically significant, the difference was small, on the order of 0.25 D. However, as noted earlier, Hispanics were overrepresented in the population of children with more than 1 D of residual accommodation compared with the study population. It is not clear what may be responsible for these small differences in residual

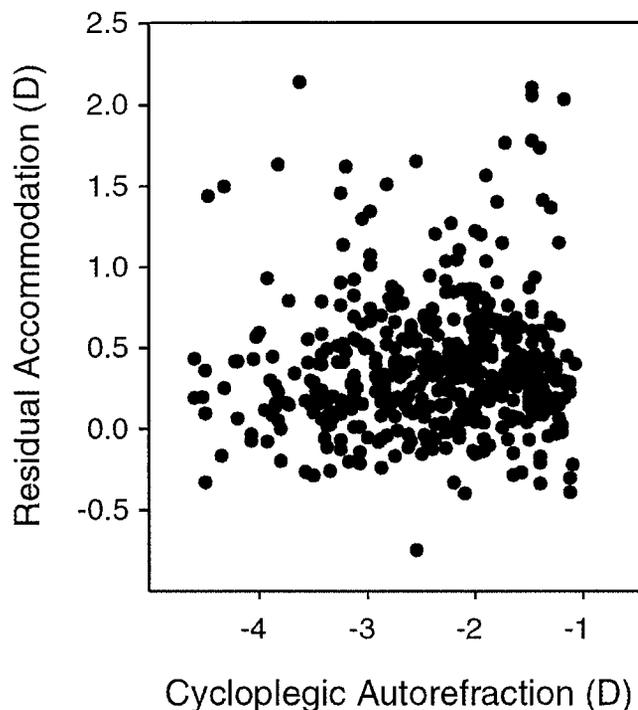## Residual Accommodation & Cycloplegic Autorefraction

FIGURE 4.   Residual accommodation in the right eye for all 469 children by spherical equivalent cycloplegic autorefraction.
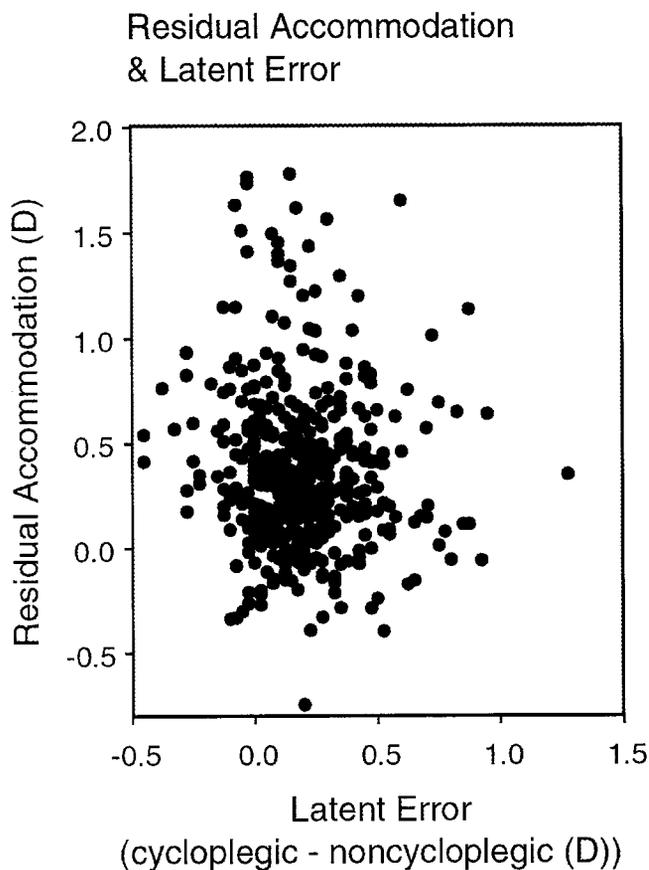
Residual Accommodation & Latent Error

FIGURE 5. Residual accommodation in the right eye of all 469 myopic children by the difference between cycloplegic and noncycloplegic spherical equivalent autorefraction (the latent refractive error).

accommodation among the various ethnic groups. Although differences in iris structure have been reported between irises of European and African subjects,[47] there is no published information on iris structure in individuals of Hispanic descent. Other possibilities include differences in the ethnic representation of the children recruited at each of the centers, small differences in the time required to complete the residual accommodation measures, and slight differences among the centers in the implementation of the standard protocol.

When presented with a 3 D accommodative demand and encouraged to accommodate, these myopic children, on average, demonstrated less than 0.50 D of accommodation after the application of 1% tropicamide. This result suggests that in myopic children, considerably less than 0.50 D of accommodation would be expected during routine clinical subjective refraction or autorefraction performed under 1% tropicamide where accommodation is discouraged by blurring the target with plus lenses and providing essentially a zero accommodative demand, either optically or by placing the target at 6 m. Given the small amount of residual accommodation present after the application of tropicamide, it can be concluded that 1% tropicamide is an effective cycloplegic agent for myopic children. In addition, residual accommodation was not associated with age, gender, iris color, refractive error, or latent error, suggesting that these factors should be of no concern when using 1% tropicamide as a cycloplegic agent in myopic children.

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APPENDIX

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