Published in final edited form as:

Invest Ophthalmol Vis Sci. 2005 November ; 46(11): 4032–4039.

Nine-Year Refractive Changes in the Barbados Eye Studies

Suh-Yuh Wu¹, Yun Joo Yoo¹, Barbara Nemesure¹, Anselm Hennis^{2,3}, M. Cristina Leske¹, and the Barbados Eye Studies Group

¹From the Department of Preventive Medicine, Stony Brook University, Stony Brook, New York;

²the Ministry of Health, Barbados, West Indies; and

³the Chronic Disease Research Center, School of Clinical Medicine and Research, University of the West Indies, Barbados, West Indies.

Abstract

Purpose—To describe 9-year changes in refractive errors and estimate incidence of myopia and hyperopia in adults of African-descent, along with associated risk factors.

Methods—The 9-year follow-up of the Barbados Eye Studies (1997–2003) reexamined 2793 surviving cohort members (81% participation). Refractive errors were determined by automated refraction. Myopia/hyperopia were defined as spherical equivalent < -0.5 diopters (D)/ $> +0.5$ D, and the cutoff for moderate-high myopia/hyperopia was 3.0 D. Incidence rates of myopia/hyperopia were estimated by the product-limit approach, based on eyes without such conditions at baseline. Risk factors were evaluated by logistic regression in discrete time hazard models.

Results—Nine-year refraction changes varied by age. Persons aged 40 to 49 years experienced hyperopic shifts (median, +0.38 D), whereas persons ≥ 60 years had myopic shifts (median, -0.75 D). Overall 9-year incidence was 12.0% for myopia and 29.5% for hyperopia; rates were 3.6% and 2.0% for moderate-high myopia and hyperopia, respectively. Myopia risk increased with age, baseline nuclear lens opacities (risk ratio [RR] = 1.7; 95% confidence interval [CI]: 1.01–2.9), glaucoma (RR = 6.0, 95% CI: 3.9–9.3), and ocular hypertension (RR = 2.0, 95% CI: 1.3–3.0), while cortical lens opacities decreased risk (RR = 0.6, 95% CI: 0.4–0.9). Incidence of moderate-high myopia was also related to baseline age, nuclear opacities, glaucoma, male gender (RR = 1.7, 95% CI: 1.0–2.8), and diabetes history (RR = 1.9, 95% CI: 1.01–3.5). Hyperopia risk decreased with older age, male gender, and glaucoma diagnosis.

Conclusions—Refractive errors continue to develop frequently in older adults. Nuclear lens opacities, glaucoma, and diabetes increase the risk of older-onset myopia, a result of public health relevance to this and similar African-origin populations.

Refractive errors are the most frequent ocular disorders, affecting approximately one third of adults aged 40 years or older in the United States and Western Europe.¹ Genetic and environmental factors are thought to play a role in the development of refractive errors, but the true underlying mechanisms involved remain unclear. Although refractive errors can be corrected, the economic burden incurred can be substantial, given their high prevalence. Furthermore, uncorrected or inadequately corrected refractive errors have been shown to be a major cause of visual impairment in population-based studies,^{2–8} signifying high public health relevance. Several studies have provided data on prevalence and temporal changes in refractive errors in various adult populations.^{9–22} We reported a high prevalence of myopia (22%) and

Corresponding author: Suh-Yuh Wu, Department of Preventive Medicine, Stony Brook University, HSC L3 086, Stony Brook, NY 11794-8036; swu@notes.cc.sunysb.edu..

Supported by Grants EY07625, EY07617, and EY014921 from the National Eye Institute, Bethesda, Maryland.

Disclosure: S.-Y. Wu, None; Y.J. Yoo, None; B. Nemesure, None; A. Hennis, None; M.C. Leske, None

hyperopia (47%) among the predominantly black adult participants in the Barbados Eye Studies (BESs), aged 40 to 84 years. These refractive errors were related to concomitant ocular conditions. To our knowledge, however, no longitudinal data on refraction are available in persons of African descent. The objectives of this study were to (1) describe changes in refractive errors over 9 years; (2) provide incidence estimates; and, (3) determine associated risk factors for incident myopia and hyperopia in African-origin participants in the Barbados Eye Studies (BESs).

Methods

Background

The Barbados Eye Studies (BESs; 1987–2003), funded by the National Eye Institute, are epidemiologic investigations of the prevalence, incidence, and risk factors for major eye diseases in a population predominantly of African descent, with the same ancestral origin as African-Americans. The baseline prevalence study, the Barbados Eye Study (BES, 1987–1992),²³ was based on a simple random sample of Barbadian-born citizens, 40 to 84 years of age, with 84% participation. The demographic composition of BES participants closely resembled the census population. Of the 4631 persons examined at the study site, 4314 (93%) were black, 184 (4%) were mixed (black and white), and 133 (3%) were white/other by self-report. The surviving cohort was invited for reexaminations to determine the incidence and progression of these eye diseases after 4 years ($n = 3427$, 85% of those eligible)²⁴ and 9 years ($n = 2793$, 81% of those eligible).²⁵ As described previously, the latter participants were younger and less likely to have hypertension than were nonparticipants.²⁵

Protocols

The study protocols at baseline²³ and both follow-up visits^{24,25} were standardized and included various ophthalmic and other measurements, such as the determination of best corrected visual acuity with a Ferris-Bailey chart, automated perimetry (Humphrey; Carl Zeiss Meditec, Dublin, CA), applanation tonometry, lens grading, and color stereo photography of the disc and macula. A comprehensive interview on demographics, medical and family history, and environmental and other factors was completed during dilation. Noncycloplegic refractive error was measured with the same refractor (Humphrey Automated Refractor model 530; Carl Zeiss Meditec) throughout the three study visits. If the refractor could not be used or refraction was unreliable, the participant's present correction, if any, was determined with a lensometer (only in 1% to 2% of the study population). In this report, refractive errors were based on Humphrey autorefraction measures. The study adhered to the tenets of the Declaration of Helsinki and was approved by the institutional review board (IRB) of participating institutions. Informed consent was obtained from all study participants after explanation of the nature and possible consequences of the study.

Definitions

Refractive errors in an eye were represented by the spherical equivalent (sum of spherical power and half cylindrical power) from the Humphrey refraction. Changes in refraction in an eye at 9 years were defined as the refraction at the 9-year visit minus the refraction at baseline. Myopia was defined as a spherical equivalent < -0.5 D and hyperopia as a spherical equivalent > 0.5 D. Moderate-high myopia and hyperopia were defined by cutoff of < -3 D and > 3 D, respectively. Incidence of myopia or hyperopia was defined as development of myopia or hyperopia at the follow-up visit, whereas no such condition was present at baseline. The incidence of moderate-high myopia was defined as the development of moderate-high myopia by the 9-year follow-up, among eyes without that condition at baseline. The incidence of moderate-high hyperopia was similarly defined.

Lenses were graded using the Lens Opacities Classification System (LOCS) II at the slit lamp. A LOCS score of ≥ 2 defined nuclear (NO), PSC (P), and cortical (C) opacities.²⁶ Open-angle glaucoma (OAG) was defined by specific study criteria based on the presence of optic disc and visual field defects not attributable to other causes.²³ Ocular hypertension included persons with an intraocular pressure (IOP) >21 mm Hg or with a history of IOP-lowering treatment, but without glaucoma visual field defects or disc damage. For the purposes of this report, the term glaucoma included OAG and suspected OAG (with some but not all the optic disc and visual field criteria for OAG).

Statistical Analysis

The distribution of 9-year changes in refraction was determined among persons with refraction data at both baseline and 9-year follow-up visits. The cumulative 9-year incidence of myopia/hyperopia was estimated by the product-limit approach,²⁷ which allows the use of data from persons with 4 years of follow-up only. Factors associated with incident myopia and hyperopia were evaluated by logistic regression with discrete time hazard models.²⁸ Potential risk factors included age, gender, education, occupation, diabetes history (predominantly type 2 diabetes), and major ocular conditions, including lens opacities and glaucoma at baseline. The correlation for refractive changes between right and left eyes was high ($r = 0.75$), and the prevalence rates reported at baseline were based on data from right eyes.¹⁵ Therefore, results presented in this report (refraction change, incidence estimates, and associated factors) were based on data from right eyes. Risk factor evaluations also explored the Generalized Estimating Equation (GEE) approach,²⁹ which includes data from both eyes while accounting for correlations between eyes.

Results

At the 9-year visit, 2612 of the 2793 participants were of African descent. Of these, 2391 (91.5%) had complete refraction data both at baseline and the 9-year follow-up. Analyses were based on 2230 persons (2128 had data for right eyes and 2123 had data for left eyes) after excluding 103 persons with a history of cataract surgery and 58 with visual acuity 20/200 or worse, due to the reduced reliability of their refractions. Comparisons of baseline characteristics indicated that persons excluded were older (mean $\pm$ SD: 68.8 ± 9.5 years) than those included (mean $\pm$ SD: 53.7 ± 9.4 years) and, after adjusting for age, more likely to have diabetes, lower education, refractive errors, and other age-related ocular conditions such as lens opacities and glaucoma ($P < 0.05$). No significant differences were found with regard to gender, blood pressure, a history of smoking, drinking, and cardiovascular disease.

Table 1 presents age- and gender-specific 9-year changes in refractive errors. The mean overall 9-year change was very small, but in the direction of a slight myopic shift (i.e., negative change: mean, -0.08 D; 95% CI: -0.13 to -0.03). The median overall change, however, had a positive sign (median, $+0.13$ D). On average, a hyperopic shift (i.e., positive change, was observed in persons 40 to 49 years of age at baseline: mean = $+0.47$ D in 9 years), whereas a myopic shift was noted in persons 50 years of age or more. The magnitude of the myopic shift was broadened in those 60 to 69 years of age, but leveled off in those aged 70 years or more. Women tended to have smaller myopic shifts than men overall, having more hyperopic shifts in the youngest age group ($+0.57$ D vs. $+0.34$ D) and less myopic shift in the oldest age group (-0.65 D vs. -0.96 D). As indicated in Table 1, only 6% of men and 2% of women 40 to 49 years of age had shifts toward myopia larger than -0.5 D, compared with 67% of men and 46% of women in the oldest age group. Overall, 23.5% of the study population had a shift toward myopia more than -0.5 D and 26% had a shift toward hyperopia more than 0.5 D. Table 2 shows stratification by cataract status, which revealed a general myopic shift across all age groups in persons with nuclear opacities at baseline (overall mean change $\pm$ SD: -0.85 ± 1.54 D). Among those without

nuclear opacities, patterns were similar to those in the overall study population, with myopic shifts mainly seen in age groups of 60 years or more, whereas shifts toward hyperopia (mean change $\pm$ SD: 0.47 ± 0.75 D) occurred in those 40 to 49 years of age. Changes in refractive errors were also evaluated by baseline refractive status. Results showed no significant differences among emmetropic ($n = 759$), myopic ($n = 322$), and hyperopic eyes ($n = 1047$) at baseline, with age-adjusted means (95% CI) being -0.11 D (95% CI: -0.19 to -0.03 D), -0.12 D (95% CI: -0.24 to -0.00 D), and -0.04 D (95% CI: -0.11 to 0.02 D), respectively.

Table 3 presents the 9-year cumulative incidence of myopia and hyperopia among eyes without refractive errors at baseline. The overall 9-year incidence was 12% (95% CI: 10.6%–13.4%) for myopia and 29.5% (95% CI: 26.9%–32.1%) for hyperopia. Although the frequency of myopia was similar in the men (12.9%) and the women (11.5%), incidence of hyperopia appeared to be higher in the women (33.3%) than in the men (25.1%; $P < 0.05$). The 9-year incidence of moderate-high myopia was low, being 3.6% (95% CI: 2.8%–4.4%); rates increased with age from 0.8% at 40 to 49 years to 12.5% at 70 years or older. The incidence of moderate-high hyperopia was very low, 2.0% (95% CI: 1.4%–2.5%), with a slightly higher ($P < 0.05$) incidence in women (2.7%) than in men (0.9%).

We also examined possible cohort effects by graphic exploration of the refraction patterns at each study visit against age and year of birth. Figure 1 presents prevalence of myopia by birth cohort and age group, where each person may contribute up to three data points from all study visits, including only subgroups with $n \geq 100$. Results indicated no clear cohort effect. There was no consistent pattern when comparing the older and the younger birth cohorts for each age group. Although myopia prevalence was slightly higher in persons 50 to 59 years who were born later than younger cohorts (1940–1944 vs. 1935–1939), the increase was very small and not statistically significant.

As seen in Table 4, the risk of development of myopia at 50 to 59 years was 3.5 times higher than at 40 to 49 years. The risk increased to 7.5 to 9 times higher for those 60 years or older, compared with the youngest age group. No significant association with incident myopia was found for gender, education, occupation, or diabetes. The presence of nuclear opacities at baseline increased the risk of myopia (RR = 1.7, 95% CI: 1.01–2.89). Although eyes with any cortical opacities at baseline had a higher crude incidence (16.1%) than those without (10.8%), cortical opacities decreased myopia risk (RR = 0.6, 95% CI: 0.4–0.9) after adjustment for nuclear and PSC opacities and other factors. The low number of PSC cases precluded any meaningful assessment. The baseline presence of glaucoma (RR = 6.0, 95% CI: 3.9–9.3) and ocular hypertension (RR = 2.0, 95% CI: 1.3–3.0) was also associated with 9-year incidence of myopia. Additional analyses using LOCS II grades as categorical variables were conducted, although more severe opacities (LOCS II score of >2) were infrequent: only 0.4% for nuclear, 0.04% for PSC, and 9.2% for cortical opacities. Results showed that myopia risk increased ($P < 0.05$) with increasing severity of nuclear opacities. Incidence of myopia was found to decrease with advancing cortical opacities. Increasing age, on the other hand, decreased the risk of hyperopia (Table 4). Men were less likely to have hyperopia than women (RR = 0.7, 95% CI: 0.6–0.95). No statistically significant associations were found between baseline lens opacities of any type and incident hyperopia, although nuclear opacities had an adjusted RR of 0.6. Glaucoma was negatively associated with 9-year incidence of hyperopia (RR = 0.4, 95% CI: 0.2–0.8). A similar trend toward a negative association was noted for ocular hypertension, but it was of borderline statistical significance (RR = 0.6, 95% CI: 0.4–1.03, $P = 0.07$). No significant interactions were found between age and cataract, whether assessed as dichotomized or categorical variables. Additional analyses using the GEE approach yielded similar results.

Associations with incident moderate-high myopia are shown in Table 5. Results show an increasing risk at older ages, with ninefold relative risks for persons 70 years of age or older (RR = 9.1; 95% CI: 3.3–25.0), compared with those 40 to 49 years at baseline; in addition, the men were significantly more prone to severe myopia (RR = 1.7; 95% CI: 1.0–2.8) than were the women. Persons with diabetes history had a nearly twofold increased risk of myopia < -3 D (RR = 1.9; 95% CI: 1.01–3.5). Nuclear opacities conferred a substantially increased risk (RR = 3.6; 95% CI: 2.0–6.7), whereas cortical opacities decreased the risk. Glaucoma, but not ocular hypertension, remained significantly associated with incident moderate-high myopia. The very low incidence of moderate-high hyperopia led to limited power to detect associations. Among all factors evaluated, only female gender (RR = 3.8; 95% CI: 1.6–8.7) was significantly associated with incident moderate-high hyperopia.

Discussion

The natural history of refractive errors among older adults has not been widely studied until the past decade. Most research has focused on myopia in children, as this condition is mainly considered to occur at young ages. More recent population studies, involving predominantly European-origin participants, have shown that refractive shifts continue in older adulthood.^{19,21,22} The BESs provide the first longitudinal data, to our best knowledge, on refractive error changes in a large adult African-origin population. Over the 9-year follow-up period, refraction changes varied according to age. Persons 40 to 49 years of age at baseline experienced a hyperopic shift (mean, +0.47 D; median, +0.38 D) with only 4% having changes less than -0.5 D, whereas persons 60 years of age or more had refractive error shifts toward myopia (mean = -0.88 D; median = -0.75 D), with more than 50% of participants having myopic shifts.

The pattern of shift toward hyperopia among younger adults and the shift toward myopia among older adults is consistent with longitudinal observations in other population studies in Australia and the United States.^{19,21,22} The 9-year changes in refractive errors in our study were also consistent with the baseline prevalence data from the BESs, which showed an increasing prevalence of myopia and a decreasing prevalence of hyperopia after 60 years of age.¹⁵ Similar results were found in some^{17,18} but not other studies.^{10,11,13,16,30} The age patterns observed in our investigation indicate that actual longitudinal changes with age are a more likely explanation than a cohort effect, which was not apparent in our study. The shifts toward hyperopia in younger adults, as they increased in age during follow-up, seemed consistent with age-related biometric data from Chinese adults in Singapore.³¹ In that cross-sectional study, hyperopia was more prevalent in the older than in younger members of the 40 to 59 year age group, an increase that was principally explained by shorter axial lengths and lesser vitreous chamber depths with age.³¹ An additional contributor to the hyperopic shifts in younger adults from our study may be that nuclear cataract has a later onset (after 50 years). The myopic shifts in older adults thus may be largely influenced by the presence of nuclear cataract at baseline or at follow-up. In fact, baseline nuclear opacities and advancing age both independently increased the risk of myopia (Table 4). The 9-year incidence of myopia continued to increase with age, even in persons without nuclear opacities at baseline, from 3.3% in persons aged 40 to 49 years to 10.6%, 24.4%, and 29.2% in the subsequent age groups. Most of the older participants without nuclear opacities at baseline had nuclear cataract develop by follow-up, with frequencies being 8% and 40% in the two younger age groups, 76% in persons aged 60 to 69 years, and 90% in persons aged 70 years or older.

The Blue Mountains Eye Study (BMES) reported a 5-year hyperopic change in persons aged 49 to 54 years (+0.42 D) and a myopic shift (-0.22 D) in those aged 75 years or more. Myopic shifts of greater than 0.5 D were seen in only 3% of the younger age group, but they continuously increased to 28% in the older group.²¹ In the Beaver Dam Eye Study (BDES),

only 4% of participants 59 years of age or less had a shift toward myopia more than -0.5 D during a 10-year period, whereas 33% of those 70 years or more had such myopic shifts.²² Myopic shifts at older ages appeared to be more substantial in BESs than in these two studies, and the reversal in age pattern occurred at younger ages. In BESs, a slight myopic shift was noticeable in persons as young as 50 to 59 years of age, and a marked shift toward myopia started at 60 to 69 years. In contrast, considerable myopic shifts in the BMES and BDES were not observed until 75 years of age at the 5-year follow-up and until 70 years of age at the 10-year follow-up, respectively. This finding may be partially attributable to the lower rate of cataract surgery in our study.²⁵

The women in the BESs population were more prone to development of hyperopia than were the men ($RR = 1.4$). Our results appear to support findings from various cross-sectional evaluations that reported a positive relationship between female gender and hyperopia.^{10,12,13,15,17,18} The men had a 70% higher risk of moderate-high myopia ($RR = 1.7$). The somewhat larger 9-year myopic shift in the men (-0.11 D) than in the women (-0.06 D) was also statistically significant ($P = 0.03$), after adjustment for age, lens opacities, and glaucoma status. Longitudinal investigations of refractive error change in BMES²¹ and BDES,^{19,22} however, showed no gender differences. The BESs protocol did not include measurements of axial length or keratometry. However, variations in ocular dimensions have been found in other adult populations and may partially explain the age and gender differences in refraction.^{31,32}

Education and near-work related occupations were not related to the development of myopia or hyperopia during 9 years of follow-up, consistent with findings from BDES, where education showed no effect on the longitudinal refraction changes.²² Additional analyses also showed no significant interactions between education and occupation, as well as between age and each of these factors. In the BESs, near-work occupational categories were based on self-reported lifetime occupation (“what kind of work have you done for *most* of your life”). Such a definition may not accurately reflect the extent and intensity of close-up activities of the participants. Genetic and environmental factors, and their interactions, may contribute to refractive errors, as has been mostly discussed in children.³³ Therefore, our results may be susceptible to uncontrolled confounding from factors such as near-work activity early in life and family history of refractive errors, which were not included in our data collection.

Although no association was noted between diabetes and incident myopia/hyperopia based on the cutoff of 0.5 D, persons with a history of diabetes had a nearly twofold risk of development of moderate-high myopia (< -3 D). In an adult clinic population in Denmark, a preponderance of myopia was reported in persons with diabetes (compared with those without).^{34,35} In contrast, the presence of diabetes in BDES was related to a larger shift toward hyperopia²²; furthermore, diabetes did not predict 5-year refractive change in BMES.²¹ Transient changes of refraction in diabetes could be myopic or hyperopic, depending on whether changes occur in the refractive indices or in the curvatures of the lens.³⁶ The relationship between diabetes and myopia thus merits further confirmation from other studies.

Eyes with nuclear opacities at baseline had a 1.7-fold risk of myopia and a 3.6-fold risk of moderate-high myopia at follow-up. The association of refractive errors to cataract, particularly nuclear cataract, has been reported in several cross-sectional population studies of adults.^{15–18,32,37,38} In one study in which the relation between myopia and cataract morphology was investigated, investigators concluded that simple myopia does not predispose to cataract, but is the product of cataract—in particular, of nuclear sclerosis.³⁹ When examining the cross-sectional relationship of age-related cataract to refractive errors and biometric measurements, Wong et al.³⁸ found that nuclear cataract was associated with myopia but not with axial ocular dimensions. These observations are consistent with the index-myopia hypothesis that increasing nuclear sclerosis of the lens with age causes a myopic shift in refraction. In addition

to the association between baseline nuclear opacities and incident myopia found in our study, data from several other longitudinal studies appear to support such a causal relationship. In the BDESS, no association was found between baseline myopic refraction and 5-year incident nuclear cataract,⁴⁰ but a significant relationship was reported between baseline nuclear sclerosis and a shift toward myopia after 10 years of follow-up.²² In the BMES, the presence of nuclear cataract at baseline was associated with a 5-year myopic shift.²¹ One small study also showed a significant myopic shift among persons with nuclear cataract.⁴¹ However, myopia could also be related to the development of nuclear opacities, as shown from the significant association of baseline myopia to incident nuclear opacities, as found in separate evaluations of BMES⁴² and BESs⁴³ data. The complicated interrelationship between nuclear cataract and myopia therefore needs further investigation.

The association of cortical cataract and refractive errors has not been established clearly. In the BESs, the presence of cortical opacities at baseline was negatively associated with incident myopia (RR = 0.6) after a 9-year follow-up. This relationship reflects a role for the *cortical only* opacity type, since it was found after adjusting for other coexisting types of opacities, especially nuclear, which sometimes accompany cortical opacities. Although results were consistent with baseline findings from BES, there is no obvious explanation for such a relationship. The polarity of spherical aberration was shown to be negative in eyes with nuclear cataract, but was positive in eyes with cortical cataract⁴⁴; such disparity may have different effects on refractive errors.

The cross-sectional association of glaucoma and myopia has been demonstrated in various clinic-based and case-control studies.^{45–47} Associations between IOP and refractive errors were also found in some^{47–49} but not all reports.^{50–52} In the older white population of the BMES, a strong relationship between myopia and glaucoma (two- to threefold) was found, as well as a borderline association between myopia and ocular hypertension.⁵³ In the large population survey conducted to identify patients for the Early Manifest Glaucoma Trial, myopia was reported as a major risk factor for glaucoma—particularly for normal-tension glaucoma.⁵⁴ Investigation of our baseline data also shows a positive association of myopia to glaucoma and ocular hypertension, with a negative association with hyperopia.¹⁵ Findings from the longitudinal data in the BESs cohort were thus consistent with results from our baseline cross-sectional evaluation, as they confirmed the relationship between myopia and glaucoma/ocular hypertension. Although glaucoma, ocular hypertension, and incident myopia appear to be linked, the temporal association of these conditions is not intuitively clear. The general impression is that myopia may predispose to glaucoma, rather than being its consequence; however, the association between baseline glaucoma/ocular hypertension and subsequent development of myopia in this adult population suggests otherwise. Because myopia and glaucoma both show changes in ocular connective tissue, they may share common pathways.⁵⁵ The linkage between myopia and glaucoma may not necessarily have a single causal explanation. Increased IOP can cause axial elongation of the globe and myopia in a previously emmetropic eye—a process more likely to occur in congenital or juvenile glaucoma.⁵⁵ Studies also have shown that reduction of IOP may prevent progressive myopia.⁵⁶ In sum, the physiological and clinical interpretation of these relationships remains in doubt.

In addition to the population-based design, major strengths of our study include the long-term follow-up of the cohort, with credible participation, as well as the standardized protocol for refractive errors and other outcomes at all study visits. However, losses to follow-up are inevitable in such a long-term study, and, as expected, nonparticipants were older.²⁵ The current results exclude persons with cataract surgery or very poor visual acuity, an approach similarly taken by other population-based studies on refractive errors. These exclusions could lead to selection biases, as those excluded may also be older and have a higher likelihood of ocular conditions such as cataract and glaucoma at baseline. Results may thus underestimate

the incidence of myopia and overestimate the incidence of hyperopia, with possible attenuation of risk estimates. The infrequent presence of PSC opacities in this population did not allow an appropriate evaluation of this potential risk factor.

CONCLUSIONS

Refractive changes beyond early adulthood were observed in this older adult population of African origin. During the 9 years of follow-up, myopic shifts were observed at younger ages than in European-derived populations. Lens opacities, glaucoma, and diabetes, which are frequent in persons of African descent, increased the risk of subsequent myopia or moderate-high myopia. These prevalent factors may be involved in the development of older-onset myopia, further contributing to visual problems in this high-risk population.

Acknowledgements

The authors thank the Barbados Eye Studies participants for taking part in the study and the Ministry of Health, Barbados, West Indies, for their role in the study.

References

1. The Eye Diseases Prevalence Research Group. The prevalence of refractive errors among adults in the United States, Western Europe, and Australia. *Arch Ophthalmol* 2004;122:495–505. [PubMed: 15078666]
2. Tielsch JM, Sommer A, Witt K, et al. Blindness and visual impairment in an American urban population. The Baltimore Eye Survey. *Arch Ophthalmol* 1990;108:286–290. [PubMed: 2271016]
3. Attebo K, Mitchell P, Smith W. Visual acuity and the causes of visual loss in Australia: The Blue Mountains Eye Study. *Ophthalmology* 1996;103:357–364. [PubMed: 8600410]
4. Foran S, Wang JJ, Mitchell P. Causes of incident visual impairment. *Arch Ophthalmol* 2002;120:613–619. [PubMed: 12003611]
5. Weih LM, VanNewkirk MR, McCarty CA, Taylor HR. Age-specific causes of bilateral vision impairment. *Arch Ophthalmol* 2000;118:264–269. [PubMed: 10676793]
6. VanNewkirk MT, Weih L, McCarty CA, Taylor HR. Cause-specific prevalence of bilateral visual impairment in Victoria, Australia. The Visual Impairment Project. *Ophthalmology* 2001;108:960–967. [PubMed: 11320028]
7. Munoz B, West SK, Rubin GS, et al. Causes of blindness and visual impairment in a population of older Americans. The Salisbury Eye Evaluation Study. *Arch Ophthalmol* 2002;118:819–825. [PubMed: 10865321]
8. Munoz B, West SK, Rodriguez J, et al. Blindness, visual impairment and the problem of uncorrected refractive error in a Mexican-American population: Proyecto VER. *Invest Ophthalmol Vis Sci* 2002;43:608–614. [PubMed: 11867574]
9. Sperduto RD, Seigel D, Roberts J, Rowland M. Prevalence of myopia in the United States. *Arch Ophthalmol* 1983;101:405–407. [PubMed: 6830491]
10. Katz J, Tielsch JM, Sommer A. Prevalence and risk factors for refractive errors in an adult inner city population. *Invest Ophthalmol Vis Sci* 1997;38:334–340. [PubMed: 9040465]
11. Wang Q, Klein BEK, Klein R, Moss S. Refractive status in the Beaver Dam Eye Study. *Invest Ophthalmol Vis Sci* 1994;35:4344–4347. [PubMed: 8002254]
12. Hyams SW, Pokotilo E, Shkurko G. Prevalence of refractive errors in adults over 40: a survey of 8102 eyes. *Br J Ophthalmol* 1977;61:428–432. [PubMed: 871471]
13. Attebo K, Ivers RQ, Mitchell P. Refractive errors in an older population: The Blue Mountains Eye Study. *Ophthalmology* 1999;106:1066–1072. [PubMed: 10366072]
14. Lewallen S, Lowdon R, Courtright P, Mehl GL. A population-based survey of the prevalence of refractive error in Malawi. *Ophthalmic Epidemiol* 1995;2:145–149. [PubMed: 8963918]
15. Wu SY, Nemesure B, Leske MC. Refractive errors in a black adult population: The Barbados Eye Study. *Invest Ophthalmol Vis Sci* 1999;40:2179–2184. [PubMed: 10476781]

16. Wensor M, McCarty CA, Taylor HR. Prevalence and risk factors of myopia in Victoria, Australia. *Arch Ophthalmol* 1999;117:658–663. [PubMed: 10326965]
17. Wong TY, Foster PJ, Hee J, et al. Prevalence and risk factors for refractive errors in adult Chinese in Singapore. *Invest Ophthalmol Vis Sci* 2000;41:2486–2494. [PubMed: 10937558]
18. Cheng CY, Hsu WM, Liu JH, et al. Refractive errors in an elderly Chinese population in Taiwan: The Shipai Eye Study. *Invest Ophthalmol Vis Sci* 2003;44:4630–4638. [PubMed: 14578378]
19. Lee KE, Klein BEK, Klein R. Changes in refractive error over a 5-year interval in the Beaver Dam Eye Study. *Invest Ophthalmol Vis Sci* 1999;40:1645–1649. [PubMed: 10393030]
20. Bengtsson B, Grodum K. Refractive changes in the elderly. *Acta Ophthalmol Scand* 1999;77:37–39. [PubMed: 10071146]
21. Guzowski M, Wang JJ, Rochtchina E, et al. Five-year refractive changes in an older population. *Ophthalmology* 2003;110:1364–1370. [PubMed: 12867393]
22. Lee KE, Klein BEK, Klein R, Wong TY. Changes in refraction over 10 years in an adult population: The Beaver Dam Eye Study. *Invest Ophthalmol Vis Sci* 2002;43:2566–2571. [PubMed: 12147586]
23. Leske MC, Connell AMC, Schachat A, et al. The Barbados Eye Study: prevalence of open-angle glaucoma. *Arch Ophthalmol* 1994;112:821–829. [PubMed: 8002842]
24. Leske MC, Connell AMS, Wu S-Y, et al. Incidence of open-angle glaucoma. *Arch Ophthalmol* 2001;119:89–95. [PubMed: 11146731]
25. Leske MC, Wu SY, Nemesure B, et al. 9-Year incidence of lens opacities in the Barbados Eye Studies. *Ophthalmology* 2004;111:483–490. [PubMed: 15019323]
26. Leske MC, Connell AMS, Wu SY, Hyman L, Schachat A. the Barbados Eye Study Group. Prevalence of lens opacities in the Barbados Eye Study. *Arch Ophthalmol* 1997;115:105–111. [PubMed: 9006434]
27. Kaplan EL, Meier P. Nonparametric estimation from incomplete observations. *J Am Stat Assoc* 1958;53:457–481.
28. Singer JD, Willett JB. *Applied Longitudinal Data Analysis. Modeling Change and Event Occurrence*. New York: Oxford University Press Inc.; 2003.
29. Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika* 1986;73:13–22.
30. McCarty CA, Livingston PM, Taylor HR. Prevalence of myopia in adults: implications for refractive surgeons. *J Refractive Surgery* 1997;13:229–234.
31. Wong TY, Foster PJ, Ng TP, et al. Variation in ocular biometry in an adult Chinese population in Singapore: the Tanjong Pagar Survey. *Invest Ophthalmol Vis Sci* 2001;42:73–80. [PubMed: 11133850]
32. Weale RA. Epidemiology of refractive errors and presbyopia. *Surv Ophthalmol* 2003;48:515–543. [PubMed: 14499819]
33. Mutti DO, Mitchell GL, Moeschberger ML, et al. Parental myopia, near work, school achievement, and children's refractive error. *Invest Ophthalmol Vis Sci* 2002;43:3633–3640. [PubMed: 12454029]
34. Fledelius HC. Is myopia getting more frequent?—a cross-sectional study of 1416 Danes aged 16 years+. *Acta Ophthalmol (Copenh)* 1983;61:545–559. [PubMed: 6605647]
35. Fledelius HC. Myopia and diabetes mellitus with special reference to adult-onset myopia. *Acta Ophthalmol (Copenh)* 1986;64:33–38. [PubMed: 3962616]
36. Mäntyjärvi M. Myopia and diabetes. A review. *Acta Ophthalmologica suppl* 1988;185:82–85.
37. Lim R, Mitchell P, Cumming RG. Refractive associations with cataract: the Blue Mountains Eye Study. *Invest Ophthalmol Vis Sci* 1999;40:3021–3026. [PubMed: 10549667]
38. Wong TY, Foster P, Johnson GJ, Seah SKL. Refractive errors, axial ocular dimensions, and age-related cataracts: the Tanjong Pagar Survey. *Invest Ophthalmol Vis Sci* 2003;44:1479–1485. [PubMed: 12657582]
39. Brown NAP, Hill AR. Cataract: the relation between myopia and cataract morphology. *Br J Ophthalmol* 1987;71:405–414.
40. Wong TY, Klein BE, Klein R, et al. Refractive errors and incident cataracts: the Beaver Dam Eye Study. *Invest Ophthalmol Vis Sci* 2001;42:1449–1454. [PubMed: 11381046]

41. Pesudovs K, Elliott DB. Refractive error changes in cortical, nuclear, and posterior subcapsular cataracts. *Br J Ophthalmol* 2003;87:964–967. [PubMed: 12881335]
42. Younan C, Mitchell P, Cumming RG, et al. Myopia and incident cataract and cataract surgery: The Blue Mountains Eye Study. *Invest Ophthalmol Vis Sci* 2002;43:3625–3632. [PubMed: 12454028]
43. Leske MC, Wu SY, Nemesure B, Hennis A. Risk factors for incident nuclear opacities. *Ophthalmology* 2002;109:1303–1308. [PubMed: 12093655]
44. Kuroda T, Fujikado T, Maeda N, et al. Wavefront analysis in eyes with nuclear or cortical cataract. *Am J Ophthalmol* 2002;134:1–9. [PubMed: 12095801]
45. Prodos SM, Becker B, Morton WR. High myopia and primary open-angle glaucoma. *Am J Ophthalmol* 1966;62:1038–1043. [PubMed: 5957877]
46. Perkins ES, Phelps CD. Open angle glaucoma, ocular hypertension, low-tension glaucoma, and refraction. *Arch Ophthalmol* 1982;100:1464–1467. [PubMed: 7115175]
47. Seddon JM, Schwartz B, Flowerdew G. Case-control study of ocular hypertension. *Arch Ophthalmol* 1983;101:891–894. [PubMed: 6860199]
48. Tomlinson A, Phillips CI. Applanation tension and axial length of the eyeball. *Br J Ophthalmol* 1970;54:548–553. [PubMed: 5458678]
49. David R, Zangwill LM, Tessler Z, Yassur Y. The correlation between intraocular pressure and refractive status. *Arch Ophthalmol* 1985;103:1812–1815. [PubMed: 4074170]
50. Daubs JG, Crick RP. Effect of refractive error on the risk of ocular hypertension and open-angle glaucoma. *Trans Ophthalmol Soc UK* 1981;101:121–126. [PubMed: 6964218]
51. Wallace J, Lovell HG. Glaucoma and intraocular pressure in Jamaica. *Am J Ophthalmol* 1969;67:93–100. [PubMed: 5782867]
52. Bengtsson B. Some factors affecting the distribution of intraocular pressure in a population. *Acta Ophthalmol (Copenh)* 1972;50:33–46. [PubMed: 5067783]
53. Mitchell P, Hourihan F, Sandbach J, Wang JJ. The relationship between glaucoma and myopia: the Blue Mountains Eye Study. *Ophthalmology* 1999;106:2010–2015. [PubMed: 10519600]
54. Grodum K, Heijl A, Bengtsson B. Refractive error and glaucoma. *Acta Ophthalmol Scand* 2001;79:560–566. [PubMed: 11782219]
55. Fong DS, Epstein DL, Allingham RR. Glaucoma and myopia: are they related? *Int Ophthalmol Clin* 1990;30:215–218. [PubMed: 2199391]
56. Pruett RC. Progressive myopia and intraocular pressure: what is the linkage?—a literature review. *Acta Ophthalmologica Suppl* 1988;185:117–127.

Appendix

The Barbados Eye Studies Group

Principal Investigator: M. Cristina Leske

Coordinating Center

Stony Brook University, Stony Brook, NY: M. Cristina Leske, Barbara Nemesure, Suh-Yuh Wu, Leslie Hyman, Xiaowei Li, Lixin Jiang, Ling Yang, Kasthuri Sarma, Karen Kelleher, and Melinda Santoro.

Data Collection Center

Ministry of Health, Bridgetown, Barbados, West Indies: Anthea M. S. Connell, Anselm Hennis, Ann Bannister, Muthu A. Thangaraj, Coreen Barrow, Patricia Basdeo, Kim Bayley, and Anthanette Holder.

Fundus Photography Reading Center

The Johns Hopkins University, Baltimore, MD: Andrew P. Schachat, Judith A. Alexander, Cheryl J. Hiner, Noreen B. Javornik, Deborah A. Phillips, Reva W. Strozynski, and Terry W. George.

Advisory Committee

Trevor Hassell (Department of Cardiology), Henry Fraser (Chronic Diseases Research Centre), Clive Gibbons (Department of Ophthalmology), School of Clinical Medicine and Research, University of the West Indies, Queen Elizabeth Hospital, Barbados, West Indies.

Figure 1.
Prevalence of myopia by birth cohort and age in the BESs.

Table 1

Age- and Gender-Specific 9-Year Change in Spherical Equivalent

Baseline Age (y)	n	Male	n	Female	n	Total
40-49	377	+0.34 ± 0.66 (0.38)	508	+0.57 ± 0.80 (0.50)	885	+0.47 ± 0.75 (0.38)
Mean ± SD (median) (D)		6.1		2.2		3.8
< -0.5 D (%)		33.2		45.9		40.5
> 0.5 D (%)						
50-59	262	-0.10 ± 1.03 (0.00)	423	-0.15 ± 1.16 (0.13)	685	-0.14 ± 1.11 (0.13)
Mean ± SD (median) (D)		24.1		22.9		23.4
< -0.5 D (%)		21.0		22.5		21.9
> 0.5 D (%)						
60-69	167	-0.87 ± 1.55 (-0.75)	272	-0.92 ± 1.36 (-0.63)	439	-0.90 ± 1.43 (-0.63)
Mean ± SD (median) (D)		55.7		54.8		55.1
< -0.5 D (%)		6.0		7.0		6.6
> 0.5 D (%)						
70+	49	-0.96 ± 0.94 (-1.00)	70	-0.65 ± 1.37 (-0.44)	119	-0.78 ± 1.22 (-0.75)
Mean ± SD (median) (D)		67.4		45.7		54.6
< -0.5 D (%)		6.1		18.6		13.5
> 0.5 D (%)						
Total	855	-0.11 ± 1.13 (0.13)	1273	-0.06 ± 1.24 (0.25)	2128	-0.08 ± 1.20 (0.13)
Mean ± SD (median) (D)		24.8		22.7		23.5
< -0.5 D (%)		22.6		28.3		26.0
> 0.5 D (%)						

Table 2
Nine-Year Refractive Changes by Presence of Nuclear Opacities at Baseline

Baseline Age (y)	Nuclear Opacities at Baseline			
	No		Yes	
	<i>n</i>	Change (D)	<i>n</i>	Change (D)
40–49	880	0.47 ± 0.75 (0.38)	0	—
50–59	666	–0.11 ± 1.08 (0.13)	15	–1.09 ± 2.00 (–0.88)
60–69	394	–0.90 ± 1.41 (–0.63)	42	–1.10 ± 1.44 (–1.25)
70+	73	–0.93 ± 1.03 (–0.75)	46	–0.54 ± 1.44 (–0.50)
Total	2013	–0.04 ± 1.16 (0.13)	103	–0.85 ± 1.54 (–0.88)

Data are expressed as the mean ± SD (median).

Table 3

Cumulative 9-Year Incidence of Myopia and Hyperopia

Age (y)	Male		Female		Total	
	n	Incidence, % (95% CI)	n	Incidence, % (95% CI)	n	Incidence, % (95% CI)
Myopia*						
40-49	374	3.9 (1.8-6.0)	490	2.9 (1.4-4.5)	864	3.3 (2.1-4.6)
50-59	277	11.6 (7.6-15.6)	470	10.4 (7.4-13.3)	747	10.9 (8.5-13.2)
60-69	191	27.7 (20.4-35.0)	319	24.6 (19.4-29.8)	510	25.7 (21.5-30.0)
70+	79	38.3 (22.7-53.8)	126	22.0 (12.0-32.1)	205	28.4 (19.6-37.2)
Total	921	12.9 (10.5-15.3)	1405	11.5 (9.7-13.3)	2326	12.0 (10.6-13.4)
Hyperopia*						
40-49	336	33.2 (27.9-38.5)	401	42.4 (37.4-47.5)	737	38.3 (34.6-42.0)
50-59	145	22.4 (15.1-29.7)	142	30.2 (22.1-38.2)	287	26.3 (20.8-31.7)
60-69	109	9.7 (3.9-15.4)	122	12.3 (5.9-18.7)	231	11.1 (6.8-15.5)
70+	78	7.3 (0.0-15.1)	76	11.8 (18.9-21.7)	154	9.6 (3.2-15.9)
Total	668	25.1 (21.5-28.7)	741	33.3 (29.6-37.0)	1409	29.5 (26.9-32.1)
Moderate-high myopia [†]						
40-49	437	0.8 (0.0-1.8)	562	0.7 (0.0-1.4)	999	0.8 (0.2-1.3)
50-59	310	1.9 (0.2-3.6)	501	1.4 (0.3-2.5)	811	1.6 (0.7-2.5)
60-69	228	10.4 (5.9-14.9)	359	8.5 (5.3-11.6)	587	9.2 (6.6-11.8)
70+	111	18.5 (8.3-28.7)	154	8.3 (1.9-14.6)	265	12.5 (6.9-18.2)
Total	1086	4.4 (3.0-5.7)	1576	3.1 (2.2-4.0)	2662	3.6 (2.8-4.4)
Moderate-high hyperopia [†]						
40-49	457	0.3 (0.0-0.8)	570	2.1 (0.9-3.4)	1027	1.3 (0.6-2.1)
50-59	320	0.7 (0.0-1.7)	486	3.5 (1.7-5.2)	806	2.4 (1.3-3.5)
60-69	235	2.9 (0.4-5.5)	339	1.8 (0.2-3.4)	574	2.2 (0.9-3.6)
70+	124	0	154	6.0 (0.5-11.5)	278	3.4 (0.3-6.5)
Total	1136	0.9 (0.3-1.5)	1549	2.7 (1.8-3.6)	2685	2.0 (1.4-2.5)

* Myopia/hyperopia: spherical equivalent < -0.5D/>0.5D.

[†] Moderate-high myopia/hyperopia: spherical equivalent < -3D/>3D.

Table 4

Associations of 9-Year Incidence of Myopia/Hyperopia

Factor	Myopia			Hyperopia		
	n	Incidence (%)	Adjusted RR (95% CI)*	n	Incidence (%)	Adjusted RR (95% CI)*
Main model (lens opacities: yes/no)						
Age (y)						
40–49	864	3.3	1.0	737	38.3	1.0
50–59	747	10.9	3.5 (2.2–5.7)*	287	26.3	0.7 (0.5–0.94)*
60–69	510	25.7	9.3 (5.7–15.0)*	231	11.1	0.3 (0.2–0.6)*
70+	205	28.4	7.5 (3.9–14.5)*	154	9.6	0.3 (0.1–0.7)*
Gender						
Female	1405	11.5	1.0	741	33.3	1.0
Male	921	12.9	1.2 (0.9–1.6)	668	25.1	0.7 (0.6–0.95)*
Education (y)						
<9	323	18.0	1.0	196	19.2	1.0
≥9	1949	10.7	0.8 (0.6–1.1)	1186	31.3	1.2 (0.8–1.8)
Near-work-related Occupation†						
No	1566	13.0	1.0	870	28.5	1.0
Yes	749	9.8	0.8 (0.6–1.1)	531	31.2	1.0 (0.7–1.2)
Diabetes history						
No	2028	11.6	1.0	1237	30.1	1.0
Yes	295	15.3	1.1 (0.7–1.7)	168	25.1	1.0 (0.7–1.4)
Nuclear opacities						
No	2186	11.2	1.0	1254	31.3	1.0
Yes	129	30.2	1.7 (1.01–2.89)*	140	7.4	0.6 (0.2–1.4)
PSC opacities						
No	2298	12.0	1.0	1383	29.8	1.0
Yes	7	0.0	<0.001 (0–>100)	4	0	<0.001 (0–>100)
Cortical opacities						
No	1800	10.8	1.0	1150	31.9	1.0
Yes	494	16.1	0.6 (0.4–0.9)*	226	14.4	0.8 (0.5–1.3)
Glaucoma status†						
No glaucoma	1995	9.5	1.0	1157	31.9	1.0
Any glaucoma	116	44.7	6.0 (3.9–9.3)*	93	9.2	0.4 (0.2–0.8)*
Ocular hypertension	213	20.7	2.0 (1.3–3.0)*	157	21.1	0.6 (0.4–1.03)
Separate model (with LOCS II grades)						
Nuclear opacities						
0	1285	7.9	1.0	820	34.2	1.0
1	901	16.1	1.1 (0.8–1.6)	434	25.1	1.1 (0.8–1.8)
2	119	29.4	1.8 (0.96–3.2)	107	6.6	0.5 (0.2–1.4)
≥3	10	30.0	4.5 (1.02–19.9)*	33	11.1	0.8 (0.2–3.7)
Cortical opacities						
0, trace	1520	9.4	1.0	987	33.2	1.0
1	280	18.7	1.0 (0.6–1.4)	163	22.6	1.2 (0.8–2.0)
2	283	15.8	0.6 (0.4–0.97)*	149	12.2	0.7 (0.4–1.3)
≥3	211	16.2	0.3 (0.3–0.89)*	77	19.7	1.3 (0.6–2.9)

* $P < 0.05$; adjusted to covariates listed in the table.

† Including professional, managerial, clerical, electrical, and technical.

‡ Excluding two persons with other types of glaucoma.

Table 5
Associations of 9-Year Incidence of Moderate-High Myopia

Factor	<i>n</i>	Incidence (%)	Adjusted RR (95% CI) [*]
Age, years			
40–49	999	0.8	1.0
50–59	811	1.6	1.4 (0.5–3.7)
60–69	587	9.2	10.0 (4.3–23.3) [*]
70+	265	12.5	9.1 (3.3–25.0) [*]
Gender			
Female	1576	3.1	1.0
Male	1086	4.4	1.7 (1.0–2.8) [*]
Education (y)			
<9	388	6.0	1.0
≥9	2215	3.2	0.7 (0.4–1.3)
Near-work-related occupation [†]			
No	1776	4.2	1.0
Yes	873	2.6	0.7 (0.4–1.2)
Diabetes history			
No	2317	3.4	1.0
Yes	339	5.5	1.9 (1.01–3.5) [*]
Nuclear opacities			
No	2454	2.6	1.0
Yes	192	21.3	3.6 (2.0–6.7) [*]
PSC opacities			
No	2624	3.5	1.0
Yes	8	0.0	<0.001 (0–>100)
Cortical opacities			
No	2051	3.0	1.0
Yes	567	5.1	0.5 (0.3–0.95) [*]
Glaucoma status [‡]			
No glaucoma	2258	2.6	1.0
Any glaucoma	146	18.4	5.6 (3.0–10.4) [*]
Ocular hypertension	256	5.2	1.3 (0.6–2.6)

^{*} $P < 0.05$; adjusted to covariates listed in the table.

[†] Including professional, managerial, clerical, electrical, and technical.

[‡] Excluding two persons with other types of glaucoma.