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Racial Disparities in Uncorrected and Undercorrected Refractive Error in the United States

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Purpose. To identify risk factors for inadequately corrected refractive error in the United States.

Methods. This cross-sectional study included 12,758 participants 12 years of age and older from the 2005 to 2008 National Health and Nutrition Examination Survey. The primary outcome was the proportion of individuals with inadequate refractive correction for whom refractive correction would result in a visual acuity of 20/40 or better. The primary predictor was race/ethnicity. Secondary predictors included age, sex, annual household income, education, insurance, type of refractive error, current corrective lens use, presenting and best corrected visual acuity, cataract surgery, glaucoma, and age-related macular degeneration.

Results. Overall, 50.6% of subjects had a refractive error which was correctable to 20/40 or better with refraction. The percentage of subjects with correctable refractive error who were inadequately corrected was 11.7%. Odds of inadequate refractive correction were significantly greater in Mexican Americans and non-Hispanic blacks than in their non-Hispanic white counterparts in all age groups, with the greatest disparity in the 12- to 19-year-old group. Other risk factors associated with inadequate refractive correction in adults but not in teenagers included low annual household income, low education, and lack of health insurance.

Conclusions. Racial disparities in refractive error correction were most pronounced in those under 20 years of age, as well as in adults with low annual household income, low education level, and lack of health insurance. Targeted efforts to provide culturally appropriate education, accessible vision screening, appropriate refractive correction, and routine follow-up to these medically underserved groups should be pursued as a public health strategy.

Keywords: ethnic disparities, healthcare access, NHANES, racial disparities, refractive error

Refractive error is one of the most common causes of visual impairment[1–9] and the second leading cause of treatable blindness worldwide.[2–6,10–13] Uncorrected refractive error has been recognized as a significant cause of avoidable visual disability and was included as a priority eye disease in *Vision 2020: The Right to Sight*, a global initiative to eliminate avoidable blindness by the year 2020.[14]

To assess the prevalence of uncorrected refractive error in children of different ethnic origins and cultural settings worldwide, the Refractive Error Study in Children[15] was conducted over the past decade and reported a prevalence of uncorrected refractive error ranging from 3% to 7% in children in developing and developed countries.[16–26] Uncorrected refractive error, especially among children and adolescents, has extensive social and economic impact worldwide, including limiting educational and employment opportunities.[27]

In the United States, several studies have assessed the prevalence of visual impairment and refractive error by using data from the National Health and Nutrition Examination Survey (NHANES),[28] a large population-based survey conducted annually. Clinically important refractive error defined as myopia ≤ -1.00 diopter (D) or hyperopia ≥ 3.00 D affects half of the adult population in the United States, and an increasing prevalence of myopia has been noted over the past 3 decades.[29–30] A previous study estimated that 6.4% of individuals over age 12 have visual impairment $\leq$ 20/50, and visual acuity in 83% of these individuals could be substantially improved with refractive correction.[31]

Despite the extensive evidence worldwide that visual impairment due to uncorrected refractive error causes a significant public health burden, there are many people in the United States and other industrialized countries who live without appropriate refractive correction. This study aimed to identify risk factors for uncorrected and undercorrected refractive error resulting in visual impairment, using data from the NHANES, with an emphasis on identifying racial and ethnic disparities in access to adequate refractive correction.

Methods

Sample and Population

We used data from the 2005 to 2008 NHANES, a cross-sectional series of interviews and examinations of the civilian, noninstitutionalized US population, administered by the Centers for Disease Control and Prevention. The purpose of NHANES is to make publically available de-identified health-related information pertaining to the US population. NHANES uses a stratified

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multistage sampling design with a weighting scheme to accurately estimate disease prevalence in the US population.

Our analysis included all NHANES participants between the years 2005 and 2008 who (1) were aged 12 years or older at the time of the examination and (2) had no history of refractive surgery. Subjects were excluded if they were unable to complete the visual acuity examination or were unable to answer the survey question about whether they already wore glasses or contact lenses for distance vision. The vision examination was conducted only in subjects aged 12 years or older, so children under the age of 12 were not included in this study population.

Measures

The primary predictor variable was race/ethnicity, determined by self-report on a survey questionnaire and subsequently organized by NHANES into 5 categories: Mexican American, Other Hispanic, non-Hispanic white, non-Hispanic black, and other and multiracial. Participants were first asked "Do you consider yourself Hispanic/Latino?" If they responded "yes," then they were asked to indicate "the group that represents your Hispanic origin or ancestry." Participants who self-identified as "Mexican American" were coded as such, regardless of their other race/ethnicity identifiers. Otherwise, self-identified "Hispanic" ethnicity was coded as "Other Hispanic." All non-Hispanic participants were asked, "What race do you consider yourself to be?" and were subsequently classified as non-Hispanic white, non-Hispanic black, or other non-Hispanic race, including non-Hispanic multiracial. In an effort to investigate a possible association between race/ethnicity minority status and inadequate refractive correction, the non-Hispanic white group was selected as the reference standard to which all other groups were compared.

Secondary predictor variables, and possible confounders, included age, sex, annual household income, education level, health insurance coverage, severity and type of refractive error, current glasses or contact lens use, presenting visual acuity, best corrected visual acuity, self-reported history of cataract surgery, self-reported glaucoma, and self-reported age-related macular degeneration (AMD). Subjects were divided into 3 age categories: 12 to 19 years old, 20 to 39 years old, and 40 or more (40+) years old. Subjects aged 12 to 19 might still have been attending school at the time of their NHANES participation, so the education variable was included only in the analysis for subjects in the other 2 subgroups aged 20+ years. The question regarding history of cataract surgery was asked only of subjects aged 20+ years, and the questions regarding glaucoma and AMD were asked only of subjects aged 40+ years. Refractive error was measured with an Auto Refractor model ARK-760 instrument (Nidek Co., Ltd., Gamagori, Japan). Trained technicians obtained three measurements from each eye, and the median spherical equivalent of each eye was calculated by taking the sum of the spherical power and half of the cylindrical power. The spherical equivalent measurements from the subject's two eyes were averaged to determine the overall mean spherical equivalent for the subject. We based our refractive error categories on those used by Vitale et al.[29] in their study of refractive error using the NHANES database. Clinically important myopia and hyperopia were defined as a spherical equivalent ≤ -1.00 D and ≥ 3.00 D, respectively. Myopia severity was further categorized based on criteria previously used in a study of myopia and glaucoma in the United States using the NHANES database.[32] Emmetropia was defined as between –0.99 D and +3.00 D, mild myopia was defined as –1.00 D to –2.99 D, moderate myopia as –3.00 D to –5.99 D, and severe myopia as ≤ -6.00 D. Clinically meaningful astigmatism was defined as a cylindrical power with an absolute value of ≥ 1.50 D in 1 or both eyes. Presenting visual acuity and best corrected visual acuity were also measured with the Auto Refractor model ARK-760 instrument (Nidek) with a built-in visual acuity chart. The initial test included measurement of "presenting visual acuity" with distance correction, if any, that the subject wore on the day of the examination. If the subject's presenting visual acuity was 20/30 or worse, a "best corrected visual acuity" aided by refractive correction was subsequently measured. Data from the eye with better vision was used to define presenting visual acuity and best corrected visual acuity for this analysis. A threshold of 20/40 was used by Vitale et al.[31] in their study of visual impairment using the NHANES database, and that threshold was also deemed appropriate for this analysis, due in part to the fact that such a cutoff is commonly used for maintenance of a driver's license and for determining whether cataract surgery is indicated.

The primary outcome variable for this study was the proportion of individuals with inadequate refractive correction to achieve a visual acuity of 20/40 or better for whom refractive correction might result in visual acuity of 20/40 or better. Subjects' vision status was categorized by incorporating information about their presenting visual acuity, best corrected visual acuity, and whether they already wore glasses or contact lenses for distance vision. Subjects were classified as "does not need refractive correction" if their presenting visual acuity was 20/40 or better and they did not report wearing glasses or contact lenses. Subjects were classified as having a "visual impairment that cannot be corrected with refraction" if their presenting visual acuity was 20/50 or worse and their best corrected visual acuity remained 20/50 or worse. Subjects were classified as having "appropriate refractive correction" if their presenting visual acuity was 20/40 or better and they reported wearing glasses or contact lenses. Subjects were classified as having "undercorrected refractive error" if their presenting visual acuity was 20/50 or worse, their best corrected visual acuity was 20/40 or better, and they reported wearing glasses or contact lenses. Lastly, subjects were classified as having "uncorrected refractive error" if their presenting visual acuity was 20/50 or worse, their best corrected visual acuity was 20/40 or better, and they do not report wearing glasses or contact lenses.

Data Analysis

For examination of study population characteristics, we compared the distribution of each predictor variable across subjects in each age group, using the design-adjusted Rao-Scott Pearson-type χ^2 test. The overall prevalence of inadequately corrected refractive error was calculated for subjects in all age and race/ethnicity groups; subjects with inadequately corrected refractive error included those with uncorrected as well as undercorrected refractive error. The relative prevalence of inadequately corrected refractive error was calculated by totaling the number of subjects with uncorrected and undercorrected refractive error and dividing by the total number of subjects with correctable refractive error. Subjects who did not require refractive correction and those whose visual impairment could not be corrected with refraction were excluded from this relative percent calculation. Such subjects, by definition, would not benefit from refractive correction. Next, multivariate logistic regression models were created to identify independent predictors for inadequate refractive correction in subjects with correctable refractive error while adjusting for potential confounders. Once again, only subjects with correctable refractive error were included in this analysis. Next, to examine the joint effect of race/ethnicity and other risk factors, the relative prevalence of inadequate refractive correction among subjects of each race/ethnicity was calculated for each risk factor subgroup. In an effort to most accurately calculate confidence intervals around estimates for the US national population, we performed all data analyses (Stata version 12.0 software; Stata Statistical Software, College Station, TX, USA) using weighted data, calculating standard errors of population estimates using Taylor linearization methods.

Results

The 2005 to 2008 NHANES database yielded 13,897 participants aged 12 years and older, of which 12,852 participants had no history of refractive surgery. After excluding subjects who were unable to complete the visual acuity examination or answer the survey question about whether they wore glasses or contact lenses for distance vision, the study population consisted of 12,758 subjects.

Characteristics of the study population are described in Table 1. Distribution of subjects in each age group was 3209 aged 12 to 19 years; 3345 aged 20 to 39 years; and 6204 aged 40+ years. Overall, 51.1% of subjects were male. Distribution of race/ethnicity was 8.6% Mexican American, 4.3% other Hispanic, 70.0% non-Hispanic white, 11.6% non-Hispanic black, and 5.5% other and multiracial. The prevalence of glasses or contact lens use was 48.2% overall, lowest in subjects aged 12 to 19 years old (34.3%), and highest in subjects aged 40+ years old (57.7%). The prevalence of having a presenting visual acuity 20/50 or better was 7.6% overall and higher in subjects aged 12 to 19 years old (10.0%) than in subjects 20+ years old (7.2%).

Subject's vision status was classified in 5 categories based upon presenting visual acuity, best corrected visual acuity, and whether they reported wearing glasses or contact lenses (Table 2). Overall, 48.0% of all subjects did not require refractive correction to achieve a visual acuity of 20/40 or better; 1.4% of subjects had a visual impairment that could not be improved to 20/40 or better even with refractive correction; 44.7% of subjects already had the appropriate refractive correction to achieve a visual acuity of 20/40 or better; 2.7% of subjects had an undercorrected refractive error, and their presenting visual acuity was 20/50 or worse with their current corrective lenses and could be improved to 20/40 or better with additional refractive correction; and 3.3% of subjects had uncorrected refractive error and did not currently wear any corrective lenses, although their visual acuity could be improved to 20/40 or better with refractive correction. The absolute prevalence of correctable refractive error was 50.6%, and the absolute prevalence of inadequately corrected refractive error, including uncorrected or undercorrected refractive error, was 5.9%. The proportion of subjects with correctable refractive error who were inadequately corrected was 11.7% overall. This parameter was highest in the 12 to 19 year age group (23.7%) and in the Mexican American race/ethnicity group (27.3%).

Multivariate logistic regression was performed to identify independent predictors of inadequate refractive correction in subjects with correctable refractive error, adjusting for confounding variables (Table 3). In subjects aged 12 to 19 years old, male sex (odds ratio [OR], 1.5; 95% confidence interval [CI], 1.0–2.2, $P = 0.04$), Mexican American race (OR, 2.8; 95% CI, 2.0–4.0; $P < 0.0001$), and non-Hispanic black race (OR, 3.3; 95% CI, 2.1–5.1; $P < 0.0001$) were associated with significantly increased odds of having inadequate refractive correction. In subjects aged 20 to 39 years old, male sex (OR, 1.6; 95% CI, 1.0–2.6; $P = 0.04$), Mexican American race (OR, 1.8; 95% CI, 1.1–3.1; $P = 0.02$), non-Hispanic black race (OR, 2.2; 95% CI, 1.5–3.3; $P < 0.0001$), annual household income of <$20,000 (OR, 1.7; 95% CI, 1.0–2.9; $P = 0.04$), <ninth grade education (OR, 9.5; 95% CI, 3.5–26.0; $P < 0.0001$), ninth to 11th grade education (OR, 3.3; 95% CI, 1.7–6.2; $P = 0.001$), and high school graduate equivalent education (OR, 1.7, 95% CI, 1.1–2.7; $P = 0.001$) were associated with significantly increased odds of having inadequate refractive correction. In subjects aged 40+ years, Mexican American race (OR, 1.9; 95% CI, 1.3–2.8; $P = 0.003$), non-Hispanic black race (OR, 2.0; 95% CI, 1.4–2.9; $P < 0.0001$), other or multiracial ethnicity (OR, 2.3; 95% CI, 1.1–4.8; $P = 0.03$), annual household income of <$20,000 (OR, 1.7; 95% CI, 1.1–2.6; $P = 0.02$), <ninth grade education (OR, 2.5; 95% CI, 1.5–4.3; $P = 0.001$), lack of health insurance coverage (OR, 2.0; 95% CI, 1.2–3.4; $P = 0.008$), astigmatism (OR, 1.6; 95% CI, 1.1–2.2; $P = 0.02$), and self-reported AMD (OR, 1.8; 95% CI, 1.0–3.3; $P = 0.04$) were associated with significantly increased odds of having inadequate refractive correction. Greater myopia severity was associated with significantly decreased odds of inadequate refractive correction in all age groups.

The joint effect of race/ethnicity and other risk factors was investigated by calculating the relative prevalence of inadequate refractive correction in multiple subgroup analyses (Table 4). Mexican Americans and non-Hispanic blacks had a higher prevalence of inadequately corrected refractive error than their non-Hispanic white counterparts within every strata of each risk factor subgroup, except for the college educated subgroup, where the prevalence was 3.5% in Mexican Americans and 5.1% in non-Hispanic whites.

Within the subpopulation of subjects with undercorrected refractive error, mild myopia was the most prevalent type of refractive error in all race/ethnicity groups, and the prevalence of moderate and severe myopia was higher in Mexican American (13.4% and 8.9%, respectively) and non-Hispanic black (19.9% and 5.8%) groups than in the non-Hispanic white (11.0% and 5.0%, respectively) group (Table 5).

Discussion

This study of a population-based sample of US residents aged 12 years old and older found the overall prevalence of correctable refractive error to be 50.6%. Within this subpopulation, 88.3% had adequate refractive correction resulting in a presenting visual acuity of 20/40 or better, but 11.7% had undercorrected or uncorrected refractive error resulting in a presenting visual acuity of 20/50 or worse. Mexican American and non-Hispanic black race/ethnicities were the strongest predictors for inadequate refractive correction in every age group and socioeconomic strata. More than one-third of all Mexican American and African American teenagers with correctable refractive error lacked adequate refractive correction. Low annual household income and low education level were especially strong predictors in adults aged 20 to 30 years old, which points to socioeconomic barriers for adults in accessing and maintaining routine eye care. Approximately one-third of Mexican Americans with an annual household income of <$45,000 or less than a high school education who had correctable refractive error lacked adequate refractive correction. Interestingly, Mexican Americans with a college education or beyond had a low prevalence of inadequate refractive correction that was similar to that of their Caucasian counterparts. Even among those with health insurance, approximately 20% of Mexican Americans and African Americans with correctable refractive error lacked adequate refractive correction, compared to only 8% of Caucasians. This disparity was even more considerable among those who did not have health insurance, where 30% of African Americans and 40% of Mexican Americans lacked adequate refractive correction compared to only 14% of Caucasians. These results

Table 1. Characteristics of the Study Population*

Characteristic	% of Subjects in the Age Group			Total	P Value†
	12–19 Years Old	20–39 Years Old	40+ Years Old		
Number of subjects	3209	3345	6204	12,758	
Males	49.1	49.6	52.5	51.1	0.03
Race/ethnicity					<0.0001
Mexican American	11.5	12.4	5.6	8.6	
Other Hispanic	5.4	5.6	3.3	4.3	
Non-Hispanic white	62.6	63.2	76	70	
Non-Hispanic black	14.6	12.5	10.3	11.6	
Other and multiracial	5.8	6.3	4.9	5.5	
Annual household income‡					0.005
<$20,000	15.3	14.7	15.2	15	
$20,000–$44,999	24.5	26.6	27.6	26.9	
$45,000–$74,999	22.2	27.1	22.2	23.8	
≥$75,000	35.4	28.7	32.4	31.7	
≥$20,000	2.7	2.8	2.6	2.7	
Education§					<0.0001
<Ninth grade	n/a	4.5	7.6	6.5	
Ninth–11th grade	n/a	13.7	11.6	12.4	
HS grad/GED equivalent	n/a	23.8	26.6	25.5	
Some college	n/a	34.4	28.4	30.6	
College grad and beyond	n/a	23.7	25.8	25	
Health insurance coverage	85.4	70.1	87.1	81.3	<0.0001
Refractive error‖					<0.0001
Emmetropia	70.1	67.8	69.3	68.9	
Mild myopia	16.8	16.5	16.6	16.6	
Moderate myopia	9.6	10	8	8.9	
Severe myopia	2.7	5	3	3.6	
Hyperopia	0.9	0.8	3.1	2	
Astigmatism#	11.3	14.8	29	21.8	<0.0001
Wears glasses/contacts	34.3	38.4	57.7	48.2	<0.0001
Presenting visual acuity					0.006
20/40 or better	90	92.8	92.8	92.4	
20/50 or worse	10	7.2	7.2	7.6	
Best corrected visual acuity					0.07
20/40 or better	91	88.7	86.7	87.8	
20/50 or worse	9	11.3	13.3	12.2	
Cataract surgery**	n/a	0.3	10.4	6.6	<0.0001
Glaucoma**	n/a	n/a	5	n/a	n/a
AMD**	n/a	n/a	3.2	n/a	n/a

GED, general education development; HS, high school; n/a, not applicable.

* All proportions are weighted estimates of the US population, taking into account NHANES' complex sampling design.

† All P values are unadjusted and were calculated using the design-adjusted Rao-Scott Pearson χ^2 test.

‡ Participants who were unable to provide a more specific annual household income were asked to indicate whether the household income exceeded $20,000 per year.

§ Information about education level was not included for subjects 12 to 19 years old because some of those subjects might still have been in school at the time of the examination and survey.

‖ Refractive error was defined as the mean spherical equivalent for 2 eyes. Emmetropia (–0.99 to 2.99 D), mild myopia (–1.00 to –2.99 D), moderate myopia (–3.00 to –5.99 D), severe myopia (≤–6.00 D), hyperopia (≥3.00 D).

\# Astigmatism was defined as a cylindrical power with an absolute value of ≥1.50 D in 1 or both eyes. Visual acuity was measured with distance correction, if any, that the subject wore on the day of the examination. In subjects presenting with visual acuity of 20/30 or worse, a best corrected visual acuity aided by refractive correction was also measured.

** Self-reported history of cataract surgery was assessed only in subjects aged 20+ years; self-reported history of glaucoma was assessed only in subjects aged 40+ years; and self-reported age-related macular degeneration (AMD) was assessed only in subjects aged 40+ years.

suggest that having health insurance is not adequate for many non-Caucasian patients to seek the vision care they need if they do not realize the importance of routine follow-up visits to obtain updated prescriptions. Additional targeted efforts to provide culturally appropriate education may be necessary to encourage patients to seek routine eye care visits. Among Mexican Americans with correctable refractive error, 17% of those with moderate myopia and 18% of those with severe myopia did not have adequate refractive correction, compared to only 3% of Caucasians. This suggests that Mexican

Table 2. Vision Status of Study Population*

	% of Subjects by Age and Ethnicity								
Vision Status	**12–19 Years**	**20–39 Years**	**40+ Years**	**Mexican American**	**Other Hispanic**	**Non-Hispanic White**	**Non-Hispanic Black**	**Other and Multiracial**	**Total**
Does not need refractive correction†	60.7	57.6	38.8	62.0	54.7	44.7	55.6	46.3	48.0
Visual impairment cannot be corrected with refraction‡	0.9	1.0	1.8	2.0	2.6	1.3	1.7	0.7	1.4
Has appropriate refractive correction§	29.3	35.3	54.4	26.1	33.9	49.4	33.9	44.9	44.7
Undercorrected refractive error‖	4.5	2.6	2.3	3.2	3.0	2.3	4.0	3.7	2.7
Uncorrected refractive error#	4.6	3.5	2.7	6.6	5.7	2.4	4.8	4.4	3.3
Overall prevalence of correctable refractive error**	38.4	41.4	59.4	36.0	42.6	54.1	42.6	52.9	50.6
Overall prevalence of inadequately corrected refractive error††	9.1	6.2	5.0	9.8	8.8	4.7	8.8	8.0	5.9
Relative percentage of subjects with correctable refractive error who were inadequately corrected‡‡	23.7	14.9	8.4	27.3	20.5	8.6	20.6	15.1	11.7

* All proportions are weighted estimates of the US population characteristics, taking into account NHANES' complex sampling design.
† Presenting visual acuity is 20/40 or better, does not wear glasses or contacts for distance vision.
‡ Presenting visual acuity is 20/50 or worse, and best corrected visual acuity is still 20/50 or worse.
§ Presenting visual acuity is 20/40 or better, wears glasses or contacts for distance vision.
‖ Presenting visual acuity is 20/50 or worse, best corrected visual acuity is 20/40 or better, wears glasses or contacts for distance vision.
\# Presenting visual acuity is 20/50 or worse, best corrected visual acuity is 20/40 or better, does not wears glasses or contacts for distance vision.
** Percentage of all subjects with correctable refractive error, calculated as the sum of those with appropriate refractive correction, undercorrected refractive error, and uncorrected refractive error.
†† Percent of all subjects with inadequately corrected refractive error, calculated as the sum of those with undercorrected and uncorrected refractive error.
‡‡ Relative percentage of subjects with inadequately corrected refractive error, calculated by dividing the prevalence of inadequately corrected refractive error by the prevalence of all correctable refractive error.

Americans may wait until their vision is more severely impaired before visiting an eye care professional, possibly due to lack of access, lack of education, or other socioeconomic barriers.

Our results support findings from previous large population-based studies which assessed racial disparities in ophthalmic health access and outcomes in the United States. A prior analysis of subjects aged 12 years or older from the 1999 to 2002 NHANES database estimated the prevalence of visual impairment due to uncorrected refractive error to be 6.4% overall with 83.3% correctable with refraction.[31] The prevalence of correctable visual impairment was higher in Hispanic (9.2%), non-Hispanic black (6.9%), and other and multiracial (9.3%) subjects than in non-Hispanic white (4.1%) subjects.[31] In comparison, our analysis of the more recent 2005 to 2008 NHANES found a similar prevalence of inadequately corrected refractive error in all subjects aged 12 years and older (5.9%). The prevalence was higher in Mexican American (9.8%), other Hispanic (8.8%), non-Hispanic black (8.8%), and other and multiracial subjects (8.0%) than in the non-Hispanic white group (5.7%), suggesting that there has not been much improvement in eliminating these racial disparities over the past decade.

There are several possible explanations for our findings pertaining to these race/ethnicity disparities. Mexican Americans and other Hispanics, African Americans, and other ethnic minorities, including some Asian groups, have been historically medically underserved in the United States and may not have the same access to ophthalmic care compared to Caucasians. A previous study of adults in the United States from the 2008 National Health Interview Survey (NHIS) database reported lower rates of annual ophthalmic care visits among Hispanic (36.9%) subjects than among non-Hispanic black (47.2%) and non-Hispanic white (52.6%) subjects.[33] This difference may be due to lack of education and awareness about the necessity of routine ophthalmic care visits or lack of affordable options for ophthalmic care in these underserved groups.

Access to routine eye care may differ by race in part because of disparities in insurance coverage. It should be noted, however, that the NHANES database does not specify whether vision benefits are included in subject's insurance coverage plan, which undoubtedly impacts subjects' access to ophthalmic care providers for refractive correction and follow-up care. Despite adjustment for insurance coverage in our multivariate model, race/ethnicity remained independently associated with inadequately corrected refractive error.

Another explanation for the racial disparities in obtaining appropriate refractive correction may be income. It is likely that many low income subjects who had undergone an initial ophthalmic evaluation were found to have a correctable refractive error and were aware of their need for corrective lenses yet were unable to afford the recommended glasses or contact lenses. Such a possibility was supported by a study using the 2008 NHIS database, which reported higher rates of being unable to afford eyeglasses when needed among subjects of Hispanic (26.7%) race/ethnicity than in non-Hispanic black (15.3%) and non-Hispanic white (16.0%) race/ethnicity.[33] Our study also identified low annual household income as a predictor for inadequate refractive correction, and the prevalence of inadequate refractive correction was higher among low-income Mexican Americans and African Americans than low-income Caucasians.

Table 3. Multivariate Logistic Regression Identifying Predictors For Inadequate Refractive Correction in Subjects With Correctable Refractive Error

Predictor	All Subjects			Age 12–19			Age 20–39			Age 40+		
	OR*	95% CI*	*P* Value	OR*	95% CI*	*P* Value	OR*	95% CI*	*P* Value	OR*	95% CI*	*P* Value
Age												
12–19 years old	1.9	1.4–2.4	<0.0001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
20–39 years	1.0	(reference)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
40+ years	0.5	0.4–0.7	<0.0001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sex												
Male	1.4	1.1–1.7	0.005	1.5	1.0–2.2	0.04	1.6	1.0–2.6	0.04	1.2	0.8–1.6	0.4
Female	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a
Race/ethnicity												
Mexican American	2.3	1.7–3.1	<0.0001	2.8	2.0–4.0	<0.0001	1.8	1.1–3.1	0.02	1.9	1.3–2.8	0.003
Other Hispanic	1.9	1.2–2.9	0.005	1.4	0.8–2.7	0.3	1.6	0.8–2.9	0.2	1.8	0.9–3.6	0.1
Non-Hispanic white	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a
Non-Hispanic black	2.1	1.7–2.7	<0.0001	3.3	2.1–5.1	<0.0001	2.2	1.5–3.3	<0.0001	2.0	1.4–2.9	<0.0001
Other and multiracial	1.7	1.1–2.6	0.02	2.1	0.9–5.3	0.1	1.2	0.6–2.7	0.6	2.3	1.1–4.8	0.03
Annual household income†												
<$20,000	2.0	1.5–2.7	<0.0001	0.9	0.5–1.6	0.7	1.7	1.0–2.9	0.04	1.7	1.1–2.6	0.02
$20,000–$44,999	1.3	1.0–1.7	0.03	0.9	0.5–1.3	0.3	0.9	0.6–1.7	0.9	1.5	0.9–2.3	0.1
$45,000–$74,999	0.9	0.7–1.2	0.4	0.8	0.5–1.3	0.3	0.9	0.5–1.5	0.6	1.3	0.7–2.2	0.4
≥$75,000	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a
≥$20,000	1.7	0.8–3.5	0.2	1.2	0.2–7.6	0.8	2.1	0.7–6.6	0.2	1.2	0.7–2.2	0.4
Education‡												
<Ninth grade	n/a	n/a	n/a	n/a	n/a	n/a	9.5	3.5–26.0	<0.0001	2.5	1.5–4.3	0.002
Ninth–11th grade	n/a	n/a	n/a	n/a	n/a	n/a	3.3	1.7–6.2	0.001	1.6	0.9–2.7	0.1
HS grad/GED equivalent	n/a	n/a	n/a	n/a	n/a	n/a	1.7	1.0–2.7	0.001	1.3	0.7–2.3	0.4
Some college	n/a	n/a	n/a	n/a	n/a	n/a	1.1	0.6–2.0	0.7	1.2	0.7–2.2	0.4
College grad and beyond	n/a	n/a	n/a	n/a	n/a	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a
Health insurance coverage												
Yes	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a
No	1.7	1.3–2.3	0.001	1.6	0.9–3.0	0.1	1.2	0.8–2.0	0.4	2.0	1.2–3.4	0.008
Refractive error§												
Emmetropia	0.9	0.8–1.1	0.6	1.4	0.9–2.1	0.2	0.9	0.6–1.4	0.8	0.8	0.6–1.1	0.1
Mild myopia	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a
Moderate myopia	0.2	0.1–0.3	<0.0001	0.2	0.1–0.3	<0.0001	0.2	0.1–0.4	<0.0001	0.3	0.1–0.6	0.002
Severe myopia	0.2	0.2–0.4	<0.0001	0.2	0.1–0.6	0.002	0.3	0.2–0.6	0.001	0.3	0.1–0.8	0.02
Hyperopia	0.3	0.1–0.6	0.003	n/a	n/a	n/a	0.9	0.2–3.7	0.9	0.1	0.1–0.4	<0.0001
Astigmatism‖												
Yes	1.4	1.1–1.8	0.005	0.8	0.6–1.3	0.4	1.1	0.8–1.6	0.6	1.6	1.1–2.2	0.02
No	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a	1.0	(reference)	n/a
Cataract surgery¶												
Yes	n/a	n/a	n/a	n/a	n/a	n/a	0.5	0.1–5.4	0.6	1.1	0.7–1.8	0.5
No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.0	(reference)	n/a
Glaucoma¶												
Yes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.9	0.5–1.5	0.6
No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.0	(reference)	n/a
AMD¶												
Yes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.8	1.0–3.3	0.04
No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.0	(reference)	n/a

* 95% CI, 95% confidence interval; GED, General Education Development; HS, high school; n/a, not applicable; OR, odds ratio.

† Participants who were unable to provide a more specific annual household income were asked to indicate whether the household income exceeded $20,000 per year.

‡ Information about education level was not included for subjects aged 12 to 19 years old because some of these subjects might still have been in school at the time of the examination and survey.

§ Refractive error was defined as the mean spherical equivalent of the 2 eyes. Emmetropia (–0.99 to 2.99 D), mild myopia (–1.00 to –2.99 D), moderate myopia (–3.00 to –5.99 D), severe myopia (≤ –6.00 D), hyperopia (≥3.00 D).

‖ Astigmatism was defined as a cylindrical power with an absolute value of ≥1.50 D in 1 or both eyes

¶ Self-reported history of cataract surgery was assessed only in subjects aged 20+ years; self-reported history of glaucoma was assessed only in subjects aged 40+ years; and self-reported age-related macular degeneration (AMD) was assessed only in subjects aged 40+ years.

Investigative Ophthalmology & Visual Science

Table 4. Joint Effect of Race/Ethnicity and Other Risk Factors on Inadequate Refractive Correction in Subjects With Correctable Refractive Error

Parameter	Sample Size	% of Subjects With Correctable Refractive Error Who Were Inadequately Corrected: Mexican American	Other Hispanic	Non-Hispanic White	Non-Hispanic Black	Other and Multiracial	Total	*P* Value
Sex								
Male	2633	30.5	26.0	9.5	24.3	19.2	13.3	<0.0001
Female	3422	24.9	17.3	8.0	18.2	11.7	10.6	<0.0001
Age								
12–19 years	1205	36.9	27.3	17.0	37.3	27.6	23.7	<0.0001
20–39 years	1305	30.9	24.9	10.9	23.0	11.7	14.8	<0.0001
40+ years	3545	18.5	14.9	6.8	14.3	14.7	8.4	<0.0001
Annual household income*								
<$20,000	1232	32.4	20.6	16.4	24.5	24.6	19.9	0.008
$20,000–$44,999	1785	31.6	28.2	9.0	20.9	20.3	13.4	<0.0001
$45,000–$74,999	1247	18.4	16.1	5.9	20.6	10.0	8.6	<0.0001
≥$75,000	1428	16.1	10.3	7.1	15.4	11.7	8.3	0.004
≥$20,000	168	31.4	30.4	14.1	10.6	13.1	16.0	0.3
Education†								
<Ninth grade	517	47.9	24.3	15.7	18.4	41.7	25.8	0.0005
Ninth–11th grade	652	30.0	23.5	14.6	24.5	24.7	18.5	0.02
HS grad/GED equivalent	1177	25.6	30.7	8.9	18.3	16.8	11.4	<0.0001
Some college	1373	12.3	13.8	7.0	16.2	7.4	8.5	0.004
College grad and beyond	1127	3.5	1.6	5.1	12.4	11.1	5.9	0.01
Health insurance coverage								
Yes	5066	20.2	13.9	8.0	18.7	14.1	10.1	<0.0001
No	978	40.9	42.8	13.7	29.2	20.7	21.9	<0.0001
Refractive error‡								
Emmetropia	2688	29.3	22.8	10.2	17.8	21.1	13.1	<0.0001
Mild myopia	1805	33.0	29.9	12.1	30.4	16.2	16.7	<0.0001
Moderate myopia	910	16.9	3.5	3.1	14.5	4.7	5.0	<0.0001
Severe myopia	302	18.2	17.1	3.0	9.3	5.1	4.6	0.007
Hyperopia	256	2.1	2.4	3.2	8.1	22.1	4.6	0.03
Astigmatism§								
Yes	1973	28.1	19.9	10.7	22.2	17.2	13.4	<0.0001
No	3818	27.2	21.2	7.9	19.9	14.8	11.3	<0.0001
Cataract surgery‖								
Yes	531	18.0	9.0	11.3	13.3	6.1	11.4	0.7
No	4319	25.0	19.7	7.5	17.8	13.6	10.2	<0.0001
Glaucoma‖								
Yes	264	4.9	11.1	7.9	13.4	0.0	8.4	0.6
No	3269	19.1	15.2	6.7	14.5	14.5	8.4	<0.0001
AMD‖								
Yes	146	13.0	5.4	13.0	27.5	67.1	14.5	0.03
No	3364	18.7	14.9	6.5	14.3	12.8	8.1	<0.0001

GED, General Education Development; HS, high school.

* Participants who were unable to provide a more specific annual household income were asked to indicate whether the household income exceeded $20,000 per year.

† Information about education level was not included for subjects aged 12 to 19 years old because some of those subjects might still have been in school at the time of the examination and survey.

‡ Refractive error was defined as the mean spherical equivalent of the 2 eyes. Emmetropia (–0.99 to 2.99 D), mild myopia (–1.00 to –2.99 D), moderate myopia (–3.00 to –5.99 D), severe myopia (≤ –6.00 D), hyperopia (≥3.00 D).

§ Astigmatism was defined as a cylindrical power with an absolute value of ≥1.50 D in 1 or both eyes.

‖ Self-reported history of cataract surgery was assessed only in subjects aged 20+ years, self-reported history of glaucoma was assessed only in subjects aged 40+ years, and self-reported age-related macular degeneration (AMD) was assessed only in subjects aged 40+ years.

There are several limitations to our study, including the generalized classification of racial/ethnic groups. For example, the "other Hispanic" group includes a diverse array of Hispanic subjects who are not Mexican American, the "non-Hispanic white" group includes Middle Eastern subjects who are generally considered ethnically distinct from others classified in this group, and the extremely broad "other and multiracial" group includes all East Asians, South Asians, and non-Hispanic

Table 5. Types of Undercorrected Refractive Error*

	% of Refractive Errors by Ethnicity						
	Mexican American	Other Hispanic	Non-Hispanic White	Non-Hispanic Black	Other and Multiracial	Total	*P* Value†
Refractive error‡							
Emmetropia	30.7	33.2	37.4	20.2	59.6	35.2	0.02
Mild myopia	47.0	52.4	43.6	54.2	13.0	43.9	
Moderate myopia	13.4	5.5	11.0	19.9	12.4	12.6	
Severe myopia	8.9	7.6	5.0	5.8	3.0	5.5	
Hyperopia	0.0	1.3	3.0	0.0	12.0	2.7	
Astigmatism§							0.5
Yes	31.3	28.3	38.2	33.9	24.7	35.2	
No	68.8	71.7	61.8	66.1	75.3	64.8	

* All proportions are weighted estimates of the US population characteristics, taking into account NHANES' complex sampling design.

† All *P* values are unadjusted and were calculated using the design-adjusted Rao-Scott Pearson χ^2 test.

‡ Refractive error was defined as the mean spherical equivalent for the 2 eyes. Emmetropia (–0.99 to 2.99 D), mild myopia (–1.00 to –2.99 D), moderate myopia (–3.00 to –5.99 D), severe myopia ($\leq$ –6.00 D), hyperopia ($\geq$3.00 D).

§ Astigmatism was defined as a cylindrical power with an absolute value of $\geq$1.50 D in 1 or both eyes.

multiracial subjects. These categories consist of very diverse groups of subjects not commonly considered to be one racial/ethnic group. However, because our study focused on the barriers to vision care access rather than molecular genetics of disease inheritance, these popular definitions of race/ethnicity seem to fit commonly accepted classifications in the United States, and thus, the overly simplistic race/ethnicity categories used in NHANES are likely useful in understanding disparate access to care in our society. Additional studies using databases with more specific information about race/ethnicity would be required to investigate uncorrected refractive error as a cause of correctable visual impairment among those of various ethnic origins residing in the United States. Another limitation was that it was ascertained whether subjects wore corrective lenses for distance vision by using a question that might have been misunderstood. For example, some patients who normally wore glasses and forgot to wear them on the day of the examination might have answered the survey question incorrectly. This could be a potential source of bias rather than random error if the question was more commonly misunderstood by some race/ethnicity groups than others. Furthermore, refraction measurements in NHANES were performed using an autorefractor without subsequent refinement with subjective refraction. To the extent that there might have been greater accommodation in subjects of one race/ethnicity versus another, there is the potential for bias toward greater myopia in the former versus the latter group, particularly given that cycloplegic refraction was not used to supplement autorefraction. Furthermore, the use of noncycloplegic refraction would tend to overestimate the prevalence of myopia and underestimate the prevalence of hyperopia. Most studies of refractive error measure this parameter under cycloplegia,[34,35] and the use of noncycloplegic refraction in epidemiological studies may result in considerable measurement errors, particularly in school-age children between 7 and 18 years of age.[36] These errors become less significant in older populations, especially after the fifth decade, due to reduction in accommodation with age.[37] Because our study population included all subjects aged 12 years and older, cycloplegic refraction would have been a more appropriate method than that used in the study, especially among the younger age groups. However, because our study was a secondary analysis using the NHANES database and the NHANES protocol did not include cycloplegic refraction, we were limited to using noncycloplegic autorefraction data. The impact of such error associated with non-cycloplegic refraction would result in bias only to the extent that it differentially influenced the various race/ethnicity groups included in our study, and there is no reported scientific evidence supporting such a difference. Because our study is a cross-sectional population-based study, we cannot draw any conclusions about the mechanism by which Mexican American or African American race/ethnicity may lead to inadequately corrected refractive error. Furthermore, we cannot draw any conclusions about the direction of causation, and it is certainly possible that the association we identified between inadequately corrected refractive error and low socioeconomic status is partly attributable to inadequately corrected refractive error resulting in limited educational and employment opportunities. Finally, our study defines 20/40 as the acceptable visual acuity cutoff, in part due to an arbitrary standard being used by some for maintenance of a driver's license or determining whether cataract surgery is indicated. Although such a cutoff may allow us to distinguish those who would most benefit from refractive correction, one could argue that in industrialized countries such as the United States, public health measures should aim to allow every individual, especially school-age children, to achieve their best possible corrected visual acuity.

In summary, we found non-Caucasian race/ethnicity to be a significant risk factor for inadequately corrected refractive error resulting in visual impairment in our study population of adolescents, adults, and the elderly in the United States. Race/ethnicity disparities seem to be more pronounced in subjects with low annual household income, low education level, and lack of health insurance coverage but persist even in subjects with higher income, higher education (up to "some college"), and with health insurance. Although most individuals across all socioeconomic strata are able to obtain corrective lenses when they are needed, some medically underserved race/ethnicity groups are unable to obtain appropriately updated prescriptions and therefore live with undercorrected refractive error. The lack of appropriate refractive correction has extensive social and economic impact including limiting educational and employment opportunities, which exacerbates the disparity between non-Caucasian and Caucasian populations. Targeted efforts to provide culturally appropriate education, accessible vision screening, appropriate refractive correction, and routine follow-up, particularly to Mexican Americans, African Ameri-

Investigative Ophthalmology & Visual Science

cans, and other medically underserved groups, may be a worthwhile public health strategy. Further studies are needed to investigate potential reasons for such racial disparities in obtaining appropriate refractive correction, which may include poor education and awareness regarding the need for ophthalmic care, lack of insurance or access to healthcare facilities, as well as insufficient funds to purchase the necessary refractive correction.

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References

1. Dandona R, Dandona L. Refractive error blindness. *Bull World Health Org*. 2001;79:237–243.
2. Negrel AD, Minassian DC, Sayek F. Blindness and low vision in southeast Turkey. *Ophthalmic Epidemiol*. 1996;3:127–134.
3. Mansour AM, Kassak K, Chaya M, Hourani T, Sibai A, Alameddine MN. National survey of blindness and low vision in Lebanon. *Br J Ophthalmol*. 1997;81:905–906.
4. Zerihun N, Mabey D. Blindness and low vision in Jimma Zone, Ethiopia: results of a population-based survey. *Ophthalmic Epidemiol*. 1997;4:19–26.
5. Van Newkirk MR, Weih L, McCarty CA, Taylor HR. The cause-specific prevalence of bilateral visual impairment in Victoria, Australia: the Visual Impairment Project. *Ophthalmology* 2001;108:960–967.
6. Tielsch JM et al. Blindness and visual impairment in an American urban population: the Baltimore Eye Survey. *Arch Ophthalmol*. 1990;108:286–290.
7. Attebo K, Mitchell P, Smith W. Visual acuity and the causes of visual loss in Australia: the Blue Mountain Eye Study. *Ophthalmology* 1996;103:357–364.
8. Taylor HR, Livingston PM, Stanislavsky YL, McCarty CA. Visual impairment in Australia: distance visual acuity, near vision, and visual field findings of the Melbourne Visual Impairment Project. *Am J Ophthalmol*. 1997;123:328–337.
9. Dandona L, Dandona R, Naduvilath TJ, et al. Burden of moderate visual impairment in an urban population in southern India. *Ophthalmology* 1999;106:497–504.
10. Memon MS. Prevalence and causes of blindness in Pakistan. *Journal of Pakistan Medical Association*. 1992;42:196–198.
11. Ayed S, Negrel AD, Nabli M, Kamel N, Jebri AM, Siddhorm M. Prevalence and causes of blindness in Tunisian Republic—results of a national survey conducted in 1993. *Sante* 1998;8: 275–282.
12. Dandona L, Dandona R, Srinivas M, et al. Blindness in the Indian state of Andhra Pradesh. *Invest Ophthalmol Vis Sci*. 2001;42:908–916.
13. Li S, Xu J, He M, Wu K, Munoz SR, Ellwein LB. A survey of blindness and cataract surgery in Doumen county, China. *Ophthalmology* 1999;106:1602–1608.
14. World Health Organization. Global Initiative For the Elimination of Avoidable Blindness. WHO/PBL/97.61 Rev. 2. Geneva, World Health Organization; 2000.
15. Negrel AD, Maul E, Pokharel GP, et al. Refractive error study in children: sampling and measurement methods for a multicountry survey. *Am J Ophthalmol*. 2000;129:421–426.
16. Pokharel GP, Negrel AD, Munoz SR, Ellwein LB. Refractive error study in children: results from Mechi Zone, Nepal. *Am J Ophthalmol*. 2000;129:436–444.
17. Sapkota YD, Adhikari BN, Pokharel GP, Poudyal BK, Ellwein LB. The prevalence of visual impairment in school children of upper-middle socioeconomic status in Kathmandu. *Ophthalmic Epidemiol*. 2008;15:17–23.
18. Zhao J, Pan X, Sui R, et al. Refractive error study in children: results from Shunyi District, China. *Am J Ophthalmol*. 2000; 129:427–435.
19. He M, Zeng J, Liu Y, et al. Refractive error and visual impairment in urban children in southern China. *Invest Ophthalmol Vis Sci*. 2004;45:793–799.
20. He M, Huang W, Zheng Y, et al. Refractive error and visual impairment in school children in rural southern China. *Ophthalmology*. 2007;114:374–382.
21. Goh PP, Abqariyah Y, Pokharel GP, Ellwein LB. Refractive error and visual impairment in school-age children in Gombak District, Malaysia. *Ophthalmology*. 2005;112:678–685.
22. Dandona R, Dandona L, Srinivas M, et al. Refractive error in children in a rural population in India. *Invest Ophthalmol Vis Sci*. 2002;43:615–622.
23. Murthy GV, Gupta SK, Ellwein LB, et al. Refractive error in children in an urban population in New Delhi. *Invest Ophthalmol Vis Sci*. 2002;43:623–631.
24. Naidoo KS, Raghunandan A, Mashige KP, et al. Refractive error and visual impairment in African children in South Africa. *Invest Ophthalmol Vis Sci*. 2003;44:3764–3770.
25. Salomao SR, Cinoto RW, Berezovsky A, et al. Prevalence and causes of visual impairment in low-middle income school children in Sao Paulo, Brazil. *Invest Ophthalmol Vis Sci*. 2008; 49:4308–4313.
26. Maul E, Barroso S, Munoz SR, et al. Refractive error study in children: results from La Florida, Chile. *Am J Ophthalmol*. 2000;129:445–454.
27. Naidoo KS, Jaggernath J. Uncorrected refractive errors. *Indian J Ophthalmol*. 2012;60:432–437.
28. Centers for Disease Control and Prevention, National Center for Health Statistics. National Health and Nutrition Examination Survey Data. Hyattsville, MD: US Department of Health and Human Services, Centers for Disease Control and Prevention. 2005. Available at: http://www.cdc.gov/nchs/nhanes.htm. Accessed March 19, 2012.
29. Vitale S, Ellwein L, Cotch MF, Ferris FL III, Sperduto R. Prevalence of refractive error in the United States, 1999-2004. *Arch Ophthalmol*. 2008;126:1111–1119.
30. Vitale S, Sperduto RD, Ferris FL III. Increased prevalence of myopia in the United States between 1971-1972 and 1999-2004. *Arch Ophthalmol*. 2009;127:1632–1639.
31. Vitale S, Cotch MF, Sperduto RD. Prevalence of visual impairment in the United States. *JAMA*. 2006;295:2158–2163.
32. Qiu M, Wang SY, Singh K, Lin SC. Association between myopia and glaucoma in the United States population. *Invest Ophthalmol Vis Sci*. 2013;54:830–835.
33. Zhang X, Cotch MF, Ryskulova A, et al. Vision health disparities in the United States by race/ethnicity, education, and economic status: findings from two nationally representative surveys. *Am J Ophthalmol*. 2012;154(suppl 6):S53–62.e1.

34. Fotedar R, Rochtchina E, Morgan I, Wang JJ, Mitchell P, Rose KA. Necessity of cycloplegia for assessing refractive error in 12-year-old children: a population-based study. *Am J Ophthalmol*. 2007;144:307–309.
35. Anera RG, Soler M. de la Cruz Cardona J, Salas C, Ortiz C. Prevalence of refractive errors in school-age children in Morocco. *Clin Exp Ophthalmol*. 2009;37:191–196.
36. Zhao J, Mao J, Luo R, Li F, Pokharel GP, Ellwein LB. Accuracy of noncycloplegic autorefraction in school-age children in China. *Optom Vis Sci*. 2004;81:49–55.
37. Fotouhi A, Morgan IG, Iribarren R, Khabazhoob M, Hashemi H. Validity of noncycloplegic refraction in the assessment of refractive errors: the Tehran Eye Study. *Acta Ophthalmologica* 2012;90:380–386.