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Estimating the Rate of Progressive Visual Field Damage in Those with Open-Angle Glaucoma, from Cross-Sectional Data

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Abstract

Purpose—To estimate the rate of visual field progression in open-angle glaucoma (OAG) subjects, by using data from population-based cross-sectional studies.

Methods—Subjects with OAG were identified in nine surveys of randomly sampled populations using standard criteria for glaucomatous optic neuropathy. Subjects were of European, African, Chinese, and Hispanic ethnicity. The measure of OAG damage was the mean deviation (MD) of an automated visual field test (Humphrey Field Analyzer; Carl Zeiss Meditec, Inc., Dublin, CA). The rate of progression was the mean of all subjects' damage in the worse eye divided by an average time since onset. Time since onset was estimated from age-specific prevalence rates.

Results—A total of 1066 subjects with OAG contributed visual field data. The mean worsening in decibels per year was: European-derived, −1.12; Hispanic, −1.26; African-derived, −1.33; and Chinese −1.56 (difference among ethnicities, $P = 0.16$). The mean duration of disease was lowest among Chinese persons at 10.5 years (95% CI: 8.8–12.6) and was highest in African-derived subjects at 15.4 years (95% CI: 14.6–15.9). The progression rate was not consistently related to age or gender. By combining disease duration and progression rate, the model predicted that 15% or fewer of the worse eyes would reach the end of the field damage scale in the patient's lifetime.

Conclusions—The estimates of typical worsening per year in the worse eye among subjects with OAG suggested slightly more rapid progression than in some clinic-based studies. The rate did not differ significantly by ethnicity or gender, but was worse in those with known, treated OAG and in pseudophakic subjects.

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Glaucoma is the second most prevalent cause of blindness worldwide[1] and open-angle glaucoma (OAG) is a major ocular disease in adults in the United States.[2] OAG management comprises 10% of all eye care costs under Medicare,[3] with 25 million patient visits per year, as of 2000,[4] and annual drug costs estimated at $4 billion in the United States in 2004.[5,6] To make proper public health decisions regarding OAG, it is vital to know the rate at which persons with the disease lose visual function.

Recent clinical trials show that intraocular pressure (IOP)–lowering therapy is effective in slowing the incidence and progression of OAG.[7–9] However, the rate at which OAG progressively worsens is poorly documented, despite many clinical studies[10–14] and clinical trials.[15–17] In part, there is a lack of data because OAG injures the eye slowly. Thus, cohort studies must observe patients for extended periods, with unavoidable loss to follow-up. Furthermore, the instruments and software used to measure visual field defects change in a shorter time frame than the duration of OAG in the individual person. For example, clinical trials generally follow-up patients for only 5 to 8 years, whereas it is estimated from statistical modeling that the duration of OAG from onset to death in the average patient is from 13 to 16 years.[18] In addition, the methods used to measure progressive worsening vary among studies, with some favoring event-based methods in which change is judged by crossing a fixed criterion, whereas others use trend-based methods such as regression. Possibly due to these difficulties, clinically based data show widely variable rates of progression.

There is ample evidence that persons with diagnosed OAG have more significant injury than those in whom the disease is as yet undetected.[19] This is a logical consequence of screening methods, such as drivers' license examinations, that identify persons who have already lost visual acuity in one eye. Thus, to specify the true rate of worsening in OAG, population-based studies have the advantage that they lack selection bias. Indeed, five reports of four population-based studies[20–24] have described populations evaluated at two time points, reporting rates for incident OAG. Unfortunately, population studies, even those with thousands of overall examinees, identify relatively few persons with OAG. Furthermore, it is difficult to measure progressive change from only two visual field measurements. Thus, it is not likely that randomly sampled patients with OAG will ever be followed-up in sufficient numbers and for a long enough time for estimates of the true rate of OAG progression to be made.

To address this problem, we developed a model that calculates OAG incidence from age-specific prevalence using cross-sectional survey data to estimate the average rate of progression for an individual with OAG,[25] based on an approach suggested by Leske et al.[26] Since OAG does not spontaneously disappear and produces either stable or worsening damage, the increment in prevalence at each succeeding age in a cross-sectional study is a measure of the number of new cases added (incidence). The model assumes that those with OAG have mortality rates similar to those of the general population, a finding that has been generally supported,[27–31] but with dissent from one interview study[32] and among subgroups of patients with treated OAG.[33] Model predictions of OAG incidence using this approach have produced results quite similar to those obtained in longitudinal cohort studies.[34,35] We reasoned that if one could calculate incidence from prevalence, then the progression rate of representative subjects with OAG could be deduced from age-specific damage levels found in population-based surveys.

The present study greatly extends a prior analysis[25] of OAG progression in which we had only nonautomated visual field data and relatively few subjects with OAG. At that time, OAG incidence was not as well documented. The incidence has subsequently been estimated from population-based data,[20,21,23] claims data,[36] and clinic-based data.[37] In the present study, we modeled OAG visual field progression using age-specific damage data from nine large population-based studies. Since there is a known difference in OAG prevalence and blindness

rates among persons of different self-reported ethnicities, we determined OAG progression rates by ethnicity. In addition, there have been no consistent gender differences in the age-specific prevalence or blindness rates in OAG, though one report found that women may have a more rapid progression rate.[7] Unfortunately, the number of persons in that trial was too few to determine how significant these gender differences might be. We also evaluated other risk factors for progression, including prior OAG diagnosis and history of prior cataract surgery.

Methods

Glaucoma Subject Selection

The data for this research were obtained under research protocols approved by the Institutional Review Board of the Johns Hopkins University School of Medicine or were received as de-identified data for secondary analysis and conformed to the tenets of the Declaration of Helsinki for human experimentation. For each prior survey that contributed data, all persons who had been identified as having OAG were eligible for inclusion, according to the definitions applied during each study. However, we included only eyes that satisfied standardized OAG definitional criteria,[38] which define glaucomatous optic neuropathy as the presence of a vertical cup-to-disc ratio equal or greater than the 97.5 percentile for the population being studied or an asymmetry of cup-to-disc ratio between eyes of greater than 0.2. For the studies reported herein, 0.7 was the cup-to-disc ratio definition. In addition, to qualify as OAG, the same eye had to satisfy the criterion for an abnormal, automated visual field test (Humphrey Field Analyzer [HFA], Carl Zeiss Meditec, Inc., Dublin, CA): a Glaucoma Hemifield Test result “outside normal limits” and at least three test points in one hemifield at the 0.5% probability of abnormality level on the pattern deviation plot.

Persons who are incapable of performing a visual field test can be defined as having OAG in the Foster et al.[38] classification if they have a cup-to-disc ratio of 0.9 or greater, even if no reliable field test was obtained (category 2). However, for this study, these persons provided no measure of damage in the field, and they could not provide data for inclusion. Alternatively, persons could qualify as having OAG if, in the judgment of the investigator, the eye was blind due to OAG (with visual acuity worse than 20/400), the optic disc was not visible, and the visual field was not formally testable (category 3). For example, the latter applied to eyes with high intraocular pressure (IOP), dense ocular media, and a temporal island of remaining field by confrontation. This group was the only one in which IOP was considered in the definition of OAG. In most subjects included in our study, the optic disc and visual field findings were the defining features of OAG. Eyes that had a diagnosis of OAG, but were blind and unable to perform the visual field test, were assigned the lowest mean deviation (MD) score recorded for that particular study in its visual field test. The lowest MD was either −30 or −32 dB, depending on the version of the field instrument and algorithm used.

The strengths and weaknesses of this classification for OAG have been evaluated and compared to other diagnostic criteria.[39] Its categorization of OAG is more conservative than the criteria of studies in which unspecified subjective analysis by glaucoma experts has been used to determine OAG status. Although we cannot state whether the present definitional method is more or less valid than the subjective evaluation by expert observers, it is less prone to unmeasurable bias, it allows comparisons across prevalence survey data, and it is strict enough that it is unlikely that persons who do not have OAG are included.

The studies included in this preliminary analysis are the Baltimore Eye Survey Follow-up Study (BESF),[40] Proyecto Vision and Eye Research (VER),[41] the Salisbury Eye Evaluation (SEE),[42] Los Angeles Latino Eye Study (LALES),[43] Barbados Eye Study (BES),[44] Melbourne Visual Impairment Study (VIP),[45] Malmö Eye Survey (MES)),[19] Tanjong Pagar Study (TPS),[46] and the Liwan Eye Study (LES).[47] The detailed methodologies for these studies are reported

elsewhere. Each used stratified cluster sampling techniques to identify adults who were characteristic of the population of interest, except the BES which used a simple random sample. The BESF was a re-examination 8 years after the original survey of the survivors of an originally random-cluster–sampled population. The two studies among Hispanic persons were performed in areas predominately inhabited by Mexican-Americans. All used a version of the HFA (Carl Zeiss Meditec, Inc.) automated visual field perimeter in a threshold program. These were: HFA1, standard algorithm (BESF, BES); HFA1, Fastpac algorithm (VIP); HFA2, SITA Fast algorithm (SEE, VER, LES); HFA2, standard algorithm (MES, TPS); and HFA2, SITA Standard algorithm (LALES).

Past cataract surgery was recorded for individual eyes in all studies. Past treatment of glaucoma was recorded for subjects who reported taking prescription glaucoma eye drops or those who had any indication or history of trabeculectomy, laser treatment for glaucoma, or other glaucoma surgery.

Statistical Methods

In brief, the degree of visual field damage was categorized by the mean deviation (MD) of the field test in decibels (dB) in each eye. The primary analysis was performed for the worse eye, under the assumption that this was the initial eye injured and would denote better the time since disease onset. Data for the better eye were used in a secondary analysis.

If we consider a hypothetical group of persons all of whom develop OAG at age 30, and we examine them at age 50, the average damage for the group would express the rate at which injury progressed over 20 years since onset. In this simple case, dividing the average MD from field testing by the time since age of onset of disease, or duration (20 years) would lead to an estimate of average individual progression, since all individuals would have the same duration of disease. But, in real populations, new cases develop over time, so that the average damage for a group at age 50 is a mixture of persons with different times of onset. The calculation of the average individual damage rate requires taking age-specific incidence into account to generate the time since onset for each age.

We calculated an average time since age of onset of disease for each age using the following approach. At each age, there are persons who have had the disorder for some period and persons who are newly entering the cohort with initial disease. The incidence of OAG by age determines the proportion of new cases at each age. We calculated age- and ethnicity-specific incidence rates for OAG from age-specific OAG prevalence estimates,[1] using a method published by Leske et al.[26] This approach makes the well-founded assumptions that (1) OAG does not disappear after onset; (2) the mortality risk is the same in OAG and non-subjects with OAG; and (3) OAG is a stable disease—that is, its age-specific incidence stays relatively constant over many years (though it increases with age). Our models found that incidence increases with age nonlinearly. Because the incidence of OAG varies significantly by ethnicity, we calculated separately the estimates for European-derived (SEE, BESF, VIP, MES), African-derived (SEE, BESF, BES), Hispanic (VER, LALES), and Chinese (TPS, LES) persons.

To calculate average progression rate, we used these calculated incidences to produce a mean duration of OAG by age and ethnicity. Given age-specific prevalence, the probability of the development of OAG during an age interval *i* is:

$$G_i = \frac{P_{i+1} - P_i}{1 - P_i} \quad (1)$$

where P_i is the prevalence of OAG at age interval *i.* G_i is a probability, and is different from the incidence rate of OAG, as it is usually collected, since G_i is the probability of disease in

the absence of the competing risk of death. In this study, age categories are single year categories.

The number of people with incident OAG at age k will be G_k, N_k, where N_k is the number of people who have not died and do not have OAG at the beginning of age category k. Then,

$$N_k = N_{k-1}(1 - G_{k-1})(1 - M_{k-1}) = N_1 \prod_{l=1}^{k-1} (1 - G_l)(1 - M_l) \tag{2}$$

where M_k is the probability of dying during age category k.

To estimate the age-specific mean duration of OAG, we assumed that the individual progression rate is the same for all individuals of a specific ethnicity, once OAG is diagnosed. Since incidence of OAG increases at older ages, in a cross-sectional group, there will be many subjects with very little damage at older ages and some with significant damage. We assumed that the damage level was solely based on the length of time of having OAG.

The mean duration of OAG at age i is based on the mean length of time glaucoma subjects at age i have had OAG. This is a weighted average, weighted by the number of subjects who already have OAG before age i:

$$D_i = \frac{\sum_{k=1}^{i} (i-k) G_k N_k \prod_{j=k}^{i} (1 - M_j)}{\sum_{k=1}^{i} G_k N_k \prod_{j=k}^{i} (1 - M_j)} \tag{3}$$

where $(i - k)$ is the length of time in years a person has had OAG, age k is the age of onset of OAG, and i is the current age. We used age 30 as the lowest value of k, since the probability of OAG's developing before 30 years of age is very low in the models developed from population data.[1]

and

$$\prod_{j=k}^{i} (1 - M_j)$$

is the proportion of those with incident OAG at age k who do not die before age i.

Substituting for N_k from equation 2:

$$\begin{aligned} D_i &= \frac{\sum_{k=1}^{i} (i-k) G_k \prod_{l=1}^{k-1} (1 - G_l) N_1 \prod_{j=1}^{i} (1 - M_j)}{\sum_{k=1}^{i} G_k \prod_{l=1}^{k-1} (1 - G_l) N_1 \prod_{j=1}^{i} (1 - M_j)} \\ &= \frac{\sum_{k=1}^{i} (i-k) G_k \prod_{l=1}^{k-1} (1 - G_l)}{\sum_{k=1}^{i} G_k \prod_{l=1}^{k-1} (1 - G_l)} \end{aligned} \tag{4}$$

Thus, age-specific mean duration of OAG is dependent only on the probability of having age of onset of OAG at a specific age, k. Let

$$L_k = G_k \prod_{l=1}^{k-1} (1 - G_l)$$

be called the likelihood of getting OAG at age *k* and not before.

To calculate the progression rate for each individual in the cross-sectional data set, his or her MD in the worse eye was divided by the calculated mean duration for his or her age and ethnicity. Age-specific averages of this result for all individuals in each ethnic group were used as the group progression rates in dB/year. ANOVA methods were used to estimate mean progression rates by ethnicity and to test for differences by gender, history of cataract surgery, or history of OAG treatment. Study was entered into the model as a random effect, to adjust for possible study clustering.

Standard errors for the individual progression rates were estimated by using a bootstrap with two parts. In the first part, we assumed that age-specific prevalence rates were binomially distributed (*n*, *p*), where *n* is the number of subjects in an age category, and *p* is the estimate of prevalence for that age category. Prevalence rates were sampled for each ethnic group study in Quigley and Broman,[1] and a bootstrap curve of the time since age of onset was calculated. The second part of the bootstrap resampled subjects with OAG with replacement by ethnicity. The first part of the bootstrap accounted for the variation due to the prevalence estimates, whereas the second part of the bootstrap accounted for the variation due to the cross-sectional data. Then, new progression estimates were created for each bootstrapped subject, and new average rates of progression were calculated. This bootstrap was performed 1000 times for an estimate of the variation in the average progression rates.

To calculate overall mean duration, we averaged across the age categories:

$$D = \frac{\sum_{i=1}^{100} \sum_{k=1}^{i} (i-k) G_k \prod_{l=1}^{k-1} (1-G_l)}{\sum_{i=1}^{100} \sum_{k=1}^{i} G_k \prod_{l=1}^{k-1} (1-G_l)} \quad (5)$$

Percentiles of age-specific duration and overall duration were calculated using the following method: each duration length $(i - k)$ was repeated a specific number of times:

$$NL_k = NG_k \prod_{l=1}^{k-1} (1-G_l),$$

where $N = 100{,}000$, for $k = 1$ to i. This created a distribution of duration lengths for each age category, and percentiles could be calculated from these distributions. Confidence intervals were calculated by using a bootstrap, as just described.

Results

The nine surveys had 1140 subjects with OAG, of which 1066 provided visual field data for this analysis (Table 1). Subjects with OAG differed significantly among studies in age, gender, and ethnic distribution. There were more women than men in the European- and African-derived categories, whereas the opposite was true among Hispanic and Chinese participants. The unilateral blindness rate due to OAG was highest in African-derived and Chinese persons, compared with European and Hispanics. Of interest, the cataract surgery rate was highest among Hispanics (25%) compared with the other groups. The proportion with past treatment or known OAG was highest among European-derived persons (76%), intermediate for African-derived persons (44%), and only 16% among Hispanic and Chinese participants. Missing visual field data (due to category 2 OAG) were more common among the Chinese and African-derived groups.

Age-specific prevalence and probability of incident OAG rose with older age and differed by ethnicity (Figs. 1, 2). Probability of incident OAG rose with age in all ethnicities in greater

than linear fashion. It was highest at younger ages among African-derived persons, the differences by ethnicity narrowed in older age groups. One-year incidence rates from the BES[24] and VIP[21] studies were estimated from published data and were somewhat higher than our estimates for the comparable ethnicities, but their 95% CIs overlapped with our model data (Fig. 2).

The calculations of age-specific, average time since age of onset of OAG was highest for African-derived persons, with similar average time since age of onset for whites and Hispanics (Fig. 3; Table 2).

The average individual progression rate in the worse eye was not significantly different among the four ethnic groups ($P = 0.17$, ANOVA; Table 3). It was numerically lowest among European-derived persons (−1.12 dB/y) and highest among Chinese persons (−1.56 dB/y). There was no significant difference in progression rates between the men and the women ($P = 0.89$).

There was a significant difference in the relationship of age to progression by ethnicity ($P < 0.0001$), but the effect was not consistently in one direction. The progression rate in two ethnic groups changed with age, with a slower progression in older African-derived persons and an increase in progression rate with age among European persons. In Chinese and Hispanic persons, there was no significant change with age (Fig. 4; Table 4). The relationship of progression and age in the African-derived group may have been mainly due to a few younger persons with abnormally high MD from the BES study. We cannot tell whether this was due to some unknown factor in how field tests were administered, or a genuine feature of that group.

The rate of progression in the better eye could not be calculated in the same way as that in the worse eye, because the estimation depended on the assumption that damage began with disease onset. Because we assumed that damage began in the worse eye, we could not make the same assumption for the better eye, since we know that damage is often asymmetric in severity and onset. As a result, we calculated the better eye–worse eye ratio in decibels of MD by ethnicity. The result was, on average, 0.45 for European-derived, 0.50 for Hispanics, 0.55 for Chinese, and 0.56 for African-derived persons.

Progression was estimated to be higher among pseudophakic subjects with OAG than in phakic ones ($P < 0.0001$; ANOVA; Table 5); however, there were no significant differences among ethnicities with respect to the effect of pseudophakia. Similarly, progression was higher in those with previously diagnosed and treated OAG compared with untreated cases ($P < 0.0001$; ANOVA). Table 6 shows that only the Chinese subjects differed significantly from other ethnicities in the effect of past treatment. Progression in European-derived subjects with previously treated OAG was significantly lower than among previously treated Chinese subjects ($P = 0.007$). There were no significant differences in progression in European, African, and Hispanic subjects with a history of treatment.

Discussion

We estimated the rate of OAG progression from cross-sectional, population-based data. Our approach was motivated by the impracticality of measuring the rate of progression in an unbiased manner from longitudinal follow-up of individual clinic-based cases. Since OAG lasts 15 years in the average patient, as estimated in our duration metric, it is unlikely that any study will be undertaken to collect consistent data over such a long period—in part, because visual field testing methods change both their hardware and software in a shorter time frame than 15 years. Thus, it is improbable that any study will measure functional OAG damage over the full duration of disease with the same instrument and algorithm. In addition, few studies have begun the long-term follow-up of subjects with OAG by selecting them randomly from

the population. Recruited members of clinical trial studies and convenience samples of clinic-based patients are not representative of the natural history of all persons affected by OAG in a population, as evidenced by half or more of those identified in population-based studies being unaware they had OAG.

Our data were based on a large number of subjects with OAG identified by random sampling, which minimizes selection bias. In addition, we used uniform diagnostic criteria for OAG for all studies. This uniformity allows comparability with future estimates by eliminating the subjectivity inherent in definitions of OAG determined by subjective expert agreement. The diagnostic criteria used in the present study have been shown to be conservative in denoting those with OAG,[39] but are quite unlikely to suffer from misclassification. Whereas our data sets represent the field findings at one time point in each subject, the nature of the analysis solves the problem of consistency in testing, since all were tested on algorithms of the HFA automated perimeter.

The progression rates estimated herein are more rapid than some published estimates. Most of the previous data come from clinic-based OAG cases that may represent a selected view of damage. For example, in clinical trials data, follow-up is aggressively enforced, patients are conscious participants in experimental comparisons, and treatment is often free. These factors may provide a best-case scenario for progression rates in ideally treated OAG. The Early Manifest Glaucoma Trial (EMGT) used OAG cases mostly identified by random selection from the population of Malmö and Helsingborg, Sweden. In the 122 untreated subjects with OAG from the EMGT, the decline in MD in was −0.6 ± 0.8 dB/year.[8] Participants in the EMGT were 68 years of age at baseline, and our model estimated the progression rate at this age for European-derived persons to be −0.80 (95% CI −0.90 to −0.59) dB/year. Those who had undergone past OAG treatment or surgery or had more than moderate field loss were excluded from EMGT, which would probably reduce the progression rate by eliminating cases that were more aggressive. The only other clinical trial that followed established OAG cases without treatment was the Collaborative Normal Tension Glaucoma Study (CNGTS), which reported a progression rate of −0.4 ± 3.65 dB/year for 79 subjects.[7] However, all persons in the CNTGS had a mean IOP lower than 21 mm Hg at baseline, and since progression is related to IOP level,[48–50] this might reduce their rate compared with all persons with OAG. In this study we were unable to determine whether IOP levels differed between populations, since methods of applanation tonometry were nonstandardized between studies. However, there are no comparable clinical trials data from large numbers of untreated African-derived, Hispanic, or Chinese populations. Thus, our estimate for progression rate appears to be consistent with the available information, though appropriately somewhat higher, given the known differences in subjects.

All other trials and case series that report a rate of OAG progression include only treated persons, and their rate of progression is lower than that for untreated trial participants and our estimates, as expected if IOP-lowering treatment is at least somewhat effective. The Glaucoma Laser Trial and Collaborative Initial Glaucoma Treatment Study each found no significant worsening in their treated OAG cases during their studies.[15,16] Both studies recruited new OAG cases without prior treatment at a relatively early stage of disease. The Advanced Glaucoma Intervention Study, on the other hand, found a mean worsening in treated OAG of −0.2 dB/year, in a comparatively older population, that had already failed to be controlled on maximum tolerated medication.[17] Other analyses have summarized clinical experience in large specialty offices and have generally found rates of progression in treated OAG that are lower than those reported in the present study.[13]

Age is a consistent risk factor for prevalence of OAG, and incidence increases with age. But, this does not mean that the progression rate would necessarily increase with age. Indeed, our

model suggests that the average progression rate does not consistently either worsen or improve with age in the various ethnicities studied. Likewise, we found no difference between men and women in progression rates. Gender has been inconsistently associated with OAG prevalence.[1,51]

There were modest differences in estimated progression among ethnic groups that were not statistically significant. Although the Chinese had the highest estimated progression rate, the number of subjects in this group was too small to determine significant differences from other ethnic groups. The prevalence of OAG is substantially higher among African-derived and Hispanic persons than in European-derived.[40–45] The substantial differences in prevalence and morbidity of OAG are probably due to a combination of factors, including treatment disparities and longer duration of disease. Indeed, the diagnosis and treatment rates for European-derived persons across studies were far higher than for the other ethnicities, even when, as in the Baltimore and Salisbury studies (BESF, SEE), subjects lived in the same municipality. Since treatment has a beneficial effect, this may have produced a lower rate among European-derived persons. Yet, we found that those who had known OAG and who reported present or past treatment had higher progression rates in every ethnic group. The most likely explanation is that those with identified OAG have worse disease and were identified by their greater damage (ascertainment bias).

The same explanation probably applies to our finding that pseudophakic subjects with OAG had a greater progression rate. Cataract could be a confounding variable in our study, since the primary outcome, MD, is affected by cataract independently of OAG. Since pseudophakes have no lens opacity, this effect would not apply to them. We included pseudophakic status as an independent variable, with the expectation that the removal of cataract might lead to better MD score and lower estimated progression rate. However, it is known that cataract removal leads to only rather limited improvement in MD in subjects with OAG.[52,53] If the degree of OAG injury in pseudophakes were otherwise similar to our phakic subjects with OAG, then they should have (slightly) better MD values and show less progression by our calculations, all other factors being equal. Instead, pseudophakic subjects had higher progression rates, perhaps because those with worse OAG were more likely to have lens opacity that necessitated cataract surgery.

A likely contributing factor to the greater progression and morbidity of OAG in African-derived persons is their longer average duration of disease. Our calculation showed that despite having a shorter life expectancy, African-derived persons have OAG for up to 2.3 years longer than European-derived persons. This comes directly from higher incidence of disease at an earlier age. Potentially compounding their greater visual loss may be factors not measured in our study, including differences in access to care and acceptance of and response to treatment. A logical conclusion is that African-derived persons merit more intensive efforts to identify those with OAG at earlier ages than European-derived persons.

It might be questioned whether MD is the best measure to judge progression, since its diffuse representation of damage may not be specific to OAG damage. The Glaucoma Hemifield Test and Glaucoma Change Assessment detect localized differences, but are not amenable to use in generating continuous, parametric rate estimates. The PSD index cannot be used in this analysis, since it rises with initial damage, but declines again at the later stages of damage in an inverted U-shape. Other indices, such as the AGIS or CIGTS scores, track closely with MD and have inherent nonlinearities that may make them inappropriate as scales.[54] We included studies that used algorithms for automated field testing on the HFA1 or HFA2 instruments. Comparisons of results with these algorithms as implemented on the two versions of the HFA have shown that MD values are quite similar,[55,56] although test–retest variability is higher for SITA Fast in those with significant damage.[57] The similarity was, in fact, actively designed

into these algorithms by the manufacturer to maximize backward compatibility when new algorithms were introduced. While measured sensitivity at individual points is 1.6 dB higher with SITA Fast than with Full Threshold, Artes et al.[54] concluded that the small differences between the SITA and standard algorithms are unlikely to impact on the detection of glaucomatous field loss.

Our progression estimates do not represent the natural history of OAG, as some subjects were treated. IOP-lowering treatment under ideal conditions in clinical trials slows progression by 50%.[7–9] Yet, adherence to treatment is suboptimal in the general patient population, which is more comparable to our population data, with patients having drugs available to use on only approximately 70% of days.[58] Thus, the effect of treatment on progression would be modest. If 50% of a population are prescribed eye drops, use them 70% of the time, and when using them achieve a 50% reduction in progression, the net effect of treatment would reduce progression rates by less than 20% ($0.5 \times 0.7 \times 0.5$). Thus, while our estimates may be somewhat lower in populations with higher treatment rates (European-derived), the net effect of this treatment under these assumptions is modest at best.

The mean progression rates that are estimated herein can be used to predict the likelihood of severe vision loss in OAG. Our data give the average duration of disease at each age and the limit of these estimates for each ethnicity is the typical duration of OAG. Using the mean duration of disease and the average rate of progression together (Table 7), we see that the mean damage expected in the group with the highest progression (African-derived) is 20.5 dB, or loss of two thirds of the scale of MD in logarithmic units. If we use the 85th percentile value for duration in each ethnicity, nearly all these worse eyes would reach the terminal MD value in the perimetric scale (30 dB), and would be judged blind or at least terminally impaired in their lifetime, suggesting that the unilateral blindness rate would be in the range of 15% of subjects with OAG (1 – 85%).

Our method did not allow direct calculation of the progression rate in the better eye. Instead, we made a proportion for each subject of the MD value in the better eye to that in the worse eye, yielding the result that the better eye had approximately half the damage on the logarithmic MD scale of that in the worse eye. The comparative magnitude of damage in the better eye compared with the worse eye on a population basis is a previously unreported finding, indicating that either better eyes progress more slowly, or more likely, that they begin to be injured at a later time in the life of the patient. If we ascribe the proportionate damage from the worse eye (Table 7) to estimate mean lifetime loss in the better eye, the typical OAG patient suffers moderate damage in the second eye (Table 8). We can use the confidence limits of the duration data to generate the percentage of better eyes that would reach the end of the MD scale (30 dB). Thus, our progression data find that the proportion of all OAG patients expected to become bilaterally blind (30 dB MD loss in both worse and better eye), would be greater in African-derived and Chinese persons and would comprise fewer than 1 in 20 persons with OAG overall. These estimates are consistent with blindness rates reported from population-based surveys.[1]

In summary, we have presented a method of estimating progression of visual field damage among subjects with OAG from cross-sectional, population-based data in 1066 patients with visual field damage estimates. The model makes predictions that are consistent with available information on untreated OAG, and can be interpreted to demonstrate differences among ethnicities in OAG manifestations that are consonant with previous observations. The greater morbidity of OAG in African-derived persons may be a multifactorial response to inherent susceptibilities, including longer duration of disease combined with a somewhat greater progression rate and sociocultural factors. The data can serve as benchmarks for estimation of blindness and impairment that can be useful in public health planning and in clinical research.

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References

1. Quigley HA, Broman AT. The number of people with glaucoma worldwide in 2010 and 2020. Br J Ophthalmol 2006;90:262–267. [PubMed: 16488940]
2. Friedman DS, Wolfs RC, O'Colmain BJ, et al. Prevalence of open-angle glaucoma among adults in the United States. Arch Ophthalmol 2004;122:532–538. [PubMed: 15078671]
3. Ellwein LB, Urato CJ. Use of eye care and associated charges among the Medicare population: 1991–1998. Arch Ophthalmol 2002;120:804–811. [PubMed: 12049587]
4. Schappert, SM. Office visits for glaucoma: United States, 1991–92; advance data from vital and health statistics. Hyattsville, MD: National Center for Health Statistics; 1995. p. 262
5. Fiscella RG, Green A, Patuszynski DH, Wilensky J. Medical therapy cost considerations for glaucoma. Am J Ophthalmol 2003;136:18–25. [PubMed: 12834665]
6. Hourihan F, Mitchell P. Factors associated with use of glaucoma medications in a population of older people: The Blue Mountains Eye Study. Aust NZ J Ophthalmol 1999;27:176–179.
7. Collaborative Normal-Tension Glaucoma Study Group. Comparison of glaucomatous progression between untreated patients with normal-tension glaucoma and patients with therapeutically reduced intraocular pressures. Am J Ophthalmol 1998;126:487–497. [PubMed: 9780093]
8. Heijl A, Leske MC, Bengtsson B, Hyman L, Bengtsson B, Hussein M. Reduction of intraocular pressure and glaucoma progression: results from the Early Manifest Glaucoma Trial. Arch Ophthalmol 2002;120:1268–1279. [PubMed: 12365904]
9. Kass MA, Heuer DK, Higginbotham EJ, et al. The Ocular Hypertension Treatment Study: a randomized trial determines that topical ocular hypotensive medication delays or prevents the onset of primary open-angle glaucoma. Arch Ophthalmol 2002;120:701–713. [PubMed: 12049574]
10. Eid TM, Spaeth GL, Bitterman A, Steinmann WC. Rate and amount of visual loss in 102 patients with open-angle glaucoma followed up for at least 15 years. Ophthalmology 2003;110:900–907. [PubMed: 12750087]
11. Kwon YH, Kim CS, Zimmerman MB, Alward WL, Hayreh SS. Rate of visual field loss and long-term visual outcome in primary open-angle glaucoma. Am J Ophthalmol 2001;132:47–56. [PubMed: 11438053]
12. Lee AC, Sample PA, Blumenthal EZ, Berry C, Zangwill L, Weinreb RN. Infrequent confirmation of visual field progression. Ophthalmology 2002;109:1059–1065. [PubMed: 12045044]
13. Rasker MT, van den Enden EA, Bakker D, Hoyng PF. Rate of visual field loss in progressive glaucoma. Arch Ophthalmol 2000;118:481–488. [PubMed: 10766133]
14. Smith SD, Katz J, Quigley HA. Analysis of progressive change in automated visual fields in glaucoma. Invest Ophthalmol Vis Sci 1996;37:1419–1428. [PubMed: 8641844]
15. Glaucoma Laser Trial Research Group. The Glaucoma Laser Trial (GLT): 6. Treatment group differences in visual field changes. Am J Ophthalmol 1995;120:10–22. [PubMed: 7611312]
16. The Advanced Glaucoma Intervention Study (AGIS): 4. Comparison of treatment outcomes within race: seven-year results. Ophthalmology 1998;105:1146–1164. [PubMed: 9663215]
17. Lichter PR, Musch DC, Gillespie BW, et al. Interim clinical outcomes in the Collaborative Initial Glaucoma Treatment Study comparing initial treatment randomized to medications or surgery. Ophthalmology 2001;108:1943–1953. [PubMed: 11713061]
18. Quigley HA, Vitale S. Models of open-angle glaucoma prevalence and incidence in the United States. Invest Ophthalmol Vis Sci 1997;38:83–91. [PubMed: 9008633]
19. Grodum K, Heijl A, Bengtsson B. A comparison of glaucoma patients identified through mass screening and in routine clinical practice. Acta Ophthalmol Scand 2002;80:627–631. [PubMed: 12485284]

20. Leske MC, Connell AM, Wu SY, et al. Incidence of open-angle glaucoma: the Barbados Eye Studies. The Barbados Eye Studies Group. Arch Ophthalmol 2001;119:89–95. [PubMed: 11146731]
21. Mukesh BN, McCarty CA, Rait JL, Taylor HR. Five-year incidence of open-angle glaucoma: the visual impairment project. Ophthalmology 2002;109:1047–1051. [PubMed: 12045042]
22. Wilson MR, Kosoko O, Cowan CL Jr, et al. Progression of visual field loss in untreated glaucoma patients and glaucoma suspects in St. Lucia, West Indies. Am J Ophthalmol 2002;134:399–405. [PubMed: 12208252]
23. Bengtsson BO. Incidence of manifest glaucoma. Br J Ophthalmol 1989;73:483–487. [PubMed: 2788015]
24. Leske MC, Wu SY, Honkanen R, et al. Nine-year incidence of open-angle glaucoma in the Barbados Eye Studies. Ophthalmology 2007;114:1058–1064. [PubMed: 17397925]
25. 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;122:355–363. [PubMed: 8794708]
26. Leske MC, Ederer F, Podgor M. Estimating incidence from age-specific prevalence in glaucoma. Am J Epidemiol 1981;113:606–613. [PubMed: 7223741]
27. Bengtsson B. Survival of elderly ophthalmic out-patients. Acta Ophthalmol (Copenh) 1984;62:725–730. [PubMed: 6507061]
28. Borger PH, van Leeuwen R, Hulsman CA, et al. Is there a direct association between age-related eye diseases and mortality? The Rotterdam Study. Ophthalmology 2003;110:1292–1296. [PubMed: 12867381]
29. Klein R, Klein BE, Moss SE. Age-related eye disease and survival: The Beaver Dam Eye Study. Arch Ophthalmol 1995;113:333–339. [PubMed: 7887847]
30. Shrum KR, Hattenhauer MG, Hodge D. Cardiovascular and cerebrovascular mortality associated with ocular pseudoexfoliation. Am J Ophthalmol 2000;129:83–86. [PubMed: 10653417]
31. Grodum K, Heijl A, Bengtsson B. Glaucoma and mortality. Graefes Arch Clin Exp Ophthalmol 2004;242:397–401. [PubMed: 15029499]
32. Lee DJ, Gomez-Marin O, Lam BL, Zheng DD. Glaucoma and survival: the National Health Interview Survey 1986–1994. Ophthalmology 2003;110:1476–1483. [PubMed: 12917160]
33. Lee AJ, Wang JJ, Kifley A, Mitchell P. Open-angle glaucoma and cardiovascular mortality: the Blue Mountains Eye Study. Ophthalmology 2006;113:1069–1076. [PubMed: 16815396]
34. Minassian DC, Reidy A, Coffey M, Minassian A. Utility of predictive equations for estimating the prevalence and incidence of primary open angle glaucoma in the UK. Br J Ophthalmol 2000;84:1159–1161. [PubMed: 11004103]
35. Wu SY, Nemesure B, Leske MC. Observed versus indirect estimates of incidence of open-angle glaucoma. Am J Epidemiol 2001;153:184–187. [PubMed: 11159164]
36. Sloan FA, Brown DS, Carlisle ES, Ostermann J, Lee PP. Estimates of incidence rates with longitudinal claims data. Arch Ophthalmol 2003;121:1462–1468. [PubMed: 14557184]
37. Schoff EO, Hattenhauer MG, Ing HH, et al. Estimated incidence of open-angle glaucoma in Olmsted County, Minnesota. Ophthalmology 2001;108:882–886. [PubMed: 11320017]
38. Foster PJ, Buhrmann R, Quigley HA, Johnson GJ. The definition and classification of glaucoma in prevalence surveys. Br J Ophthalmol 2002;86:238–242. [PubMed: 11815354]
39. 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;41:3309–3321. [PubMed: 11006219]
40. 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;266:369–374. [PubMed: 2056646]
41. 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;119:1819–1826. [PubMed: 11735794]

42. 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;124:1625–1630. [PubMed: 17102012]
43. Varma R, Ying-Lai M, Francis BA, et al. Prevalence of open-angle glaucoma and ocular hypertension in Latinos: the Los Angeles Latino Eye Study. Ophthalmology 2004;111:1439–1448. [PubMed: 15288969]
44. Leske MC, Connell AM, Schachat AP, Hyman L. The Barbados Eye Study: prevalence of open angle glaucoma. Arch Ophthalmol 1994;112:821–829. [PubMed: 8002842]
45. Weih LM, Nanjan M, McCarty CA, Taylor HR. Prevalence and predictors of open-angle glaucoma: results from the visual impairment project. Ophthalmology 2001;108:1966–1972. [PubMed: 11713063]
46. 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;118:1105–1111. [PubMed: 10922206]
47. 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;47:2782–2788. [PubMed: 16799014]
48. Leske MC, Heijl A, Hussein M, Bengtsson B, Hyman L, Komaroff E. Factors for glaucoma progression and the effect of treatment: the early manifest glaucoma trial. Arch Ophthalmol 2003;121:48–56. [PubMed: 12523884]
49. Gordon MO, Beiser JA, Brandt JD, et al. The Ocular Hypertension Treatment Study: baseline factors that predict the onset of primary open-angle glaucoma. Arch Ophthalmol 2002;120:714–720. [PubMed: 12049575]
50. The AGIS Investigators. The Advanced Glaucoma Intervention Study (AGIS): 7. The relationship between control of intraocular pressure and visual field deterioration. Am J Ophthalmol 2000;130:429–440. [PubMed: 11024415]
51. 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;47:4254–4261. [PubMed: 17003413]
52. The AGIS Investigators. Effect of cataract on visual field and visual acuity. The Advanced Glaucoma Intervention Study, report 6. Arch Ophthalmol 2000;118:1639–1652. [PubMed: 11115258]
53. Smith SD, Katz J, Quigley HA. Effect of cataract extraction on the results of automated perimetry in glaucoma. Arch Ophthalmol 1997;115:1515–1519. [PubMed: 9400784]
54. Katz J. Scoring systems for measuring progression of visual field loss in clinical trials of glaucoma treatment. Ophthalmology 1999;106:391–395. [PubMed: 9951496]
55. Artes PH, Iwase A, Ohno Y, Kitazawa Y, Chauhan BC. Properties of perimetric threshold estimates from Full Threshold, SITA Standard, and SITA Fast strategies. Invest Ophthalmol Vis Sci 2002;43:2654–2659. [PubMed: 12147599]
56. Bengtsson B, Heijl A. Comparing significance and magnitude of glaucomatous visual field defects using the SITA and Full Threshold strategies. Acta Ophthalmol Scand 1999;77:143–146. [PubMed: 10321527]
57. Budenz DL, Rhee P, Feuer WJ, McSoley J, Johnson CA, Anderson DR. Comparison of glaucomatous visual field defects using standard full threshold and Swedish interactive threshold algorithms. Arch Ophthalmol 2002;120:1136–1141. [PubMed: 12215086]
58. Quigley HA, Friedman DS, Hahn SR. Evaluation of practice patterns for the care of open-angle glaucoma compared with claims data. The Glaucoma Adherence and Persistency Study. Ophthalmology 2007;114:1599–1606. [PubMed: 17572498]discussion 1597–1598

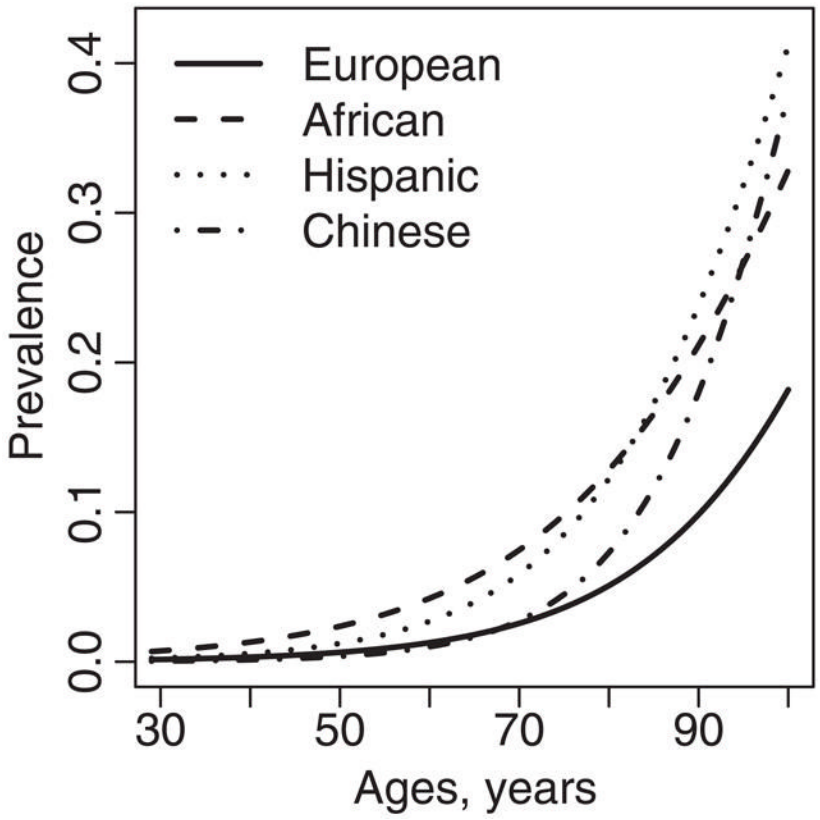

Figure 1.
Age-specific prevalence by ethnicity. Prevalence curves generated by Quigley and Broman[1] from 34 population-based OAG prevalence surveys.

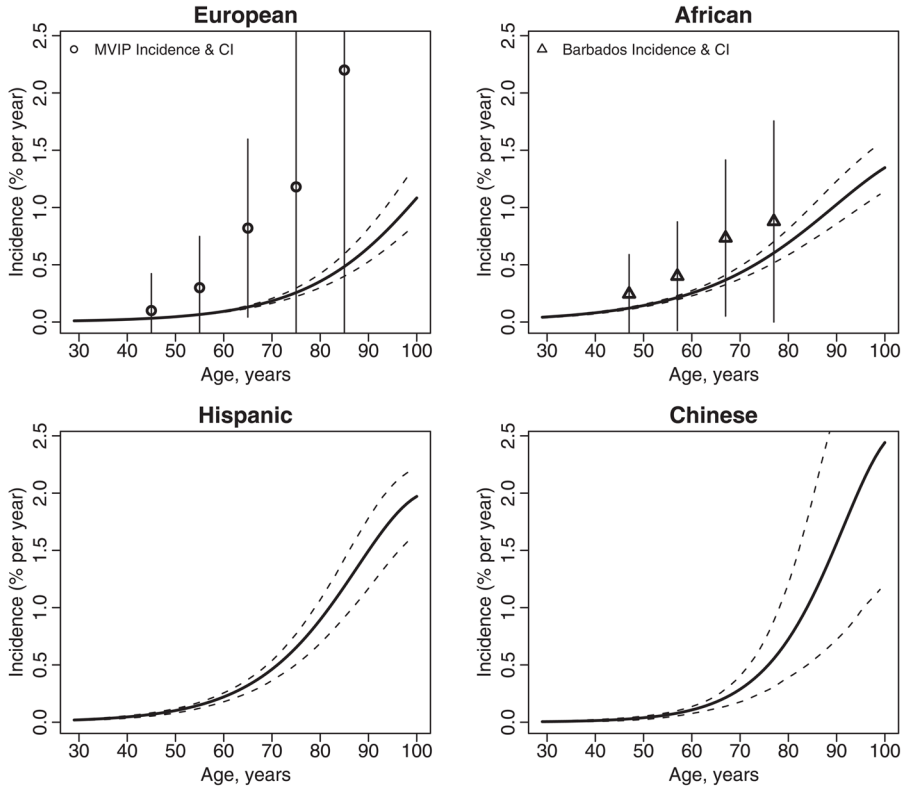

Figure 2.

Age-specific incidence by ethnicity. Incidence estimates (*solid lines*) for OAG in four ethnicities generated from age-specific prevalences in Figure 1. The 95% CI for our estimates (*dashed lines*) overlap the data from two individual direct measurements of incidence in population surveys (*circles* and *flags*, mean and 95% CI). These are the Melbourne VIP study (shown in European-derived curve, *top left*) and the Barbados Eye Study data (shown in African-derived curve, *top right*).

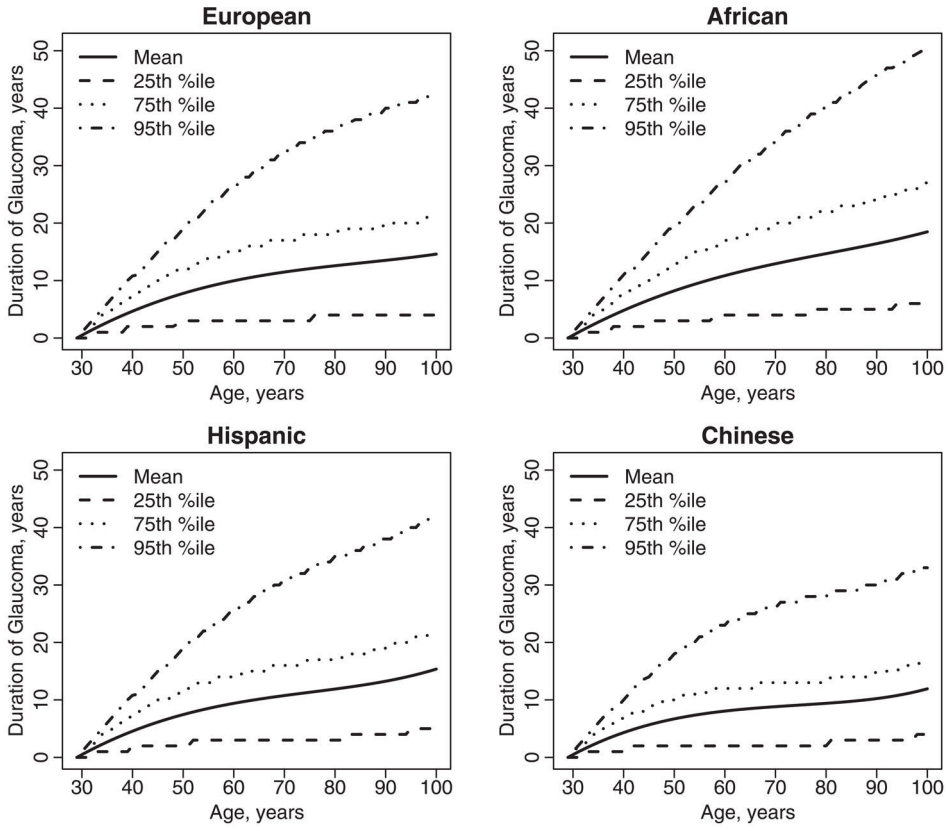

Figure 3.

Duration curves by ethnicity. We calculated the average age at OAG onset for each age, to arrive at a mean duration of disease at each age from 30 years onward. The mean value (*solid line*) and 25th, 75th, and 95th percentiles are shown for this value. The mean duration of disease reached a maximum of about 15 years in the ethnicity with the highest value (African-derived). See also Table 2.

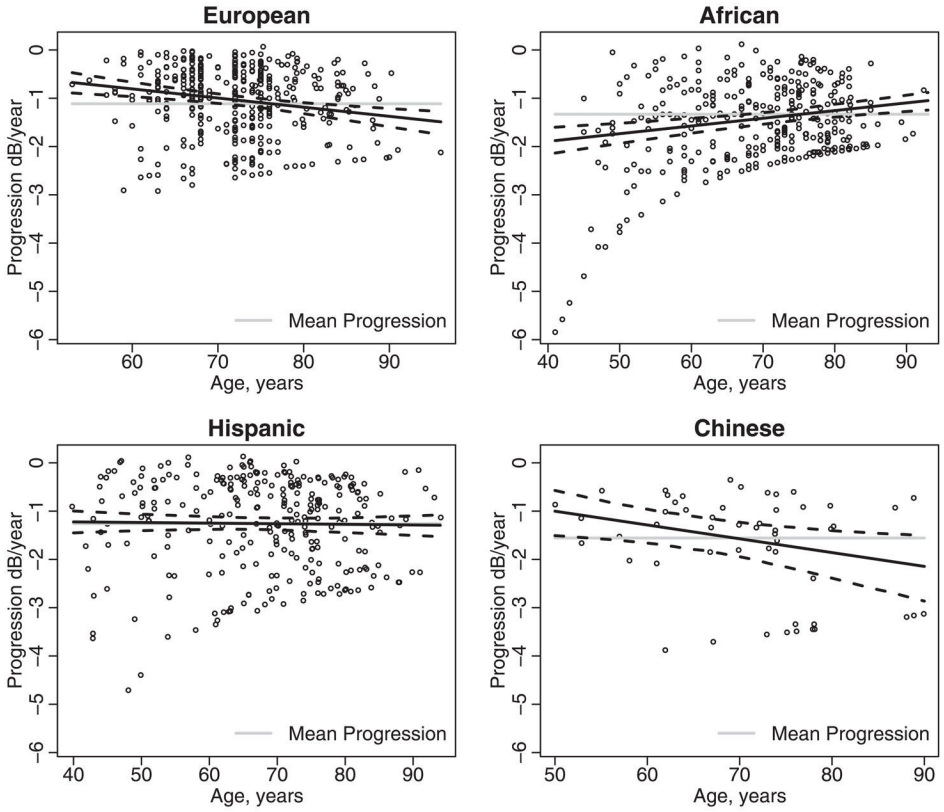

Figure 4.

Progression rate by age for four ethnicities. (○) Mean progression rate estimate for individual subjects; *gray line*: mean progression rate for each ethnicity. *Black line*: the change in progression estimate by age with its 95% CI. The progression rate was worse (more minus) with age in European-derived, slower with age in African-derived, while unchanged with age in Chinese and Hispanic subjects.

Table 1

Glaucoma Subject Characteristics

Total	***N* = 1140**	**European (*n* = 392)**	**African (*n* = 404)**	**Hispanic (*n* = 282)**	**Chinese (*n* = 62)**	***P* (Diff. among Ethnicities)**
Missing MD in worse eye*		17 (4.3%)	41 (10.2)	4 (1.4)	12 (19.3)	$P < 0.0001$
MD data available	*N* = 1066	375	363	278	50	
Age (y)	40–49	0 (0.0)	18 (5.0)	25 (9.0)	0 (0.0)	$P < 0.0001$
	50–59	11 (2.9)	52 (14.3)	37 (13.3)	5 (10.0)	
	60–69	129 (34.4)	85 (23.4)	75 (27.0)	14 (28.0)	
	70–79	185 (49.3)	142 (39.1)	92 (33.1)	23 (46.0)	
	80+	50 (13.3)	66 (18.2)	49 (17.6)	8 (16.0)	
Gender	Men	160 (42.7)	151 (41.6)	148 (53.2)	33 (66.0)	$P < 0.0001$
	Women	215 (57.3)	212 (58.4)	130 (46.8)	17 (34.0)	
Assigned low MD score for blind eye	1 Eye	17 (4.5)	72 (19.8)	11 (4.0)	8 (16.0)	$P < 0.0001$
	Both eyes	2 (0.5)	27 (7.4)	3 (1.1)	1 (2.0)	
Cataract surgery in worse eye	Yes	47 (12.6)	34 (9.4)	70 (25.3)	5 (10.0)	$P < 0.0001$
Glaucoma treatment in worse eye	Yes	281 (75.5)	158 (43.6)	44 (15.8)	8 (16.0)	$P < 0.0001$

Data are the number of subjects (percentage of total group); ethnic descriptions are self-descriptions as reported in each study by persons of European, African, Hispanic, or Chinese derivation.

* No available visual field MD and eye not blind from OAG.

Table 2

Time since Onset by Ethnicity

	Average Duration (y)	95% CI	95th Percentile Duration	95% CI
European	13.1	12.2–13.8	38	36–40
African	15.4	14.6–15.9	43	41–44
Hispanic	13.0	12.1–13.6	37	34–39
Chinese	10.5	8.8–12.6	30	25–37

Table 3

Mean Progression Rate by Ethnicity

	n	dB/year	95% CI	*z*-Score *P*[*]
European	375	−1.12	−1.25, −1.02	—
African	363	−1.33	−1.48, −1.18	0.06
Hispanic	278	−1.26	−1.40, −1.12	0.60
Chinese	50	−1.56	−1.98, −1.18	0.19

[*] Difference from European ethnicity; difference among races $P = 0.17$ (ANOVA).

Table 4

Progression Rate Change with Age, by Ethnicity

	n	dB/y	95% CI	*z*-Score *P*[*]
European	375	−0.02	−0.03 to −0.01	—
African	363	0.02	0.01 to 0.02	<0.0001
Hispanic	278	−0.001	−0.008 to 0.006	0.03
Chinese	50	−0.03	−0.05 to −0.01	0.51

[*] Difference from European ethnicity; difference among races with respect to age relationship to progression rate, $P < 0.0001$ (ANOVA).

Table 5

Progression by Pseudophakia, Worse Eye

	No Pseudophakia				Pseudophakia			
	n	**dB/y**	**95% CI**	***z*-Score *P*** *	***n***	**dB/y**	**95% CI**	***z*-Score *P*** *
European	326	−1.08	−1.23 to −0.96	—	47	−1.31	−1.54 to −1.11	—
African	326	−1.26	−1.42 to −1.11	0.16	34	−1.71	−1.96 to −1.45	0.29
Hispanic	207	−1.13	−1.30 to −0.97	0.88	70	−1.60	−1.85 to −1.36	0.19
Chinese	45	−1.48	−1.91 to −1.13	0.26	5	−2.36	−3.58 to −1.31	0.12

Lens status is missing in one Hispanic, two European and three African subjects.

* Difference between European ethnicity and each of the other ethnicities.

Table 6

Progression by Past Glaucoma Treatment, Worse Eye

	No Glaucoma Treatment				Past Glaucoma Treatment			
	n	**dB/y**	**95% CI**	***z*-Score *P*** *	***n***	**dB/y**	**95% CI**	***z*-Score *P*** *
European	91	−0.92	−1.08 to −0.80	—	281	−1.27	−1.44 to −1.34	—
African	204	−1.07	−1.22 to −0.91	0.26	158	−1.59	−1.79 to −1.40	0.22
Hispanic	234	−1.19	−1.35 to −1.05	0.36	44	−1.65	−1.97 to −1.36	0.52
Chinese	42	−1.40	−1.80 to −1.06	0.17	8	−2.66	−3.52 to −1.94	0.007

Medical history is missing for three European subjects and one African subject.

* Difference between European ethnicity and each of the other ethnicities.

Table 7

Estimate of Unilateral Blindness Rates from Duration and Progression Data

	Mean Progression Rate (dB/y)	Mean Duration (y)	Mean Damage (dB)	85th Percentile Duration (y)	Top 15% Damage (dB)
European	−1.12	13.1	−14.7	25	−28.0
African	−1.33	15.4	−20.5	30	−39.9
Hispanic	−1.26	13.0	−16.4	25	−31.5
Chinese	−1.56	10.5	−16.4	20	−31.2

The values of damage are derived from model projections and in some cases exceed the full range that could occur in an individual eye in actual testing.

Table 8

Better Eye Progression to Severe Damage

	Better Eye Proportionate Damage (%)	Average Damage (dB)	% with at Least 30 dB Loss (%)
European	45%	−6.6	0.3%
African	56%	−11.5	7%
Hispanic	50%	−8.2	1.5%
Chinese	55%	−9.0	3%