Objective: To report the baseline prevalence of refractive error in the study population.

Design: A multicenter, longitudinal, observational study of refractive error and ocular development in children from 4 ethnic groups.

Patients and Methods: The study population included 2523 children (534 African American, 491 Asian, 463 Hispanic, and 1035 white) in grades 1 to 8 (age, 5-17 years). Myopia was defined as −0.75 diopters (D) or more and hyperopia as +1.25 D or more in each principal meridian, and astigmatism was defined as at least a 1.00-D difference between the 2 principal meridians (cycloplegic autorefraction).

Results: Overall, 9.2% of the children were myopic, 12.8% were hyperopic, and 28.4% were astigmatic. There were significant differences in the refractive error prevalences as a function of ethnicity ($\chi^2$, $P<.001$), even after controlling for age and sex (polychotomous logistic regression, $P<.001$). For myopia, Asians had the highest prevalence (18.5%), followed by Hispanics (13.2%). Whites had the lowest prevalence of myopia (4.4%), which was not significantly different from African Americans (6.6%). For hyperopia, whites had the highest prevalence (19.3%), followed by Hispanics (12.7%). Asians had the lowest prevalence of hyperopia (6.3%) and were not significantly different from African Americans (6.4%). For astigmatism, Asians and Hispanics had the highest prevalences (33.6% and 36.9%, respectively) and did not differ from each other ($P=.17$). African Americans had the lowest prevalence of astigmatism (20.0%), followed by whites (26.4%).

Conclusion: There were significant differences in the prevalence of refractive errors among ethnic groups, even after controlling for age and sex ($P<.001$).

Arch Ophthalmol. 2003;121:1141-1147
Table 1. Prevalence of Myopia in Children From Selected Studies

<table>
<thead>
<tr>
<th>Source</th>
<th>Ethnicity</th>
<th>Sample Size</th>
<th>Age Range, y</th>
<th>Myopia Criterion</th>
<th>Testing Method</th>
<th>Cycloplegia</th>
<th>Prevalence, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle and Wissmann</td>
<td>White, black</td>
<td>13 536</td>
<td>12-17</td>
<td>Negative lenses, spherical equivalent</td>
<td>Neutralize lenses</td>
<td>No</td>
<td>31.8</td>
</tr>
<tr>
<td>Chen et al</td>
<td>Asian, black, white, Hispanic</td>
<td>469</td>
<td>6-7</td>
<td>−0.50 D or more myopia, spherical equivalent</td>
<td>Retinoscopy</td>
<td>No</td>
<td>3.7</td>
</tr>
<tr>
<td>Laatikainen and Erkki</td>
<td>Finnish</td>
<td>11 822</td>
<td>7-15</td>
<td>−0.50 D or more myopia</td>
<td>Retinoscopy</td>
<td>Yes</td>
<td>9.9</td>
</tr>
<tr>
<td>Lam et al</td>
<td>Chinese (Hong Kong)</td>
<td>142</td>
<td>6-17</td>
<td>More than −0.50 D of myopia, spherical equivalent</td>
<td>Subjective refraction</td>
<td>No</td>
<td>52.1</td>
</tr>
<tr>
<td>Lin et al</td>
<td>Taiwanese</td>
<td>11 178</td>
<td>7-18</td>
<td>−0.25 D or more myopia, spherical equivalent</td>
<td>Autorefraction</td>
<td>Yes</td>
<td>76.0</td>
</tr>
<tr>
<td>Zadnik et al</td>
<td>White</td>
<td>716</td>
<td>6-13</td>
<td>−0.75 D or more myopia in both meridians</td>
<td>Autorefraction</td>
<td>Yes</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Abbreviation: D, diopters.

4 ethnic groups. The 4 ethnic groups targeted for enrollment were African Americans (primarily from Eutaw, Ala), Asians (primarily from Irvine, Calif), Hispanics (primarily from Houston, Tex), and whites (primarily from Orinda, Calif). All children in grades 1 through 8 (age, 5-17 years) during the academic year 1997-1998 were eligible to enroll unless they met our exclusion criteria. The exclusion criteria were aphakia in the right eye, narrow anterior chamber angles, a history of seizures, difficulty with eye drops in the past, extreme apprehension at the first study visit, or the inability of the investigators to perform all of the key measures (autokeratometry, videophakometry, cycloplegic autorefraction, and ultrasonography). Measurements were made on the right eye only. Inclusion in this study required cycloplegic autorefraction.

Each study site was responsible for recruitment. Recruitment was done through communication with the children’s parents. This communication included direct mailings, materials sent home with the children, and publicity at school-based meetings of parents.

Each CLEERE Study site received approval from its affiliated institutional review board (University of Alabama-Birmingham, Birmingham; Southern California College of Optometry, Fullerton; University of Houston, Houston; Tex; University of California, Berkeley). Centralized human subjects approval was obtained from the biomedical sciences institutional review board at Ohio State University (Columbus), including approval of the individual informed consent documents. A parent or guardian provided consent, and each child provided assent before any testing was done. Local school boards, superintendents, and school principals also approved the study.

ETHNICITY

The study goal was to recruit at least 400 children from the targeted ethnic group at each site. Each site had a primary ethnic group as its goal for recruitment, but all sites welcomed children of any ethnicity. Ethnicity was categorized by parent report on a medical history questionnaire. The parents’ choices were the 6 ethnic categories used by the National Institutes of Health and the US Census Bureau prior to the year 2000 (American Indian or Alaskan Native; Asian or Pacific Islander; black, not of Hispanic origin; Hispanic; white, not of Hispanic origin; and other or unknown).14

Children whose parents marked more than 1 ethnic category were assigned to the primary ethnic group for the given site if the target ethnic group was 1 of the 2 that were designated. For example, a child in Irvine whose parent marked both African American and Asian would be designated as Asian. This multiple ethnicity assignment occurred for only 43 (1.7%) of the 2523 children.

If the parent-reported ethnicity designation was missing, then ethnicity was based on investigator observation of the child. This investigator designation occurred for only 5.3% of the 2523 children (n=134). Agreement between ethnicity determination by investigator and the parent report of ethnicity (for children with both pieces of information) was high (κ=0.95; 95% confidence interval [CI], 0.93-0.96).15 Children whose ethnic group was designated as “other or unknown” were not included in this report (n=57).

CYCLOPLEGIA

Topical eye drops were used to induce corneal anesthesia and cycloplegia. At the Eutaw, Houston, and Irvine sites, each child received 1 drop of 0.3% proparacaine, followed immediately by 1 drop of 1% cyclopentolate and 1 drop of 1% tropicamide. Autorefraction occurred no earlier than 30 minutes after the first drop was instilled. A pilot study done prior to the CLEERE Study found that this drop combination was effective in inducing cycloplegia after 30 minutes, with minimal residual accommodation in children with dark irises.16 At the Orinda site, a second drop of 1% tropicamide was used instead of cyclopentolate and was instilled 5 minutes after the first 2 drops. Autorefraction occurred no earlier than 25 minutes after the instillation of the first 2 drops. The 2 drops of tropicamide were shown to induce adequate cycloplegia for the purpose of measuring refractive error in children and to be comparable with using cyclopentolate.17 The difference in residual accommodation between these 2 cycloplegic methods was less than ± 0.10 D.17 The 2 tropicamide drops were used to ensure internal consistency with the data in the Orinda Longitudinal Study of Myopia, which used these drops prior to its expansion into the CLEERE Study.15

MEASUREMENT

Cycloplegic refractive error was measured by autorefraction with the Canon R-1 (Canon USA, Lake Success, NY). During autorefraction of the right eye, the left eye was occluded with an eye patch. The autorefractor’s free viewing space was illuminated with a small, fluorescent light from the examiner’s side of the instrument. The child fixated his or her gaze on 20/30-size letters on a near point test card viewed through a +4.00-D Badal lens. The letters were first presented at optical infinity, then moved to a position of maximum clarity for myopic chil-
children or to a position of maximum plus with slight blur for hyperopic children. Proper fixation was monitored by viewing the child’s eye movements on the autorefractor’s monitor screen. At least 10 autorefractor readings were taken with the eye in primary gaze.

The 10 spherocylindrical refractions were averaged using the method described by Harris.\textsuperscript{18} This method treats each spherocylinder as a vector, which can then be manipulated by standard linear algebra matrices to provide means and SDs for sphere, cylinder, and axis. All data presented average these 10 readings per eye, and we report the resultant average spherical equivalent for the right eye of each child.

The calibration of each site’s autorefractor was checked against individual model eyes at least once each month or whenever the autorefractor was moved to another school site, whichever was more frequent. The site-specific difference between the autorefractor readings and the model eye was subtracted from all autorefractor readings using the method of Harris.\textsuperscript{18}

Data were sent to the Optometry Coordinating Center at Ohio State University College of Optometry, where they were reviewed and double data-entered. Quality control included obtaining additional information for forms with data that were incomplete, missing, or outside the expected range.

REFRACTIVE ERROR DEFINITION

Myopia was defined as $-0.75\, \text{D}$ or more in each principal meridian, hyperopia as $+1.25\, \text{D}$ or more in each principal meridian, and astigmatism as at least a $1.00\, \text{D}$ difference in refractive error between the 2 principal meridians. Classification was made first for myopia and hyperopia. Those not meeting these criteria were then evaluated for astigmatism. Emmetropia was defined as any refractive error not classified as myopia, hyperopia, or astigmatism. For comparison with other studies, refractive errors are also presented for myopia of $-0.50\, \text{D}$ or more in each principal meridian, for hyperopia of $+1.00\, \text{D}$ or more in each principal meridian, and for astigmatism of at least a $1.25\, \text{D}$ difference between the 2 principal meridians.

STATISTICAL METHODS

Descriptive statistics were generated using SAS software (SAS Institute, Version 6, Cary, NC).\textsuperscript{19} Prevalences presented for this sample were calculated unadjusted for age and sex. Polychotomous logistic regression models were used to compare among ethnic groups, controlling for age and sex, with outcomes indicating whether the subject had myopia, emmetropia, hyperopia, or astigmatism. While the comparisons made were on the basis of an a priori hypothesis, an a level of .01 was used because of the multiple comparisons made. When comparisons are made among groups, it is important to distinguish between statistically significant and clinically significant differences, especially when the sample size is large. Given our large number of subjects in each major ethnic group, a clinically meaningful difference was specified before any analyses were performed. For the purpose of these analyses, a clinically significant difference in the refractive error prevalence between 2 ethnic groups was established as at least 5%.

RESULTS

The study presents the results for 2523 children (of 2583 enrolled) who had complete data. Fifty-seven children in the “other” ethnicity classification and 3 children with incomplete data (ie, no cycloplegic autorefraction results) were excluded. Subjects included were equally divided by sex (50.9% boys, 49.1% girls). There were 534 African American (21.2%), 491 Asian (19.5%), 463 Hispanic (18.3%), and 1035 white (41.0%) children. The mean±SD ages were similar among ethnic groups, but the Asian children were younger (9.70±2.11 years) and the African American children were older (10.40±2.50 years) (1-way analysis of variance, $P<.001$). The mean±SD age for white children was 9.90±2.30 years and for Hispanic children was 10.20±2.27 years. The overall mean±SD age was 10.00±2.32 years.

OVERALL PREVALENCE

The overall prevalence of myopia in the study population was 9.2% (95% CI, 8.1%-10.3%); the prevalence of hyperopia was 12.8% (95% CI, 11.5%-14.1%); and the prevalence of emmetropia was 49.5% (95% CI, 47.5%-51.5%). The overall prevalence of astigmatism was 28.4% (95% CI, 26.6%-30.2%). As expected, there was a significant difference in the mean age for the 4 refractive error groups: myopia, 11.04±2.28 years; hyperopia, 9.15±2.28 years; emmetropia, 10.01±2.28 years; and astigmatism, 10.05±2.28 years (1-way analysis of variance, $P<.001$). The prevalence of myopia increased with age when compared with emmetropia (odds ratio $[\text{OR}]$, 1.21; 95% CI, 1.14-1.29; $P<.001$), the prevalence of hyperopia compared with emmetropia decreased with age (OR, 0.84; 95% CI, 0.79-0.89; $P<.001$), and the prevalence of astigmatism compared with emmetropia did not change with age (OR, 1.01; 95% CI, 0.97-1.07; $P=.74$).

The overall prevalence of myopia increased slightly if the definition of myopia was changed from $-0.75\, \text{D}$ or more myopia in each principal meridian (9.2%) to $-0.50\, \text{D}$ or more myopia in each principal meridian (10.5%). However, the overall prevalence of hyperopia increased by almost 10% if the definition was changed from $+1.25\, \text{D}$ or more hyperopia in each principal meridian (12.8%) to $+1.00\, \text{D}$ or more hyperopia in each principal meridian (22.0%). The prevalence of astigmatism decreased if the definition increased from $-1.00\, \text{D}$ (28.4%) to $-1.25\, \text{D}$ (15.1%) of astigmatism (Table 2).

SEX

The sex-specific prevalences for myopia in this study population were 11.5% in girls and 7.1% in boys; for hyperopia, 13.1% in girls and 12.6% in boys; and for emmetropia, 48.1% in girls and 50.9% in boys. For astigmatism, the prevalences were 27.4% in girls and 29.4% in boys. Only the prevalence of myopia differed significantly by sex (polychotomous logistic regression, $P<.001$). However, using the predetermined 5% criterion for clinical significance, these sex differences would not be considered clinically important.

ETHNICITY

The prevalence of myopia among the different ethnic groups in the study population ranged from 4.4% to 18.5%, and the prevalence of hyperopia ranged from 6.3% to 19.3% (Table 3). Emmetropia was the most common refractive error among all ethnic groups. The preva-
Table 2. Effect of Changing Refractive Error Definition on the Prevalence of Myopia, Hyperopia, and Astigmatism

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Myopia, %</th>
<th>Hyperopia, %</th>
<th>Astigmatism, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.50 D*</td>
<td>–0.75 D†</td>
<td>+1.00 D‡</td>
</tr>
<tr>
<td>Overall</td>
<td>10.5</td>
<td>9.2</td>
<td>22.0</td>
</tr>
<tr>
<td>African American</td>
<td>8.6</td>
<td>6.6</td>
<td>12.2</td>
</tr>
<tr>
<td>Asian</td>
<td>19.8</td>
<td>18.5</td>
<td>12.0</td>
</tr>
<tr>
<td>Hispanic</td>
<td>14.5</td>
<td>13.2</td>
<td>20.7</td>
</tr>
<tr>
<td>White</td>
<td>5.2</td>
<td>4.4</td>
<td>32.4</td>
</tr>
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</table>

Abbreviation: D, diopeters.
*Or more myopia in each principal meridian.
†Or more hyperopia in each principal meridian.
‡Difference between the 2 principal meridians.

Table 3. Prevalence of Refractive Error as a Function of Ethnicity in the CLEERE Study Sample*†

<table>
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<tr>
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<td>273 (26.4)</td>
</tr>
<tr>
<td>Emmetropia</td>
<td>358 (67.0)</td>
<td>204 (41.6)</td>
<td>172 (37.2)</td>
<td>516 (49.9)</td>
</tr>
</tbody>
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Abbreviation: CLEERE, Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error.
*Myopia is defined as –0.75 diopters (D) or more myopia in each principal meridian, hyperopia as +1.25 D or more hyperopia in each principal meridian, and astigmatism as at least a 1.00-D difference between the 2 principal meridians, and emmetropia as refractive errors not otherwise classified.
†Data are given as number (percentage) of children.

Figure 1. Prevalence of refractive error using categorical data for children from 4 ethnic groups in the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error Study in 1997-1998. The definitions for these categorical data were: –0.75 diopters (D) or more in each principal meridian for myopia, +1.25 D or more in each principal meridian for hyperopia, and at least a 1.00-D difference between the 2 principal meridians for astigmatism. Emmetropia was defined as any refractive error not in one of the other categories. For simple myopia and hyperopia, agreement between meridians was classified as values within ±0.37 D of each other based on the repeatability of the measurement. For example, an eye with a vertical meridian of –0.75 D and a horizontal meridian of +1.00 D was categorized as having simple myopia. An eye with a vertical meridian of –0.50 D and a horizontal meridian of –1.75 D was categorized as having compound myopic astigmatism. SM indicates simple myopia; CMA, compound myopic astigmatism; SH, simple hyperopia; CHA, compound hyperopic astigmatism; SMA, simple myopic astigmatism; SHA, simple hyperopic astigmatism; MA, mixed astigmatism; and EM, emmetropia.

Figure 2. Cumulative frequency graph showing the relationship between astigmatism and ethnicity. The prevalence of astigmatism differed significantly among the 4 ethnic groups. For astigmatism, Asians and Hispanics had the highest prevalence and did not differ from each other with regard to risk of astigmatism compared with emmetropia (P=.17). African Americans had the lowest prevalence, followed by whites. Neither age nor sex changed the relationship between astigmatism and ethnicity.

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The prevalence of refractive error among the 4 ethnic groups differed significantly (χ²=236.15, P<.001), even after controlling for age and sex (polychotomous logistic regression, P<.001). The prevalence of refractive errors using categorical data for each ethnic group is shown in Figure 1. The categories shown reinforce the general pattern seen for myopia, hyperopia, and astigmatism overall. For example, whites had the highest prevalence of hyperopia in general and the highest prevalence of all subtypes of hyperopia.

For myopia, Asians had the highest prevalence, followed by Hispanics. African Americans and whites had the lowest prevalence of myopia. The prevalence of myopia differed significantly for all comparisons, with the following exceptions: African Americans did not differ from whites (P=.69, unadjusted for age and sex), and Hispanics and Asians did not differ significantly from each other (P=.24). For hyperopia, whites had the highest prevalence, followed by Hispanics, African Americans, and Asians. The prevalence of hyperopia compared with emmetropia differed significantly for all comparisons among refractive error groups, with the exceptions of Asians vs African Americans (P=.07) and Hispanics vs whites (P=.48).

The prevalence of astigmatism in the different ethnic groups was African American, 20.0%; Asian, 33.6%; Hispanic, 36.9%; and white, 26.4%. The prevalence of astigmatism differed significantly among the 4 ethnic groups. For astigmatism, Asians and Hispanics had the highest prevalence and did not differ from each other with regard to risk of astigmatism compared with emmetropia (P=.17). African Americans had the lowest prevalence, followed by whites. Neither age nor sex changed the relationship between astigmatism and ethnicity.

**CUMULATIVE FREQUENCY**

Many studies define refractive errors using the spherical equivalent (sphere + 0.5 × cylinder). So that our results can be compared with other studies, the spherical equivalent cumulative frequencies are shown in Figure 2.
The refractive error for each ethnic group is distributed similarly. In the myopic portion of the curve, Asians have the highest cumulative frequencies.

**COMMENT**

The overall prevalence of refractive errors in this study population was 9.2% for myopia, 12.8% for hyperopia, and 28.4% for astigmatism. Comparing the 4 ethnic groups, there was more myopia in Asians and Hispanics and less myopia in African Americans and whites. There was more hyperopia in whites and Hispanics and less hyperopia in Asians and African Americans. There was more astigmatism in Hispanics and Asians and less astigmatism in whites and African Americans. The range of differences in refractive errors was smallest for hyperopia (13.0%), largest for astigmatism (16.9%), and intermediate for myopia (14.1%).

It is difficult to compare these results with those reported in other studies. This difficulty occurs because there are different definitions of refractive errors, different measurement techniques, different cycloplegia states, different age groups, and different ethnic groups. If this study population were compared with previous studies, assuming there were no differences (definitions, measurement techniques, cycloplegia, age groups, and/or ethnicity), then the results would show that in general:

1. The prevalence of myopia in the CLEERE Study is similar to many studies, except for a study by Lam et al that found a prevalence of myopia of 52% in a small study of children in Hong Kong.
2. The prevalence of hyperopia is similar to other studies but is lower than one that found prevalences of 41.5% and 58.2% in Taiwanese children living in the mountains.
3. The prevalence of astigmatism is higher in other studies except for a study by Mohindra of Navajo and Zuni first- and second-graders, where the prevalences of astigmatism were 37% and 45.3%, respectively.

The prevalence of refractive error reported for the children in this study used relatively conservative definitions. The prevalence of hyperopia and astigmatism in this study increased with small changes in definitions. Table 2 shows the effect of this change in the definition for astigmatism.

The effect of changing definitions can be observed across studies, but comparisons can be difficult. For example, Lin and coworkers found the prevalence of myopia to be 76% by age 15 years in a study of Taiwanese children aged 7 to 18 years, using a definition of −0.25 D or more (spherical equivalent). In the present study, which included children aged 5 to 17 years, the prevalence of myopia, using the criterion of Lin and coworkers, would be about 17% compared with 9.2% using our more conservative criterion.

Analysis of the cross-sectional CLEERE data in the baseline year shows that the prevalence of myopia increases with age, the prevalence of hyperopia decreases with age, and the prevalence of astigmatism does not change with age. These changes were observed across the cross-sectional cohort and, to our knowledge, have not been shown before in a single study of children representing these 4 ethnic groups.

**STUDY OUTCOMES**

There are several issues that could affect the results and the prevalences reported here. These issues include the potential volunteer bias of the study population, the validity and reliability of the autorefractor results, and the parental designation of ethnicity. If the study had a volunteer bias, such as a bias to overenroll children with significant refractive errors, then these results would tend to overestimate the prevalence of refractive error compared with that in the general population. If the autorefractor did not provide valid and reliable results, then the primary outcome measure for this study would be suspect. If the parents did not accurately report their ethnicity, then the children in this study would be incorrectly classified.

**STUDY VOLUNTEER BIAS**

For a study of refractive error prevalence in children to be of maximum value, a randomly selected study population of sufficient size is needed. One potential weakness of this and other studies referenced in this report is the unknown representativeness of the study population. However, we found no statistically significant difference in the refractive error distribution of children in Orinda (Orinda Longitudinal Study of Myopia results) when comparing vision screening results of participants to nonparticipants. While there is no evidence to suggest that the CLEERE Study enrollees had greater or smaller proportions of children with significant refractive error compared with children who did not enroll, we plan to investigate this question. All children in the third and fifth grades at the Eutaw, Houston, and Irvine sites, regardless of CLEERE Study enrollment status, will be examined through a vision screening. We will examine any systematic differences in refractive error and ethnicity between CLEERE Study participants and nonparticipants.
The validity of the Canon R-1 has been assessed by comparing the difference between the R-1 and cycloplegic subjective refraction results. The mean difference for sphere power was not statistically significant (mean, 0.10 D). The R-1 precision in eyes without cycloplegia during a single testing session is about 0.32 D for sphere power and 0.32 D for cylinder power. The repeatability of Canon R-1 cycloplegic subjective refraction results is both reliable and valid. The use of parental self-report for assessing the ethnicity of children in this study is a common approach for determining ethnicity and is used by the US Census Bureau. This concept of race reflects self-identification by people according to race or races with which they most closely identify. However, there is potential for error in the case of families with parents of different ethnicities. In this study, there were parents who reported more than one ethnicity for their child (43 children) and other parents who did not report their child's ethnicity (134 children). For assignment of mixed ethnicities, we arbitrarily used the ethnicity of the target ethnic group at the particular site. In theory, this may lead to overassignment to some ethnic groups. Because this only occurred in a small number of children, it appears unlikely to have had any significant effect on the results. Assignments were made to all 4 ethnic groups, with equal numbers of Asians and whites, followed by African Americans and then Hispanics.
tive errors are a major public health problem. The implications of this research are that there are a large number of children who are handicapped visually in their everyday classroom, recreational, and other activities. These uncorrected refractive errors have the potential to make learning more difficult and to reduce or self-limit the choices that children make in their daily activities. New policies need to be developed to address this public health problem.

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