Hypertension, Diabetes, and Longitudinal Changes in Intraocular Pressure

Anselm Hennis, MRCP(UK), PhD,[1,2,3] Suh-Yuh Wu, MA,[3] Barbara Nemesure, PhD,[3] M. Cristina Leske, MD, MPH,[3] for the Barbados Eye Studies Group[2,3,4]

Purpose: Diabetes and hypertension are recognized risk factors for raised intraocular pressure (IOP). This report examines the longitudinal relationship of hypertension and diabetes to a 4-year IOP change in a black population with high prevalence of these conditions.

Design: Population-based cohort study of a simple random sample of residents of Barbados, West Indies, aged ≥40 years.

Participants: A total of 2996 persons without open-angle glaucoma or receiving IOP-lowering medication at baseline.

Methods: Participants underwent standardized examinations including applanation tonometry, measurement of blood pressure, and anthropometric indices; a detailed interview; various ocular measurements; and venipuncture for glycosylated hemoglobin (GHb). Diabetes was defined by self-reported physician diagnosis and hypertension by blood pressure ≥140/90 mmHg and/or treatment history.

Main Outcome Measures: The 4-year person-based IOP change between baseline and follow-up was defined as the more positive IOP difference in either eye.

Results: An IOP >21 mmHg at baseline was more likely in black and in mixed (black and white) participants (age-gender adjusted odds ratio [OR], 3.9 and 3.8, respectively) than in whites. Similarly, these groups had more hypertension (age-gender adjusted OR, 2.4 and 2.1, respectively) and diabetes (age-gender adjusted OR, 3.9 and 1.7, respectively) than did whites. Mean IOP in black participants increased by 2.5 (standard deviation, 3.9) mmHg over 4 years. Multiple regression analyses showed that baseline diabetes history and hypertension, as well as older age, elevated GHb, higher blood pressures, and lower baseline IOP were associated with a 4-year increase of IOP. The association between diabetes history/GHb and IOP increase became borderline/nonsignificant when persons who underwent cataract surgery during follow-up were excluded.

Conclusions: This report provides new data on the relationship of systemic factors to longitudinal increases in IOP in an African-origin population. Results highlight the increased risk of elevated IOP in populations with high prevalences of diabetes and hypertension. *Ophthalmology 2003;110:908–914 © 2003 by the American Academy of Ophthalmology.*

Elevated intraocular pressure (IOP) is a major risk factor for the development of primary open-angle glaucoma (OAG).[1] Cross-sectional studies confirm positive associations between raised IOP and several factors, such as increased age,[2–8] elevated blood pressure (BP),[6,8–13] diabetes or elevated glycosylated hemoglobin,[5,6,11,14–16] obesity,[3,5,6,10,17,18] and glaucoma family history.[5,6] Of these factors, hypertension and diabetes have been consistently linked to IOP in most of the populations studied, but the underlying mechanisms remain unclear. Both conditions are highly prevalent among westernized black populations, with hypertension and diabetes affecting as many as 20% and 10% of all adults aged 20 years and older, respectively,[19–21] and contributing significantly to the burden of ill health and mortality. An evaluation of the impact of hypertension and diabetes on IOP is particularly relevant in these populations, who also have a high prevalence and incidence of OAG.[4,22,23] Prospective studies might assist our understanding of the links of hypertension and diabetes to subsequent changes in IOP, thereby providing clues to the etiology. This report examines longitudinal associations of BP, diabetes, and IOP in the predominantly black population of the Barbados Eye Studies. The aim was to determine whether hypertension and diabetes were related to longitudinal changes in IOP among participants without OAG at baseline.

Originally received: September 17, 2001.
Accepted: October 30, 2002. Manuscript no. 210788.

[1] School of Clinical Medicine & Research, University of the West Indies, Barbados, West Indies.

[2] Ministry of Health, Barbados, West Indies.

[3] Stony Brook University, School of Medicine, Stony Brook, New York.

[4] The John Hopkins University School of Medicine, Baltimore, Maryland.

Supported by grants EY07625 and EY07617 from the National Eye Institute, Bethesda, Maryland.

Reprint requests to M. Cristina Leske, MD, MPH, Department of Preventive Medicine, University Medical Center at Stony Brook, HSC L3 086, Stony Brook, NY 11794-8036.

Material and Methods

The Barbados Eye Study (BES, 1988–1992) measured the prevalence of the major causes of visual loss and evaluated related risk

Published by Elsevier Science Inc.

ISSN 0161-6420/03/$–see front matter
doi:10.1016/S0161-6420(03)00075-7

Table 1. Comparisons of Baseline Characteristics between Barbados Incidence Study of Eye Diseases Participants and Nonparticipants

Baseline Characteristics	Participants (n = 3427)	Nonparticipants (n = 613)
Age* (yrs), mean ± SD	57.5 ± 11.5	60.4 ± 12.4
Female, %	58.1	56.3
Race, %		
Black	93.2	93.5
Mixed	4.1	3.6
White/other	2.7	2.8
IOP* (mmHg), mean ± SD	18.4 ± 4.9	19.3 ± 5.6
Diabetes history, %	16.3	16.7
Hypertension*, %	52.2	61.2
OAG, %	6.0	8.0

*$P < 0.05$.
IOP = intraocular pressure; OAG = open-angle glaucoma; SD = Standard Deviation.

factors among a nationally representative population. The cohort was identified by a simple random sample of Barbados-born citizens, 40 to 84 years of age, and the participation rate was 84%, with a total of 4631 participants completing examinations at the study site.[22] A computerized database system allowed longitudinal follow-up of the study population. Four years later, 329 participants were deceased, 34 were disabled or too ill to participate, and 228 had moved or left the island. The surviving members of the cohort were reexamined in the Barbados Incidence Study of Eye Diseases (BISED), which involved 3427 participants or 85% of those eligible (n = 4040). Table 1 compares the baseline characteristics of the BISED participants and nonparticipants. Nonparticipants were older (mean ± standard deviation [SD], 60.4 ±12.4 years versus 57.5 ± 11.5 years), more likely to be hypertensive, and had higher IOP levels at the baseline visit. There were, however, no significant differences in gender, race, diabetes history, or OAG status. The detailed study design and methods have been previously described.[22,23]

The standardized protocols for all participants in both BES and BISED included an extensive interview, BP and anthropometric measurements (waist and hip circumferences, weight, and height), ocular measurements, and venipuncture for glycosylated hemoglobin. The standardized interview obtained demographic details, medical and family history, and information about putative risk factors. Blood pressure was recorded as the average of two measurements with the Hawksley random zero sphygmomanometer, following the Hypertension Detection and Follow-up protocol.[24] Hypertension was defined as a systolic BP ≥140 mmHg and/or a diastolic BP ≥90 mmHg, and/or a history of antihypertensive treatment. Diabetes was defined according to self-reported physician diagnosis. Glycosylated hemoglobin (GHb) assays by affinity chromatography of venous whole blood[25] using Glyc-Affin GHb kits (Isolab, Akron, OH) were available for 3754 or 81% of the participants (GHb was not measured in the first months of the study). Duplicate testing of a random sample (n = 264) showed good reproducibility, with an intraclass correlation coefficient of 0.89.

Ocular measurements included refraction, best-corrected visual acuity with a Ferris-Bailey chart, Humphrey automated perimetry, lens gradings, applanation tonometry, and fundus stereo photography. A systematic 10% sample and participants with positive findings (i.e., IOP >21 mmHg, visual field defects, positive ocular history, inability to have lens gradings or photographs, OAG family history or diabetes history) were referred for a comprehensive ophthalmologic examination.

Intraocular pressure was measured by Goldmann applanation tonometry and recorded as the average of three measurements at each visit. Person-based IOP change was defined as the more positive difference in mmHg (BISED value minus BES value) in either eye. To describe longitudinal IOP changes in the cohort, the analyses excluded persons with glaucoma (definite, suspect, or other glaucoma) or receiving IOP-lowering treatment at baseline. The latter was ascertained from self-report and verified by examining the medications brought to the clinic. The definition of OAG[22,23] required the presence of both visual field defects and optic disc damage after ophthalmologic exclusion of other possible causes. Intraocular pressure was not considered in this definition.

Descriptive data are presented as mean (± SD) or median IOP values. Multiple regression analyses were used to examine factors associated with IOP changes between baseline and the 4-year follow-up study visit. Such factors included age, gender, hypertension (or BP, or antihypertensive medication), diabetes history (or GHb), pulse rate, body mass index (BMI), and waist-hip ratio.

Results

Table 2 presents the distribution of IOP, BP, and diabetes history at baseline for the 2996 participants without glaucoma or receiving IOP-lowering treatment. Mean IOP was similar among black and mixed race (black and white) participants (17.6 and 17.9 mmHg, respectively) and lower in white participants (16.2 mmHg). An IOP>21 mmHg was nearly four times as prevalent among black and mixed participants (OR, 3.9 and 3.8, respectively) than among whites after adjusting for age and gender. Black and mixed participants had a twofold higher prevalence of hypertension (odds ratio [OR], 2.4 and 2.1, respectively) than did white participants at baseline, which was mirrored by their higher mean systolic and diastolic BP. Similarly, with a prevalence of self-reported diabetes approaching 17%, black participants reported a much higher frequency of this disorder than did mixed race and white participants (8.6% and 5.6%, respectively). In view of the limited numbers of mixed race and white participants, further analyses are restricted to black participants (n = 2778).

In 4 years, IOP increased by 2.5 mmHg on average (SD, 3.9 mmHg). Although 41.8% (1160 of 2778) of participants had an IOP increase of ≥3.0 mmHg, only 5.1% (141 of 2778) had a decrease of ≥3.0 mmHg. More than 9% (259 of 2778) of the cohort had an IOP ≥25 mmHg at the 4-year follow-up. Table 3 presents the age-gender specific differences in IOP between baseline (BES) and 4-year follow-up (BISED); similar overall increases were noted among men (2.6 ± 4.0 mmHg) and women (2.4 ± 3.8 mmHg). Although the lowest mean increase in IOP (2.2 ± 3.3 mmHg) was evident among the youngest age group, the highest increase (2.9 ± 4.8 mmHg) was seen in those aged ≥70 years at baseline. Aside from the youngest group, the median 4-year IOP increases were generally greater among men than among women, although this difference was small and not statistically significant.

Table 4 presents baseline IOP and changes in the IOP distribution at follow-up by various hypertension and diabetes-related variables. At baseline, mean IOP was higher among those with elevated systolic and diastolic BP, a diagnosis of hypertension, or those receiving antihypertensive treatment. Higher IOP increases were also evident among these groups when evaluated 4 years later in BISED. Mean IOP increase was 2.6 ± 4.1 mmHg among hypertensives versus 2.4 ± 3.6 mmHg among nonhypertensives. Intraocular pressure at baseline was higher among those with a self-reported history of diabetes than among nondiabetics (18.7 ±

Table 2. Intraocular Pressure, Blood Pressure, and Diabetes History at Baseline by Ethnic Group (n = 2996)

Characteristic	Ethnic Group		
	Black (n = 2778)	*Mixed (n = 128)*	*White/Other (n = 90)*
IOP, mmHg			
Mean ± SD	17.6 ± 3.3	17.9 ± 3.4	16.2 ± 2.8
Median	17.7	18.0	16.3
>21 mmHg(%)	10.4	10.9	3.3
OR (95% CI)*	3.9 (1.2, 12.5)	3.8 (1.1, 13.8)	1.0
Systolic blood pressure, mmHg			
Mean ± SD	134.6 ± 22.2	132.8 ± 21.7	130.8 ± 18.9
Median	131.0	131.0	127.5
Diastolic blood pressure, mmHg			
Mean ± SD	81.0 ± 11.7	80.1 ± 11.0	77.6 ± 9.6
Median	80.0	79.3	78.0
Hypertension† (%)	51.6	50.8	36.7
OR (95% CI)*	2.4 (1.5,3.8)	2.1 (1.2, 3.7)	1.0
Diabetes history (%)	16.7	8.6	5.6
OR (95% CI)*	3.9 (1.6, 9.6)	1.7 (0.6, 5.1)	1.0

*Based on logistic regression model adjusted for age and gender.
†Systolic/diastolic blood pressure ≥ 140/90 mmHg and/or use of antihypertensive medication.
CI = confidence interval; IOP = intraocular pressure; OR = odds ratio; SD = standard deviation.

3.6 mmHg versus 17.4 ± 3.2 mmHg), as was the 4-year IOP increase (2.8 ± 4.7 mmHg versus 2.5 ± 3.7 mmHg). IOP changes in 4 years were similar among those with low or high pulse rate, BMI, and waist-hip ratio.

During the 4-year follow-up period, several relevant events occurred. For example, 50 persons or 1.8% of the 2778 participants were newly treated with IOP-lowering agents, and only 1% (n = 29) developed OAG. In this study cohort, the 4-year incidence of cataract extraction was 1.5% (40 of 2723). In addition, 7.6% of those without a diabetes history and 22.4% of those without hypertension at baseline newly developed these conditions after 4 years.

Table 5 presents results of final multiple regression models that retain significant ($P < 0.05$) factors for association with 4-year change in IOP among black participants. Baseline IOP was inversely associated with 4-year IOP change ($P < 0.001$). In contrast, age was positively related to an increased IOP during follow-up ($P < 0.001$), as was diabetes ($P < 0.01$). Similar results were obtained for elevated GHb (>11.5% compared with <7.1%), which was substituted for diabetes history in a separate regression model ($P = 0.004$). Hypertension was also independently related to 4-year IOP increases ($P = 0.03$), as were systolic and diastolic BP. Additional analyses were performed excluding incident cases of those receiving IOP-lowering treatment; undergoing cataract surgery; or developing OAG, diabetes, or hypertension. Results remained similar, except for analyses excluding persons having cataract surgery during the follow-up period, when borderline or nonstatistically significant results were found for diabetes history (standardized coefficient (β') = 0.04, $P = 0.06$) and GHb >11.5% ($\beta' = 0.03$, $P = 0.15$). In analyses excluding the combined groups listed previously, lower baseline IOP ($\beta' = -0.32$, $P < 0.001$), older age ($\beta' = 0.06$, $P = 0.004$), hypertension ($\beta' = 0.06$, $P = 0.008$), and diabetes history ($\beta' = 0.04$, $P = 0.05$) were similarly related to 4-year increase in IOP. Further analyses demonstrated no significant effect of a change in timing of IOP measurements (i.e., before 11 AM at the baseline visit and after 11 AM at follow-up, or vice versa). There were also no differences in analyses to assess seasonal effects (e.g., warmer months at baseline versus cooler months at follow-up) on IOP change (data not shown).

Discussion

As far as we know, this is the first report on the association of hypertension and diabetes to longitudinal changes in IOP in an African-origin population. At baseline, IOP ≥21 mmHg, hypertension and diabetes history were considerably more prevalent among black and mixed-race participants than among whites, with twofold to fourfold differences between black and white participants after adjusting for age and gender (Table 2). Overall, mean IOP increased by 2.5 ± 3.9 mmHg in black participants during the 4-year period of follow-up, with larger changes observed in the older age groups. Marginally higher but nonsignificant increases in median IOP occurred in older men compared with

Table 3. Difference in Intraocular Pressure between Baseline and 4-year Follow-up by Age and Gender in Barbados Incidence Study of Eye Diseases Black Participants (n = 2778)

Age (yrs)	n	Male Mean ± Standard Deviation (Median)	n	Female Mean ± Standard Deviation (Median)	n	Total Mean ± Standard Deviation (Median)
40–49	416	2.1 ± 3.7 (2.0)	528	2.2 ± 3.0 (2.0)	944	2.2 ± 3.3 (2.0)
50–59	295	3.0 ± 4.3 (2.7)	480	2.4 ± 3.4 (2.3)	775	2.7 ± 3.7 (2.3)
60–69	219	2.9 ± 3.9 (2.3)	401	2.4 ± 4.2 (2.0)	620	2.6 ± 4.1 (2.0)
70+	185	2.9 ± 4.4 (2.7)	254	3.0 ± 5.1 (2.3)	439	2.9 ± 4.8 (2.7)
Total	1115	2.6 ± 4.0 (2.3)	1663	2.4 ± 3.8 (2.0)	2778	2.5 ± 3.9 (2.3)

Table 4. Change in Intraocular Pressure (mmHg) between Baseline (Barbados Eye Study) and Follow-up (Barbados Incidence Study of Eye Diseases) by Various Factors

Factor	Baseline Mean ± Standard Deviation	Difference (BISED—Baseline) Mean ± Standard Deviation
Hypertension		
Yes	18.2 ± 3.4	2.6 ± 4.1
No	17.0 ± 3.1	2.4 ± 3.6
Systolic BP (mmHg)		
<120	17.0 ± 3.1	2.2 ± 3.5
(120, 140)	17.3 ± 3.2	2.6 ± 3.9
(140, 160)	18.2 ± 3.4	2.4 ± 3.7
≥160	18.9 ± 3.6	3.0 ± 4.8
Diastolic BP (mmHg)		
<70	17.1 ± 3.3	2.4 ± 4.2
(70, 90)	17.6 ± 3.3	2.5 ± 3.6
≥90	18.2 ± 3.5	2.7 ± 4.4
Hypertension treatment		
Yes	18.1 ± 3.5	2.7 ± 4.2
No	17.4 ± 3.3	2.4 ± 3.7
Pulse rate (per minute)		
> median (72)	17.8 ± 3.3	2.4 ± 4.0
≤ median (72)	17.4 ± 3.4	2.6 ± 3.8
Diabetes history		
Yes	18.7 ± 3.6	2.8 ± 4.7
No	17.4 ± 3.2	2.5 ± 3.7
GHb (%)		
≤7.1	17.5 ± 3.2	2.3 ± 3.6
(7.1, 10.0)	17.8 ± 3.4	2.3 ± 3.4
(10.0, 11.5)	19.0 ± 3.1	2.2 ± 4.1
>11.5	19.3 ± 4.2	2.8 ± 6.0
BMI (kg/m^2)		
High (> median 26.2)	17.7 ± 3.3	2.5 ± 3.6
Low (≤ median 26.2)	17.5 ± 3.4	2.5 ± 4.2
WHR		
High (> median 0.92)	17.8 ± 3.4	2.6 ± 3.9
Low (≤ median 0.92)	17.5 ± 3.3	2.4 ± 3.6

BISED = Barbados Incidence Study of Eye Diseases; BMI = body mass index; BP = blood pressure; GHb = glycosylated hemoglobin; WHR = waist-hip ratio.

women (Table 3). Participants with hypertension, elevated systolic and diastolic BP at baseline, or those receiving antihypertensive therapy had larger 4-year increases in IOP than did others. This was also evident for those reporting a history of diabetes or those with an elevated GHb. In contrast, baseline IOP was inversely related to 4-year IOP increase (Table 5). Because nonparticipants in BISED had slightly higher IOP at baseline and tended to be older and were more likely to have hypertension, the IOP increases in the BISED population might be an underestimation of the true magnitude of IOP increases in the BES population.

Ethnic Differences in Intraocular Pressure

As previously noted, elevated IOP is frequent in the BES black population.[26] Compared with whites, IOP >21 mmHg was four times as likely among black and mixed-race participants without OAG or receiving IOP-lowering treatment. Mean IOP in Afro-Caribbeans was previously found to be 17.7 (± 4.3) mmHg and 18.7 (± 5.2) mmHg in St. Lucia and Barbados, respectively,[4,26] which is higher than reported in many white[2,5,7,12,27–29] and Asian populations.[3,30] However, there are also IOP differences among black populations, because mean IOP was lower among blacks in Baltimore (16.0 ± 4.2 mmHg)[27] and rural Tanzanians (15.7 ± 4.3 mmHg).[31] These differences are likely due to variations in the distributions of associated risk factors, as well as to differences in study methods. Although the BES population was nationally representative,[22] the Baltimore and Tanzania studies were based on more selected groups.[27,31] Ocular factors such as central corneal thickness may also be important determinants of IOP, with interindividual variation in IOP measurements being significantly affected by variation in central corneal thickness.[32] Studies by Brandt et al[33] and La Rosa et al[34] indicated that black individuals have thinner central corneas than whites, which might lead to underestimates of true IOP. These results suggest that the high IOP in Afro-Caribbeans is a real finding, possibly caused in part by the high population prevalence of related risk factors, such as those investigated here.

High Blood Pressure

Hypertension is a well-recognized risk factor for elevated IOP, and there are consistent cross-sectional associations between systolic BP and IOP,[3,6,9,10,12,35] although fewer studies show a similar relationship for diastolic pressure.[5,10,11] Both elevated systolic and diastolic blood pressure were positively associated with longitudinal IOP in-

Table 5. Multiple Regression of the Difference in Intraocular Pressure between Baseline and 4-year Follow-up among Black Participants

Variables	Coefficient Estimate	Standardized Coefficient	*P* Value
Baseline IOP (per mmHg)	−0.33	−0.28	<0.001
Age (per year)	0.03	0.10	<0.001
Diabetes history (yes vs. no)	0.53	0.05	0.01
GHb>11.5% (vs. GHb < 7.1%)*	0.88	0.06	0.004
Hypertension (yes vs. no)	0.32	0.04	0.03
Systolic blood pressure (per 10 mmHg)*	0.10	0.06	<0.01
Diastolic blood pressure (per 10 mmHg)*	0.15	0.04	0.01

*Based on separate models by substituting GHb (glycosylated hemoglobin) values for diabetes history or systolic blood pressure or diastolic blood pressure for hypertension.
GHb = glycosylated hemoglobin; IOP = intraocular pressure.

creases in this study, consistent with findings from other cohort studies.[30,36] Increased systemic BP leading to increased production of aqueous humor, by means of elevated ciliary artery pressure, has been postulated as a mechanism linking BP to high IOP.[3,10] Others have proposed roles for increased sympathetic tone and serum corticosteroids.[35] These postulates do not, however, satisfactorily explain differences in the associations between systolic and diastolic BP with IOP. Although the specific mechanisms are thus unclear, it is possible that hypertension may be one of the reasons for the high IOP in our black study population.

Diabetes

Several large population-based cross-sectional studies have also documented associations between diabetes, elevated blood glucose or GHb and raised IOP,[5,6,11,15,16,37] supporting findings from many[35,38,39] but not all smaller observational studies.[40,41] A weakening of the association between IOP increase and diabetes was noted in this study after exclusion of persons undergoing cataract surgery. One possible explanation could be that persons having surgery were more likely to also have diabetes and tended to have larger IOP increases. Although etiologic links between diabetes and IOP remain unclear, several hypotheses have been advanced. Genetic factors are likely to play a role, although only limited epidemiologic data exist on the association between ocular hypertension and family history of diabetes.[42] There is also evidence that diabetes-related autonomic dysfunction is likely to increase IOP.[43] Although it has been suggested that elevated blood glucose results in the induction of an osmotic gradient with consequent fluid shifts into the intraocular space,[37] the converse situation is more likely, because elevated plasma glucose results in fluid shifts out of the intraocular compartment, with a reduction in IOP.[44]

Other Factors

Most studies report positive cross-sectional associations between age and IOP, such that IOP distributions are skewed to higher values in the elderly.[2,4,5,6,7] Age, therefore, is a potential confounder of associations between other factors and IOP.[5,35] In contrast to studies in Western populations, cross-sectional studies in Asian populations demonstrate negative associations between IOP and increased age[3,17,30] but positive associations with age when longitudinal relationships are examined. Possible explanations include selective mortality among those with higher IOP (particularly among the elderly), differences in environmental exposures leading to higher frequencies of myopia in younger groups, as well as nutritional changes, both factors in turn linked to elevated IOP.[30] Another factor likely to be of relevance is that applanation tonometry has been shown to underestimate true IOP in Asian eyes; this measurement error increases as true IOP increases,[45] thus possibly leading to underdetection of an IOP rise with age.

Consistent with longitudinal findings in populations of Asian descent,[30] age also emerged as an independent predictor of prospective IOP increase in black BES participants. Inconsistent associations between age and IOP change were, however, found in the Baltimore Longitudinal Study of Aging, a cohort composed predominantly of white, middle-aged, well-off, highly educated males.[36] No association was found between IOP change and age at baseline for those seen at yearly intervals, whereas age was negatively associated with IOP change for those reviewed at 2-year intervals. The BES and the longitudinal Japanese cohort[30] were population-based and less likely to be subject to selection bias, and both studies provide evidence for an association between increased age and longitudinal increase in IOP. There is a physiologic basis for this association. Although aging leads to reduced production of aqueous humor,[46] this is countered by structural changes in the trabecular meshwork, resulting in a net increase in IOP.[47] In an effort to reduce the inherent variability of IOP measurements, our study used the average of three IOP measurements. Although regression to the mean can be reduced by this method,[48] the negative association between initial IOP and change in IOP that we report here might still be partially due to regression to the mean. A similar relationship was found by McLeod et al.[36]

Although BMI was associated with high IOP in the BES population at baseline,[6] consistent with reports from predominantly white[5] and Japanese populations,[3,17] it was not associated with longitudinal IOP change in this study. This contrasts with findings in a Japanese population,[18,30] considerably less obese than the BES population, in whom baseline BMI was positively associated with IOP increase in analyses of retrospective data. Aside from the obvious ethnic differences, the Japanese cohort was considerably larger, and these data were based on a longer period of observation (over an 8-year period), with more power to detect small associations.

Implications

This large population-based study, with high participation rates, has confirmed cross-sectional and longitudinal associations of hypertension and diabetes to IOP. Hypertension and diabetes are potentially modifiable risk factors. Should other data confirm the findings of our study, strategies aimed at prevention or control of these conditions might be expected to lower IOP. This possibility would need to be rigorously tested in clinical trials, with particular relevance to the public health implications of IOP reduction for preventing OAG. In this regard, it is interesting to note that hypertension and diabetes were not related to prevalent OAG in the BES, although the study had ample power to detect such associations.[49] In fact, the principal factors associated with OAG were increased age, male gender, high IOP, and a family history of OAG; low BMI and cataract also were related.[49] Given that IOP is a major risk factor for OAG, the difference in risk profiles of both conditions is paradoxical, with age and OAG family history being the only common risk factors. In addition, hypertension decreased the risk of incident OAG in BISED,[50] perhaps through the increase in perfusion pressure of the optic nerve.[11–13,49] Others have reported positive associations of hypertension[8,12,13] with OAG. In contrast to the BES, the definition of OAG in these studies required an elevated IOP, a factor known to be positively associated with hypertension. Positive associations between diabetes and OAG were reported in the predominantly white populations of the Beaver Dam[14] and Blue Mountain Eye Studies,[37] although negative findings similar to the BES were reported in the more ethnically diverse population (45% black) of the Baltimore Eye Survey.[15] Another possible explanation for differences in IOP and OAG risk profiles in the BES is provided by Weih et al,[29] who showed that a family history of glaucoma is a better predictor of IOP in those with than without established OAG, whereas lifestyle and physiologic factors are more strongly related to IOP in the absence of OAG.

Conclusions

This study, conducted in an African-origin population with a high prevalence of hypertension and diabetes,[6] confirmed positive cross-sectional associations of IOP to age, BP, and diabetes (or GHb). Furthermore, it provides new data about similar longitudinal relationships. Given these observations and findings from this study, further research is necessary to evaluate mechanisms underlying positive direct associations between these conditions and IOP. Because of the potential for modifying hypertension and diabetes, research into the implications of these modifications on IOP and OAG is necessary. Trials of IOP-lowering treatments in ocular hypertension, such as the Ocular Hypertension Treatment Study,[51] as well as in OAG, such as the Early Manifest Glaucoma Trial,[52] will be of considerable importance in guiding the management of elevated IOP and early OAG.

Acknowledgments. The authors thank the Barbados Eye Studies participants and the Ministry of Health, Barbados, West Indies, for their role in the study.

The Barbados Eye Studies Group

Principal Investigator: M. Cristina Leske, MD, MPH

Coordinating Center

Stony Brook University, Stony Brook, NY: M. C. Leske, MD, MPH; Barbara Nemesure, PhD; Suh-Yuh Wu, MA; Leslie Hyman, PhD; Xiaowei Li, PhD; Shu-Hong Xie, MS; Lixin Jiang, MS; Kasthuri Sarma, Melinda Santoro, Koumudi Manthani.

Data Collection Center

Ministry of Health, Bridgetown, Barbados, West Indies: Anthea M. S. Connell, FRCS, FRCOphth; Anselm Hennis, MRCP(UK), PhD; Ann Bannister, MB, BS, MRCOphth; Muthu A. Thangaraj, MB, BS, DO; Coreen Barrow, Patricia Basdeo, Kim Bayley, Anthanette Holder.

Fundus Photography Reading Center

The Johns Hopkins University, Baltimore, MD: Andrew P. Schachat, MD; Judith A. Alexander; Noreen B. Javornik, MS; Cheryl J. Hiner; Deborah A. Phillips; Reva Ward; Terry W. George.

Local Advisory Committee

Trevor Hassell, MBBS, FRCP, FACC, GCM (Department of Cardiology) and Clive Gibbons, FRCS(Ed), FRCP, FRCOphth (Department of Ophthalmology), Queen Elizabeth Hospital; Henry Fraser, FACP, FRCP(UK), PhD, GCM (Chronic Diseases Research Center), School of Clinical Medicine and Research, University of the West Indies, Barbados, West Indies.

References

1. Leske MC. The epidemiology of open-angle glaucoma: a review. Am J Epidemiol 1983;118:166–91.
2. Klein BE, Klein R. Intraocular pressure and cardiovascular risk variables. Arch Ophthalmol 1981;99:837–9.
3. Shiose Y, Kawase Y. A new approach to stratified normal intraocular pressure in a general population. Am J Ophthalmol 1986;101:714–21.
4. Mason RP, Kosoko O, Wilson MR, et al. National survey of the prevalence and risk factors of glaucoma in St. Lucia, West Indies. Part I. Prevalence findings. Ophthalmology 1989;96: 1363–8.
5. Klein BEK, Klein R, Linton KLP. Intraocular pressure in an American community: the Beaver Dam Eye Study. Invest Ophthalmol Vis Sci 1992;33:2224–8.
6. Wu SY, Leske MC. Associations with intraocular pressure in the Barbados Eye Study. The Barbados Eye Study Group. Arch Ophthalmol 1997;115:1572–6.
7. Bonomi L, Marchini G, Marraffa M, et al. Prevalence of glaucoma and intraocular pressure distribution in a defined population. Ophthalmology 1998;105:209–15.
8. Bonomi L, Marchini G, Marraffa M, et al. Vascular risk factors for primary open angle glaucoma. The Egna-Neumarkt Study. Ophthalmology 2000;107:1287–93.
9. Bengtsson B. Some factors affecting the distribution of intraocular pressures in a population. Acta Ophthalmol (Copenh) 1972;50:33–46.
10. Bulpitt CJ, Hodes C, Everitt MG. Intraocular pressure and systemic blood pressure in the elderly. Br J Ophthalmol 1975; 59:717–20.
11. Leske MC, Podgor MJ. Intraocular pressure, cardiovascular risk variables, and visual field defects. Am J Epidemiol 1983; 118:280–7.
12. Dielemans I, Vingerling JR, Algra D, et al. Primary open-angle glaucoma, intraocular pressure, and systemic blood pressure in the general elderly population. Ophthalmology 1995;102:54–60.
13. Leske MC, Warheit-Roberts L, Wu SY. Open-angle glaucoma and ocular hypertension: the Long Island Glaucoma Case-Control Study. Ophthalmic Epidemiol 1996;3:85–96.
14. Klein BEK, Klein R, Jensen SC. Open-angle glaucoma and older-onset diabetes. The Beaver Dam Eye Study. Ophthalmology 1994;101:1173–7.
15. Tielsch JM, Katz J, Quigley HA, et al. Diabetes, intraocular pressure, and primary open-angle glaucoma in the Baltimore Eye Survey. Ophthalmology 1995;102:48–53.
16. Dielemans I, de Jong PTVM, Stolk R, et al. Primary open-angle glaucoma, intraocular pressure, and diabetes mellitus in the general elderly population. The Rotterdam Study. Ophthalmology 1996;103:1271–5.
17. Shiose S. Intraocular pressure: new perspectives. Surv Ophthalmol 1990;34:413–35.
18. Mori K, Ando F, Nimura H, et al. Relationship between

intraocular pressure and obesity in Japan. Int J Epidemiol 2000;29:661–6.
19. Harris MI, Flegal KM, Cowie CC, et al. Prevalence of diabetes, impaired fasting glucose, and impaired glucose tolerance in U. S. adults. Diabetes Care 1998;21:518–24.
20. Cooper RS, Rotimi CN, Kaufman JS, et al. Prevalence of NIDDM among populations of the African diaspora. Diabetes Care 1997;20:343–8.
21. Cooper R, Rotimi C, Ataman S, et al. The prevalence of hypertension in seven populations of west African origin. Am J Pub Health 1997;87:160–8.
22. Leske MC, Connell AMS, Schachat AP, Hyman L. The Barbados Eye Study. Prevalence of open-angle glaucoma. Arch Ophthalmol 1994;112:821–9.
23. Leske MC, Connell AMS, Wu SY, et al. Incidence of open-angle glaucoma. The Barbados Eye Studies. Arch Ophthalmol 2001;119:89–95.
24. Race, education and prevalence of hypertension. Hypertension Detection and Follow-Up Program Cooperative Group. Am J Epidemiol 1977;106:351–61.
25. Willey DG, Rosenthal MA, Caldwell S. Glycosylated hemoglobin and plasma glycoprotein assays by affinity chromatography. Diabetologia 1984;27:56–8.
26. Leske MC, Connell AMS, Wu SY, et al. Distribution of intraocular pressure. The Barbados Eye Study. Arch Ophthalmol 1997;115:1051–7.
27. Sommer A, Tielsch JM, Katz J, et al. Relationship between intraocular pressure and primary open angle glaucoma among white and black Americans. The Baltimore Eye Survey. Arch Ophthalmol 1991;109:1090–5.
28. Wensor MD, McCarty CA, Stanislavsky YL, et al. The prevalence of glaucoma in the Melbourne Visual Impairment Project. Ophthalmology 1998;105:733–9.
29. Weih LM, Mukesh BN, McCarty CA, Taylor HR. Association of demographic, familial, medical, and ocular factors with intraocular pressure. Arch Ophthalmol 2001;119:875–80.
30. Nomura H, Shimokata H, Ando F, et al. Age-related changes in intraocular pressure in a large Japanese population. A cross-sectional and longitudinal study. Ophthalmology 1999; 106:2016–22.
31. Buhrmann RR, Quigley HA, Barron Y, et al. Prevalence of glaucoma in a rural East African population. Invest Ophthalmol Vis Sci 2000;41:40–8.
32. Foster PJ, Baasanhu J, Alsbirk PH, et al. Central corneal thickness and intraocular pressure in a Mongolian population. Ophthalmology 1998;105:969–73.
33. Brandt JD, Beiser JA, Kass MA, et al. Central corneal thickness in the Ocular Hypertension Treatment Study (OHTS). Ophthalmology 2001;108:1779–88.
34. La Rosa FA, Gross RL, Orengo-Nania S. Central corneal thickness of Caucasians and African Americans in glaucomatous and nonglaucomatous populations. Arch Ophthalmol 2001;119:23–7.
35. Carel RS, Korczyn AD, Rock M, Goya I. Association between ocular pressure and certain health parameters. Ophthalmology 1984;91:311–4.
36. McLeod SD, West SK, Quigley HA, Fozard JL. A longitudinal study of the relationship between intraocular and blood pressures. Invest Ophthalmol Vis Sci 1990;31:2361–6.
37. Mitchell P, Smith W, Chey T, Healey PR. Open-angle glaucoma and diabetes. The Blue Mountains Eye Study, Australia. Ophthalmology 1997;104:712–8.
38. Klein BEK, Klein R, Moss SE. Intraocular pressure in diabetic persons. Ophthalmology 1984;91:1356–60.
39. Cristiansson J. Intraocular pressure in diabetes mellitus. Acta Ophthalmol 1961;39:155–67.
40. Bouzas AG, Gragoudas ES, Balodimos MC, et al. Intraocular pressure in diabetes. Relationship to retinopathy and blood glucose levels. Arch Ophthalmol 1971;85:423–7.
41. Seddon JM, Schwartz B, Flowerdew G. Case-control study of ocular hypertension. Arch Ophthalmol 1983;101:891–4.
42. Clark CV, Mapstone R. The prevalence of diabetes mellitus in the family history of patients with primary glaucoma. Doc Ophthalmol 1986;62:161–3.
43. Mapstone R, Clarke CV. Prevalence of diabetes in glaucoma. Br Med J 1985;291:93–5.
44. Dielemans I, Vingerling JR, Wolfs RCW, et al. The prevalence of primary open-angle glaucoma in a population-based study in The Netherlands. The Rotterdam Study. Ophthalmology 1994;101:1851–5.
45. Foster PJ, Wong JS, Wong E, et al. Accuracy of clinical estimates of intraocular pressure in Chinese eyes. Ophthalmology 2000;107:1816–21.
46. Brubaker RF, Nagataki S, Townsend DJ, et al. The effect of age on aqueous humor formation in man. Ophthalmology 1981;88:283–7.
47. Miyazaki M, Segawa K, Urakawa Y. Age-related changes in the trabecular meshwork in the normal human eye. Jpn J Ophthalmol 1987;31:558–69.
48. Yudkin PL, Stratton IM. How to deal with regression to the mean in intervention studies. Lancet 1996;347:241–3.
49. Leske MC, Connell AMS, Wu SY, et al. Risk factors for open-angle glaucoma. The Barbados Eye Study. Arch Ophthalmol 1995;113:918–24.
50. Leske MC, Wu SY, Nemesure B, Hennis A. Incident open-angle glaucoma and blood pressure. Arch Ophthalmol 2002; 120:954–9.
51. Gordon MO, Kass MA. The Ocular Hypertension Treatment Study: design and baseline description of the participants. Arch Ophthalmol 1999;117:573–83.
52. Leske MC, Heijl A, Hyman L, et al. Early Manifest Glaucoma Trial. Design and baseline data. Ophthalmology 1999;106: 2144–53.