Prevalence of Open-angle Glaucoma in Australia

The Blue Mountains Eye Study

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Purpose: The purpose of this study was to determine the prevalence of open-angle glaucoma and ocular hypertension in an Australian community whose residents are 49 years of age or older.

Subjects: There were 3654 persons, representing 82.4% of permanent residents from an area west of Sydney, Australia, who were examined. The population was identified by a door-to-door census of all dwellings and by closely matched findings from the national census.

Methods: All participants received a detailed eye examination, including applanation tonometry, suprathreshold automated perimetry (Humphrey 76-point test), and Zeiss stereoscopic optic disc photography. Glaucoma suspects were asked to return for full threshold fields (Humphrey 30–2 test), gonioscopy, and repeat tonometry.

Results: A 5-point hemifield difference on the 76-point test was found in 616 persons (19% of people tested). Humphrey 30–2 tests were performed on 336 *glaucoma suspects* (9.2% of population), of whom 125 had typical glaucomatous field defects. Two hundred three persons had enlarged or asymmetric cup–disc ratios (≥0.7 in 1 or both eyes or a cup–disc ratio difference of ≥0.3). Open-angle glaucoma was diagnosed when glaucomatous defects on the 30–2 test matched the optic disc changes, without regard to the intraocular pressure level. This congruence was found in 87 participants (2.4%), whereas an additional 21 persons (0.6%) had clinical signs of open-angle glaucoma but incomplete examination findings. Open-angle glaucoma was thus found in 108 persons, a prevalence of 3.0% (95% confidence interval [CI], 2.5–3.6), of whom 49% were diagnosed previously. An exponential rise in prevalence was observed with increasing age. Ocular hypertension, defined as an intraocular pressure in either eye greater than 21 mmHg, without matching disc and field changes, was present in 3.7% of this population (95% CI, 3.1–4.3), but there was no significant age-related increase in prevalence. The prevalence of glaucoma was higher in women after adjusting for age (odds ratio, 1.5; CI, 1.0–2.2). There was no sex difference in the age-adjusted prevalence of ocular hypertension.

Conclusions: These data provide detailed age and sex-specific prevalence rates for open-angle glaucoma and ocular hypertension in an older Australian population.
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Many large population-based studies have examined the prevalence of open-angle glaucoma (OAG). Whereas these mostly have included largely white communities, including the United Kingdom,[1,2] the United States,[3–6] Sweden,[7] Norway,[8] and the Netherlands,[9] a number of

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recent surveys have included Asian,[10] multiracial,[5] or black[11] communities, in which higher prevalence rates have been found. No previous population-based studies have reported the prevalence of glaucoma in Australia, whose population predominantly is white from northern European settlement since 1788. Descendants of the indigenous Aboriginal population comprise 1.5% of Australia's population.[12]

Some previous reports of glaucoma prevalence have included the finding of elevated intraocular pressure (IOP) as a diagnostic criterion.[8,13] However, it is recognized that elevated IOP is an inconsistent finding in OAG. Most recent studies have estimated prevalence of OAG independent of IOP level, characterizing cases of glaucoma with *normal* IOP levels as *normal-tension glaucoma.* Conversely, people with elevated IOP in the absence of typical glaucomatous visual field and optic disc signs have been termed to have *ocular hypertension* (OH).

Methods

Study Population

The Blue Mountains Eye Study (BMES) is a population-based survey of vision and common eye diseases in the Blue Mountains region, west of Sydney, Australia. This urban area has a stable and homogeneous population, representative of Australia for income and other measures of socioeconomic status,[14] but older compared with the New South Wales state average. The study was approved by the Western Sydney Area Health Service Human Ethics Committee. Written, informed consent was obtained from all participants.

The population has been described in a previous report.[15] In brief, a door-to-door census of the study region was conducted using maps developed by the Australian Bureau of Statistics.[16] All permanent noninstitutionalized residents with birthdates before January 1, 1943, were invited to attend a detailed eye examination at a local clinic. Nursing home residents were counted for comparison with the Australian census but are not included in this report. The number of eligible residents found differed from that of the Australian census conducted 3 months earlier by only six persons (0.15%).[14] Of the 4433 eligible persons, 3654 (82.4%) participated in the Eye Study from January 1992 to January 1994. Among 779 nonparticipants, 501 persons (11.3%) refused, of whom 353 (8.0%) permitted a brief interview and 148 persons (3.3%) refused both examination and interview. When eligible households were contacted to arrange appointments, 68 persons (1.5%) had died and 210 (4.8%) had moved from the area. Thus, a total of 278 persons (6.3%) identified in the census could not be examined. After this group was excluded, the response rate was 87.9%, which compares favorably with most population-based glaucoma surveys,[5,6,9] although it is not as high as that of the recent Irish study.[2]

Data Handling and Statistical Methods

Data were entered into computer databases using automatic skips and range checks. Statistical Analysis System (SAS, Statistical Analysis System for Windows; SAS Institute, Inc, Cary, NC) was used for tabulations and statistical analyses, including chi-square test, Mantel–Haensel chi-square statistic, and logistic regression analyses. In the logistic regression analyses, age was used as a continuous variable. All confidence intervals (CI) presented are 95% CIs.

Procedures

At the clinic visit, a detailed questionnaire was administered covering demographic data, medications, family history, and medical history of systemic disorders. Problems with vision, past eye diseases or eye treatment, and ocular symptoms were included. The detailed eye examination included subjective refraction, using the Beaver Dam Eye Study modification of the Early Treatment Diabetic Retinopathy Study protocol and logMAR chart.[17,18]

The visual field component of the glaucoma examination was conducted in two phases. In the first phase, subjects had a 30° suprathreshold visual field screening test (Humphrey 76-point test) of both eyes performed, applanation tonometry and stereo optic disc photography. The Humphrey Visual Field Analyzer 630 with StatPac 2 (Humphrey Instruments, Inc, San Leandro, CA) with appropriate near correction was used. In the second phase, a subset of participants were asked to return within 4 weeks for a full-threshold Humphrey 30–2 visual field test, gonioscopy, and repeat tonometry.

Applanation tonometry using a Goldmann tonometer (Haag-Streit, Bern, Switzerland) was performed using a drop of Fluress (Barnes-Hind). A single measurement was taken but repeated if judged unreliable. Anterior chamber width was assessed using the van Herick[19] method; anterior chamber, iris, and lens abnormalities were recorded; and lens photographs were taken. After pupil dilatation with tropicamide 1.0% and phenylephrine 10%, stereoscopic retinal and optic disc photographs were taken using a Zeiss fundus camera (FF3—Carl Zeiss, Oberkochen, Germany) and Kodachrome 25 film processed by Kodak (Eastman Kodak, Rochester, NY). Each participant had stereoscopic 30° color retinal photographs taken centered on the optic disc (Diabetic Retinopathy Study field 1), macula (field 2), and nonstereo photographs of modified fields 3 (lateral macula), 4 (upper temporal arcade), and 5 (lower temporal arcade).[20] Thirty-five millimeter slide transparencies were mounted in clear plastic sheets, allowing close apposition of the stereo pairs. Stereoscopic assessment of the optic disc in all participants was conducted by an ophthalmologist, who assessed the disc and field results and selected participants to be invited back for 30–2 tests.

Optic disc parameters subsequently were measured from the stereo optic disc photographs using a method described and validated previously.[21,22] This method used a Donaldson stereoviewer with a plastic template (Pickett circles no. 1203) placed under one of the stereo pair. Vertical cup–disc ratios were calculated from disc measurements, after excluding the peripapillary halo, taking care not to include areas of peripapillary atrophy. In measuring vertical diameters, the longest diameter in a range

between clock hours of 11 and 1 to 5 and 7 was taken and then used to measure both disc and optic cup.

The optic cup was determined by its contour, with the outer margin taken to be the point where its wall met the plane of the disc surface. The path of vessels helped to define the contour of the neuroretinal rim. The presence of rim thinning and extension of the cup to the superior or inferior rim of the disc was noted. Other signs recorded included presence and extent of peripapillary atrophy, hemorrhage crossing the disc margin, or a notch in the cup. All photographs were graded by one or both of two graders. One grader spent a period of training in Madison, WI. Adjudication of discrepancies was provided by the chief investigator (PM). Intraobserver and interobserver reliability was assessed in a masked fashion, on a random subsample of 100 eyes, using the intraclass correlation coefficient method.[23] The interobserver intraclass correlation coefficient was 0.91 for disc measurements, 0.89 for cup measurements, and 0.83 for cup–disc ratios. This can be interpreted as excellent agreement[24] between the two graders.

Glaucoma Suspects

Participants were defined as glaucoma suspects and asked to return for a 30–2 test if they had a history of glaucoma or OH, a hemifield difference of 5 or more points on the 76-point screening test, or optic disc signs suggesting glaucoma (cup–disc ratio 0.7 or greater, rim thinning or visible nerve fiber layer loss, or cup–disc asymmetry between the two eyes of 0.3 or greater). In assessing a hemifield difference on the 76-point test, the blind spot and the outer 30° test points were not counted, except in the nasal field. Subjects judged to have glaucomatous visual field loss on the 30–2 test were requested to return for repeat applanation tonometry and gonioscopy by the study ophthalmologist (PM) using a Goldmann 3-mirror contact lens. The Shaffer[25] grading system was used at gonioscopy. Angle pigmentation and structural angle abnormalities were assessed. Shaffer grade 1 or less was graded as angle-closure glaucoma.

Classification of 30–2 Visual Fields

All 30–2 fields were assessed by the study ophthalmologist in a masked fashion for typical glaucomatous features. The minimum diagnostic criteria required were an abnormal Humphrey 30–2 Glaucoma Hemifield Test[26–28] plus one or more of the following field defects that could not be explained on the basis of ocular or neurologic cause: (1) arcuate or paracentral scotoma, at least four contiguous points on pattern deviation plot depressed at P less than 0.5% level; (2) nasal step at least two horizontal points in width (10°) on the pattern deviation plot depressed at P less than 0.5% level; or (3) advanced glaucomatous field loss (hemispheric or severe generalized field loss, with residual temporal or central islands).

Diagnosis of Open-angle Glaucoma and Ocular Hypertension

Open-angle glaucoma was diagnosed if typical glaucomatous visual field loss on the Humphrey 30–2 test were present, combined with matching optic disc rim thinning and an enlarged cup–disc ratio (≥0.7) or cup–disc asymmetry between the two eyes of greater than or equal to 0.3, and if gonioscopy showed no signs of angle closure, rubeosis, or secondary glaucoma, other than pseudoexfoliation. Field printouts and disc photographs of OAG suspects were assessed in a masked fashion by two glaucoma specialists and two ophthalmologists conducting other population-based eye surveys in Australia. Consensus for the diagnosis of OAG by the two glaucoma specialists for cases with complete documentation was required. Ocular hypertension, using the usual clinical cut-point, was defined as an IOP greater than 21 mmHg in either eye, after excluding cases of OAG and cases of angle-closure or secondary glaucoma.

Results

Abnormal Visual Fields

There were 3241 participants (89% of those examined) who completed the 76-point test in at least 1 eye (Table 1). Of the 413 persons who did not complete this test, 37 (9%) had poor vision in both eyes, 50 (12%) could not comprehend or concentrate during the test, 25 (6%) had physical disabilities, 41 (10%) were examined in their home, and 132 (32%) were unwilling to stay for a full examination. Machine breakdown prevented 128 (31%) of participants from completing the test. Where possible, participants identified as glaucoma suspects from other signs were asked to return for perimetry if they had been unwilling to stay for the full examination or machine breakdown had occurred.

A hemifield difference (HD) of 5 points or more in 1 or both eyes was found in 616 persons (19.0% of persons completing 76-point tests). Invitations were given to 352 participants to return for the 30–2 test. In most cases, this was because of the HD, but some had optic disc signs suggesting glaucoma, without an HD on the 76-point test. Three hundred thirty-six participants, or 9.2% of those examined, completed the 30–2 test. For 12 glaucoma suspects who did not return as requested, recent 24–2 or 30–2 field results were obtained from the subject's treating ophthalmologist. The remaining subjects with an HD on the 76-point test were not asked to complete a 30–2 test because their field loss was assessed as nonglaucomatous and the optic disc appearance was considered normal. A focal defect in the outer peripheral field (often superotemporal) was present in 44%, whereas 24% had generalized constriction, 20% had diffuse noncontiguous points missing, 4% had neurologic homonymous or bitemporal defects, and 8% had specific retinal causes for pseudoglaucomatous field loss. These 8% included branch or central retinal vein occlusions, retinal coloboma, traumatic retinopathy, retinitis pigmentosa, or retinal detachment.

Grading of the 30–2 fields showed 125 participants with typical glaucomatous field defects (Table 2). Among these, 10 participants had specific nonglaucomatous causes evident, including definite anterior ischemic optic neuropathy, branch retinal vein occlusion, optic disc dru-

Table 1. Proportion of Participants Completing Visual Field Tests, Optic Disc Photographs, and Applanation Tonometry

	No.	(%)
Visual Fields		
Completed Humphrey 76-point screening test		
1 or both eyes	3241	(88.9)
Both eyes	3173	(86.8)
Had Bjerrum or confrontation field testing	64	(1.8)
Requested to return for Humphrey 30-2 field test	352	(9.6)
Completed Humphrey 30-2 field test	336	(9.2)
No visual field tests performed (either eye)	349	(9.5)
Optic Disc Photographs		
Gradable photographs taken		
1 or both eyes	3582	(98.0)
Both eyes	3568	(97.6)
No gradable disc photographs taken (either eye)	72	(2.0)
Applanation Tonometry		
Applanation tonometry performed, reliable		
1 or both eyes	3626	(99.2)
Both eyes	3617	(99.0)
No applanation tonometry (either eye)	12	(0.3)
Total	3654	(100.0)

sen, tilted disc, congenital anomaly, disc coloboma, and chorioretinitis. In 25 patients, the optic disc appearance was assessed as being within normal limits, without definite rim thinning, or any other pathologic features.

Intraocular Pressure

Applanation IOP could be measured reliably in 1 or both eyes for 3641 participants (99.6%). In 13 participants, IOP was not measured or was considered unreliable for both eyes. In a further eight right and seven left eyes, IOP could not be measured or was considered unreliable due to enucleation, rubeosis, or phthisis (Table 1). After these eyes were excluded, mean IOP for right eyes was 16.1 mmHg, median was 16.0 mmHg, and standard deviation was 2.9 mmHg, whereas for left eyes, mean IOP was 16.0 mmHg, median was 16.0 mmHg, and standard deviation was 2.9 mmHg. The distribution of IOP in right

Table 2. Examination Characteristics Indicating Glaucoma among Participants Examined

		Age Group (yrs) (no. at risk)									
		<60 (1020)		*60–69 (1309)*		*70–79 (959)*		*80+ (367)*		*Total (3654)*	
	Diagnostic Sequence (either eye)	*No.*	*(%)*	*No.*	*(%)*	*No.*	*(%)*	*No.*	*(%)*	*No.*	*(%)*
1	5-point hemifield defect on Humphrey 76-point screening visual field test	100	(9.8)	202	(15.4)	226	(23.6)	88	(24.0)	616	(16.9)
2	Typical glaucomatous visual field defect on Humphrey 30-2 field test	7	(0.7)	23	(1.8)	60	(6.3)	35	(9.6)	125	(3.4)
3	Cup:disc ratio 0.7 or over (either eye) or cup:disc ratio difference of ≥ 0.3 between the two eyes	23	(2.3)	48	(3.7)	83	(8.7)	49	(13.4)	203	(5.6)
4	Matching glaucomatous visual field defect (2) and optic disc criteria (3): "definite open-angle glaucoma"	3	(0.3)	14	(1.1)	40	(4.2)	30	(8.2)	87	(2.4)
5	Incomplete data for (2) and (3), but clinical diagnosis: "probable open-angle glaucoma"	1	(0.1)	3	(0.2)	5	(0.5)	12	(3.3)	21	(0.6)
6	Total cases of definite or probable open-angle glaucoma (4) + (5)	4	(0.4)	17	(1.3)	45	(4.7)	42	(11.4)	108	(3.0)

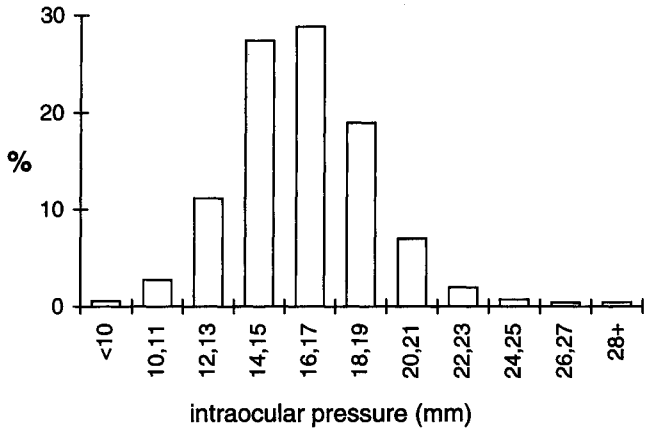

Figure 1. Distribution of intraocular pressure in 3626 right eyes (mean, 16.1 mmHg).

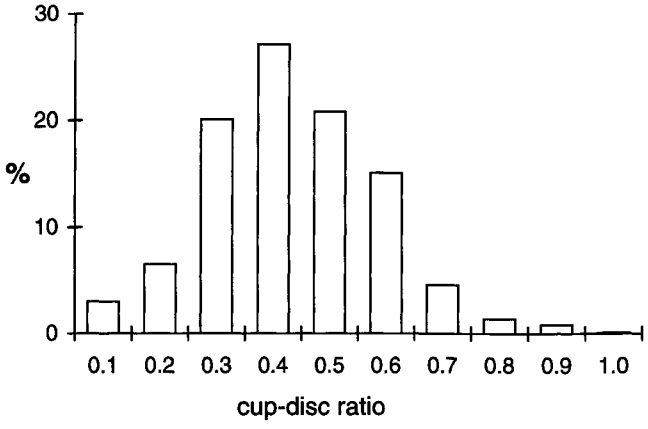

Figure 3. Distribution of vertical cup:disc ratio in 3550 right eyes (mean, 0.43).

eyes is shown in Figure 1. As shown in Figure 2, the prevalence of glaucoma increased sharply for IOPs greater than 23 mmHg, after the higher IOP of the two eyes was taken.

Optic Disc Photographs

From the 3654 participants, 3568 (97.6%) had optic disc photographs of both eyes, 14 (0.4%) had photographs of 1 eye only, and in 72 (2.0%), no optic disc photographs were taken (Table 1). Included were 39 frail, elderly persons who were examined during a home visit. For the other 33 persons, photographs were not taken because of refusal (n = 12), frailty or wheelchair (n = 9), camera malfunction (n = 5), dementia (n = 4), or poor pupil dilatation (n = 3). In 55 persons, photographs could be graded for only 1 eye. The distribution of cup–disc ratio is shown in Figure 3 for right eyes. One hundred seventy-eight participants had a cup–disc ratio of greater than or equal to 0.70 in 1 (n = 117) or both (n = 61) eyes. Cup–disc ratio asymmetry of greater than or equal to 0.3 was found in an additional 25 persons. Thus, 203 participants were classified as glaucoma suspects on the basis of a suspicious optic disc appearance in 1 or both eyes (5.6% of population).

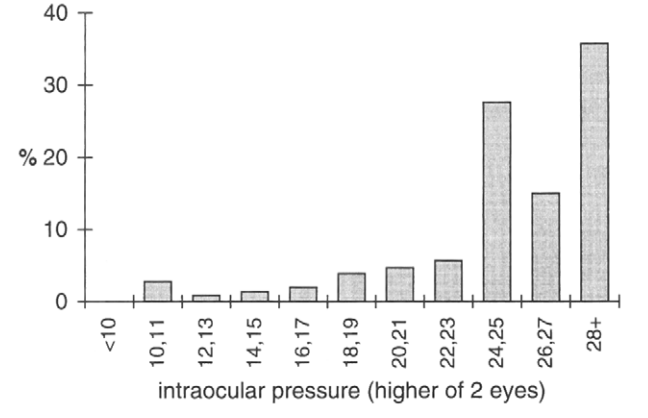

Figure 2. Prevalence of glaucoma at each intraocular pressure level (2-mmHg intervals), taking the higher pressure of the two eyes.

Patients with Open-angle Glaucoma

Congruous glaucomatous visual field and optic disc signs were present in 87 participants, here termed *definite* OAG. Open-angle glaucoma was diagnosed from the clinical features in an additional 21 participants who had incomplete signs or documentation; these cases are termed *probable* OAG. In six patients, advanced glaucomatous cupping was found, but visual fields were not performed because of poor vision from macular degeneration or stroke. In eight patients, a glaucomatous field defect was present on the 30–2 test with matching optic disc cupping and rim thinning, but the cup–disc ratio of the affected eye was measured between 0.60 and 0.69. Most had small optic disc diameters. In four persons, including three women older than 90 years of age, advanced glaucomatous cupping was observed during a home visit, but no disc photographs or visual fields were obtained. Gonioscopy was performed in most of these 21 persons with probable OAG and the results were normal.

Age, Sex, and Treatment Characteristics of Patients with Open-angle Glaucoma

Definite or probable OAG was diagnosed in 108 participants, a prevalence of 3.0% (CI, 2.5–3.6). An exponential increase in prevalence was found for increasing 10-year age groups, illustrated in Figure 4. The prevalence of glaucoma was 0.4% for people younger than 60 years of age, 1.3% for people 60 to 69 years of age, 4.7% for people 70 to 79 years of age, and 11.4% for people 80 years of age or older (chi-square$_{trend}$ = 115.9, 1 df, $P <$ 0.0001). Age- and sex-specific prevalence rates are shown in Figure 5. Women had a higher prevalence of glaucoma for each age group, but this was of borderline significance after adjusting for age (odds ratio, 1.55; CI, 1.03–2.32) using logistic regression. If cases with matching and complete data only are considered, termed definite glaucoma, the prevalence was 2.4%, with a rate of 0.3% for people

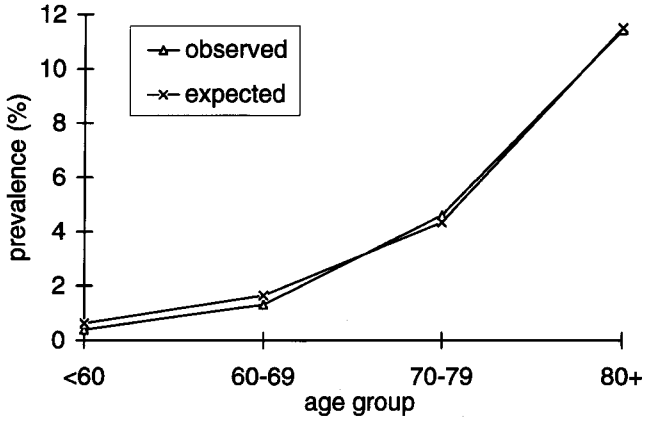

Figure 4. Observed prevelance of open-angle glaucoma compared with prevalence expected if there is an exponential increase with age.

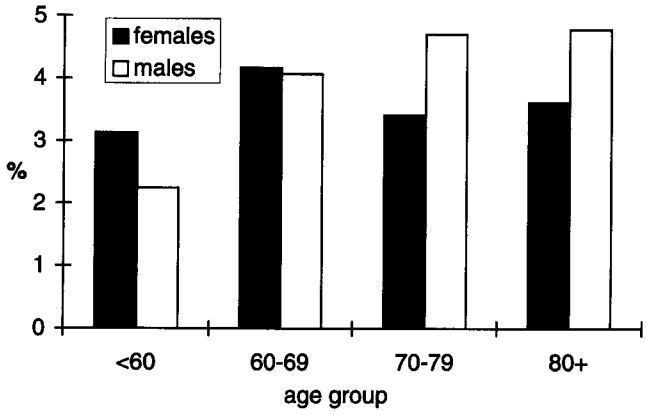

Figure 6. Age- and sex-specific prevalence of ocular hypertension in 3654 participants.

younger than 60 years of age, 1.1% for people 60 to 69 years of age, 4.2% for people 70 to 79 years of age, and 8.2% for people 80 years of age or older. These could be considered minimum prevalence estimates for the population.

The 108 glaucoma cases included 53 persons (49%) with previously diagnosed glaucoma and 55 persons (51%) who previously were undiagnosed. The previously diagnosed group included 13 persons (27%) with a history of glaucoma surgery. Elevated IOP (>21 mmHg) in 1 or both eyes was found in 13 (25%) of those diagnosed previously, with almost all receiving topical therapy. However, a similar low proportion, 14 (26%) persons previously undiagnosed with glaucoma, had elevated IOP. An elevated IOP was found in an additional five persons (9%) on a second visit. Pseudoexfoliation of the lens capsule was found in 1 or both eyes of 79 participants (prevalence, 2.2%; CI, 1.7–2.7) and in 13 (12.0%) of the persons diagnosed as having OAG.

Age, Sex, and Treatment Characteristics of Patients with Ocular Hypertension

Ocular hypertension was found in 135 persons, a prevalence of 3.7% (CI, 3.1–4.3). Unlike glaucoma, there was no significant rise in the prevalence of OH with increasing age. The prevalence of OH was 2.8% for people younger than 60 years of age, 4.1% for people 60 to 69 years of age, 4.0% for people 70 to 79 years of age, and 4.1% for people 80 years of age or older (chi-square$_{trend}$ 1.9, 1df, P = 0.17), as shown in Figure 6. The prevalence was 3.6% for women and 3.8% for men. This small sex difference was not significant, after adjusting for age (odds ratio, 0.95; CI, 0.67–1.35) using logistic regression (Fig 7). In view of the distribution of IOP found in our population, with mean IOP plus or minus 2 standard deviation indicating a *normal range* of 10 to 22 mmHg, OH alternately was diagnosed in cases with IOP greater than 22 mmHg in either eye and termed *OH2*. OH2 was found in 86 persons, a prevalence of 2.4% (CI, 1.9–2.9), and there also was no significant age-related increase in prevalence.

An additional 37 participants gave a history of glaucoma and were receiving topical therapy, including 1 who had past glaucoma surgery. These people had an IOP in both eyes less than 22 mmHg when examined and had no definite matching optic disc or visual field changes of glaucoma. Correspondence from treating ophthalmologists was received for most cases and indicated elevation of IOP in the past. Thus, a total of 172 participants (4.7%

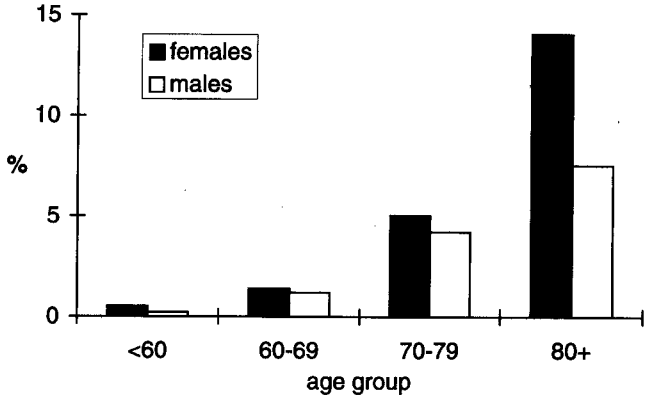

Figure 5. Age- and sex-specific prevalence of glaucoma in 3654 participants.

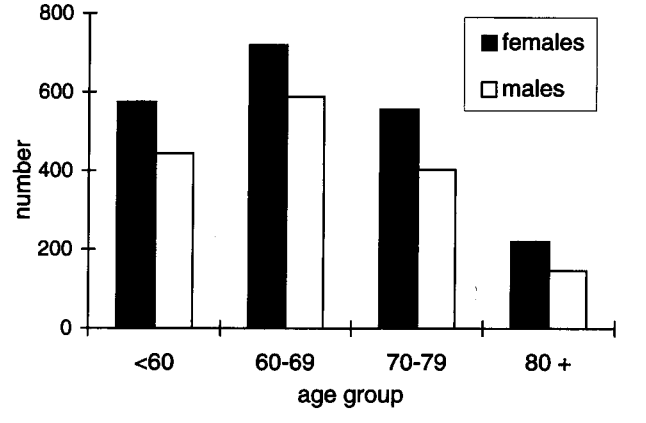

Figure 7. Age–sex distribution of 3654 participants.

of the population) may have OH, using the usual clinical definition. In this group, six (3.5%) persons had signs of pseudoexfoliation in one or both eyes.

Relation of Glaucoma to Intraocular Pressure

The prevalence of definite and probable glaucoma was assessed in relation to IOP, taking the higher pressure of the two eyes (IOP_{max}). In Figure 2, this is shown for increasing 2 mmHg IOP intervals from 10 mmHg. There were no participants with IOP_{max} less than 10 mmHg, but two participants had IOP_{max} of 10 to 11 mmHg; both had previous glaucoma surgery. The prevalence of glaucoma increased steadily from 0.9% for IOP_{max} 12 to 13 mmHg to 5.7% for IOP_{max} 22 to 23 mmHg and then increased steeply to 39% for participants with IOP_{max} greater than or equal to 28 mmHg, with the rise highly significant ($P < 0.0001$). The IOP_{max} was elevated to greater than or equal to 22 mmHg for only 25% of participants with glaucoma, partly explained by previous glaucoma surgery or current use of topical glaucoma treatment in 53 participants.

Angle-closure and Secondary Glaucoma in the Population

A history of angle-closure glaucoma, treated by surgical iridectomy or laser iridotomy, was given by nine persons, and in one person angle-closure signs were found at examination (prevalence, 0.3%). Details of the past cases were confirmed after correspondence with the treating ophthalmologist. History or signs of rubeotic glaucoma were present in an additional four persons (0.1% of the population) and other types of secondary glaucoma in two persons (prevalence, 0.05%). Signs and a history of typical anterior ischemic optic neuropathy were present in four persons (0.1%).

Discussion

Comparison of the age-specific prevalence of OAG in different countries poses difficulty because past studies examining glaucoma prevalence have used a variety of definitions[29] and different age ranges. A number of early studies also incorporated elevated IOP in the diagnosis.[8,13,30] In the current study, matching glaucomatous visual field and optic disc changes were required for a diagnosis of definite OAG, irrespective of IOP level or whether the participant was receiving glaucoma treatment. Table 3 summarizes data from selected population-based studies of glaucoma in predominantly white communities, including the most recent surveys from the United States and Europe.[1,2,5,6,9,31] Because of the steep rise in glaucoma prevalence with increasing age found in most studies, comparisons are valid only within similar age groups.

The current study (BMES) found an overall higher prevalence of definite OAG (2.4%) than did the three large U.S. studies, Framingham, 2.2%[31]; Beaver Dam,

Table 3. Comparison of Age-specific Glaucoma Prevalence Rates in Selected Population-based Studies of Predominantly White Communities

	Ferndale, UK[1] (1966)	Framingham,[32] US (Method I, 1977)	Baltimore,[5] US (whites, 1991)	Beaver Dam,[6] US (1992)	Roscommon, Ireland[2] (1993)	Rotterdam, The Netherlands[9] (1994)	Current Study
Diagnostic criteria for open-angle glaucoma	Definite disc + Goldmann perimetry defect	Disc changes + Goldmann perimetry defect (method III)	Definite disc or nerve fiber layer + Goldmann perimetry defect	Definite disc + automated perimetry defect (including "probable glaucoma")	Definite disc + automated perimetry defect (including incomplete cases)	Goldmann perimetry defect + disc or IOP	Definite disc + automated perimetry defect (including "probable glaucoma")
Age range of subjects (yrs)	40–75	52–85	40–85+	43–86	50–80+	55–85+	49–97
Subjects (response)	4231 (92%)	2675 (67%)	5308 (75%)	4926 (83%)	2186 (99%)	3062 (71%)	3654 (82%)
Ascertainment	Census	Census	Census	Census	Electoral register	Municipal registry	Census
Age Group (yrs)							
40–44	0.0		0.9				
45–49				0.2 (0.2)			
50–54	0.6		0.4		0.7	0.2	0.2 (0.4)
55–59		1.1 (1.4)		0.7 (1.3)		0.2	
60–64	0.8		0.9		1.8	0.9	1.1 (1.3)
65–69		3.4 (5.1)		0.6 (2.7)		1.8	
70–74	1.3		2.9		3.2	1.6	4.3 (4.7)
75–79		3.0 (7.2)		1.6 (6.3)		3.1	
80–84			2.2		3.1	3.3	8.2 (11.4)
85+	0.4	2.2 (3.3)	1.3	0.7 (2.1)	1.9	1.1	2.4 (3.0)

IOP = intraocular pressure.

2.1%[6]; and for white participants in the Baltimore Eye Survey, 1.3%, adjusted for nonresponse.[5] However, these three studies included a younger population than in the BMES. The overall rate also was higher than in two recent European population-based glaucoma prevalence studies: Roscommon, west Ireland, 1.9%,[2] and Rotterdam, 1.1%.[9] These studies examined a similar age range to our study, but with a smaller proportion in the oldest age group.

When definite and probable cases of OAG were combined, similar rates were found in two other studies for people younger than 65 years of age (1.4% in Framingham, 1.3% in Beaver Dam, and 1.2% in the Blue Mountains; chi-square$_{2df}$ 4.1, $P = 0.13$). For people 65 to 74 years of age, rates also were comparable for two studies (2.7% in Beaver Dam, 1.3% in Rotterdam, and 2.0% in the Blue Mountains; chi-square$_{2df}$ 5.3, $P = 0.07$). For people 70 to 79 years of age, rates were quite similar for two other studies (2.9% in Baltimore and 3.2% in Roscommon, compared with 4.7% in the Blue Mountains; chi-square$_{2df}$ 2.5, $P = 0.28$).

Our study found an exponential trend in the prevalence of OAG among people in the oldest age groups (Fig 4). This trend is less marked, although also present in the reports of some previous population-based studies. For people 75 to 85 years of age, our study found combined definite and probable glaucoma present in 8.7% of participants, which is close to the prevalence found in two other studies (7.2% in Framingham and 6.3% in Beaver Dam; chi-square$_{2df}$ 0.7, $P = 0.69$). In only two other studies has a large sample of people 85 years of age or older been examined (Rotterdam and Roscommon). In Roscommon, OAG prevalence for this age group was not stated, whereas in Rotterdam, the prevalence was only 3.3%, compared with 10.2% in our study.

Although the Roscommon study was reported as achieving a high response (99.5%), this study used an electoral register rather than door-to-door census for population ascertainment, a method that may not be as complete for older or frail individuals. Further, in Roscommon, 43% of subjects had no automated perimetry or other field tests performed. The use of IOP and disc criteria alone has been reported to have low sensitivity.[32] By comparison, 95% of participants had automated fields of at least one eye in Beaver Dam, 90% in Baltimore, and 89% in BMES. These two factors could have resulted in a lower OAG prevalence in Roscommon. The failure to perform visual fields in 11% of participants in the current study may have resulted in a small prevalence underestimate for OAG.

Methodologic differences in the criteria chosen for the final diagnosis of glaucoma also could partly explain the differences found. In Rotterdam, glaucoma suspects were defined by the presence of field defects on Humphrey suprathreshold automated perimetry, as in our study. In both studies, a similar proportion of subjects failed this test, 18% in Rotterdam and 19% in the BMES, despite some differences in the criteria chosen for failure. Similarly, 20% of subjects in Beaver Dam failed the suprathreshold screen using the Henson CFS 2000 perimeter (Keeler Instrument Corporation, Broomall, PA). In both Rotterdam and Baltimore studies, confirmation of glaucomatous field loss required manual Goldmann perimetry, the previous *gold standard*, whereas full threshold automated perimetry (Humphrey 30–2 test) was used as confirmation in the BMES. In recent years, threshold automated perimetry has become the new standard for visual field testing in clinical practice, effectively replacing manual Goldmann perimetry.[28] The Humphrey 30–2 and 24–2 tests now could be considered second-generation gold standards. Threshold automated perimetry may be more sensitive in detecting glaucomatous field loss than is manual Goldmann perimetry. In a recent report, threshold automated perimetry, particularly the glaucoma hemifield test, was found to detect visual field loss before manual Goldmann perimetry.[28]

Although there is substantial geographic variation in the prevalence of pseudoexfoliation,[33] it is difficult to assess the contribution of this sign to OAG prevalence from the reports of the other population-based glaucoma studies. In most published studies, neither pseudoexfoliation inclusion nor its prevalence has been stated. The population prevalence of pseudoexfoliation was 2.2% in the BMES compared with 1.3% in Roscommon and 1.6% in a U.S. study.[34] Twelve percent of glaucoma in the BMES was associated with pseudoexfoliation, which compares with much higher rates found in Scandinavian countries.[8,35]

The mean IOP for right eyes was 16.1 mmHg, which is close to that found in Beaver Dam (15.2 mmHg),[6] Framingham (17.0 mmHg),[31] Baltimore (17.4 mmHg),[36] and Wales (16.3 mmHg).[1] The lower mean IOP found in Rotterdam (14.6%) may have been influenced by the oral glucose load given to participants.[9] However, the prevalence of OH (3.7%) compares closely to that found in many other studies, including the Roscommon study (3.6%).[2] Both this and our study found no age-related increase in the prevalence of OH. The mean cup–disc ratio of 0.43 measured from stereo disc photographs was higher in the BMES than in other prevalence studies, 0.36 in Beaver Dam,[6] and 0.3 in Rotterdam (clinical assessment),[9] but was similar to a large clinic study, 0.42.[37] It seems unlikely that this difference would have altered significantly the glaucoma prevalence rates found.

A relatively low proportion (25%) of glaucoma cases had elevated IOP, although this may not be surprising given the snapshot nature of a single presenting IOP measure, which provides no information about peak or mean IOP or the duration of any elevation. The steady increase in OAG prevalence evident with increasing IOP_{max} and the steep rise in risk with IOP_{max} levels above 23 mmHg suggests a causal relation, particularly at high IOP levels. This trend is similar to that in Baltimore,[38] but they found overall lower rates for glaucoma among whites than in our study and confirms the relation of elevated IOP to OAG. The "continuous nature of the IOP–glaucoma relationship" found in Baltimore was confirmed in our study, and we agree that there is no clear IOP level to "distinguish between the so-called high- and low-tension-glaucomas."[38]

In the current study, 51% of people with OAG previously were undiagnosed, a figure remarkably similar to that found in Rotterdam (53%),[9] Roscommon (49%),[2] Baltimore (50% among whites),[38] and 70% in Wales,[1] when "LTG cases"

were included, despite the overall differences in glaucoma prevalence found in these studies. The current study found that the majority of people with newly diagnosed OAG 41 (75%) had a presenting IOP less than 22 mmHg, which compares with 55% in Baltimore[38] and 39% in Rotterdam.[9] This finding emphasizes the low yield likely from glaucoma screening that includes only a single IOP measurement, now shown in many studies to have low diagnostic sensitivity and specificity.[39]

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