

# Prevalence of Glaucoma in an Urban West African Population

## The Tema Eye Survey

Donald L. Budenz, MD, MPH; Keith Barton, MD, FRCS; Julia Whiteside-de Vos, MD, MPH; Joyce Schiffman, MS; Jagadeesh Bandi, MD, MPH; Winifred Nolan, MD; Leon Herndon, MD; Hanna Kim, MD; Graham Hay-Smith, MRCS(Ed), MRCOphth; James M. Tielsch, PhD; for the Tema Eye Survey Study Group

**Importance:** Multiple studies have found an increased prevalence, younger age at onset, and more severe course of glaucoma in people of African descent, but these findings are based on studies conducted outside Africa.

**Objective:** To determine the prevalence of glaucoma in an urban West African population of adults.

**Design and Setting:** A population-based, cross-sectional study of adults 40 years and older conducted from September 1, 2006, through December 31, 2008, from 5 communities in Tema, Ghana.

**Participants:** Participants from randomly selected clusters underwent a screening examination that consisted of visual acuity, frequency doubling perimetry, applanation tonometry, and optic disc photography. Participants who failed any of these tests were referred for complete examination, including gonioscopy, standard automated perimetry, and stereoscopic optic disc photography.

**Results:** A total of 6806 eligible participants were identified, and 5603 (82.3%) were enrolled in the study. The field examination referred 1869 participants (33.3%) to

the clinic examination, and 1538 (82.2%) came for complete examination. A total of 362 participants were identified as having glaucoma of any type and category. Primary open-angle glaucoma was the underlying diagnosis in 342 participants (94.5%). The prevalence of primary open-angle glaucoma was 6.8% overall, increasing from 3.7% among those 40 to 49 years old to 14.6% among those 80 years and older, and was higher in men than in women in all age groups, with an overall male-female prevalence ratio of 1.5. Of the participants with glaucoma, 9 (2.5%) were blind using World Health Organization criteria, and only 12 (3.3%) were aware that they had glaucoma.

**Conclusions and Relevance:** The prevalence of glaucoma is higher in this urban West African population than in previous studies of people of East or South African and of non-African descent. Strategies to identify affected persons and effectively manage the burden of glaucoma are needed in West Africa.

*JAMA Ophthalmol.* 2013;131(5):651-658.

Published online March 28, 2013.

doi:10.1001/jamaophthalmol.2013.1686

**G**LAUCOMA IS THE SECOND most common cause of blindness and the most common cause of irreversible blindness worldwide.<sup>1</sup> An estimated 5.9 million people will be bilaterally blind from open-angle glaucoma by 2020.<sup>2</sup> The burden of blindness from glaucoma, specifically primary open-angle glaucoma (POAG), disproportionately affects people of African descent.<sup>1</sup> Multiple studies have found an increased prevalence,<sup>3-5</sup> younger age at onset,<sup>3,6-8</sup> and more severe course<sup>7,9-12</sup> of glaucoma in people of African descent, but these findings are based on studies conducted outside Africa. As sub-Saharan Africa progresses through the demographic transition

from low mean life expectancy and high birth rates to higher life expectancy and lower birth rates,<sup>13</sup> age-related eye diseases, such as glaucoma, will substantially increase this burden.

Several population studies of glaucoma have been performed in West Africa,<sup>14-17</sup> but none has used current methods and established glaucoma case definitions.<sup>18</sup> There have been 3 well-conducted glaucoma surveys performed in sub-Saharan Africa<sup>19</sup> that were randomly sampled, were population based, and had case definitions that did not include elevated intraocular pressure (IOP)<sup>18</sup>: 1 in Kongwa, Tanzania, East Africa<sup>20</sup> and 2 in South Africa.<sup>21,22</sup> However, these studies yielded lower prevalences of glaucoma than those found in stud-

Author Affiliations are listed at the end of this article.

Group Information: A complete list of the group members appears at the end of the article.

ies of people of African descent conducted in North America,<sup>3-5</sup> possibly because of the genetic heterogeneity of groups of people of African descent and the fact that most African Americans and Afro-Caribbeans are descendants of West and not East or Southern Africa. Given the considerable genetic heterogeneity in sub-Saharan African people,<sup>23-25</sup> it is unlikely that existing studies from East and South Africa are generalizable to all sub-Saharan African populations, such as West Africa.<sup>21</sup> In addition, several authors have highlighted the need for additional studies of the prevalence and causes of blindness and visual impairment in Africa.<sup>1,2</sup> The objective of this portion of the Tema Eye Survey was to determine the age- and sex-specific prevalence of glaucoma in an urban West African population.

## METHODS

### STUDY DESIGN

The Tema Eye Survey is a cross-sectional, population-based study of 5603 individuals 40 years and older residing in 37 randomly selected clusters in 5 communities in Tema, Ghana. Details of the study design and population have been previously reported.<sup>26</sup> Participants were paid the equivalent of US \$2 for their participation in field examinations and the equivalent of US \$5 for their participation in clinic examinations and ancillary testing. If participants were asked to repeat clinic examinations or ancillary testing, an additional US \$5 was provided. The study was conducted from September 1, 2006, through December 31, 2008.

### FIELD EXAMINATION

After written informed consent was obtained, a demographic and health interview was performed. Participants had their presenting visual acuity checked using the reduced logMAR tumbling E chart<sup>27</sup> at 4 m and then 1 m, if necessary. Screening frequency doubling perimetry (Humphrey FDT; Carl Zeiss Meditec), portable applanation IOP (Tono-Pen XL; Reichert Ophthalmic Instruments), central corneal thickness by ultrasonic pachymetry (Pachmate DGH55; DGH), and dilated optic disc and macular photographs using a handheld digital fundus camera (Genesis-D; Kowa Company, Ltd) were then performed.<sup>26</sup>

Frequency doubling perimetry was conducted on both eyes of each participant using the Screening C-20-5 program. If the participant had more than one false-positive or false-negative response, the test was stopped and restarted until there was one or fewer false-positive or false-negative responses on the entire test. If the participant was unable to perform the test with one or fewer false responses in either eye, he or she was referred to the clinic for formal visual field testing and examination. A positive frequency doubling perimetry result was deemed to be more than one abnormal spot ( $P < .05$ ). If the participant tested positive, the test was repeated in that eye. If a participant had 2 positive test results in either eye, he or she was referred to the clinic for repeat frequency doubling perimetry testing and possible standard automated perimetry and ocular examination.

If occludable anterior chamber angles were excluded,<sup>28</sup> pupils were dilated using tropicamide, 1.0%, and phenylephrine, 2.5%. The Kowa Genesis-D camera was used to obtain digital photographs of the optic disc and macula.<sup>26</sup> These images were read by the Moorfields Eye Hospital Reading Center. Early in the study, anyone with a vertical or horizontal cup-disc ratio (CDR)

greater than 0.6, as read by the reading center, was contacted and given an appointment to come to the clinic for complete evaluation. However, because this criterion alone produced a high rate of false-positive results, the cutoff for referral was changed to a CDR greater than 0.725 part way through the study. This decision was supported by known statistically normal upper limits for CDRs in other African glaucoma prevalence studies that reliably determined CDRs<sup>18,20-22</sup> and results from the current study indicating that a vertical CDR (VCDR) of 0.725 represented the 97.5th percentile cutoff in this population.

The VCDR was calculated from the Moorfields Eye Hospital Reading Center's determination of the VCDR from photographs. Some participants had photographs taken in the field and the clinic. From this subset, we calculated a regression equation. For those patients who had clinic photographs and no field photographs, we used this equation to convert clinic photographic VCDRs to the same scale as the field photographs. We then combined these estimated VCDRs with the measured ones to determine the distribution of VCDRs. The VCDR was calculated as the mean of the right and left eyes. A VCDR greater than 0.725 was considered in the highest 2.5th percentile; a VCDR greater than or equal to 0.85 was considered in the highest 0.5th percentile.

### CLINIC EXAMINATION

All participants who failed the visual acuity or frequency doubling technology (FDT) tests, had a mean IOP greater than 20 mm Hg, or had a VCDR greater than 0.725 on optic disc photographs were told they might have an eye problem and given a card with an appointment date and time at the Tema Christian Eye Center for complete evaluation. Free transportation was provided to and from the clinic examination. Manifest refraction was obtained by an optometrist, and visual acuity was rechecked with the tumbling E chart with manifest refraction in a trial frame. Automated static perimetry was performed using the Humphrey Visual Field Analyzer 2 with the 24-2 Swedish Interactive Threshold Fast Algorithm using the individual's best correction with age-appropriate presbyopic correction. Clinic staff members were trained to perform visual field testing by an experienced and certified ophthalmic technician.

A complete eye examination, including gonioscopy and dilated fundus examination, was performed by a US- or UK-trained ophthalmologist (D.L.B., K.B., J.W.d.V., W.N., L.H., G.H.-S.). Participants who failed only the FDT test in the field were given the opportunity to retake this test on presentation to the clinic and opt out of complete evaluation if the FDT test result was normal. After dilation and examination, stereoscopic photographs of the optic disc and macula were taken with the Nidek 3Dx camera (Nidek, Inc). Images from the Humphrey Visual Field Analyzer 2 and Nidek camera were uploaded to the visual field and photography website and read by a glaucoma subspecialist (J.W.d.V.) and the Moorfields Eye Hospital Reading Center, respectively.

### DEFINITION AND CLASSIFICATION OF GLAUCOMA

The definition of glaucoma by Foster et al,<sup>18</sup> summarized in **Table 1**, was used in this study. The upper cutoffs (>97.5th and 99.5th percentiles) for VCDR in African eyes were greater than 0.725 and greater than 0.85, respectively, based on a calculation of the current population's distribution of the VCDR. The cause of the glaucoma was determined by the investigator after complete examination and gonioscopy according to the classification published by Foster et al.<sup>18</sup>

**Table 1. Glaucoma Definitions Used in the Tema Eye Survey**

Category	Definition <sup>18</sup>
1	VCDR >97.5th percentile for healthy population and a definite visual field defect consistent with glaucoma and no other explanation for VCDR or visual field findings Neuroretinal rim width reduced to a CDR ≤0.1 (between the 11 to 1 o'clock and 5 to 7 o'clock positions) AND a definite visual field defect consistent with glaucoma AND no other explanation for CDR or visual field findings Asymmetry of VCDR between eyes >97.5th percentile AND a definite visual field defect consistent with glaucoma AND no other explanation for VCDR or visual field findings
2	VCDR >99.5% for healthy population AND no other explanation for VCDR findings Asymmetry of VCDR >99.5% for healthy population and no other explanation for asymmetry of VCDR findings
3	Visual acuity <20/400 and IOP >99.5th percentile for normal population Visual acuity <20/400 and evidence of previous glaucoma filtering surgery or medical record confirmation of glaucomatous visual morbidity

Abbreviation: CDR, cup-disc ratio; IOP, intraocular pressure; VCDR, vertical cup-disc ratio.

### STATISTICAL ANALYSIS

For determination of the highest 99.5th percentile IOP, the mean IOP in the right and left eyes was used. The IOP distribution determined that the highest 99.5th percentile was represented by an IOP of greater than or equal to 34 mm Hg.

Prevalence rates were calculated using 3 methods. In the first, those who met the definition of POAG constituted the numerator and those who received a field examination (n = 5603) served as the denominator. The observed age- and sex-specific prevalences of POAG were calculated by dividing the number of participants with POAG in a specific age and sex group by the number of individuals who participated in the field examination in that age and sex group. The second method adjusted for nonparticipation in the clinic examination by applying the rate of disease among those who presented for the clinic examination to those who did not. This method assumed that the rate of disease was the same for those who received and did not receive the clinic examination within each age and sex stratum. The third approach adjusted for nonparticipation in the field examination by applying the age- and sex-specific rates based on the aforementioned second method to the total number of eligible participants (n = 6806).

The CIs of the prevalence estimates were calculated using the exact binomial distribution. The CIs of the adjusted prevalence estimates were calculated using the direct adjustment, weighted mean method.<sup>29</sup>

To compare with other epidemiological surveys of glaucoma, prevalence rates for the current and other relevant studies were adjusted for age and sex using the population structure of Barbados in 1990, which was 92.5% black and 2.4% mixed.<sup>30</sup> Data for blacks in the Baltimore Eye Survey were obtained for the calculations (David S. Friedman, MD, PhD, and J.M.T., written communication, June 23, 2011). Otherwise, previously reported adjusted prevalence rates for East Africa and rural and urban South Africa<sup>31</sup> were recorded.

In this study, the male-female ratios of the prevalences, both observed and adjusted for nonparticipation in field and clinic examination, were calculated. The male-female ratio of glaucoma prevalence was adjusted also for age and sex to the population structure of Ghana in 2006.<sup>32</sup> To compare with other epidemiological surveys of glaucoma, where data were available

**Table 2. Prevalence of Glaucoma in the Tema Eye Survey<sup>a</sup>**

Category	Definition <sup>18</sup>	No. of Participants (n = 5603)	Prevalence, % (95% CI)
1	VF plus optic disc changes	316	5.6 (5.1-6.3)
2	Advanced optic disc damage with unproved VF loss	23	0.4 (0.3-0.6)
3	Blind with IOP >35 mm Hg but optic disc not seen and VF impossible	23	0.4 (0.3-0.6)
<b>Total</b>		<b>362</b>	<b>6.5 (5.8-7.1)</b>

Abbreviations: IOP, intraocular pressure; VF, visual field.

<sup>a</sup>All glaucoma diagnoses.

for such calculations, the male-female ratios of glaucoma prevalence of other surveys were adjusted to the local population structure at the time the surveys were conducted. Otherwise, the adjustments or conclusions regarding male-female ratios reported by the surveys' authors were recorded.

### RESULTS

There were a total of 230 clusters available for sampling, 37 of which were randomly chosen for inclusion. The house-to-house census enumerated 6806 eligible individuals in these clusters, of whom 5603 (82.3%) came for the field examination. The field examination identified 1869 individuals (33.3%) who failed one or more screening examinations. Of these, 1538 (82.2%) came to the clinic for definitive examination by an ophthalmologist.

The mean (SD) age of the participants was 52.7 (10.9) years (range, 40-115 years). There were 3379 women (60.3%) and 2224 men (39.7%). A reasonable representative sample of the Ghanaian population was obtained despite running the study in one location.<sup>26</sup> Although 29.3% of individuals were from the Greater Accra region, 70.7% were born elsewhere in Ghana; 7.7% were from outside Ghana, from nearby Mali (n = 40), Togo (n = 37), Nigeria (n = 14), and Côte d'Ivoire (n = 13). Two thousand eighteen individuals (37.8%) stated that they had a history of an eye examination before the study.

There were 362 individuals identified as having any type of glaucoma, almost all by category 1 criteria (optic disc and visual field abnormality consistent with glaucoma, **Table 2**), for a prevalence of 6.5% (95% CI, 5.8%-7.1%). The underlying diagnosis was POAG in 342 participants (94.5%), followed by primary-angle closure glaucoma in 9 (2.5%), glaucoma secondary to trauma in 7 (1.9%), and other secondary glaucomas in 4 (1.1%). Only 12 of the 362 individuals (3.3%) with glaucoma were aware that they had it before the study, one of whom denied having it but was taking glaucoma medications. Fifty-two individuals with glaucoma (14.4%) were considered visually impaired from glaucoma (best-corrected visual acuity <20/40 but ≥20/400 in the better-seeing eye). Nine individuals (2.5%) with glaucoma had best-corrected visual acuity less than 20/400 in the better-seeing eye and were classified as blind by World Health Organization criteria.

**Table 3. Age- and Gender-Specific Prevalence of Open-angle Glaucoma**

Age, y	Female			Male			Both
	No./No.	Prevalence/100, % (95% CI)		No./No.	Prevalence/100, % (95% CI)		Prevalence/100, % (95% CI)
		Observed	Adjusted <sup>a</sup>		Observed	Adjusted <sup>a</sup>	Adjusted <sup>a,b</sup>
40-49	48/1663	2.9 (2.1-3.8)	3.1 (2.3-4.0)	40/943	4.2 (3.0-5.7)	4.6 (3.2-5.9)	3.7 (3.0-4.4)
50-59	45/939	4.8 (3.5-6.4)	5.4 (4.0-6.8)	45/648	6.9 (5.1-9.2)	7.7 (5.7-9.7)	6.3 (5.2-7.5)
60-69	40/459	8.7 (6.3-11.7)	10.0 (7.4-12.7)	53/405	13.1 (10.0-16.8)	14.6 (11.2-17.9)	12.2 (10.1-14.3)
70-79	21/210	10.0 (6.3-14.9)	11.5 (7.3-15.7)	30/186	16.1 (11.2-22.2)	17.8 (12.4-23.2)	14.6 (11.2-17.9)
≥ 80	12/108	11.1 (5.9-18.6)	12.3 (6.3-18.4)	8/42	19.0 (8.6-34.1)	20.1 (8.1-32.1)	14.6 (9.0-20.1)
<b>Total</b>	<b>166/3379</b>	<b>4.9 (4.2-5.7)</b>	<b>5.5 (4.8-6.3)</b>	<b>176/2224</b>	<b>7.9 (6.8-9.1)</b>	<b>8.7 (7.6-9.8)</b>	<b>6.8 (6.2-7.4)</b>

Abbreviation: No./No., number with glaucoma/number who received field examination.

<sup>a</sup>Adjusted prevalence was adjusted for nonparticipation in the clinic examination.

<sup>b</sup>Observed prevalence for both males and females is displayed in Table 4.

The prevalence of POAG increased with increasing age, from 3.7% among those aged 40 to 49 years to 14.6% among those 80 years and older (Table 3). Adjustment for nonparticipation in the clinic examination accounted for an 11% increase (6.8% vs 6.1%) in the estimated overall prevalence of POAG (Table 3). Further adjustment for nonparticipation in the field examination accounted for a 13% increase (6.9% vs 6.1%) in the estimated overall prevalence of POAG (data not shown). The prevalence of POAG was higher in men than in women in all age groups (Table 3). The greater prevalence of POAG in men persisted even after adjustment for differential rates of nonparticipation in the clinic (Table 3) and field (data not shown) examinations and after adjustment for the population structure of Ghana, with an adjusted ratio of 1.5 overall.

#### COMMENT

As Ghana and other sub-Saharan countries move through the epidemiological transition, chronic eye diseases in elderly populations will increase the burden of blindness in this region. The prevalence of POAG in our urban West African population increased from 3.7% among those aged 40 to 49 years to 14.6% at 80 years or older. Given the aging population of Ghana and other West African countries and considering the early age at onset and aggressive course in this population, blindness from undiagnosed and untreated glaucoma will be a significant problem in the aging population in the future. Some of the strengths of the current glaucoma survey are that it measured central corneal thickness, used automated perimetry in the field and clinic, used masked reading centers for evaluation of digitally produced visual fields and optic disc photographs, and did not require elevated IOP for the diagnosis of glaucoma.

A comparison of different population prevalence studies is difficult because of the differences in sampling methods, sample sizes, definitions of glaucoma, type of examiners, diagnostic tools, local population structures at the times the studies were conducted, age and sex variations in field and clinic examination participation rates, and reporting of observed vs age- and/or sex-adjusted prevalence. Table 4 and Table 5 compare the ob-

served age-specific prevalence of POAG in the Tema Eye Survey with similar population-based surveys of high quality<sup>19</sup> conducted in other African (South and East) and African-derived (North American) peoples. The current study suggests a higher prevalence and younger age at onset of glaucoma compared with studies of people residing in the United States and in South or East Africa and more similar to studies of people of African descent residing in the Caribbean. The age-specific and adjusted prevalences of POAG (and their 95% CIs) for the studies summarized in Table 4 and Table 5 suggest that POAG has the earliest age of onset in Ghana and St Lucia, the steepest increase with age in Barbados, and the highest adjusted total prevalence in Ghana and the Caribbean, followed by Baltimore and East and South Africa. These findings support the hypothesis that POAG is more prevalent and occurs at a younger age in populations of West African descent. Comparison of the prevalences of POAG, adjusted for age and sex to a standard population, in survey samples of different ethnicities suggests that glaucoma prevalence is highest in Ghanaians and Afro-Caribbeans and lowest in European-derived populations, with that of Latinos or Hispanics, African Americans, Japanese, East and South Africans, Chinese, Malay, and Indian Asians between the 2 extremes (Table 5 and eTable 1; <http://www.jamaophth.com>).<sup>33-47</sup>

The high prevalence of POAG in West African-derived peoples may be related to a genetic causal variant.<sup>48-50</sup> Ghanaians have a striking genetic homogeneity,<sup>51-54</sup> whereas most East and many South Africans have greater genetic heterogeneity.<sup>55,56</sup> Afro-Caribbeans and African Americans are primarily of West African origin. Their percentage of West African genetic composition depends on the intermingling of their ancestors with individuals of European, Native American, and Asian or other African ancestry. The higher prevalence of POAG in Afro-Caribbeans than in African Americans might be related to a higher West African genetic admixture.<sup>57,58</sup> Environmental factors, gene-gene and gene-environment interactions, epigenetics, natural selection, and genetic drift also may play a role.<sup>25,59,60</sup> Primary open-angle glaucoma is a complex disease both mechanistically and genetically.<sup>61-63</sup> Environmental factors could influence the phenotypic expression of POAG as they do other com-

**Table 4. Observed Age-Specific Prevalence of OAG in People of African Descent**

Source	No. Enrolled	No. of OAG Cases	Response, %	Female, %	Observed Prevalence/100 by Age, % (95% CI)				
					40-49 y	50-59 y	60-69 y	70-79 y	≥80 y
Tema Eye Survey, 2006-2008	5603	342	82	60.3	3.4 (2.7-4.1)	5.7 (4.6-6.9)	10.8 (8.8-13.0)	12.9 (9.7-16.6)	13.3 (8.3-19.8)
St Lucia, <sup>4</sup> 1986-1987	1300	147	87	66.5	7.3 (4.8-10.6)	8.7 (5.8-12.7)	15.2 (11.3-20.0)	9.5 (6.3-13.9) <sup>a</sup>	9.5 (6.3-13.9) <sup>a</sup>
Barbados (black and mixed), <sup>5</sup> 1988-1992	4498	308	84	57.1	1.4 (0.8-2.2)	4.1 (3.0-5.4)	6.7 (5.3-8.4)	14.8 (12.5-17.4)	23.2 (17.9-29.3)
Baltimore Eye Survey, <sup>3</sup> 1985-1988	2395	100	84	62.5 <sup>b</sup>	1.0 (0.4-2.1)	3.6 (2.3-5.3)	5.1 (3.4-7.2)	7.7 (4.9-10.5)	10.9 (4.8-17.0)
East Africa, <sup>20</sup> 1996	3268	100	90	55.4	1.7 (1.1-2.5)	3.2 (2.2-4.5)	4.7 (3.1-7.0)	5.6 (3.1-9.2)	4.4 (1.2-11.3)
South Africa, urban, <sup>21</sup> 1998	839	31	75	66.6	0.6	2.4	4.2	6.0	10.7
South Africa, Rural, <sup>22</sup> 1998-1999	1005	28	90	72.1	1.2 (0.2-3.4)	1.9 (0.6-4.3)	2.8 (1.1-5.8)	4.9 (2.2-9.3)	7.7 (2.1-19.7)

Abbreviation: OAG, open-angle glaucoma.

<sup>a</sup>Prevalence was not reported separately for ages 70 to 79 and 80 years and older but for age 70 years and older.

<sup>b</sup>David S. Friedman, MD, PhD, and J.M.T., The Johns Hopkins Bloomberg School of Public Health, written communication, June 23, 2011.

plex genetic diseases, such as hypertension and diabetes mellitus, that are more prevalent among West African-derived peoples.<sup>64</sup> Latitude, sun exposure, vitamin D metabolism, diet, exercise, and other environmental differences could alter the risk of POAG in those exposed and in subsequent generations.<sup>61-63,65,66</sup>

In the current study, the prevalence of POAG was higher in men than in women in all age groups before and after adjustment for nonparticipation in the field and clinic examinations. Women were 60.3% of the current study's total sample compared with 51.8% of Ghana's population 40 years and older in 2006.<sup>32</sup> The prevalence of POAG remained higher in men even after adjustment for the population structure of Ghana by age and sex in 2006, with a ratio of 1.5. Several previous studies<sup>5,34,35,39,43</sup> have reported a higher prevalence of glaucoma in men than in women in individuals of African, European, Indian Asian, and Asian heritage, with male-female ratios of 1.2 to 1.8, whereas others,<sup>3,4,38,41,46,47</sup> including one of Latino ethnicity, have demonstrated a ratio closer to 1 (eTable 2). In the Barbados Eye Study, the prevalence of POAG was higher in men than in women in all age categories, with an age-adjusted prevalence ratio of 1.4.<sup>5</sup> In the Baltimore Eye Survey, the prevalence of POAG was slightly higher overall in black males than in black females, but this finding was not consistent across all age categories and was not significant when adjusted for the population structure of blacks in the United States in 1988.<sup>3</sup> The South African urban and rural surveys found a higher age-adjusted prevalence of all glaucomas in men than in women but the prevalence of POAG failed to reach statistical significance.<sup>21,22</sup> In the St Lucia study,<sup>4</sup> no difference was found in POAG prevalence by sex. Study results could vary because of differences in sample sizes, diagnostic criteria, population structures, or participation rates by age and sex. Survey results also could vary because of sample population differences in hormonal, reproductive, or dietary factors; body mass

**Table 5. Total Prevalence of Open-angle Glaucoma in People of African Descent**

Source	Total Prevalence, % (95% CI)	
	Observed	Adjusted
Tema Eye Survey, 2006-2008	6.1 (5.5-6.8)	8.0 (7.4-8.6) <sup>a</sup>
St Lucia, <sup>4</sup> 1986-1987	10.2 (8.5-12.0)	9.6 (8.0-11.2) <sup>a</sup>
Barbados (black and mixed), <sup>5</sup> 1988-1992	6.8 (6.1-7.7)	7.4 (6.7-8.1) <sup>a</sup>
Caribbean total		7.8
Baltimore Eye Survey, <sup>3</sup> 1985-1988	4.2 (3.0-5.0)	4.4 (3.6-5.2) <sup>a,b</sup>
East Africa, <sup>20</sup> 1996	3.1 (2.5-3.8)	3.6 <sup>31,c</sup>
South Africa, urban, <sup>21</sup> 1998	3.7 (2.5-5.3)	3.5 <sup>31,c</sup>
South Africa, rural, <sup>22</sup> 1998-1999 <sup>c</sup>	2.8 (1.8-4.2)	3.2 <sup>31,c</sup>

<sup>a</sup>Adjusted for age and sex using the population structure of Barbados in 1990.<sup>30</sup>

<sup>b</sup>David S. Friedman, MD, PhD, and J.M.T., The Johns Hopkins Bloomberg School of Public Health, written communication, June 23, 2011.

<sup>c</sup>Data not available for 95% CI calculations.

index; or other environmental, genetic, or epigenetic factors.<sup>67-73</sup> The preponderance of evidence suggests that the prevalence of POAG is greater in men than in women.<sup>74</sup>

Most glaucoma identified in this survey was POAG (94.5%). Only 2.5% of participants with glaucoma had closed angle as the cause. In a clinic-based survey in Accra, Ghana, Herndon and associates<sup>75</sup> found that POAG represented approximately 70% (44% confirmed and 30% suspected) and primary angle closure represented 6.6% of glaucoma cases. Interestingly, even with a comprehensive examination, 12.7% of the people had glaucoma of indeterminate subtype. Selected populations in South Africa (Bantu/Zulu) have demonstrated a surprisingly high prevalence of pseudoexfoliation glaucoma<sup>76</sup>;

we observed no such cases. A recent study in people of African descent, including participants in the current study, had a low frequency of variants of the *LOXLI* gene<sup>77</sup> known to be associated with pseudoexfoliation syndrome.<sup>78</sup> These differences in causes of glaucoma support the hypothesis that the West African population is phenotypically and genetically distinct from the southern African population with regard to glaucoma.

The current study found that 96.7% of participants diagnosed as having glaucoma were unaware they had the disease before our examination. A nonrandomly collected survey of 1843 Ghanaians 30 years and older found a similar result.<sup>17</sup> In developing regions in Africa and South Asia, the percentage of undiagnosed glaucoma in the population studied has been reported to be greater than 90%<sup>17,20-22,39-41</sup> compared with studies in developed countries, which reveal the rate of undiagnosed glaucoma to be approximately 50% to 75%.<sup>3-5,33-38</sup> It is unclear whether this is related to differences in methods for identifying glaucoma or overall access to eye care professionals in developing vs developed countries or to improved efforts to screen high-risk populations in the developing world. The current study suggests that glaucoma screening may be particularly beneficial in developing countries, although its cost-effectiveness needs to be assessed in these settings.<sup>79</sup>

We acknowledge that there are several limitations with the current study, which are discussed in greater detail in a previous publication.<sup>26</sup> First, a nationwide survey might have provided better estimates of the prevalence of glaucoma in Ghana. This was not feasible for budgetary and logistical reasons.<sup>26</sup> The study population was ethnically diverse in that most of the participants were born in regions outside the Tema district study area. We recognize, however, that the results may not be generalizable to the rest of Ghana or all of West Africa. Second, the percentage of female participants in our study (60.3%) was higher than for the Ghana population 40 years and older (51.8%) in 2006.<sup>32</sup> One reason for this is that more women are available during weekdays to participate, particularly in developing countries where fewer women work outside the home. A third practical limitation of the current study is that participants were examined by 7 different ophthalmologists rather than by the same ophthalmologist. Most of the investigators were glaucoma subspecialists with many years of experience diagnosing anterior segment, optic nerve, and retinal diseases. More important, the diagnosis of glaucoma was based solely on visual fields read by a masked glaucoma specialist (J.W.d.V.) and fundus photographs read by masked readers at a reading center. Thus, we do not believe this to be a significant limitation.

In summary, the current study demonstrates a high prevalence of POAG in an urban West African setting. The high prevalence of glaucoma is similar to that found in Caribbean populations of African descent, possibly because they are more similar genetically than to people in East and South Africa. There was a higher prevalence in men than in women in all age groups.

**Submitted for Publication:** May 24, 2012; final revision received September 25, 2012; accepted October 11, 2012.

**Published Online:** March 28, 2013. doi:10.1001/jamaophthalmol.2013.1686

**Author Affiliations:** Department of Ophthalmology, Bascom Palmer Eye Institute, Miller School of Medicine, University of Miami, Department of Ophthalmology, Miami, Florida (Drs Budenz and Bandi, Ms Schiffman); Glaucoma Service, Moorfields Eye Hospital (Drs Barton, Nolan, and Hay-Smith), and Department of Epidemiology and Genetics, Institute of Ophthalmology, University College London (Dr Barton), London, United Kingdom; The Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland (Drs Whiteside-de Vos and Tielsch); Duke University Eye Center, Durham, North Carolina (Dr Herndon); and Stanford University School of Medicine, Palo Alto, California (Dr Kim). Dr Budenz is with the Department of Ophthalmology, University of North Carolina at Chapel Hill. Dr Kim is with Department of Ophthalmology, Bascom Palmer Eye Institute, Miller School of Medicine, University of Miami, Miami, Florida.

**Correspondence:** Donald L. Budenz, MD, MPH, Department of Ophthalmology, University of North Carolina, CB7040, Chapel Hill, NC 27599-7040 (dbudenz@med.unc.edu).

**Conflict of Interest Disclosures:** None reported.

**Group Members:** The Tema Eye Survey Study Group members are as follows: Department of Ophthalmology, Bascom Palmer Eye Institute, Miller School of Medicine, University of Miami, Miami, Florida: Jagadeesh Bandi, MD, MPH, Donald L. Budenz, MD, MPH, William Feuer, MS, Joyce Schiffman, MS. National Institute for Health Research Biomedical Research Centre for Ophthalmology, Moorfields Eye Hospital, London, United Kingdom: Keith Barton, MD, Tunde Peto, MD, PhD, Ferenc Sallo, Graham Hay-Smith, MRCS(Ed), MRCOphth, Winnie Nolan, MD. Duke University Eye Center, Durham, North Carolina: Leon Herndon, MD. The Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland: James Tielsch, PhD, Julia Whiteside-de Vos, MD, MPH\*. Department of Ophthalmology, Stanford University, Palo Alto, California: Peter Egbert, MD, Hanna Kim, MD. Unit of Ophthalmology, University of Ghana Medical School, Ghana, Africa: Stephen Akafo, MD. International Aid, Spring Lake, Michigan: Faye Kragt, COMS. Department of Ophthalmic Epidemiology, Institute of Ophthalmology, University College London, London, United Kingdom: Pak Sang Lee, MPhil. Tema Christian Eye Centre, Tema, Ghana: Shine Amaglo, Maureen Armarh, Steven Boakye, Frank Boateng, Michaela Clemens, MS, Patience Dadzie, RN, Paulina Darkenu, Ernest Elikem, Sarah Mehta, BA, George Wood.

\*Dr Whiteside-de Vos was not affiliated with The Johns Hopkins Bloomberg School of Public Health while conducting study activities in Ghana.

**Funding/Support:** This study was supported by grants awarded to International Aid, Spring Lake, Michigan, from Pfizer, Inc, and the Allergan Foundation; unrestricted core grant NIH P30 EY014801 awarded to the University of Miami by the National Institutes of Health, Bethesda, Maryland; an unrestricted grant to Research to Prevent Blindness, Inc, New York, New York; a Mid-Career Physician Scientist Award from the American Glaucoma So-

ciety (Dr Budenz); and National Eye Institute Training grant T32 EY 07127, Clinical Trials Training Program in Vision Research (Dr Whiteside-de Vos).

**Online-Only Material:** The eTables are available at <http://www.jamaophth.com>.

**Additional Contributions:** Pak Sang Lee, MPhil, of the National Institute for Health Research Biomedical Research Center for Ophthalmology, UCL Institute of Ophthalmology, and Moorfields Eye Hospital, London, United Kingdom, provided technical training and support on this study, and Emily West Gower, PhD, of Wake Forest University (previously of The Johns Hopkins University) provided advice regarding adjustment of prevalence rates.

## REFERENCES

1. Resnikoff S, Pascolini D, Etya'ale D, et al. Global data on visual impairment in the year 2002. *Bull World Health Organ*. 2004;82(11):844-851.
2. Quigley HA, Broman AT. The number of people with glaucoma worldwide in 2010 and 2020. *Br J Ophthalmol*. 2006;90(3):262-267.
3. Tielsch JM, Sommer A, Katz J, Royall RM, Quigley HA, Javitt J. Racial variations in the prevalence of primary open-angle glaucoma: the Baltimore Eye Survey. *JAMA*. 1991;266(3):369-374.
4. Mason RP, Kosoko O, Wilson MR, et al. National survey of the prevalence and risk factors of glaucoma in St. Lucia, West Indies, part I: prevalence findings. *Ophthalmology*. 1989;96(9):1363-1368.
5. Leske MC, Connell AM, Schachat AP, Hyman L. The Barbados Eye Study: prevalence of open angle glaucoma. *Arch Ophthalmol*. 1994;112(6):821-829.
6. Wilensky JT, Gandhi N, Pan T. Racial influences in open-angle glaucoma. *Ann Ophthalmol*. 1978;10(10):1398-1402.
7. Grant WM, Burke JF Jr. Why do some people go blind from glaucoma? *Ophthalmology*. 1982;89(9):991-998.
8. Wilson R, Richardson TM, Hertzmark E, Grant WM. Race as a risk factor for progressive glaucomatous damage. *Ann Ophthalmol*. 1985;17(10):653-659.
9. Hiller R, Kahn HA. Blindness from glaucoma. *Am J Ophthalmol*. 1975;80(1):62-69.
10. Sommer A, Tielsch JM, Katz J, et al. Racial differences in the cause-specific prevalence of blindness in east Baltimore. *N Engl J Med*. 1991;325(20):1412-1417.
11. Quigley HA, Tielsch JM, Katz J, Sommer A. Rate of progression in open-angle glaucoma estimated from cross-sectional prevalence of visual field damage. *Am J Ophthalmol*. 1996;122(3):355-363.
12. Musch DC, Lichter PR, Guire KE, Standardi CL. The Collaborative Initial Glaucoma Treatment Study: study design, methods, and baseline characteristics of enrolled patients. *Ophthalmology*. 1999;106(4):653-662.
13. United Nations Economic Commission for Africa. The state of demographic transition in Africa. 2000. [http://www.uneca.org/eca\\_resources/publications/fssd/state\\_of\\_demographic\\_transition\\_in\\_africa.pdf](http://www.uneca.org/eca_resources/publications/fssd/state_of_demographic_transition_in_africa.pdf). Accessed April 4, 2011.
14. Neumann E, Zauberman H. Glaucoma survey in Liberia. *Am J Ophthalmol*. 1965;59:8-12.
15. Guzek JP, Anyomi FK, Fiadoyor S, Nyonator F. Prevalence of blindness in people over 40 years in the Volta region of Ghana. *Ghana Med J*. 2005;39(2):55-62.
16. Ekwerekwu CM, Umeh RE. The prevalence of glaucoma in an onchoendemic community in south-eastern Nigeria. *West Afr J Med*. 2002;21(3):200-203.
17. Ntim-Amponsah CT, Amoaku WM, Ofosu-Amaah S, et al. Prevalence of glaucoma in an African population. *Eye (Lond)*. 2004;18(5):491-497.
18. Foster PJ, Buhrmann R, Quigley HA, Johnson GJ. The definition and classification of glaucoma in prevalence surveys. *Br J Ophthalmol*. 2002;86(2):238-242.
19. Sommer A. Ocular hypertension and normal-tension glaucoma: time for banishment and burial. *Arch Ophthalmol*. 2011;129(6):785-787.
20. Buhrmann RR, Quigley HA, Barron Y, West SK, Oliva MS, Mmbaga BB. Prevalence of glaucoma in a rural East African population. *Invest Ophthalmol Vis Sci*. 2000;41(1):40-48.
21. Rotchford AP, Kirwan JF, Muller MA, Johnson GJ, Roux P. Temba glaucoma study: a population-based cross-sectional survey in urban South Africa. *Ophthalmology*. 2003;110(2):376-382.
22. Rotchford AP, Johnson GJ. Glaucoma in Zululand: a population-based cross-sectional survey in a rural district in South Africa. *Arch Ophthalmol*. 2002;120(4):471-478.
23. Tishkoff SA, Reed FA, Friedlaender FR, et al. The genetic structure and history of Africans and African Americans. *Science*. 2009;324(5930):1035-1044.
24. Campbell MC, Tishkoff SA. African genetic diversity: implications for human demographic history, modern human origins, and complex disease mapping. *Annu Rev Genomics Hum Genet*. 2008;9:403-433.
25. Kosoko-Lasaki O, Gong G, Haynatzki G, Wilson MR. Race, ethnicity and prevalence of primary open-angle glaucoma. *J Natl Med Assoc*. 2006;98(10):1626-1629.
26. Budenz DL, Bandi J, Barton K, et al; Tema Eye Survey Study Group. Blindness and visual impairment in an urban West African population: the Tema Eye survey. *Ophthalmology*. 2012;119(9):1744-1753.
27. Bourne RR, Rosser DA, Sukudom P, et al. Evaluating a new logMAR chart designed to improve visual acuity assessment in population-based surveys. *Eye (Lond)*. 2003;17(6):754-758.
28. Patel KH, Javitt JC, Tielsch JM, et al. Incidence of acute angle-closure glaucoma after pharmacologic mydriasis. *Am J Ophthalmol*. 1995;120(6):709-717.
29. Kahn HA, Sempos CT. *Adjustment of Data Without Use of Multivariate Models: Statistical Methods in Epidemiology*. New York, NY: Oxford University Press; 1989: 87-95.
30. Caricom Capacity Development Programme (CCDP). *Round of Population and Housing Census Sub-Project: National Census Report Barbados*. 2000:30, 219-224. <http://www.google.com/url?sa=t&source=web&cd=22&ved=0CCIQFjABOBQ&url=http%3A%2F%2Fwww.caricomstats.org%2Ffiles%2FPublications%2FNCR%2520Reports%2FBarbados.pdf&rct=j&q=Barbados%20Statistical%20Service%201990%20Population%20and%20Housing%20Census%20Report%2C%20Vol%201&ei=girZTcqvO6Hx0gG5rvn7Aw&usq=AFQjCNHHqJjSPDLFIuRYKQjxBlmzByqg>. Accessed November 24, 2011.
31. Johnson GJ, Quigley HA. The glaucomas. In: Johnson GJ, Minassian DC, Weale RA, West SK, eds. *Epidemiology of Eye Diseases*. London, England: Arnold; 2003: 226-227.
32. US Bureau of the Census, International Programs, International Database. Mid-year population by five year age groups and sex—custom region, 2006. <http://www.census.gov/population/international/data/idb/region.php?N=%20Results%20&T=10&A=separate&RT=0&Y=2006&R=-1&C=GH>. Accessed February 5, 2013.
33. Klein BE, Klein R, Sponsel WE, et al. Prevalence of glaucoma: the Beaver Dam Eye Study. *Ophthalmology*. 1992;99(10):1499-1504.
34. Kahn HA, Leibowitz HM, Ganley JP, et al. The Framingham Eye Study, I: outline and major prevalence findings. *Am J Epidemiol*. 1977;106(1):17-32.
35. Wolfs RC, Borger PH, Ramrattan RS, et al. Changing views on open-angle glaucoma: definitions and prevalences: the Rotterdam Study. *Invest Ophthalmol Vis Sci*. 2000;41(11):3309-3321.
36. Mitchell P, Smith W, Attebo K, Healey PR. Prevalence of open-angle glaucoma in Australia: the Blue Mountains Eye Study. *Ophthalmology*. 1996;103(10):1661-1669.
37. Quigley HA, West SK, Rodriguez J, Munoz B, Klein R, Snyder R. The prevalence of glaucoma in a population-based study of Hispanic subjects: Proyecto VER. *Arch Ophthalmol*. 2001;119(12):1819-1826.
38. Varma R, Ying-Lai M, Francis BA, et al; Los Angeles Latino Eye Study Group. Prevalence of open-angle glaucoma and ocular hypertension in Latinos: the Los Angeles Latino Eye Study. *Ophthalmology*. 2004;111(8):1439-1448.
39. Ramakrishnan R, Nirmalan PK, Krishnadas R, et al. Glaucoma in a rural population of southern India: the Aravind comprehensive eye survey. *Ophthalmology*. 2003;110(8):1484-1490.
40. Garudadri C, Senthil S, Khanna RC, Sannapaneni K, Rao HB. Prevalence and risk factors for primary glaucomas in adult urban and rural populations in the Andhra Pradesh Eye Disease Study. *Ophthalmology*. 2010;117(7):1352-1359.
41. Vijaya L, George R, Baskaran M, et al. Prevalence of primary open-angle glaucoma in an urban south Indian population and comparison with a rural population: the Chennai Glaucoma Study. *Ophthalmology*. 2008;115(4):648-654, e1. doi:10.1016/j.ophtha.2007.04.062.
42. Raychaudhuri A, Lahiri SK, Bandyopadhyay M, Foster PJ, Reeves BC, Johnson GJ. A population based survey of the prevalence and types of glaucoma in rural West Bengal: the West Bengal Glaucoma Study. *Br J Ophthalmol*. 2005;89(12):1559-1564.
43. Wang YX, Xu L, Yang H, Jonas JB. Prevalence of glaucoma in North China: the Beijing Eye Study. *Am J Ophthalmol*. 2010;150(6):917-924.
44. He M, Foster PJ, Ge J, et al. Prevalence and clinical characteristics of glaucoma in adult Chinese: a population-based study in Liwan District, Guangzhou. *Invest Ophthalmol Vis Sci*. 2006;47(7):2782-2788.
45. Foster PJ, Oen FT, Machin D, et al. The prevalence of glaucoma in Chinese residents of Singapore: a cross-sectional population survey of the Tanjong Pagar district. *Arch Ophthalmol*. 2000;118(8):1105-1111.
46. Shen SY, Wong TY, Foster PJ, et al. The prevalence and types of glaucoma in Malay people: the Singapore Malay eye study. *Invest Ophthalmol Vis Sci*. 2008;49(9):3846-3851.
47. Iwase A, Suzuki Y, Araie M, et al; Tajimi Study Group, Japan Glaucoma Society. The prevalence of primary open-angle glaucoma in Japanese: the Tajimi Study. *Ophthalmology*. 2004;111(9):1641-1648.
48. Jiao X, Yang Z, Yang X, et al. Common variants on chromosome 2 and risk of

- primary open-angle glaucoma in the Afro-Caribbean population of Barbados. *Proc Natl Acad Sci U S A*. 2009;106(40):17105-17110.
49. Liu Y, Qin X, Schmidt S, Allingham RR, Hauser MA. Association between chromosome 2p16.3 variants and glaucoma in populations of African descent. *Proc Natl Acad Sci U S A*. 2010;107(15):E61. doi:10.1073/pnas.0913838107.
  50. Zhang K, Jiao X, Chen Y, et al. Reply to Liu et al: differential effects of chromosome 2p16.3 variants on glaucoma in African derived populations. *Proc Natl Acad Sci U S A*. 2010;107(15):E62 <http://www.pnas.org/content/107/15/E62.full>. Accessed February 5, 2013.
  51. Adeyemo AA, Chen G, Chen Y, Rotimi C. Genetic structure in four West African population groups. *BMC Genet*. 2005;6:38. doi:10.1186/1471-2156-6-38.
  52. Reed FA, Tishkoff SA. African human diversity, origins and migrations. *Curr Opin Genet Dev*. 2006;16(6):597-605.
  53. Sikora M, Laayouni H, Calafell F, Comas D, Bertranpetit J. A genomic analysis identifies a novel component in the genetic structure of sub-Saharan African populations. *Eur J Hum Genet*. 2011;19(1):84-88.
  54. Bryc K, Auton A, Nelson MR, et al. Genome-wide patterns of population structure and admixture in West Africans and African Americans. *Proc Natl Acad Sci U S A*. 2010;107(2):786-791.
  55. Scheinfeldt LB, Soi S, Tishkoff SA. Colloquium paper: working toward a synthesis of archaeological, linguistic, and genetic data for inferring African population history. *Proc Natl Acad Sci U S A*. 2010;107(suppl 2):8931-8938.
  56. Campbell MC, Tishkoff SA. The evolution of human genetic and phenotypic variation in Africa. *Curr Biol*. 2010;20(4):R166-R173.
  57. Murray T, Beaty TH, Mathias RA, et al. African and non-African admixture components in African Americans and an African Caribbean population. *Genet Epidemiol*. 2010;34(6):561-568.
  58. Benn-Torres J, Bonilla C, Robbins CM, et al. Admixture and population stratification in African Caribbean populations. *Ann Hum Genet*. 2008;72(pt 1):90-98.
  59. Relton CL, Davey Smith G. Epigenetic epidemiology of common complex disease: prospects for prediction, prevention, and treatment. *PLoS Med*. 2010;7(10):e1000356.
  60. Marigorta UM, Lao O, Casals F, et al. Recent human evolution has shaped geographical differences in susceptibility to disease. *BMC Genomics*. 2011;12:55. doi:10.1186/1471-2164-12-55.
  61. Sacca SC, Bolognesi C, Battistella A, Bagnis A, Izzotti A. Gene-environment interactions in ocular diseases. *Mutat Res*. 2009;667(1-2):98-117.
  62. Ray K, Mookherjee S. Molecular complexity of primary open angle glaucoma: current concepts. *J Genet*. 2009;88(4):451-467.
  63. Allingham RR, Liu Y, Rhee DJ. The genetics of primary open-angle glaucoma: a review. *Exp Eye Res*. 2009;88(4):837-844.
  64. Amoah AG, Owusu SK, Adjei S. Diabetes in Ghana: a community based prevalence study in Greater Accra. *Diabetes Res Clin Pract*. 2002;56(3):197-205.
  65. Clarke EE. A comparative analysis of the age distribution and types of primary glaucoma among populations of African and Caucasian origins. *Ann Ophthalmol*. 1973;5(10):1055-1071.
  66. Fan BJ, Wiggs JL. Glaucoma: genes, phenotypes, and new directions for therapy. *J Clin Invest*. 2010;120(9):3064-3072.
  67. Pasquale LR, Willett WC, Rosner BA, Kang JH. Anthropometric measures and their relation to incident primary open-angle glaucoma. *Ophthalmology*. 2010;117(8):1521-1529.
  68. Wang SY, Singh K, Lin SC. The association between glaucoma prevalence and supplementation with the oxidants calcium and iron. *Invest Ophthalmol Vis Sci*. 2012;53(2):725-731.
  69. Zanon-Moreno V, Garcia-Medina JJ, Zanon-Viguer V, Moreno-Nadal MA, Pinazo-Duran MD. Smoking, an additional risk factor in elder women with primary open-angle glaucoma. *Mol Vis*. 2009;15:2953-2959.
  70. Kang JH, Pasquale LR, Willett WC, et al. Dietary fat consumption and primary open-angle glaucoma. *Am J Clin Nutr*. 2004;79(5):755-764.
  71. Wise LA, Rosenberg L, Radin RG, et al. A prospective study of diabetes, lifestyle factors, and glaucoma among African-American women. *Ann Epidemiol*. 2011;21(6):430-439.
  72. Kang JH, Wiggs JL, Haines J, Abdrabou W, Pasquale LR. Reproductive factors and NOS3 variant interactions in primary open-angle glaucoma. *Mol Vis*. 2011;17:2544-2551.
  73. Pasquale LR, Kang JH. Female reproductive factors and primary open-angle glaucoma in the Nurses' Health Study. *Eye (Lond)*. 2011;25(5):633-641.
  74. Rudnicka AR, Mt-Isa S, Owen CG, Cook DG, Ashby D. Variations in primary open-angle glaucoma prevalence by age, gender, and race: a Bayesian meta-analysis. *Invest Ophthalmol Vis Sci*. 2006;47(10):4254-4261.
  75. Herndon LW, Challa P, Abudia-Danso B, et al. Survey of glaucoma in an eye clinic in Ghana, West Africa. *J Glaucoma*. 2002;11(5):421-425.
  76. Rotchford AP, Kirwan JF, Johnson GJ, Roux P. Exfoliation syndrome in black South Africans. *Arch Ophthalmol*. 2003;121(6):863-870.
  77. Liu Y, Schmidt S, Qin X, et al. Lack of association between LOXL1 variants and primary open-angle glaucoma in three different populations. *Invest Ophthalmol Vis Sci*. 2008;49(8):3465-3468.
  78. Thorleifsson G, Magnusson KP, Sulem P, et al. Common sequence variants in the LOXL1 gene confer susceptibility to exfoliation glaucoma. *Science*. 2007;317(5843):1397-1400.
  79. Wittenborn JS, Rein DB. Cost-effectiveness of glaucoma interventions in Barbados and Ghana. *Optom Vis Sci*. 2011;88(1):155-163.