Epidemiology of intraocular pressure in a population screened for glaucoma*

ROBERT DAVID,¹ LINDA ZANGWILL,¹ DAVID STONE,²
AND YUVAL YASSUR¹

From the ¹Middle East Eye Research Institute, Department of Ophthalmology, and ²Department of Epidemiology, Faculty of Health Sciences, Ben Gurion University of the Negev, Beer Sheva, Israel

SUMMARY This study evaluated the association between intraocular pressure and various sociodemographic characteristics, ocular findings, and cardiovascular risk factors in a population screened for glaucoma. A total of 2594 subjects older than 40 years residing in three urban areas of southern Israel participated. Of those screened 6.1% had a raised intraocular pressure (IOP $\geq$ 21). The mean IOP increased with age, was higher among persons born in Africa or Asia than those born in Europe or America, higher among myopes than hypermetropes and among those with an enlarged cup-disc ratio (CDR). Analysis of variance tests indicated that refractive status, CDR, age, country of birth, and diabetes were each independently associated with IOP. In addition, associations between raised intraocular pressure and age, country of birth, myopia, CDR, diabetes, and glaucoma in the family were found.

A raised intraocular pressure is a major ophthalmologic risk factor for the development of glaucomatous visual field defects. The prevalence of ocular hypertension is estimated to be between 5 and 10%.¹⁻⁴ Unfortunately the aetiology of this condition and its relationship to glaucoma is not well understood.

This study uses data from the glaucoma screening of a population in southern Israel to investigate the epidemiology of intraocular pressure. Its objectives were to estimate the prevalence of ocular hypertension in the general population and to analyse the relationship of intraocular pressure to various sociodemographic characteristics, ocular findings, and systemic risk factors.

Material and methods

A population screening examination for glaucoma performed between 1982 and 1984 in three urban areas in southern Israel was the source of information for this study. Details of the screening protocol have been published elsewhere.⁵

There were two parts to the examination—an interview and an eye examination—performed at

two stations. On arrival each subject was interviewed by a medical student and the following data were recorded: year of birth, sex, country of birth, systemic illness (diabetes, hypertension requiring current medication, other cardiovascular conditions, and 'other'), history of haemodynamic shock, family history of glaucoma, and description of life style with regard to physical activity. Subjects reporting occasional hypertension, or not receiving medication for it, were not considered as hypertensives for this survey. A subject was considered diabetic if he or she was on a diabetic diet with or without additional regular medications. Cardiovascular conditions (other than hypertension) were heart or peripheral vascular diseases as documented by current medication and/or past admissions to hospital. As to life style, four categories of physical activity were defined as follows: sedentary (e.g., sedentary occupation, no regular physical activity), sedentary with occasional mild physical activity, medium physical activity, and marked physical activity (e.g., strenuous job or housewife, climbs stairs to apartment, etc.). Past haemodynamic shock was recorded when a subject recalled a major operation, accident, or other occasion necessitating blood transfusions.

The eye examinations were carried out by ophthalmologists with at least three years' experience. The parameters recorded were:

* This paper was presented in part at the Second NEI Symposium on Eye Disease Epidemiology, June 1985.

Correspondence to Dr R David.

Intraocular pressure (IOP). This was measured with the Goldmann applanation tonometer on either the Haag-Streit 900 or Topcon LD2 slit-lamp. The average of three consecutive readings was recorded for each eye. For the purposes of analysis, ocular hypertension was defined as an IOP greater than or equal to 21 mmHg in at least one eye.

Optic disc assessment. The optic disc of every eye was examined with the direct ophthalmoscope and, whenever possible, through a non-dilated pupil. The cup-disc ratio (CDR) was judged by contour (and not by colour). Three categories of CDR were recorded ($\text{CDR} \leq 0.3$, $\text{CDR} > 0.3$ and ≤ 0.5 , and $\text{CDR} > 0.5$) for both the horizontal and vertical meridian.

Refractive status. Determination of refractive status was made according to the subject's distance spectacles and recorded as emmetrope ($+2.00$ to -2.00 dioptres), hypermetrope ($+2.25$ dioptres or more), myope (-2.25 to -5.00 dioptres), and high myopes (more than -5.00 dioptres). The glasses were tested with a lensometer by an ophthalmic nurse or optometrist.

The χ^2 test, analysis of variance, and t test methods were used to assess statistical significance.

RESPONSE RATE

Of the 4993 who received invitations 2594 (53%) responded. A survey of a sample of the non-respondents was conducted, the results of which are reported elsewhere.⁵ In short, a comparison of socio-demographic characteristics of respondents with non-respondents indicated that there was no significant difference in the composition of the two groups in terms of sex or country of birth. However, the respondents were younger than the non-respondents (χ^2 test, $p < 0.001$). The respondents had a smaller proportion of persons over 70 years of age than non-respondents (12.1% versus 19.2% respectively). In a similar manner the respondents had a larger proportion of persons between the ages of 40 and 49 (38.1% versus 36.7%) and between the ages of 50 and 59 (30.5% versus 25.3%) than non-respondents.

Results

The intraocular pressure was measured in 2547 people (5068 eyes). One hundred and fifty five of the persons with IOP measurements available were found to be ocular hypertensives (21 mmHg or more in at least one eye). The prevalence of ocular hypertension in the screened population was therefore 6.1%.

The mean and standard deviation of the IOP of the right eye was 14.96, SD 4.24, mmHg, of the left 14.86, SD 4.03, mmHg. The median for both eyes was 14 mmHg.

The mean IOP by age is presented in Table 1. The mean IOP was found to increase incrementally by age from 14.35 mmHg among subjects under 50 years old to 15.49 mmHg among those over 70 years. This difference in means was statistically significant ($p < 0.001$) as determined by a one-way analysis of variance.

There was no difference in mean IOP between males and females. The mean and standard deviation of the IOP of the right eye for males was 15.00, SD 4.51, mmHg and for females 14.94, SD 3.99, mmHg. The mean IOP was found to be significantly higher (t test, $p \leq 0.001$) among persons of North African or Asian birth than persons of European or American birth, 15.39, SD 4.42, and 14.53, SD 3.64, respectively. These results are presented in Table 2.

The age adjusted distribution of subjects by sex and country of birth was found to be significantly different ($p < 0.01$) among persons with raised IOP than normotensives. 9.8% of the 556 men and 7.5% of the 649 women born in Asia or Africa were found to have an IOP > 20 , whereas only 4.6% of the 691 women and 6.1% of the 659 men born in Europe or America had a raised IOP. These results are presented in Fig. 1 and Table 3.

The age distribution of persons with raised IOP was also significantly different (χ^2 test, $p < 0.001$) from that of normotensives. While over 9% of persons aged 70 years and above ($n = 365$) had a raised IOP, only 3.2% of persons under 50 years of age ($n = 878$), 6.0% of persons 50–59 years ($n = 780$) and 8.4% of persons between the ages of 60 and 69 ($n = 571$) had such elevation. These results are presented in Fig. 2 and Table 4.

INTRAOCULAR PRESSURE AND CUP-DISC RATIO

The four recorded CDR measurements, right hori-

Table 1 Mean IOP by age (right eye)

Age (years)	n	%	Mean IOP	SD
40–49	862	34	14.35	3.07
50–59	760	30	15.13	4.72
60–69	554	22	15.35	3.94
70+	357	14	15.49	5.67
Total	2533	100	14.96	4.24

($F = 9.84$, significance of $F < 0.001$).

Table 2 Mean IOP by country of birth (right eye)

Country of birth	n	%	Mean IOP	SD
American or European	1338	54	14.53	3.64
Asian or African	1166	46	15.39	4.42
Total	2504	100	14.93	4.04

$t = 5.33$, $p < 0.001$.

Fig. 1 Age adjusted distribution of ocular hypertension by sex and country of birth. x axis: sex and country of birth. y axis: percentage with ocular hypertension. Solid: percentage with ocular hypertension.

zontal, right vertical, left horizontal, and left vertical, were collapsed into two new variables, CDR of the right eye, and CDR of the left eye as follows: >0.50 in at least one meridian, between 0.3 and 0.5 but no higher in at least one meridian, and <0.3 in both meridians.

We found a strong association ($p < 0.001$) between intraocular pressure and CDR. 23% of subjects with an IOP >21 mmHg had a CDR greater than 0.5, whereas only 4.5% of those with an IOP less than 14 mmHg had a CDR >0.5 . These results are presented in Fig. 3 and Table 5.

The same association was found when the mean IOP was calculated for the three groups of CDR: a significantly higher (analysis of variance, $p < 0.001$) mean IOP was found among persons with a large (>0.5) cup-disc ratio. These results are presented in Table 6.

Table 3 Age adjusted distribution of ocular hypertension by sex and country of birth

Sex	Country of birth	Percentage ocular hypertension	n
Male	American and European	6.1	659
Male	Asian and African	9.6	556
Female	American and European	4.6	491
Female	Asian and African	7.5	649

Table 4 Age distribution of ocular hypertensives

Age (yr)	Percentage ocular hypertension	n
Less than 50	3.2	878
50 to 59	6.0	780
60 to 69	8.4	571
70 to 79	9.5	365

Fig. 2 Raised intraocular pressure by age. x axis: age. y axis: percentage with ocular hypertension. Solid: percentage with ocular hypertension.

(ANOVA: $F=9.84$, Significance of $F < .001$)

Fig. 3 Distribution of IOP by cup-disc ratio. x axis: intraocular pressure (mmHg). y axis: percentage by IOP category. Solid: cup-disc ratio <0.3. Cross hatching: cup-disc ratio 0.3 to 0.5. Single line hatching: cup-disc ratio >0.5.

INTRAOCULAR PRESSURE AND REFRACTIVE STATUS

The mean IOP was found to increase incrementally from a mean of 14.22 mmHg in hypermetropes to 15.44 mmHg in high myopes. This tendency was found to be statistically significant by analysis of variance ($p < 0.001$). This finding has been described in detail in a previous report.⁵

SYSTEMIC AND LIFE STYLE VARIABLES

Age adjusted odds ratios (OR) and confidence limits (CI) were calculated for the association of raised intraocular pressure with the cardiovascular risk variables and other conditions by the Mantel-Haenszel pooled odds ratio across age strata and are presented in Table 7. The odds ratio of a person having a raised IOP with a history of glaucoma in the family is over twice that of a person without a history of glaucoma in the family (OR=2.32, 95% CI 1.35 to 4.00). The odds of a diabetic or a person with a sedentary life style having ocular hypertension were one and a half times that of a non-diabetic or active person OR=1.58 and 1.41 respectively. Persons with cardiovascular disease or haemodynamic shock had lower odds of having ocular hypertension than persons without the condition, OR=0.51 and 0.69 respectively. Systemic hypertension was not found to be associated with a raised intraocular pressure. It should be noted that all the confidence intervals, except for that of history of glaucoma in the family, included 1.

Analysis of variance was used to examine the relationship between mean IOP and other ocular, demographic, and medical conditions. Each variable that was associated with the dichotomous IOP variable (IOP > 20 mmHg or IOP < 21 mmHg) was entered into an analysis of variance test. Age, physical activity, diabetes, CDR, and refractive

Table 5 Distribution of IOP by cup-disc ratio

IOP (mmHg)	Right cup-disc ratio							
	<30%		30-50%		>50%		Total	
	n	%	n	%	n	%	n	%
<14	845	68.6	331	26.9	56	4.5	1232	100
15-17	463	66.8	185	26.7	45	6.5	693	100
18-20	267	66.9	109	27.3	23	5.8	399	100
21+	69	57.5	23	19.2	28	23.3	120	100
Total	1644	67.3	648	26.5	152	6.2	2444	100

Table 6 Mean IOP by cup-disc ratio (right eye)

Cup-disc ratio	Mean IOP	SD	n
<0.3	14.83	4.02	1632
0.3 to 0.5	14.85	3.67	641
>0.5	17.28	6.70	146

Analysis of variance $F = 24.00$, significance of $F < 0.001$.

Table 7 Age adjusted percentage prevalence of raised IOP by condition

Condition	Percentage of persons with IOP ≥ 21 mmHg		Odds ratio (95% confidence limits)
	Has condition	Does not have condition	
Hypertension (n=2542)	7.2	5.8	1.06 (0.98-1.15)
Diabetes (n=2543)	10.5	5.7	1.58 (0.81-3.06)
Cardiovascular disease (n=2538)	5.0	6.3	0.59 (0.27-1.25)
Haemodynamic shock (n=2530)	4.4	6.3	0.69 (0.36-1.32)
Lifelong sedentary life style (n=671)			
Sedentary versus marked physical activity	8.8	5.2	1.41 (0.57-3.47)
Glaucoma in family (n=2333)	11.4	5.6	2.32 (1.35-4.00)

Table 8 Analysis of variance: mean intraocular pressure of the right eye

Independent variables	F value	Significance of F
MAINEFFECTS		
Cup-disc ratio	21.19	0.001
Physical activity	7.54	0.001
Refractive status	5.82	0.001
Diabetes	5.23	0.021
Age (covariate)	11.49	0.001

R²=0.044.

status were each independently associated with a mean IOP after controlling for all dependent variables in both the right and left eye. These results are presented in Table 8. Family history of glaucoma was substituted for diabetes in an analysis of variance and found to be significant ($p=0.013$) in the left eye, but not significant ($p=0.061$) in the right eye. Systemic hypertension was not found to be independently associated with mean IOP in either eye ($p>0.05$) when substituted for diabetes in the analysis. Two-way interactions were examined between each independent variable in each analysis. The only interactions that were found to be consistent in terms of statistical significance in both eyes were those between physical activity and refraction ($p<0.001$) and refraction and diabetes ($p>0.05$). The amount of variance explained by the models was between 3 and 6%.

Discussion

There have been several population based studies from which to estimate the prevalence of raised intraocular pressure. The prevalence estimates of this study, 6.1% for IOP $\geq$ 21 mmHg, compare well with other studies despite somewhat different methods of measurement in each study.

These estimates are based on 2594 persons or only 53% of the target study population. However, little difference was found between the age and sex distribution of respondents and non-respondents. It might be expected, however, that persons with eye problems or relatives with eye problems would be more likely to participate in the screening. The estimate of prevalence of raised intraocular pressure in the screened population might therefore be an overestimate of the prevalence in the general population. On the other hand, since persons over 70 years old are relatively underrepresented in the screened population, our estimate of the prevalence of elevated intraocular pressure is likely to be an underestimate of the prevalence in the general population.

The increase in mean IOP with increasing age, cup

disc ratio, and myopia shown in our results also confirms evidence from other studies.^{6,7}

Although the differences in IOP by age were statistically significant, the actual differences were small and therefore the clinical importance questionable.

It is not clear why persons born in Asia or Africa were found to have higher intraocular pressure than those born in Europe or America. The difference may be related to a darker iris pigmentation among persons from Asia or Africa. Several investigators have found that segments of the population, particularly blacks, tend to have a higher intraocular pressure than whites.^{3,8,9,10} Hiller *et al.*⁹ also found that iris pigmentation was associated with mean IOP, even after controlling for race. On the other hand Shiose and Kawase¹¹ have found that the distribution of IOP among the Japanese is generally lower than that of western societies. Since iris pigmentation was not assessed in this study, it is impossible to determine whether this or other factors are associated with the difference in mean intraocular pressure.

Positive associations between increased IOP and diabetes, glaucoma in the family, and systemic hypertension have been reported by others,^{4,10,12} some even showing an association between IOP and blood pressure.^{4,10,11}

We found diabetes to be associated with the mean IOP but not with ocular hypertension, a possible reason for this being the somewhat arbitrary cut-off point of 21 mmHg which defined ocular hypertension in this study.

Our study did not confirm the association between IOP and systemic hypertension previously reported.^{4,10} There might be two reasons for this. (1) We defined systemic hypertension based on the self-reported taking of antihypertensive medications and not based on a blood pressure measurement as other investigators; and (2) there was a relatively small number of persons with systemic hypertension and/or raised IOP. Therefore conclusions about the association between IOP and systemic hypertension based on this study would be tentative at best.

Refractive status has been shown to be associated with intraocular pressure^{7,13-15} and was therefore included in the analysis of variance.

There has been some discussion of the accuracy and reproducibility of test results obtained during screening for glaucoma.^{2,16-19} Interobserver variations in tonometry and optic disc assessment were evaluated on 103 respondents during this screening process and the results are published elsewhere.²⁰

In conclusion, this study lends further support to the hypothesis that intraocular pressure is associated with age, country of birth (ethnic origin?), cup-disc ratio, refractive status, glaucoma in the family, and

diabetes. However, there are probably many other as yet unidentified factors that contribute to the variation of mean IOP in a population as indicated by the small amount of variance attributed by the analysis of variance to the factors investigated in this study.

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Accepted for publication 16 October 1986.