Chapter 2

The Epidemiology of Glaucoma

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Core Messages

- Glaucoma is second to cataract as a leading cause of global blindness and is the leading cause of irreversible visual loss.
- In 2002, 37 million individuals were blind worldwide, with glaucoma accounting for 12.3% of these individuals.
- By the year 2020 it is estimated that there will be almost 80 million people in the world with open-angle glaucoma and angle-closure glaucoma. The majority of these individuals will have open-angle glaucoma. Of those with ACG, it is predicted that 70% will be women and 87% will be Asian.
- Bilateral blindness from glaucoma is projected to affect 8.4 million individuals worldwide by 2010 and greater than 11 million by 2020. Globally, glaucoma is a significant cause of vision loss that disproportionately affects women and Asians.
- Risk factors for open-angle glaucoma include increased age, African ethnicity, family history, increased intraocular pressure, myopia, and decreased corneal thickness.
- Risk factors for angle closure glaucoma include Inuit and Asian ethnicity, hyperopia, female sex, shallow anterior chamber, short axial length, small corneal diameter, steep corneal curvature, shallow limbal chamber depth, and thick, relatively anteriorly positioned lens.

2.1 Introduction

Glaucoma is second only to cataract as a leading cause of global blindness [46], and is the leading cause of irreversible visual loss, largely due to primary open-angle glaucoma (POAG). In 2002, it was estimated that 161 million individuals worldwide had visual impairment and 37 million were blind. Glaucoma accounted for 12.3% of global blindness, while cataract accounted for 47.8% (see Fig. 2.1). Visual impairment from glaucoma weighs a heavier burden in the least developed regions, and affects adults more than children and women more than men [46].

By the year 2010 it is estimated that there will be 60.5 million people in the world with open-angle glaucoma (OAG) and angle-closure glaucoma (ACG). By the year 2020 this number is predicted to increase to 79.6 million. The majority (74%) of these individuals will have OAG. Of the group with ACG, 70% will be women and 87% will be Asian. Bilateral blindness from glaucoma is projected to affect 8.4 million individuals worldwide by 2010 and greater than 11 million by 2020. Globally, glaucoma is a significant cause of vision loss that disproportionately affects women and Asians [42].

In the United States, more than three million Americans are projected to have glaucoma by the year 2020. Glaucoma blindness is almost three times higher in African Americans than white Americans, and POAG is the leading cause of blindness in African Americans [14].

There is no doubt that as the economic burden of all healthcare rises, there will be new challenges regarding the distribution and delivery of healthcare, and the burden of glaucoma is no exception. It was recently estimated that 17.8% of direct medical costs of major eye diseases in the United States were attributable to patients with glaucoma, representing a substantial portion given that the annual total direct medical costs for these disorders was estimated to be $16.2 billion [45]. As the US population ages and as medical care for glaucoma increases, the challenge involved in meeting these costs will undoubtedly increase.

2.2 Primary Open-Angle Glaucoma

It has been estimated that by 2010, almost 45 million people will have OAG worldwide, and by 2020 this number is expected to increase to 58.5 million. Almost

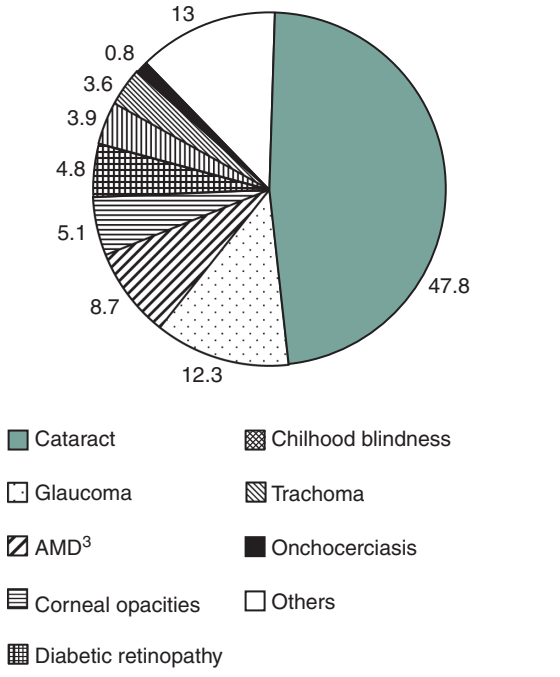

Fig. 2.1 Global causes of blindness as a percentage of total blindness in 2002 Reprinted with permission from [46]

half (47%) of these people will reside in Asia while 24% will be European. The mean prevalence is estimated to be 1.96%. Women are expected to comprise >55% of those with OAG because of their increased longevity compared to men [42].

In the United States, the overall prevalence of OAG in individuals ≥40 years old is 1.86%, affecting 1.57 million whites and 398,000 black individuals. In 2020, due to the rapidly aging population, it is estimated that this number will grow to 3.36 million [14].

2.2.1 Increased IOP

Elevated intraocular pressure (IOP) is the most important known risk factor for the development of POAG, and its reduction remains the only clearly proven treatment. Several studies have confirmed that reduction of IOP at any point along the spectrum of disease severity reduces progression (Early Manifest Glaucoma Treatment Trial to Advanced Glaucoma Intervention Study). Also, IOP reduction reduces the development of POAG in patients with ocular hypertension (OHT) and reduces progression in patients with glaucoma despite normal IOP, as seen in the Collaborative Normal Tension Glaucoma Study.

In the past decade, two studies have provided insight about risk factors for developing glaucoma among patients with OHT. The Ocular Hypertension Treatment Study (OHTS) and the European Glaucoma Prevention Study (EGPS) each studied a large population of individuals with elevated IOP but normal visual fields and normal optic discs. The OHTS showed that the progression to glaucoma was reduced from 9.4 to 4.4% over five years if the IOP was reduced at least 20%. The EGPS found that during follow-up, a higher IOP was associated with an increased risk of developing OAG (9% per mm Hg over a five-year period) [35].

Both EGPS and OHTS reported that among patients with OHT, thin central cornea thickness was a risk factor for the development of glaucoma. The etiology for this increased risk is uncertain [13, 19].

They also reported that older baseline age, increased vertical cup-to-disc ratios, and greater pattern standard deviations on the Humphrey automated perimeter were predictive factors for OAG [7, 19, 35].

At this time, the risk associated with long-term fluctuation of IOP over months to years remains controversial. The EGPS and Early Manifest Glaucoma Treatment Trial found that long-term IOP fluctuations were not associated with progression of glaucoma [35], while the AGIS study found an increased risk of glaucoma progression with increased long-term IOP fluctuation, especially in patients with low IOP [5, 39].

While increased IOP is a strong risk factor for the development of glaucoma, it must be remembered that many people with glaucoma have untreated IOPs of 21 mm Hg or less. In general, it is estimated that approximately 50% of POAG is of the normal tension variety. However, studies have found a wide range in the prevalence of normal tension glaucoma among individuals with OAG. For example, normal tension glaucoma was diagnosed in 1/3 of the OAG patients in the Barbados Eye Studies, and 85% of the individuals with OAG in a Chinese population [20, 31].

2.2.2 Age

Studies consistently agree that increasing age is a risk factor for the development of glaucoma in general and for patients with OHT. In a population of white individuals in Wisconsin, the prevalence of OAG in the group aged 43–54 years was 0.9%, while it was significantly greater in individuals 75 years of age or older, at 4.7% [24]. In the Barbados Eye Studies, the incidence of POAG was 2.2% for those aged 40–49 years at baseline and 7.9% for those greater than 70 years of age, with a relative risk of developing glaucoma of 3.8 for the older age group [31].

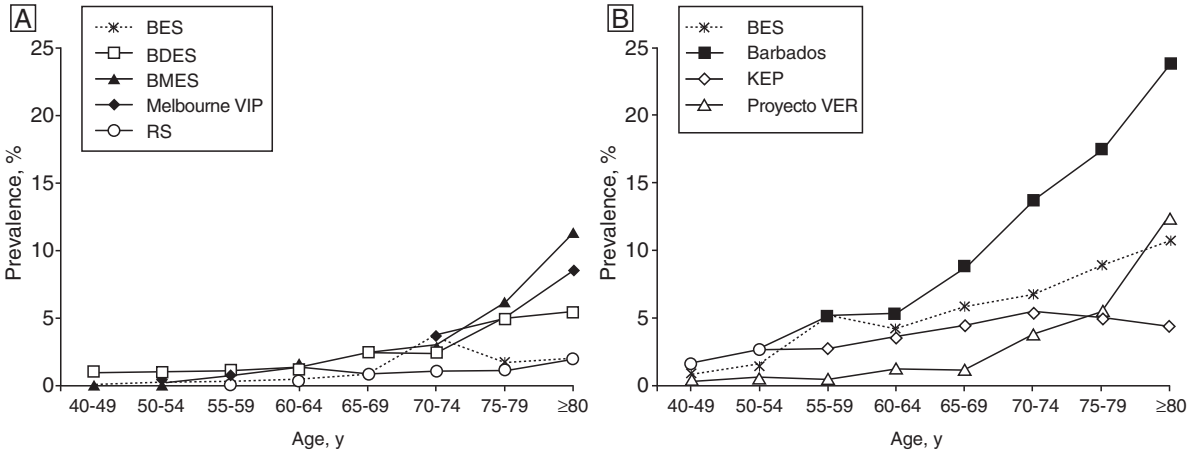

Fig. 2.2 Prevalence of glaucoma in white (**A**) and black and Hispanic (**B**) subjects. *BES*, Baltimore Eye Survey, Baltimore, MD; *BDES*, Beaver Dam Eye Study, Beaver Dam, WI; *BMES*, Blue Mountains Eye Study, Sydney, NSW; *Melbourne VIP*, Melbourne Visual Impairment Project, Melbourne, VIC; *RS*, Rotterdam Study, Rotterdam, the Netherlands; *Barbados*, Barbados Eye Study, Barbados, West Indies; *KEP*, Kongwa Eye Project, Tanzania; and *Proyecto VER*, Vision Evaluation Research, Nogales and Tucson, AZ. Reprinted with permission from The Eye Diseases Prevalence Research Group [14]

Figure 2.2 shows that the prevalence of OAG increases with age in all depicted ethnicities [14]. The results of a recent meta-analysis to predict prevalence of OAG in adults confirmed that the prevalence of OAG increases with age (see Table 2.1) [14]. Increasing age is considered to be a surrogate risk factor for currently unknown factors such as increased deterioration of tissue or ganglion cells, increased duration of exposure to other risk factors, or poorer adherence to therapy or decreased ability to afford therapy [2].

2.2.3 Family History

Family history has consistently been shown to be a risk factor for glaucoma [27]. In the Barbados Family Study of Open-Angle Glaucoma, 40% of probands had at least one affected family member, one in five siblings had OAG, and a quarter of the family members had definite or suspected glaucoma [30]. Also, in the Rotterdam Glaucoma Study and the Baltimore Eye Survey, the risk of OAG was much higher for first-degree relatives [50].

Family history may reflect similarity in genes directly related to the development of glaucoma, or may reflect genetic similarity related to IOP or optic nerve anatomy that may influence the development of glaucoma. Alternatively, family history may be a reflection of increased access to healthcare and eye exams, and therefore associated with an increased chance of being detected, or a shared environmental exposure.

2.2.4 Sex

Whether sex is associated with an increased risk of glaucoma is a controversial issue. In the Barbados Eye Studies and the Beaver Dam Eye Study there was no statistically significant increased risk with sex [24, 31]. In the Melbourne and Rotterdam studies there was a trend towards increased risk for OAG in males; however, this difference did not reach statistical significance, possibly due to small sample sizes [10, 38]. The Eye Disease Prevalence Research group found no difference between the prevalence of glaucoma between men and women for the white, black and Hispanic populations [14].

2.2.5 Ethnicity

Ethnicity is imperfectly defined, given the inconsistent application of variables that are sometimes used to define ethnicity, including language, skin color, and geographic residence, as well as the variability that exists within populations that are classically defined as one ethnicity (i.e., variability exists among "the Chinese"). Nonetheless, ethnicity is used as a gross representation of genetic or other unknown differences between populations, and trends regarding the relationship between ethnicity and glaucoma have been established.

It is clear that African descent is associated with a higher risk of developing glaucoma compared with individuals of

Table 2.1 Prevalence of open-angle glaucoma in adults in the United States

Age (years)	European-derived (%)	Blacks (%)
50–54	F: 0.89	F: 2.24
70–74	F: 2.16	F: 5.89
≥80	F: 6.94	F: 9.82

Notes:
F = female

There were no statistically significant differences in prevalence between males or females in European-derived, black or Hispanic ethnicities.

The prevalence rates in Hispanics were not significantly different from those for European-derived adults, but had lower prevalence compared to blacks, with an odds ratio of 0.41.

Overall, the black subjects had almost three times the prevalence rates of European-derived individuals.

Data from the Eye Diseases Prevalence Research Group [14].

European descent [14, 29, 42, 49], as seen in Fig. 2.2. The estimated incidence of OAG is 2–5 times higher for individuals of African descent compared to their European-derived counterparts.

Recently, results from nine years of follow-up from the Barbados Eye Studies showed that the nine-year incidence of POAG was 4.4% in this population of individuals predominantly of African descent. When including cases of probable and definite POAG, the incidence rose to 9.4% [31]. Studies of European-derived populations show the five-year incidence of definite glaucoma to be 0.5–0.6% and 1.1–1.8% for definite and probable cases of OAG [10, 38].

The Eye Disease Prevalence Research Group [14] conducted a meta-analysis of several studies on the prevalence of OAG in the world, and extrapolated that data to the United States census population to estimate the prevalence in the United States. They approximated that 1.57 million whites and 398,000 individuals of African descent have glaucoma in the United States, and in 2020 approximately 3.36 million Americans will have glaucoma, due to the rapidly aging population. The overall prevalence of OAG is 1.86%. In every age group, there was a higher prevalence of OAG in individuals of African descent compared with European-derived individuals (See Table 2.1).

It is uncertain why there is an increased risk of developing glaucoma among individuals of African descent, although genetic [12] or environmental factors have been suggested. The prevalence of OAG in African Americans in the Baltimore Eye Survey was 4.2%, while it was 7% in the Africans of the Barbados Eye study, and for the participants in the Barbados Eye Study with a mixed ancestry it was 3.3%, suggesting an influence of ancestral factors. Among the subpopulations of people of African descent, the prevalence is variable: highest in St. Lucia and Ghana (8.8% and 7.7%, respectively) and lower in Tanzania and South Africa (4.2% and 2.9%, respectively) [4, 34, 40, 47].

Several factors could be involved with the higher risk conferred to Africans. Physiologic differences in the optic disc or thinner corneas compared with their peers may be involved. Social differences including less access to health care may also be influential [2].

Asians have a lower risk of OAG compared to individuals of African descent, and show a prevalence similar to those of European descent. The prevalence of POAG in a Chinese population in the Liwan District was 2.1%, similar to the prevalence seen in Chinese Singaporeans [16, 20].

The prevalence of OAG in Latinos appears to be higher than in European-derived individuals. In the Los Angeles Latino Eye Study (LALES), the prevalence of glaucoma in predominantly Mexican-derived Latinos was 4.74%. Prevalence increased with age, with those 40–49 years of age having a prevalence of 1.32%, whereas for those greater than 80 years old it was 21.76%. An astounding 75% of individuals with OAG or OHT were previously undiagnosed [53]. Another study of Latinos found the overall prevalence of OAG to be 1.97%, with an increased prevalence with age (0.50% for those 41–49 years old to 12.63% for those ≥80 years old). Also, in this study, similar to LALES, 62% of individuals were previously not diagnosed with OAG [43].

Native Americans have not been studied as extensively as other US populations, but one study of Northwest American Indians showed some surprising results. Individuals from three tribes from Oregon, Washington and Idaho had a prevalence of glaucoma of 6.2%, and all of the affected individuals had normal-tension glaucoma [33].

2.2.6 Myopia

Although myopia is not classically included as a risk factor for glaucoma because of concerns over selection bias, prior clinic-based studies have identified myopia as a risk factor. The Blue Mountains Eye Study, a population-based study of white Australians, showed that moderate-to-high myopia (spherical equivalent of −3.00 D or greater) was associated with a two- to threefold increased risk of having glaucoma. The risk was higher (OR, 3.3) for moderate-to-high myopia than for low myopia (OR, 2.3) [36]. A similar association was found in a European-derived population in the US [56]. There also appears

to be an increased risk of glaucoma in myopic Chinese individuals. In another population-based study, Chinese with high myopia (greater than −6 D refractive error) were at higher risk of being diagnosed with glaucoma compared to the group consisting of all other refractive errors (odds ratio 2.28) [54]. The increased risk conferred by myopia does not appear to be related to IOP.

Mechanisms for the relationship between myopia and glaucoma have been postulated and include (1) increased susceptibility of myopic nerves to glaucomatous damage, (2) shearing forces across the lamina cribrosa by the sclera, (3) other connective tissue changes, or (4) a genetic link [54].

2.2.7 Other Risk Factors

Several studies have suggested a relationship between migraine and glaucoma, including the Blue Mountain Eye Study [41, 55]. In the Collaborative Normal Tension Glaucoma Study, the risk ratios for migraine, disk hemorrhage and female gender were 2.58, 2.72, and 1.85, respectively [11]. Vasospasm in the region of the optic nerve is considered to be the likely cause. However, other studies have not found evidence of a relationship between OAG and migraine headache [25].

Studies have been conflicting regarding the relationship of diabetes and risk of glaucoma. The Baltimore Eye Study found that diabetics had an increased IOP compared to nondiabetics, but that they had a lower risk for OAG [2]. However, this finding may be secondary to selection bias, since diabetics are more likely to be evaluated by an eye doctor and then diagnosed with glaucoma than nondiabetics. Alternatively, the Beaver Dam Eye Study found an increased risk of glaucoma in individuals with adult-onset diabetes [26].

The influence of blood pressure on the optic nerve is complex, and whether hypertension (HTN) increases the risk of OAG remains undetermined. Blood pressure influences optic nerve perfusion; however, the specific parameters that may be related to the development of glaucoma are unknown. While some studies have shown no clear association between blood pressure and OAG [23, 51], others have shown a positive relationship [3, 28, 37], while another has shown a reduced risk of OAG with HTN [32].

Elevated systemic blood pressure has been associated with higher IOP [3]. In the Beaver Dam Eye Study, elevated IOP was associated with increased systolic and diastolic blood pressures. They found a 0.21 mm Hg increase in IOP for a 10 mm Hg increase in systolic and 0.43 mm Hg increase in IOP for a 10 mm Hg increase in diastolic blood pressure [28]. However, the Blue Mountains Eye Study showed a 50% increased risk of OAG with HTN independent of IOP, especially in individuals with poorly controlled, treated HTN [37]. The mechanism by which HTN may cause OAG is unclear. It may be that sustained HTN causes microvascular damage, or impaired autoregulation, or that treatment of HTN causes nocturnal hypotensive episodes [37].

Another parameter of interest is pulse pressure, which is defined as the difference between systolic and diastolic blood pressure. Some studies have shown that a higher pulse pressure is associated with a higher prevalence of OAG [23]. Low diastolic blood pressure is not uncommon in the elderly, and this may result in a higher pulse pressure in the setting of arterial stiffness, which may also be present in the elderly. High pulse pressure may impair ocular autoregulation. With impaired autoregulation, vessels may not be able to respond to a low diastolic blood pressure in order to maintain perfusion, which then may result in ischemia and optic nerve damage [23].

Diastolic perfusion pressure is defined as the difference between diastolic blood pressure and IOP. Several studies have shown an increased risk of OAG with low diastolic perfusion pressure [3, 32, 51]. The Rotterdam study showed that for a population of individuals treated for HTN, a low diastolic perfusion pressure was associated with a lower risk of normal-tension OAG [23] and higher risk of high-tension OAG [23, 51]. In the setting of elevated IOP, higher blood pressure may be needed to maintain perfusion to protect the disc [23].

Treated HTN may be related to subtle changes in the optic disc, since individuals without glaucoma in the Thessaloniki Eye Study had increased cup area, increased cup-to-disc ratio and decreased rim areas compared with individuals with elevated diastolic blood pressure or normal, untreated diastolic blood pressure. Similar findings were also seen for individuals with low pulse pressure. These findings suggest that low diastolic blood pressure secondary to the treatment of HTN may be associated with optic nerve fiber loss and changes in the optic disc structure [52].

2.3 Primary Angle-Closure Glaucoma

In the year 2010, it is estimated that ACG will account for 26% of glaucoma worldwide, with a mean prevalence of 0.69%. By 2020 there will be 21 million people with ACG and 87% of them will reside in Asia. Due to the greater longevity of women and the higher prevalence of ACG in women, women are expected to comprise 70% of individuals with ACG [42].

Narrow angles are more prevalent in Asians than Europeans, and by 2010 it is estimated that primary angle-closure glaucoma will be responsible for about 50% of the global burden of blindness due to glaucoma [42], and the majority of these individuals will be in Asia [42, 46].

Whether evolution, genetics, migration patterns, or environmental factors are responsible for the higher prevalence of narrow angles in Asians remains uncertain.

While primary angle closure glaucoma (PACG) tends to be more common in Asians compared to Europeans, [42] POAG remains more common than PACG in most Asian populations. However, PACG is responsible for a disproportionate amount of blindness caused by glaucoma [16, 20].

2.3.1 Risk Factors

Female gender, older age, shallow anterior chamber, short axial length, small corneal diameter, steep corneal curvature, shallow limbal chamber depth, and thick relatively anteriorly positioned lens are risk factors for developing primary angle closure (PAC) [6, 17, 18, 21]. One of the most easily measured variables is the anterior chamber depth, and many studies have shown that shorter anterior chamber depth is related to a higher prevalence of PAC [21]. The most recent study regarding these anatomical differences compared contralateral eyes of patients who had an acute angle closure attack with controls. The contralateral eyes had shorter axial lengths, thicker lenses, shallower anterior chambers, steeper radii of corneal curvature and smaller anterior chamber volumes compared to controls. Despite these differences, there was not adequate predictive power to identify which contralateral eyes would develop ACG [18, 43].

Gonioscopy is the mainstay for diagnosing primary angle closure suspects (PACS), and PAC. The Framingham study, which predominantly included individuals of European descent, reported that 3.8% of eyes had angles with Shaffer grade ≤2 by gonioscopy, while 47.8% of a Vietnamese population in the US had similar Shaffer grading. In a Burmese population, the prevalence of anatomically narrow angles (as defined by ≤ 90° of visible posterior trabecular meshwork) was 5.7%. Individuals with anatomically narrow angles were more likely to be older than 50 years and female [6].

In Mongolia and Singapore, occludable angles were found in 6.4 and 6.3%, respectively, while [21] in a group of adult Chinese in the Liwan Eye Study, 11% had narrow angles. Twenty percent of these had peripheral anterior synechiae, indicating PAC [22].

The reasons for the higher prevalence of ACG in Asians are thought to be secondary to anatomical characteristics such as shorter axial lengths in Asians; however, all studies have not confirmed such racial anatomic differences [8, 21]. The increased prevalence of ACG in Asians may be explained by multiple risk factors or possible physiological differences [18, 44].

2.3.2 Prevalence

In Asian populations, the prevalence of PACS has been reported to be 1.4–10.1%, while that of PAC has ranged from 1.4 to 3.1%. Although PACG is approximately three times more common in Asian populations compared to European-derived populations [21], this prevalence varies by region within Asia. Mongolian and Chinese populations tend to be affected more, while variable prevalence is seen in Southeast Asia and India.

In a population in northern Mongolia, the prevalence of PACG was 1.4%, while the prevalence of gonioscopically occludable angles was 6.4% and the prevalence of POAG was 0.5% [15]. In a Burmese population, the prevalence of PAC (defined as anatomically narrow angle associated with peripheral anterior synechiae or elevated IOP) was 1.5%, and the risk of PAC was significantly greater in women [6]. In a population of Chinese 50 years of age and older in the Liwan district, the prevalence of PAC—based on (1) posterior trabecular meshwork not being visible for ≥270° and (2) IOP > 95th percentile of the normal population and/or presence of peripheral anterior synechiae or evidence of anterior segment ischemia after increased IOP—was 2.4% overall; however, it was three times higher in women (3.3%) than men (1.1%) and increased with age [20]. The prevalence of PACG in this population was 1.5%, with women again being affected significantly more than men (1.6% vs. 1.3%, respectively) [20]. In a Southern Indian population, for individuals 40 years of age or older, the prevalence of PACG was 1.08%, while the prevalence of occludable angles without ACG was 2.21% [9]. Most eyes had chronic ACG and 42% of individuals with PACG had blindness in one or both eyes.

To more fully understand the health burden of PACS and PAC, Thomas et al. calculated the number needed to treat (NNT) to prevent progression from PACS to PAC or from PAC to PACG. The NNT to prevent one person with PACS from progressing to PAC is six over five years, and the NNT to prevent one person with PAC from progressing to PACG is five over five years [48]. Given the potentially blinding consequences associated with untreated PACS or PAC, these relatively low NNTs reflect the real potential benefit of screening. However, in developing countries, population-based screening is challenging.

Alaska's northwestern Eskimos were shown to have a prevalence of glaucoma of 0.65%, with 10 of the 11 cases being PACG. In Eskimos older than 40 years of

age, PACG occurred at a rate of 2.65%, but women were affected almost four times as often as men, and there was a high prevalence of occludable angles (17%) [1].

The prevalence of PACG in European-derived people appears to be much lower compared to Asians, and has been reported to be 0.04% in the Beaver Dam study, 0.06% in Melbourne, 0.09% in Wales, 0.4% in Baltimore, 0.6% in North Italy [21].

Summary for the Clinician

- Glaucoma is the second leading cause of preventable blindness and is the leading cause of irreversible visual loss. By the year 2020 it is estimated that there will be almost 80 million people in the world with glaucoma. The majority of these individuals will have OAG. Of those with ACG, 70% will be women and 87% will be Asian. Bilateral blindness from glaucoma is projected to affect 11 million individuals worldwide by 2020.
- Risk factors for open-angle glaucoma include increased age, African or Latino ethnicity, family history, increased IOP, myopia, and decreased corneal thickness. Possible risk factors for OAG include diurnal intraocular pressure variation, long-term intraocular pressure variation, sleep apnea, Hispanic or Indian ethnicity, and migraine.
- Risk factors for angle-closure glaucoma include increased age, female gender, Asian ethnicity, shallow anterior chamber, short axial length, small corneal diameter, steep corneal curvature, shallow limbal chamber depth, and a thick or anteriorly positioned lens.
- Because 50% or more of those individuals with glaucoma are unaware of their diagnosis; more effort is needed to effectively screen high-risk groups and to educate society about the preventability and consequences of glaucoma.

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