AMERICAN ACADEMY OF OPHTHALMOLOGY
The Eye M.D. Association

Global Prevalence of Glaucoma and Projections of Glaucoma Burden through 2040

A Systematic Review and Meta-Analysis

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Purpose: Glaucoma is the leading cause of global irreversible blindness. Present estimates of global glaucoma prevalence are not up-to-date and focused mainly on European ancestry populations. We systematically examined the global prevalence of primary open-angle glaucoma (POAG) and primary angle-closure glaucoma (PACG), and projected the number of affected people in 2020 and 2040.

Design: Systematic review and meta-analysis.

Participants: Data from 50 population-based studies (3770 POAG cases among 140 496 examined individuals and 786 PACG cases among 112 398 examined individuals).

Methods: We searched PubMed, Medline, and Web of Science for population-based studies of glaucoma prevalence published up to March 25, 2013. Hierarchical Bayesian approach was used to estimate the pooled glaucoma prevalence of the population aged 40–80 years along with 95% credible intervals (CrIs). Projections of glaucoma were estimated based on the United Nations World Population Prospects. Bayesian meta-regression models were performed to assess the association between the prevalence of POAG and the relevant factors.

Main Outcome Measures: Prevalence and projection numbers of glaucoma cases.

Results: The global prevalence of glaucoma for population aged 40–80 years is 3.54% (95% CrI, 2.09–5.82). The prevalence of POAG is highest in Africa (4.20%; 95% CrI, 2.08–7.35), and the prevalence of PACG is highest in Asia (1.09%; 95% CrI, 0.43–2.32). In 2013, the number of people (aged 40–80 years) with glaucoma worldwide was estimated to be 64.3 million, increasing to 76.0 million in 2020 and 111.8 million in 2040. In the Bayesian meta-regression model, men were more likely to have POAG than women (odds ratio [OR], 1.36; 95% CrI, 1.23–1.52), and after adjusting for age, gender, habitation type, response rate, and year of study, people of African ancestry were more likely to have POAG than people of European ancestry (OR, 2.80; 95% CrI, 1.83–4.06), and people living in urban areas were more likely to have POAG than those in rural areas (OR, 1.58; 95% CrI, 1.19–2.04).

Conclusions: The number of people with glaucoma worldwide will increase to 111.8 million in 2040, disproportionally affecting people residing in Asia and Africa. These estimates are important in guiding the designs of glaucoma screening, treatment, and related public health strategies. *Ophthalmology 2014;121:2081-2090 © 2014 by the American Academy of Ophthalmology.*

Supplemental material is available at www.aaojournal.org.

Glaucoma is the leading cause of global irreversible blindness. It has been estimated that 60.5 million people were affected by primary open-angle glaucoma (POAG) and primary angle-closure glaucoma (PACG) globally in 2010.[1–3] Because of the rapid increase in aging populations worldwide, accurate estimation of the current glaucoma prevalence and future projections of the number of people with glaucoma are critical for the formulation of adequate health policies tailored for the diverse populations worldwide.

The risk and subtypes of glaucoma vary among races and countries. In the United States, blacks have a higher POAG prevalence than whites.[4,5] While the prevalence of POAG in East Asian populations is higher than that of PACG,[6–9] Mongolians and Burmese are more affected by PACG than POAG.[10,11] Nevertheless, the current estimates of glaucoma prevalence from different population studies have several limitations that render accurate comparisons among them challenging. In particular, different studies vary in age group structures, sample size, geographic regions, ethnicity,

Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.ophtha.2014.05.013
ISSN 0161-6420/14

examination methods, and glaucoma definitions.[12] Therefore, it is challenging to systematically examine the global trends of glaucoma.

There have been attempts to pool glaucoma prevalence estimates from different populations using meta-analysis.[2,13–15] Most notably, Quigley and Broman[2] reported worldwide glaucoma prevalence estimates in 2010 and 2020. Nevertheless, these previous estimates were determined approximately 1 decade ago and may be out of date. Furthermore, previous reviews focused more on populations of European ancestry. In recent years, there has been a rapid emergence of population-based studies in Asia, providing an opportunity to allow better estimation of global glaucoma prevalence.[7–11,16–33] Considering Asia represents approximately 60% of world populations, inclusion of data from contemporary Asian studies may provide a more up-to-date estimation of global glaucoma prevalence.

In this study, we aimed to estimate the global prevalence and future projections of glaucoma burden using the Hierarchical Bayesian (HB) approach. The HB model takes into account heterogeneity across populations and study characteristics, thus allowing more dissimilar studies to be included without compromising the validity of the integrated estimates.[34,35] Findings in this study will be useful for the design of glaucoma screening, treatment, rehabilitation, and related public health strategies.

Methods

Systematic Review Process

The review followed the Meta-Analysis of Observational Studies in Epidemiology guidelines for reporting our systematic reviews and meta-analyses.[36] We performed a literature search in the electronic databases of PubMed, Medline, and Web of Science. We limited our search to English publications and made a final search on March 25, 2013.

In our literature search, we included a combination of keywords, such as glaucoma, prevalence, epidemiology, population, and survey, in the form of title words or medical subject headings (Appendix A, available at www.aaojournal.org). Two reviewers (Y-C.T., X.L.) completed the literature search independently. In addition, the 2 reviewers further cross-checked reference lists of all identified articles to identify other relevant studies. This adopted strategy identified all articles used in previous reviews.[2,13,14,32]

Inclusion and Exclusion Criteria

The criteria for study inclusion were based on the examination guidelines for glaucoma-related population-based studies reported previously.[12,37] We included studies that met the following inclusion criteria: (1) population-based study of POAG or PACG from a defined geographic region, (2) clear definition on random or clustered sampling procedure, (3) 70% participation rate of the eligible population participants, (4) optic disc evaluation by ophthalmologists using slit-lamp biomicroscopy or fundus photography, (5) visual field testing with automated static perimetry was at least conducted among participants who were glaucoma suspects, (6) anterior chamber angle/depth evaluation determined by slit-lamp examination or gonioscopy was at least conducted among participants who were glaucoma suspects, and (7) POAG and PACG case definitions were based on structural or functional evidence of glaucomatous optic neuropathy evaluated by optic disc evaluation or visual field testing, respectively, and independent of intraocular pressure measurement. Thus, our POAG definition included persons with intraocular pressure at all levels.

However, we excluded studies if they (a) were interview, hospital, or clinic-based; (b) consisted of volunteer participants or participants with self-reported glaucoma; (c) did not report sampling strategy; (d) were published in languages other than English; and (e) reported the number of eyes with glaucoma as opposed to the number of individuals.

Two reviewers (Y-C.T., X.L.) independently selected the studies for final inclusion on the basis of these criteria. Disagreements between the 2 were resolved and adjudicated by the senior author (C-Y.C.).

Data Extraction

We extracted the following data from each study: region(s) in which the study was conducted, age group (only for POAG analysis), gender, habitation types (urban, rural, or mixed), ethnicity of study sample, year of study conducted, and participation response rate. We classified region(s) in which the study was conducted according to the United Nations' classification of macro-geographic continental regions, namely, Asia, Africa, Europe, north America, Latin America and the Caribbean, and Oceania.[38]

Bayesian Pooling of Glaucoma Prevalence

To address the issue of heterogeneity across studies, we used the HB approach to estimate the global prevalence of POAG, PACG, and glaucoma (defined as POAG and PACG combined). This approach allows us to take into account the different age distributions and effects of ethnicity and geographic region across studies, so that the final prevalence estimates reflect these sources of variability. Furthermore, the HB approach also takes into account within-study variability. This modeling approach also has been adopted and described in previous literature.[14,35,39]

Meta-analysis can be naturally described in a hierarchical structure in an HB model. Briefly, in our analysis, we used the HB approach to estimate the logit of glaucoma prevalence by modeling the hierarchical structure of the data extracted, taking into account the differences in age distribution, ethnicity, and geographic region across and within studies. We modeled the logit of glaucoma prevalence as a linear combination of covariates that varies across studies (i.e., age, ethnicity, geographic region) to account for between-study variability. We specified the number of people with glaucoma (y_{ij}) as binomially distributed: $y_{ij} \sim Binomial(n_{ij}, p_{ij})$, where n_{ij} was the total number of participants and p_{ij} was the prevalence of glaucoma in the i^{th} study for the j^{th} category of the varying covariate (e.g., some studies may consist of >1 dataset within the same study, where j >1). For example, when ethnic group was specified as j, the model would allow us to account for the variability between various ethnic groups in the same study. In our Bayesian approach, the prevalence of glaucoma p_{ij} was considered as a random variable that had a probability density function. Thus, the logit transformation of p_{ij} follows a Normal distribution: $logit(p_{ij}) = u_{ij}$ and $u_{ij} \sim Normal(\mu_{ij}, \sigma^2)$, where $\sigma^2 = 1/_{\tau}$. Full details of the model are further specified in Appendix B (available at www.aaojournal.org).

We fitted the Bayesian model with the Markov chain Monte Carlo algorithm and obtained the posterior distributions for the logit of glaucoma prevalence. We then converted these estimations back to prevalence and represented them as means along with 95% credible intervals (CrIs), which represent the range of values within which the true value of an estimate is expected to be within 95% probability.

Projection Estimates

The World Population Prospects of the United Nations consist of the latest results of national population consensus and demographic surveys from countries worldwide and take into account mortality rate and fertility rate in its projection of world population number.[40] We incorporated the population projection data from the World Population Prospects of the United Nations into our age- and region-adjusted Bayesian model (refer to details in Appendix B, available at www.aaojournal.org). Specifically, the projected number of individuals with glaucoma was first given by the multiplication between the age- and region-specific prevalence rates and the corresponding population number data. We then obtained the posterior distributions of the projected number of individuals with glaucoma for years 2013 to 2040 and derived the final projection estimates from these posterior distributions. Age group−specific prevalence rates were assumed to be constant over the next 27 years for our global projection to the year 2040.

Bayesian Meta-Regression Modeling

We used the Bayesian meta-regression model to model the logit of POAG prevalence while adjusting for relevant covariates (refer to details in Appendix B, available at www.aaojournal.org). We first performed an age- and gender-adjusted model followed by a multiple adjusted model, adjusting for age, gender, habitation type, response rate, and year of study conducted. We did not concurrently include ethnicity and world regions in the same model as covariates because they were strongly collinear to each other. The coefficients of covariates were all treated as fixed effects. Random effects were incorporated in the models to account for between-study variability.

Because of the small number of PACG cases in most of the studies conducted in non-Asian regions (particularly in Africa, north America, and Europe, as shown in Table 1, available at www.aaojournal.org), age- and gender-specific PACG data were available in only 18 studies from Asia.[8,9,11,16,18,20−23,28−31,41−46] In view of this, age- and gender-stratified analyses of PACG and glaucoma (defined as POAG and PACG combined) were not performed.

Results

Figure 1 shows the article selection process for studies included in the final meta-analyses. In brief, a total of 3035 individual studies were identified and underwent review, and 2985 studies were excluded (Fig 1). Ultimately, 50 glaucoma prevalence−related articles were included in the final meta-analysis. In the event where age group, gender, and ethnic group−specific data were not readily available from published articles, we further contacted respective authors for request of relevant stratified data. For this reason, we contacted authors from 16 studies, of whom 8 replied and provided the requested stratified data. A total of 14 studies consisted of additional data on secondary glaucoma, congenital glaucoma, and other glaucoma subtypes. However, these data are not relevant to our main interest of estimating POAG and PACG prevalence in this review and thus were not included.

Summary of Included Studies

The analyses included data from 50 published articles in 53 population-based samples. We extracted POAG-related data from 48 published articles in 51 population-based samples. In addition, we extracted PACG-related data from 39 published articles in 40 population-based samples. The included data involved 3770 POAG cases among a total of 140 496 examined individuals and 786 PACG cases among 112 398 examined individuals. Table 1 (available at www.aaojournal.org) summarizes the study population samples by world regions. In brief, 24 study populations were from Asia,[6,8−11,16−31,42−50] 5 were from Africa,[51−55] 12 were from Europe,[56−67] 7 were from north America,[4,5,68−70] 2 were from Latin America and the Caribbean,[71,72] and 3 were from Oceania.[73,74] Of the 48 published articles on POAG prevalence, 37 consisted of data stratified by both age group and gender. These 37 articles were used for Bayesian meta-regression modeling for POAG prevalence.

Global Prevalence Estimates of Glaucoma

Table 2 shows the pooled prevalence and number estimates of glaucoma for the population aged 40 to 80 years. The overall global prevalence of glaucoma was 3.54% (95% CrI, 2.09−5.82). The global prevalence of POAG was 3.05% (95% CrI, 1.69−5.27), and the global prevalence of PACG was 0.50% (95% CrI, 0.11−1.36). Figure 2 (available at www.aaojournal.org) shows the prevalence estimate for each study.

Variations in Glaucoma Prevalence across Regions and Ethnicity

The prevalence varied across geographic regions and ethnic groups (Table 2, Fig 3, and Fig 4, available at www.aaojournal.org). The prevalence of glaucoma (4.79%; 95% CrI, 2.63−8.03) and POAG (4.20%; 95% CrI, 2.08−7.35) was highest in Africa, and the prevalence of PACG was highest in Asia (1.09%; 95% CrI, 0.43−2.32). Across ethnicity, people of African ancestry had the highest prevalence of glaucoma (6.11%; 95% CrI, 3.83−9.13) and POAG (5.40%; 95% CrI, 3.17−8.27). Asians had the highest prevalence of PACG (1.20%; 95% CrI, 0.46−2.55).

For POAG, we performed a Bayesian meta-regression analysis (Table 3) and found that the odds ratio (OR) of POAG in people residing in Africa was 2.39 (95% CrI, 1.17−4.53) compared with those residing in Asia after adjusting for age and gender. Nevertheless, this relationship became insignificant after further adjusting for habitation type, response rate, and year of study conducted. However, after adjusting for age, gender, habitation type, response rate, and year of study conducted, the OR of POAG in people of African ancestry was 2.05 (95% CrI, 1.11−3.43, data not shown) when compared with Asians and 2.80 (95% CrI, 1.83−4.06) when compared with people of European ancestry.

Effect of Age on Primary Open-Angle Glaucoma Prevalence

The OR of POAG prevalence was 1.73 (95% CrI, 1.63−1.82) with each decade increase in age (Table 3), after adjusting for gender, habitation type, response rate, and year of study conducted. We further examined the effect of age on POAG prevalence, stratified by geographic regions and ethnic groups (Fig 5). In general, we found that the trend of POAG prevalence with age increment differed by region. In this regard, multivariable adjusted meta-regression analysis (Table 4, available at www.aaojournal.org) further showed that people residing in Oceania and north America had greater ORs of POAG per decade age increment compared with other regions. Across ethnicity, although the prevalence of POAG was highest in people of African ancestry at all ages, Hispanics and people of European ancestry showed a steeper increase in POAG prevalence with age compared with African ancestry and Asians (Fig 5). Multivariable meta-regression analysis (Table 4, available at www.aaojournal.org) consistently showed that Hispanics and people of European ancestry had evidently greater ORs of POAG per decade increase in age than people of African ancestry and Asians.

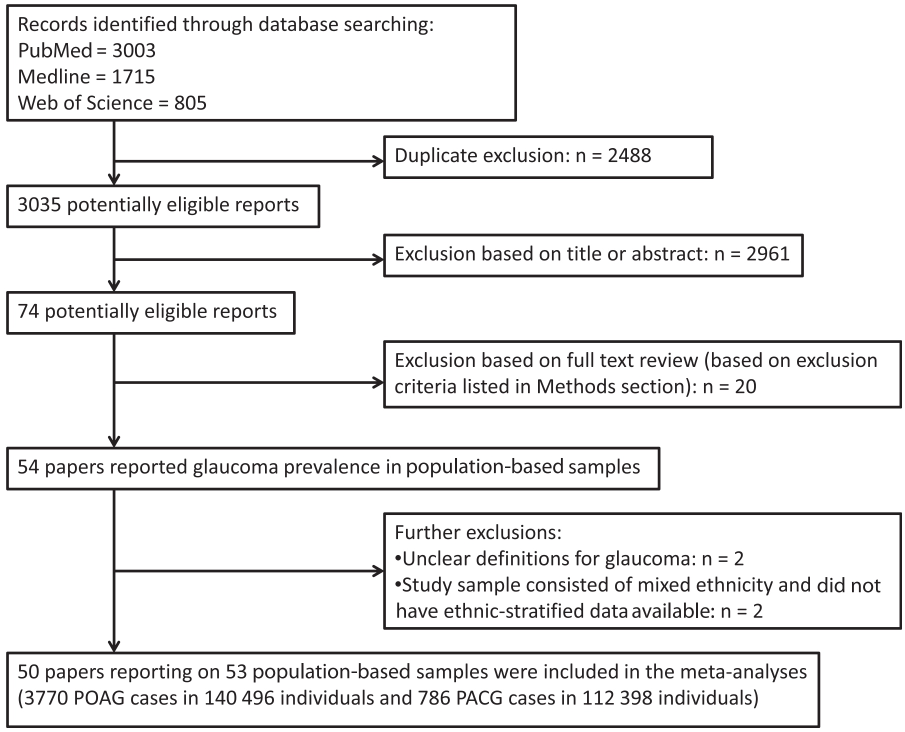

Figure 1. Summary of article selection process. PACG = primary angle-closure glaucoma; POAG = primary open-angle glaucoma.

Effect of Gender and Habitation Area on Primary Open-Angle Glaucoma Prevalence

After adjusting for age, habitation type, response rate, and year of study conducted, we found that men were more likely to have POAG than women (OR, 1.36; 95% CrI, 1.23–1.52) (Table 3). Likewise, after adjusting for age, gender, habitation type, response rate, and year of study conducted, people living in urban habitation areas were more likely to have POAG than those in rural areas (OR, 1.58; 95% CrI, 1.19–2.04) (Table 3).

Number of People with Glaucoma Worldwide from 2013 to 2040

In 2013, the total number of people (aged 40–80 years) with glaucoma was estimated to be 64.3 million (Table 2). Asia alone accounted for approximately 60% of the world's total glaucoma cases, and Africa had the second highest number of glaucoma cases with 8.3 million (13%). In addition, Asia also accounts for 53.4% of worldwide POAG cases and 76.7% of worldwide PACG cases.

We estimated that the number of people (aged 40–80 years) with glaucoma worldwide will increase by 18.3% to 76 million in 2020 and by 74% to 111.8 million in 2040 compared with 2013 (Table 5 and Table 6, available at www.aaojournal.org). Much of the increase in the number of glaucoma cases would be attributable to significant increases in Asia and Africa (Fig 6). In addition, Asia will still contain the greatest number of people with POAG and PACG in 2040 with increments of 18.8 million (79.8%) and 9.0 million (58.4%), respectively, from 2013. Africa will post an increment in glaucoma cases by 130.8% (10.9 million) from 2013 to 2040. On the contrary, there will be only

Table 2. Pooled Prevalence (%) and Number of People (Aged 40–80 Years, in Millions) with Primary Open-Angle Glaucoma, Primary Angle-Closure Glaucoma, and Glaucoma in 2013

	POAG		PACG		Glaucoma (POAG and PACG Combined)	
World Region	*Prevalence*	*Number*	*Prevalence*	*Number*	*Prevalence*	*Number*
Asia	2.31 (1.44–3.44)	23.54 (18.32–29.73)	1.09 (0.43–2.32)	15.47 (6.26–32.41)	3.40 (2.26–5.02)	39.00 (27.78–55.80)
Africa	4.20 (2.08–7.35)	7.03 (4.25–10.60)	0.60 (0.16–1.48)	1.26 (0.34–3.30)	4.79 (2.63–8.03)	8.29 (5.16–12.30)
Europe	2.51 (1.54–3.89)	5.36 (3.99–7.11)	0.42 (0.13–0.98)	1.41 (0.43–3.37)	2.93 (1.85–4.40)	6.77 (4.94–9.24)
North America	3.29 (1.83–5.53)	2.97 (1.96–4.29)	0.26 (0.03–0.96)	0.39 (0.04–1.38)	3.55 (1.98–5.81)	3.36 (2.21–4.94)
Latin America and the Caribbean	3.65 (1.90–6.54)	5.01 (2.70–8.88)	0.85 (0.14–3.00)	1.59 (0.31–5.24)	4.51 (2.44–7.90)	6.59 (3.61–11.95)
Oceania	2.63 (1.16–4.83)	0.20 (0.10–0.33)	0.35 (0.05–1.15)	0.05 (0.01–0.16)	2.97 (1.38–5.23)	0.25 (0.13–0.42)
Worldwide	3.05 (1.69–5.27)	44.11 (31.32–60.94)	0.50 (0.11–1.36)	20.17 (7.39–45.86)	3.54 (2.09–5.82)	64.26 (43.83–94.65)

Data in parentheses are 95% CrIs.
PACG = primary angle-closure glaucoma; POAG = primary open-angle glaucoma.
Number of people (aged 40–80 years) in 2013 was estimated on the basis of World Population Prospects: The 2012 Revision from Department of Economic and Social Affairs, United Nations. Worldwide population number (aged 40–80 years) in 2013 was 2.33 billion.

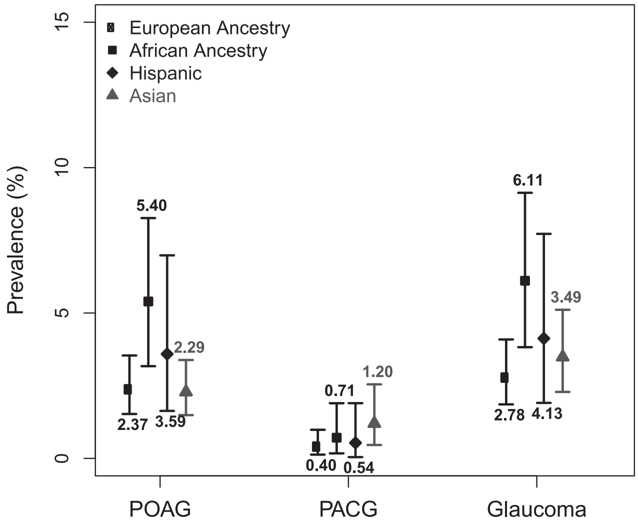

Figure 3. Pooled prevalence estimates of primary open-angle glaucoma (POAG), primary angle-closure glaucoma (PACG), and glaucoma by ethnic groups.

a mild increment in POAG and PACG cases in the regions of Europe, north America, and Oceania from 2013 to 2040.

Table 3. Demographic Factors Associated with Primary Open-Angle Glaucoma

	Odds Ratio (95% CrI)*	
	Age and Gender Adjusted	*Multiple Adjusted*†
Age, per decade increase	1.75 (1.65–1.84)	1.73 (1.63–1.82)
Gender		
Women	1.0 [Reference]	1.0 [Reference]
Men	1.36 (1.23–1.51)	1.36 (1.23–1.52)
Geographic region		
Asia	1.0 [Reference]	1.0 [Reference]
Africa	2.39 (1.17–4.53)	1.97 (0.92–3.72)
Europe	0.87 (0.56–1.32)	0.69 (0.35–1.18)
North America	1.36 (0.66–2.56)	1.23 (0.53–2.50)
Latin America and the Caribbean	2.21 (0.96–4.56)	1.53 (0.52–3.41)
Oceania	0.98 (0.41–1.97)	0.83 (0.30–1.92)
Urban/rural		
Rural	1.0 [Reference]	1.0 [Reference]
Urban	1.51 (1.17–1.90)	1.58 (1.19–2.04)
Mixed	2.18 (0.55–5.77)	1.90 (0.47–5.44)
Ethnicity		
European ancestry	1.0 [Reference]	1.0 [Reference]
African ancestry	2.88 (1.97–4.10)	2.80 (1.83–4.06)
Hispanic	1.28 (0.44–3.14)	2.00 (0.57–5.15)
Asian	1.12 (0.77–1.55)	1.43 (0.82–2.34)
Response rate	6.03 (0.17–32.25)	10.85 (0.15–65.61)
Year of study conducted	1.00 (0.97–1.03)	1.00 (0.97–1.03)

CrI = credible interval.
*Calculated on the basis of Bayesian meta-regression model.
†Adjusted for age, gender, habitation type, response rate, and year of study conducted accordingly.

Discussion

Our analysis provides comprehensive, up-to-date estimations on the current worldwide glaucoma prevalence and future projections on the number of people with glaucoma. We estimated the global prevalence of glaucoma to be 3.54%, with the highest prevalence in Africa. The number of people with glaucoma worldwide (aged 40–80 years) will increase from 64.3 million in 2013 to 111.8 million in 2040, disproportionally affecting people residing in Asia and Africa.

Estimates of Current Global Primary Open-Angle Glaucoma and Primary Angle-Closure Glaucoma Prevalence

The pooled global prevalence of POAG was estimated to be 3.05% and that of PACG was 0.50%. In comparison, Quigley and Broman[2] previously estimated global POAG prevalence to be 1.96% and PACG prevalence to be 0.69% (overall glaucoma prevalence: 2.65%) for 2010. They similarly reported Africa as the region with the highest glaucoma prevalence. The previous estimates were generally lower than our estimates. Nevertheless, since the publication of the previous review in 2006, there has been a rapid emergence of more than 20 population-based studies, particularly from Asia.[7–11,16–31,46] With the inclusion of these recent studies in our analysis, our current review may provide more up-to-date estimates on the global burden of glaucoma. In addition, in the previous review, PACG prevalence estimates in Europe were used to extrapolate rates in African and Latin American regions because of the lack of available data in those regions. In comparison, our current analysis included actual PACG data from recent studies in African and Latin American regions.[51,53,72]

Trends of Primary Open-Angle Glaucoma and Primary Angle-Closure Glaucoma Prevalence by Ethnicity

Across ethnicity, we reported that the prevalence of POAG was distinctively higher in people of African ancestry, similar to an earlier POAG report.[14] However, the prevalence of PACG was highest in Asians. This finding provides evidence consistent with previous PACG reviews,[2,75] indicating that greater emphasis on the development of methods to identify and treat PACG would be particularly needed in Asia.

Effects of Gender and Habitation Area on Primary Open-Angle Glaucoma Prevalence

We found that men were 36% more likely to have POAG than women. With a total of 37 pooled studies, our regression model was sufficiently powered to detect a difference between the sexes. Thus, our finding provides substantial evidence that men are more likely to develop POAG.

We also found that people living in urban areas were 58% more likely to have POAG than people in rural areas. This may be explained in part by the higher prevalence of myopia in urban areas.[76] It is also interesting to speculate

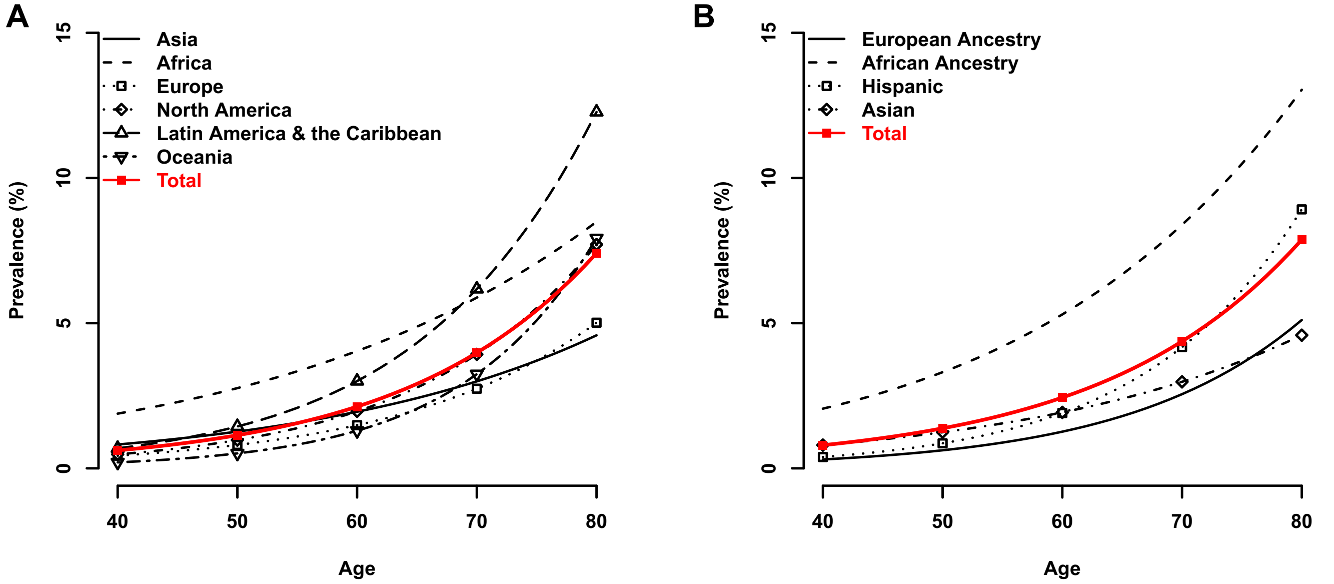

Figure 5. Age-specific prevalence of primary open-angle glaucoma (POAG) by **(A)** world regions and **(B)** ethnic groups.

that other potential differences between a rural and an urban lifestyle might contribute to differences in glaucoma prevalence; these include differences in stress, pollution, diet, physical activity, and comorbid disease. Further studies are needed to elucidate the mechanisms underlying the prevalence difference by habitation area.

Future Projection of Global Number of People with Glaucoma

By 2020, Asia will have the largest number of persons affected by POAG and PACG worldwide. In part, this is because Asia is the most populous continent, accounting for more than 60% of the world population. Thus, although the estimated prevalence of POAG and glaucoma in Asia is lower than in other regions, the sheer number of those in affected age groups leads to large absolute numbers of glaucoma cases. Our estimates of glaucoma burden can be compared directly with Quigley and Broman's previous report,[2] in which they estimated that 79.6 million people will have glaucoma worldwide in 2020 (POAG: 58.6 million; PACG: 21 million). Our analysis projected a similar number of PACG cases (23.4 million), but a slightly lower number of POAG cases (52.7 million) and total glaucoma cases (76 million) for the year 2020. Nevertheless, as discussed earlier, our analysis consisted of a more extensive and recent evidence base from Asia, particularly from India and China.[7–11,16–31] Thus, our new estimates are likely to represent more up-to-date projections.

We estimated that the global number of people with glaucoma will increase by 74% from 2013 to 2040. This mainly results from the expected change in the number of older persons, which affects some regions more than others. Although the number of elderly persons is likely to increase only slowly in Europe and North America, it is expected to increase more dramatically in Asia and Africa because of increased life expectancy in these regions.[40] These findings

Table 5. Projection of the Number of People (Aged 40–80 Years, in Millions) with Primary Open-Angle Glaucoma, Primary Angle-Closure Glaucoma, and Glaucoma in 2020 and 2040

World Region	POAG		PACG		Glaucoma (POAG and PACG Combined)	
	2020	*2040*	*2020*	*2040*	*2020*	*2040*
Asia	28.29 (21.99–35.75)	42.32 (33.03–53.34)	17.96 (7.27–37.63)	24.50 (9.93–51.35)	46.24 (33.08–65.91)	66.83 (48.39–93.77)
Africa	8.73 (5.28–13.17)	16.26 (9.86–24.59)	1.57 (0.42–4.10)	2.88 (0.77–7.51)	10.31 (6.41–15.28)	19.14 (11.89–28.30)
Europe	5.67 (4.21–7.51)	6.39 (4.79–8.42)	1.46 (0.45–3.49)	1.46 (0.45–3.50)	7.12 (5.20–9.68)	7.85 (5.76–10.55)
North America	3.52 (2.31–5.08)	4.24 (2.80–6.10)	0.42 (0.05–1.48)	0.47 (0.05–1.65)	3.94 (2.61–5.72)	4.72 (3.13–6.75)
Latin America and the Caribbean	6.22 (3.36–11.01)	10.20 (5.52–17.97)	1.89 (0.37–6.23)	2.66 (0.52–8.78)	8.11 (4.46–14.62)	12.86 (7.12–22.85)
Oceania	0.25 (0.12–0.40)	0.35 (0.18–0.58)	0.06 (0.01–0.19)	0.07 (0.01–0.24)	0.30 (0.16–0.50)	0.42 (0.22–0.69)
Worldwide	52.68 (37.27–72.92)	79.76 (56.18–111.0)	23.36 (8.57–53.12)	32.04 (11.73–73.03)	76.02 (51.92–111.7)	111.82 (76.50–162.9)

PACG = primary angle-closure glaucoma; POAG = primary open-angle glaucoma.
Number of people (aged 40–80 years) in 2013 was estimated on the basis of World Population Prospects: The 2012 Revision from Department of Economic and Social Affairs, United Nations. Worldwide population numbers (aged 40–80 years) are 2.33 billion for 2013, 2.67 billion for 2020, and 3.61 billion for 2040.

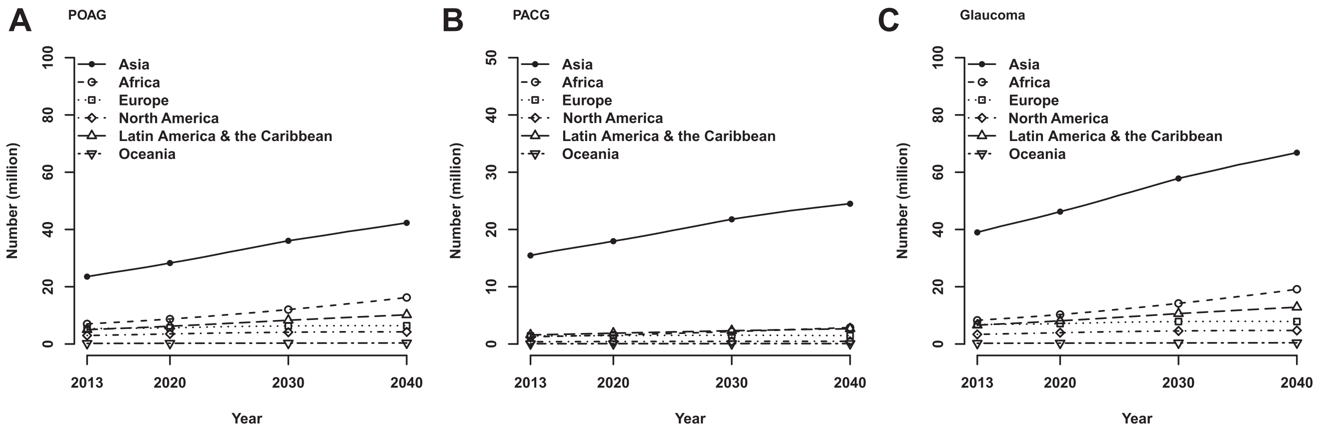

Figure 6. The change in total numbers of people with **(A)** primary open-angle glaucoma (POAG), **(B)** primary angle-closure glaucoma (PACG), and **(C)** glaucoma by world regions from 2013 to 2040. Projections were plotted with 1-year interval data.

may further underscore the need for improvements in case identification and glaucoma care services in Asia and Africa.

Study Strengths and Limitations

The strengths of our meta-analysis include critical appraisal of study quality, strict application of inclusion and exclusion criteria, and up-to-date estimates using HB modeling approaches. Of note, only studies with a participation rate of ≥70% were included. Furthermore, there was reasonable coverage of evidence for large world regions, such as Asia, Europe, and north America; these regions were well represented by a sufficient number of studies with large sample sizes. In addition, the adopted HB approach took into account heterogeneity across different study populations. This approach was also able to borrow information across other regions or ethnic groups, which was especially useful for regions with few data. Taken together, the HB approach allowed more studies to be included in the final analysis, thus potentially providing a more precise estimate of glaucoma prevalence.

This review has a few limitations. First, in large continental regions such as Africa and Latin America and the Caribbean, there were insufficient studies to entirely represent the regions. For instance, the prevalence estimate of Latin America and the Caribbean region was derived only from Barbados and Brazil. Second, we excluded non-English publications in this review. Nevertheless, most of the non-English publications did not meet our inclusion criteria (i.e., hospital, clinic-based studies). Thus, exclusion of non-English publications is unlikely to result in significant publication bias in our analysis. Third, only 37 articles with age group−stratified data were included for the Bayesian meta-regression analysis for POAG prevalence. Thus, the findings in this particular analysis may be subjected to ecological fallacy because of the exclusion of 11 articles that did not provide age-stratified data. Fourth, in our projection of glaucoma numbers, age-specific prevalence was assumed to remain constant over time. Nevertheless, change of prevalence over time is difficult to quantify because it also depends on changes of risk exposures and other environmental factors, such as public awareness and screening modalities of the disease, all of which may modify the development of the disease. However, it is interesting to note that in our Bayesian meta-regression analysis, year of study conducted had no significant effect on POAG prevalence (OR, 1.00; 95% CrI, 0.97−1.03), indicating a constant trend of prevalence from 1984 to 2010 in our reviewed literature data.

In conclusion, our study provides contemporary estimates that reflect the significant present and future burden of glaucoma globally. The current number of people (aged 40−80 years) with glaucoma worldwide is 64.3 million and is expected to increase to 76.0 million in 2020 and 111.8 million in 2040. Asia accounts for the largest number of glaucoma cases worldwide despite having a lower glaucoma prevalence. The findings of the study will be useful for the design of glaucoma screening, treatment, rehabilitation, and related public health strategies.

Acknowledgments. The authors thank Harry Quigley (Proyecto Eye Study), David Friedman (Salisbury Eye Evaluation Study), Radoslaw Kaczmarek (The Wroclaw Epidemiological Study), Hua Zhong and Yuansheng Yuan (The Yunnan Minority Eye Study), Robert Casson (Kandy Eye Study), Fotis Topouzis (The Thessaloniki Eye Study), Paul Mitchell (Blue Mountains Eye Study), and Lisandro Sakata (Projecto Glaucoma) for providing raw data for age- and gender-specific POAG prevalence rates from their respective studies.

References

1. Kingman S. Glaucoma is second leading cause of blindness globally. Bull World Health Organ 2004;82:887–8.
2. Quigley HA, Broman AT. The number of people with glaucoma worldwide in 2010 and 2020. Br J Ophthalmol 2006;90:262–7.
3. Wong TY, Loon SC, Saw SM. The epidemiology of age related eye diseases in Asia. Br J Ophthalmol 2006;90:506–11.
4. Friedman DS, Jampel HD, Munoz B, West SK. The prevalence of open-angle glaucoma among blacks and whites 73 years and older: the Salisbury Eye Evaluation Glaucoma Study. Arch Ophthalmol 2006;124:1625–30.
5. Tielsch JM, Sommer A, Katz J, et al. Racial variations in the prevalence of primary open-angle glaucoma. The Baltimore Eye Survey. JAMA 1991;266:369–74.
6. 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;111:1641–8.
7. Kim M, Kim TW, Park KH, Kim JM. Risk factors for primary open-angle glaucoma in South Korea: the Namil study. Jpn J Ophthalmol 2012;56:324–9.
8. Kim YY, Lee JH, Ahn MD, Kim CY; Namil Study Group, Korean Glaucoma Society. Angle closure in the Namil study in central South Korea. Arch Ophthalmol 2012;130:1177–83.
9. Wang YX, Xu L, Yang H, Jonas JB. Prevalence of glaucoma in North China: the Beijing Eye Study. Am J Ophthalmol 2010;150:917–24.
10. Casson RJ, Newland HS, Muecke J, et al. Prevalence of glaucoma in rural Myanmar: the Meiktila Eye Study. Br J Ophthalmol 2007;91:710–4.
11. Song W, Shan L, Cheng F, et al. Prevalence of glaucoma in a rural northern China adult population: a population-based survey in Kailu County, Inner Mongolia. Ophthalmology 2011;118:1982–8.
12. Foster PJ, Buhrmann R, Quigley HA, Johnson GJ. The definition and classification of glaucoma in prevalence surveys. Br J Ophthalmol 2002;86:238–42.
13. Eye Diseases Prevalence Research Group. Prevalence of open-angle glaucoma among adults in the United States. Arch Ophthalmol 2004;122:532–8.
14. Rudnicka AR, Mt-Isa S, Owen CG, et al. Variations in primary open-angle glaucoma prevalence by age, gender, and race: a Bayesian meta-analysis. Invest Ophthalmol Vis Sci 2006;47:4254–61.
15. Day AC, Baio G, Gazzard G, et al. The prevalence of primary angle closure glaucoma in European derived populations: a systematic review. Br J Ophthalmol 2012;96:1162–7.
16. Pan CW, Cheung CY, Aung T, et al. Differential associations of myopia with major age-related eye diseases: the Singapore Indian Eye Study. Ophthalmology 2013;120:284–91.
17. Zhong H, Li J, Li C, et al. The prevalence of glaucoma in adult rural Chinese populations of the Bai nationality in Dali: the Yunnan Minority Eye Study. Invest Ophthalmol Vis Sci 2012;53:3221–5.
18. Thapa SS, Paudyal I, Khanal S, et al. A population-based survey of the prevalence and types of glaucoma in Nepal: the Bhaktapur Glaucoma Study. Ophthalmology 2012;119:759–64.
19. Sun J, Zhou X, Kang Y, et al. Prevalence and risk factors for primary open-angle glaucoma in a rural northeast China population: a population-based survey in Bin County, Harbin. Eye (Lond) 2012;26:283–91.
20. Sawaguchi S, Sakai H, Iwase A, et al. Prevalence of primary angle closure and primary angle-closure glaucoma in a southwestern rural population of Japan: the Kumejima Study. Ophthalmology 2012;119:1134–42.
21. Qu W, Li Y, Song W, et al. Prevalence and risk factors for angle-closure disease in a rural Northeast China population: a population-based survey in Bin County, Harbin [report online]. Acta Ophthalmol 2011;89:e515–20.
22. Liang YB, Friedman DS, Zhou Q, et al; Handan Eye Study Group. Prevalence of primary open angle glaucoma in a rural adult Chinese population: the Handan Eye Study. Invest Ophthalmol Vis Sci 2011;52:8250–7.
23. Liang Y, Friedman DS, Zhou Q, et al; Handan Eye Study Group. Prevalence and characteristics of primary angle-closure diseases in a rural adult Chinese population: the Handan Eye Study. Invest Ophthalmol Vis Sci 2011;52:8672–9.
24. Kim CS, Seong GJ, Lee NH, Song KC; Namil Study Group, Korean Glaucoma Society. Prevalence of primary open-angle glaucoma in central South Korea: the Namil Study. Ophthalmology 2011;118:1024–30.
25. Sia DI, Edussuriya K, Sennanayake S, et al. Prevalence of and risk factors for primary open-angle glaucoma in central Sri Lanka: the Kandy Eye Study. Ophthalmic Epidemiol 2010;17:211–6.
26. Casson RJ, Baker M, Edussuriya K, et al. Prevalence and determinants of angle closure in central Sri Lanka: the Kandy Eye Study. Ophthalmology 2009;116:1444–9.
27. 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;115:648–54.
28. Vijaya L, George R, Arvind H, et al. Prevalence of primary angle-closure disease in an urban south Indian population and comparison with a rural population: the Chennai Glaucoma Study. Ophthalmology 2008;115:655–60.
29. 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;49:3846–51.
30. Vijaya L, George R, Arvind H, et al. Prevalence of angle-closure disease in a rural southern Indian population. Arch Ophthalmol 2006;124:403–9.
31. 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;47:2782–8.
32. Cedrone C, Mancino R, Cerulli A, et al. Epidemiology of primary glaucoma: prevalence, incidence, and blinding effects. Prog Brain Res 2008;173:3–14.
33. Wong TY, Hyman L. Population-based studies in ophthalmology. Am J Ophthalmol 2008;146:656–63.
34. Sutton AJ, Abrams KR. Bayesian methods in meta-analysis and evidence synthesis. Stat Methods Med Res 2001;10:277–303.
35. McCarron CE, Pullenayegum EM, Thabane L, et al. Bayesian hierarchical models combining different study types and adjusting for covariate imbalances: a simulation study to assess model performance. PLoS One [serial online] 2011;6:e25635. Available at: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0025635. Accessed May 14, 2014.
36. Stroup DF, Berlin JA, Morton SC, et al; Meta-analysis Of Observational Studies in Epidemiology (MOOSE) Group. Meta-analysis of observational studies in epidemiology: a proposal for reporting. JAMA 2000;283:2008–12.
37. Quigley HA, West SK, Munoz B, et al. Examination methods for glaucoma prevalence surveys. Arch Ophthalmol 1993;111:1409–15.
38. United Nations Statistical Division. Composition of macro geographical (continental) regions, geographical sub-regions, and selected economic and other groupings. Revised 2013. Available at: https://unstats.un.org/unsd/methods/m49/m49regin.htm. Accessed May 14, 2014.
39. Rudnicka AR, Jarrar Z, Wormald R, et al. Age and gender variations in age-related macular degeneration prevalence in populations of European ancestry: a meta-analysis. Ophthalmology 2012;119:571–80.
40. United Nations Population Division, Population Estimates and Projections Section. World Population Prospects: The 2012 Revision [database online]. updated April 2014. Available at: http://esa.un.org/wpp/. Accessed May 14, 2014.
41. 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;118:1105–11.
42. Bourne RR, Sukudom P, Foster PJ, et al. Prevalence of glaucoma in Thailand: a population based survey in Rom Klao District, Bangkok. Br J Ophthalmol 2003;87:1069–74.

43. Foster PJ, Baasanhu J, Alsbirk PH, et al. Glaucoma in Mongolia. A population-based survey in Hovsgol province, northern Mongolia. Arch Ophthalmol 1996;114:1235–41.
44. Yamamoto T, Iwase A, Araie M, et al; Tajimi Study Group, Japan Glaucoma Society. The Tajimi Study report 2: prevalence of primary angle closure and secondary glaucoma in a Japanese population. Ophthalmology 2005;112:1661–9.
45. Raychaudhuri A, Lahiri SK, Bandyopadhyay M, et al. A population based survey of the prevalence and types of glaucoma in rural West Bengal: the West Bengal Glaucoma Study. Br J Ophthalmol 2005;89:1559–64.
46. Senthil S, Garudadri C, Khanna RC, Sannapaneni K. Angle closure in the Andhra Pradesh Eye Disease Study. Ophthalmology 2010;117:1729–35.
47. Dandona L, Dandona R, Srinivas M, et al. Open-angle glaucoma in an urban population in southern India: the Andhra Pradesh Eye Disease Study. Ophthalmology 2000;107:1702–9.
48. Ramakrishnan R, Nirmalan PK, Krishnadas R, et al. Glaucoma in a rural population of southern India: the Aravind Comprehensive Eye Survey. Ophthalmology 2003;110:1484–90.
49. Vijaya L, George R, Paul PG, et al. Prevalence of open-angle glaucoma in a rural south Indian population. Invest Ophthalmol Vis Sci 2005;46:4461–7.
50. Al-Mansouri FA, Kanaan A, Gamra H, et al. Prevalence and determinants of glaucoma in citizens of Qatar aged 40 years or older: a community-based survey. Middle East Afr J Ophthalmol 2011;18:141–9.
51. Budenz DL, Barton K, Whiteside-de Vos J, et al; Tema Eye Survey Study Group. Prevalence of glaucoma in an urban West African population: the Tema Eye Survey. JAMA Ophthalmol 2013;131:651–8.
52. Buhrmann RR, Quigley HA, Barron Y, et al. Prevalence of glaucoma in a rural East African population. Invest Ophthalmol Vis Sci 2000;41:40–8.
53. Ntim-Amponsah CT, Amoaku WM, Ofosu-Amaah S, et al. Prevalence of glaucoma in an African population. Eye (Lond) 2004;18:491–7.
54. Rotchford AP, Johnson GJ. Glaucoma in Zulus: a population-based cross-sectional survey in a rural district in South Africa. Arch Ophthalmol 2002;120:471–8.
55. Rotchford AP, Kirwan JF, Muller MA, et al. Temba Glaucoma Study: a population-based cross-sectional survey in urban South Africa. Ophthalmology 2003;110:376–82.
56. Coffey M, Reidy A, Wormald R, et al. Prevalence of glaucoma in the west of Ireland. Br J Ophthalmol 1993;77:17–21.
57. Dielemans I, Vingerling JR, Wolfs RC, et al. The prevalence of primary open-angle glaucoma in a population-based study in The Netherlands. The Rotterdam Study. Ophthalmology 1994;101:1851–5.
58. Reidy A, Minassian DC, Vafidis G, et al. Prevalence of serious eye disease and visual impairment in a north London population: population based, cross sectional study. BMJ 1998;316:1643–6.
59. Anton A, Andrada MT, Mujica V, et al. Prevalence of primary open-angle glaucoma in a Spanish population: the Segovia Study. J Glaucoma 2004;13:371–6.
60. Bonomi L, Marchini G, Marraffa M, et al. Prevalence of glaucoma and intraocular pressure distribution in a defined population. The Egna-Neumarkt Study. Ophthalmology 1998;105:209–15.
61. Cedrone C, Culasso F, Cesareo M, et al. Prevalence of glaucoma in Ponza, Italy: a comparison with other studies. Ophthalmic Epidemiol 1997;4:59–72.
62. Ekstrom C. Prevalence of open-angle glaucoma in central Sweden. The Tierp Glaucoma Survey. Acta Ophthalmol Scand 1996;74:107–12.
63. Hirvela H, Tuulonen A, Laatikainen L. Intraocular pressure and prevalence of glaucoma in elderly people in Finland: a population-based study. Int Ophthalmol 1994−1995;18: 299–307.
64. Jonasson F, Damji KF, Arnarsson A, et al. Prevalence of open-angle glaucoma in Iceland: Reykjavik Eye Study. Eye (Lond) 2003;17:747–53.
65. Kozobolis VP, Detorakis ET, Tsilimbaris M, et al. Crete, Greece glaucoma study. J Glaucoma 2000;9:143–9.
66. Nizankowska MH, Kaczmarek R. Prevalence of glaucoma in the Wroclaw population. The Wroclaw Epidemiological Study. Ophthalmic Epidemiol 2005;12:363–71.
67. Topouzis F, Wilson MR, Harris A, et al. Prevalence of open-angle glaucoma in Greece: the Thessaloniki Eye Study. Am J Ophthalmol 2007;144:511–9.
68. Klein BE, Klein R, Sponsel WE, et al. Prevalence of glaucoma. The Beaver Dam Eye Study. Ophthalmology 1992;99: 1499–504.
69. Quigley HA, West SK, Rodriguez J, et al. The prevalence of glaucoma in a population-based study of Hispanic subjects: Proyecto VER. Arch Ophthalmol 2001;119:1819–26.
70. 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;111:1439–48.
71. Leske MC, Connell AM, Schachat AP, Hyman L; Barbados Eye Study Group. The Barbados Eye Study. Prevalence of open angle glaucoma. Arch Ophthalmol 1994;112:821–9.
72. Sakata K, Sakata LM, Sakata VM, et al. Prevalence of glaucoma in a South Brazilian population: Projeto Glaucoma. Invest Ophthalmol Vis Sci 2007;48:4974–9.
73. Mitchell P, Smith W, Attebo K, Healey PR. Prevalence of open-angle glaucoma in Australia. The Blue Mountains Eye Study. Ophthalmology 1996;103:1661–9.
74. Weih LM, Nanjan M, McCarty CA, Taylor HR. Prevalence and predictors of open-angle glaucoma: results from the Visual Impairment Project. Ophthalmology 2001;108: 1966–72.
75. Foster PJ, Johnson GJ. Glaucoma in China: how big is the problem? Br J Ophthalmol 2001;85:1277–82.
76. Marcus MW, de Vries MM, Junoy Montolio FG, Jansonius NM. Myopia as a risk factor for open-angle glaucoma: a systematic review and meta-analysis. Ophthalmology 2011;118:1989–94.

Footnotes and Financial Disclosures

Originally received: October 3, 2013.
Final revision: March 11, 2014.
Accepted: May 15, 2014.
Available online: June 26, 2014. Manuscript no. 2013-1669.

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Financial Disclosure(s):
The author(s) have made the following disclosure(s):

T.Y.W.: Member of the board of and a Consultant−Abbott, Novartis, Pfizer, Allergan, Bayer.

H.A.Q.: Consultant to and has received payment for lectures, including service on speakers bureaus−Zeiss; Expert testimony−Allergan; Receives book royalties; Stock/stock options−Graybug.

T.A.: Member of the board−Alcon, Allergan, MSD, Bausch & Lomb; Consultant−Alcon, Allergan, MSD, Bausch & Lomb, Quark; Grants pending−Alcon, Carl Zeiss Meditec, Allegan, Santen, Ellex, Ocular Therapeutics, Aquesys; Payment for lectures, including service on speakers bureaus−Alcon, Allergan, Santen, Carl Zeiss Meditec, Ellex, Pfizer.

C-Y.C.: Support−National Medical Research Council, Singapore (CSA/033/2012). The funding organization had no role in the design or conduct of this research.

Abbreviations and Acronyms:
CrI = credible interval; **HB** = Hierarchical Bayesian; **OR** = odds ratio; **PACG** = primary angle-closure glaucoma; **POAG** = primary open-angle glaucoma.

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