The Association of Intraocular Pressure With Obesity and Cardiometabolic Risk in a Young Farmworker Population

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Precis: Intraocular pressure (IOP) was found to be significantly correlated with body mass index (BMI), waist circumference, and diastolic blood pressure (DBP) in a farmworker population located in the southeast Georgia, USA. BMI was correlated with IOP, independent of systemic blood pressures.  

Purpose: Elevated IOP is a known risk factor for glaucomatous optic neuropathy and is believed to be associated with obesity and cardiometabolic diseases. The high prevalence of these conditions in the United States necessitates an evaluation of the relationship among obesity, cardiometabolic risks, and IOP among understudied younger populations.  

Materials and Methods: Farmworker data were collected from the annual Costa-Layman Health Fair between 2013 and 2017. Correlations of IOP with demographic factors, obesity, and cardiometabolic risks were analyzed using analysis of covariance, partial Pearson correlations, and linear regressions.  

Results: In the farmworker population (n = 346), the mean IOP was 15.5 mm Hg and the prevalence of ocular hypertension (IOP > 21 mm Hg) was 5.5%. BMI was correlated with IOP, independent of age and sex. Each 10 mm Hg increase in IOP corresponded with a 0.51 mm Hg increase in IOP. With adjustment for age, sex, ethnicity, systolic blood pressure, and DBP, BMI remained significantly correlated with IOP (r = 0.166, P = 0.002).  

Conclusions: Higher IOP is associated with obesity measures including BMI and waist circumference and is correlated with DBP. These findings suggest that BMI is an independent risk factor for elevated IOP.  

Key Words: obesity, cardiometabolic risk, intraocular pressure, farmworkers

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Glaucoma is a leading cause of blindness worldwide and across all ethnicities.1 It is deﬁned as an optic neuropathy with a characteristic pattern of retinal ganglion cell degeneration leading to vision loss.2 Elevated intraocular pressure (IOP), also known as ocular hypertension (OHT), is the hallmark risk factor for development and progression of glaucoma.3–5 In addition, IOP remains the only known modiﬁable risk factor, and its lowering represents the only established current treatment for glaucomatous optic neuropathy.5–7 Notably, IOP has previously been shown to be associated with a number of systemic risk factors contributing to cardiometabolic risk, diabetes mellitus, and cardiovascular disease.9 Positive associations of IOP with systolic blood pressure (SBP)9–12 and diastolic blood pressure (DBP),10–15 body mass index (BMI),12,15,17,18 waist circumference,17,18 and diabetes mellitus16,14–16 have been documented across multiple ethnicities. Existing studies have largely examined the associations between IOP and cardiometabolic risk factors in older populations (age above 40 y).9–17 However, there are limited data available assessing these associations in younger populations, particularly in understudied farmworker populations.  

We undertook a study of farmworkers residing at the Costa-Layman Farms in Trenton, SC to greater characterize the relationship among obesity, cardiometabolic risk, and IOP. This population represents a group of younger men and women (mean age 35 y) of lower socioeconomic status and a higher prevalence of cardiometabolic disorders19,20 This study aimed to examine the relationship of obesity measures (BMI, waist circumference), cardiometabolic risk factors (SBP, blood sugar levels, lipid proﬁle), and demographic factors (age, sex, ethnicity) with IOP in a younger adult population.

MATERIALS AND METHODS

Study Participants

The study participants included 346 adults from the Costa-Layman Farms in Trenton, SC who visited the annual health fair between 2013 and 2017. The Costa-Layman nursery is a wholesale supplier for perennials, located in Trenton, SC. It was established in 1990, and it consists of 3 farms. The average size of each farm is about 229 acres. Participant information was collected as part of a continued outreach program by Augusta University and health care partners to provide the farmworkers with a no-cost health assessment. Fliers were distributed among the employees and were posted on the noticeboards throughout the farms. The health fair was open to all Costa-Layman farmworkers with Spanish-speaking interpreters on-site to bridge language and communication barriers.
with the Hispanic/Latino workers. All study participants were provided with an IRB-approved consent form, and certified Spanish interpreters were available along with Spanish translated consent forms. Of a total 891 study participants spanning the study’s 5-year data collection period, 298 farmworkers were excluded from the data analysis due to lack of valid IOP measurements. Data from the first visit was utilized for participants who had attended the health fair multiple years, resulting in the exclusion of an additional 247 farmworkers. A final 346 participants with first visit measurements for IOP were included in the statistical analysis.

Anthropometry and Blood Pressure (BP)

Anthropometric measurements (height, weight, and waist circumference) were obtained using standardized procedures. Height was measured using a wall-mounted stadiometer (Tanita Corporation of America, Arlington Heights, IL) and weight was measured with an electronic scale (model CN20L: Cardinal Detecto, Webb City, MT). BMI was calculated using the Center for Disease Control (CDC) approved formula, weight (kg)/height (m²) and classified per guidelines: <18.5 kg/m² (underweight), 18.5 to 24.9 kg/m² (normal), 25.0 to 29.9 kg/m² (overweight), ≥ 30.0 kg/m² (obese).²¹ Waist circumference was measured with minimal clothing at the approximate midpoint between the lower margin of the last palpable rib and the top of the iliac crest, just below the level of the umbilicus.²² Per International Diabetes Federation guidelines, abdominal obesity is defined in women as waist circumference > 80 cm and in men as waist circumference > 90 cm.²³ SBP and DBP were measured with a manual mercury sphygmomanometer. Participants were given 5 minutes of rest before the measurements; 2 readings were taken 1 to 2 minutes apart while in a sitting position and right arm laid flat on a table. If the readings differed significantly, another 1 to 2 minutes of rest was given before a repeat measurement. Both readings were reported, and the averages were used for data analysis. BPs were classified based on the 2017 American College of Cardiology/American Heart Association guidelines: <120/ <80 mm Hg (normal), 120-129/<80 mm Hg (elevated), 130-139/80-89 mm Hg (stage 1 hypertension), >140/>90 mm Hg (stage 2 hypertension).²⁴ Anthropometry and BP measurements were performed by trained medical students and nurses of the Medical College of Georgia, Augusta University.

IOP

Applanation tonometry obtained by Tono-Pen (Bio-Rad, Hercules, CA) was conducted by certified optometrists to measure the IOP of each eye. Participants were given topical proparacaine to anesthetize the cornea, and the reading was taken 30 seconds to 1 minute following the instillation of the drops. The recorded IOPs for right and left eyes were averaged and used in the subsequent data analysis. OHT was defined as IOP >21 mm Hg, echoing the pressure cutoff utilized in landmark eye studies, such as the Los Angeles Latino Eye Study (LALES) and the Blue Mountains Eye Study.²⁵,²⁶

Biochemical Information

Venous blood samples were collected following an overnight fast, centrifuged immediately, and placed in storage at −80°C before analysis. Measures of blood sugar (fasting plasma glucose and glycosylated hemoglobin/HbA1c) and a lipid panel [total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, and triglycerides] were performed by Premier Medical Laboratory Services (Greenville, SC). Fasting plasma glucose was measured by utilizing the hexokinase and glucose-6-phosphate dehydrogenase enzymatic method. Hemoglobin A1c percentages (HbA1c) were measured using turbidimetric inhibition immunoassays. Lipid levels were measured through an enzymatic colorimetric method using an automated analyzer (Cobas c 311/501 and Cobas c 502) with Cobas enzymatic reagents. Diabetes was defined as a fasting plasma glucose level ≥126 mg/dL or HbA1c ≥ 6.5%, based on guidelines published by the American Diabetes Association.²⁷

Statistical Analysis

Statistical analysis was executed using the SPSS Statistics software (version 24; IBM Statistics, Armonk, NY) with a P-value of <0.05 to be considered statistically significant. Regarding population characteristics, categorical variables were summarized using relative frequency, whereas continuous variables were summarized by their means and SD. Differences in mean IOP by age group, sex, ethnicity, obesity, and BP category were determined using analysis of covariance with age, sex, and ethnicity as the primary covariates. Partial Pearson correlations were executed with measures of obesity (BMI and waist circumference) and cardiometabolic risk factors (SBP, DBP, fasting plasma glucose, HbA1c, total cholesterol, HDL-cholesterol, log-transformed HDL-cholesterol, LDL-cholesterol, and triglycerides) against mean IOP, adjusting for age, sex, and ethnicity. HDL-cholesterol was log-transformed and included in the data analysis due to the non-normal distribution of HDL-cholesterol data. As there is existing evidence suggesting hormonal influence on IOP²⁸ as well as differing prevalence of cardiometabolic disorders among the 2 sexes in the farmworker population,²⁹ partial Pearson correlations were executed with populations of males and females separately, in order to isolate possible sex-specific differences in correlations of cardiometabolic risk with IOP. Interactions of age and ethnicity with the associations between IOP and cardiometabolic risk factors were also examined in the regression models. Linear regression of BMI and systemic BPs with IOP as the dependent variable was performed to determine changes in IOP with incremental changes in the cardiometabolic risk factors. Linear regression was also performed with HDL-cholesterol, log-transformed HDL-cholesterol, and log-transformed LDL-cholesterol multiplied with the dichotomous sex variable to determine if the interaction between HDL-cholesterol and sex was significant. A linear regression of BMI and IOP was completed with added covariates of SBP and DBP to account for the strong link between obesity and hypertension. We elected to conduct a Pearson correlation with more of the metabolic factors included, in order to demonstrate a relationship between IOP and the metabolic risk. Correlation analysis indicates whether there is a positive or negative association between 2 variables and the strength of that association (between −1 and +1). Linear regression demonstrates the direct relationship and also how dependent variable is affected with changes in independent variable. Thus, this was valuable in the analysis of BMI and BP versus IOP. This analytical plan has been practiced in the literature.³⁰ In doing so, we were able to demonstrate the changes in IOP with changes in BP and compare to previously published studies.

RESULTS

Study Population

The study population included 346 farmworkers for whom IOP measurements were recorded. Characteristics of the
study population are summarized in Table 1. The population’s mean age was 35.4 years and was comprised of 43.6% women. Our sample was predominantly Hispanic (67.6%). Non-Hispanic blacks comprised 20.5% and non-Hispanic whites the remaining 11.8%. Regarding cardiometabolic risk, 72.0% were overweight (39.9%) or obese (32.1%), 47.4% were hypertensive — 30.6% stage 1 and 16.8% stage 2, and 8.4% were diabetic (Table 1). The prevalence of overweight, obese, and diabetic individuals approximated the numbers reported in a previous study of this population.20 The mean BMI of the population, 28.3 kg/m², was in the overweight class. The prevalence of OHT, an IOP ≥ 21 mm Hg, was 5.5%, and the mean (SD) IOP was 15.5 (3.8) mm Hg.

### Descriptive Analyses

Comparison of IOP across groups is reported in Table 2. A significant difference (P = 0.028) in IOP was found between males (16.0 mm Hg) and females (14.8 mm Hg), while controlling for age and ethnicity. Although borderline statistically insignificant (P = 0.054), IOP was higher in individuals who were overweight (15.7 mm Hg) or obese (15.8 mm Hg) than normal (15.0 mm Hg), when adjusting for age, sex, and ethnicity. Although a difference in IOP was seen by ethnicity of the study population while controlling for age and sex, with non-Hispanic black having the highest IOP followed by non-Hispanic white and Hispanic, the group difference was not statistically significant. A statistically insignificant positive trend of IOP with worse BP categorization was seen while controlling for age, sex, and ethnicity. Lastly, IOP was not associated with age in our study population when adjusting for sex and ethnicity (P = 0.694).

### Correlation Analysis

Partial Pearson correlations were conducted to investigate the associations of obesity measures and cardiometabolic risk factors and with IOP while controlling for age, sex, and ethnicity. As shown in Table 3, among the total population, obesity measured by BMI (r = 0.192), abdominal obesity measured by waist circumference (r = 0.128), and hypertension assessed by DBP (r = 0.142) were significantly correlated with IOP (P < 0.05). Blood glucose level and lipid profile did not

### Table 1. Population Characteristics

| Characteristics | Statistics |
|-----------------|------------|
| N               | 346        |
| Age, mean (SD) (y) | 35.4 (10.3) |
| Age group, N (%) |            |
| 18-29           | 119 (34.4) |
| 30-39           | 123 (35.5) |
| 40-49           | 71 (20.5)  |
| 50-59           | 28 (8.1)   |
| 60-74           | 5 (1.4)    |
| Sex, N (%)      |            |
| Male            | 195 (56.4) |
| Female          | 151 (43.6) |
| Ethnicity, N (%)|            |
| Non-Hispanic white | 41 (11.8)  |
| Non-Hispanic black | 71 (20.5)  |
| Hispanic        | 234 (67.6) |
| Anthropometrics |            |
| BMI, mean (SD) (kg/m²) | 28.3 (5.7) |
| Waist circumference, mean (SD) (cm) | 93.9 (13.8) |
| Body category, N (%)* |        |
| Normal          | 94 (27.2)  |
| Overweight      | 138 (39.9) |
| Obese           | 111 (32.1) |
| Blood pressure, mean (SD) (mm Hg) |        |
| SBP             | 122.3 (14.8) |
| DBP             | 77.6 (10.8) |
| Blood pressure category, N (%)† |        |
| Normal          | 133 (38.4)  |
| Elevated        | 48 (13.9)  |
| Hypertension    | 164 (47.4) |
| Stage 1 hypertension | 106 (30.6) |
| Stage 2 hypertension | 58 (16.8)  |
| Diabetes-related measures, mean (SD) |        |
| HbA1c           | 5.8 (1.2)  |
| Fasting glucose (mg/dL) | 102.5 (45.6) |
| Diabetes, N (%)‡ |        |
| Normal          | 29 (8.4)   |
| Lipid panel, mean (SD) (mg/dL) |        |
| Total cholesterol | 182.9 (40.5) |
| LDL-cholesterol  | 116.0 (34.8) |
| HDL-cholesterol  | 51.9 (16.7)  |
| Triglycerides    | 141.9 (91.1)  |
| IOP, mean (SD) (mm Hg) | 15.5 (3.8) |
| OHT, N (%)§     | 19 (5.5)   |

*Normal: 18.5 to 24.9 kg/m²; overweight: 25.0 to 29.9 kg/m²; obese: ≥ 30.0 kg/m².
†Blood pressure categories: normal: <120/80 mm Hg; elevated: 120-129/80 mm Hg; stage 1 hypertension: 130-139/80-89 mm Hg; stage 2 hypertension: > 140/90 mm Hg.
‡Diabetes defined as fasting plasma glucose ≥ 126 mg/dL or HbA1c ≥ 6.5%.
§OHT defined as: IOP ≥ 21 mm Hg.
BMI indicates body mass index; DBP, diastolic blood pressure; HbA1c, hemoglobin A1c; HDL, high-density lipoprotein; IOP, intraocular pressure; LDL, low-density lipoprotein; OHT, ocular hypertension; SBP, systolic blood pressure.

### Table 2. IOP Across Groups

| IOP (mm Hg) | Age group (y) | Sex | Ethnicity | OPI (P) |
|-------------|---------------|-----|-----------|---------|
|             | 18-29         | Male | Non-Hispanic white | 0.028  |
|             | 30-39         | Female | Non-Hispanic black | 0.011  |
|             | 40-49         | Hispanic | 0.111  |
|             | 50-59         | Normal | 0.054  |
|             | 60-74         | Overweight | 0.716  |
|             | 122.3 (14.8) | Elevated | Obese |        |
|             | 77.6 (10.8)  | Stage 1 hypertension | P | 0.054  |
|             | 162.3 ± 4.7  | Stage 2 hypertension | OPI | 0.716  |

*Adjusted for age and ethnicity.
†Adjusted for age and ethnicity.
‡Adjusted for age and sex.
§Adjusted for age, sex, and ethnicity.
OPI indicates intraocular pressure.
have significant correlations with IOP ($P < 0.05$). Table 3 also reports the sex-cardiometabolic risk interactions on IOP. In males, BMI ($r = 0.199$) and DBP ($r = 0.186$) were significantly correlated with IOP ($P < 0.05$). In females, besides BMI ($r = 0.176$), waist circumference ($r = 0.191$), HDL-cholesterol ($r = -0.194$), and HDL-cholesterol ratio ($r = 0.166$) were also significantly correlated with IOP ($P < 0.05$). The correlation of log-transformed HDL-cholesterol in females ($r = -0.166$) was borderline insignificant ($P = 0.050$). DBP was not significantly correlated with IOP in females ($P = 0.41$). There were no interactions of age or ethnicity with the associations between IOP and cardiometabolic risk factors ($P < 0.05$).

**Linear Regression Analysis**

A linear regression model controlling for age, sex, and ethnicity was used to visualize the incremental change of IOP with stepwise changes in BMI, SBP, DBP, and HDL-cholesterol, the results of which are contained in Table 4. The increase in IOP (mm Hg) per unit of BMI (kg/m²) was greater in males than in females. In the total study population, a significant increase ($P = 0.009$) in IOP (mm Hg) per unit of DBP (mm Hg) was found. A 10 mm Hg increase in DBP corresponded with a 0.51 mm Hg increase in IOP. In females, a 10 mg/dL increase in HDL-cholesterol corresponded with a 0.48 mm Hg decrease in IOP. A similar inverse association between HDL-cholesterol and IOP was not seen in males.

Examination of the interaction between sex and log-transformed HDL-cholesterol was found to be significant ($P < 0.001$).

**Secondary Correlation and Linear Regression Analysis**

Iterations of a Pearson correlation and linear regression of BMI versus IOP were conducted with age, sex, ethnicity, SBP, and DBP as covariates. These correlation and regression analyses with the added covariates of systemic BPs were executed to account for the strong link between obesity and elevated BP. Seen in Table 5, the correlation of IOP with BMI remained significant ($P = 0.002$).

**DISCUSSION**

Although studies of IOP in relation with obesity and cardiometabolic risk have been done in various populations across Caucasian, South Asian, East Asian, African, and Hispanic/Latino ethnicities,9–16 no study, to our knowledge, has previously investigated these relationships in a younger adult population. Farmworkers represent a unique and appropriate population to investigate such associations due to the very high prevalence of chronic metabolic diseases, in some measures surpassing those of the general US population.20,29,31,32 In addition, investigating such a population lends additional

TABLE 3. Partial Pearson Correlations of Cardiometabolic Risk Factors With IOP for Total Population and by Sex

| Cardiometabolic Risk Factor | Total Population* | Male† | Female‡ |
|----------------------------|------------------|-------|--------|
|                           | Pearson Coefficient | $P$  | Pearson Coefficient | $P$  | Pearson Coefficient | $P$  |
|---------------------------|--------------------|-------|--------------------|------|--------------------|------|
| BMI (kg/m²)              | 0.192              | <0.001| 0.199              | 0.006| 0.176              | 0.033|
| Waist circumference (cm) | 0.128              | 0.018 | 0.084              | 0.248| 0.191              | 0.021|
| SBP (mm Hg)              | 0.075              | 0.168 | 0.122              | 0.090| -0.016             | 0.845|
| DBP (mm Hg)              | 0.142              | 0.099 | 0.186              | 0.010| 0.068              | 0.410|
| HbA1c (%)                | 0.115              | 0.129 | 0.121              | 0.309| 0.112              | 0.258|
| Fasting glucose (mg/dL)  | 0.092              | 0.109 | 0.102              | 0.200| 0.073              | 0.391|
| Total cholesterol (mg/dL)| 0.051              | 0.373 | 0.059              | 0.459| 0.024              | 0.775|
| LDL-cholesterol (mg/dL)  | 0.052              | 0.370 | 0.025              | 0.754| 0.08               | 0.350|
| HDL-cholesterol (mg/dL)  | 0.023              | 0.692 | 0.135              | 0.088| -0.194             | 0.021|
| Ln HDL-cholesterol       | 0.032              | 0.579 | 0.142              | 0.072| -0.166             | 0.050|
| HDL-cholesterol ratio    | 0.016              | 0.788 | -0.078             | 0.326| 0.166              | 0.049|
| Triglycerides (mg/dL)    | 0.026              | 0.656 | -0.021             | 0.796| 0.118              | 0.163|

*Adjusted for age, sex, and ethnicity.
†Adjusted for age and race.
‡BMI indicates body mass index; DBP, diastolic blood pressure; HbA1c, hemoglobin A1c; HDL, high-density lipoprotein; IOP, intraocular pressure; LDL, low-density lipoprotein; Ln HDL, log-transformed high-density lipoprotein; SBP, systolic blood pressure.

TABLE 4. Linear Regression Coefficient for BMI, Systemic Blood Pressures, and Interaction of Sex With Log-transformed HDL-Cholesterol

| Cardiometabolic Risk Factor | Total Population* | Male† | Female‡ |
|----------------------------|------------------|-------|--------|
|                           | $B$ Coefficient | $SE$  | $P$   | $B$ Coefficient | $SE$  | $P$   |
|---------------------------|-----------------|-------|------|-----------------|-------|------|
| BMI (kg/m²)               | 0.129 (0.036)   | <0.001| 0.0154 (0.055) | 0.006 | 0.096 (0.044) | 0.033 |
| SBP (mm Hg)               | 0.020 (0.014)   | 0.168 | 0.038 (0.022) | 0.09  | -0.004 (0.019) | 0.845 |
| DBP (mm Hg)               | 0.051 (0.019)   | 0.009 | 0.075 (0.029) | 0.01  | 0.020 (0.025) | 0.41  |
| HDL-cholesterol (mg/dL)   | 0.005 (0.014)   | 0.692 | 0.031 (0.018) | 0.088 | -0.048 (0.020) | 0.021 |
| Ln HDL-cholesterol (mg/dL)| 0.406 (0.732)   | 0.579 | 1.816 (1.003) | 0.072 | -2.029 (1.024) | 0.05  |

*Adjusted for age, sex, and ethnicity.
†Adjusted for age and race.
‡BMI indicates body mass index; DBP, diastolic blood pressure; HDL, high-density lipoprotein; Ln HDL, log-transformed high-density lipoprotein; SBP, systolic blood pressure; Sex×Ln HDL, sex multiplied by log-transformed high-density lipoprotein.
insight into the health disparity of this and other underserved populations.

Although there is a relative paucity of literature on the US farmworker population, it is known to be predominately Hispanic, most commonly of Mexican origin, and of low socioeconomic status. Approximately 66% have attained less than a high school education, between 60% and 70% of workers may lack health insurance, and roughly 25% to 50% may lack authorization to work in the United States. In addition, many farmworkers have very poor literacy.29,31 Even less is known about the health of the US farmworker population. Available data on the prevalence of cardiometabolic disorders in farmworkers are somewhat variable,20,29,31 but appear to be comparable to the overall US Hispanic/Latino population, which itself exceeds the national average in prevalence of certain cardiovascular disorders, such as diabetes mellitus.33,34 In addition, as work from the California Agricultural Worker Health Survey has demonstrated, there may be significant differences in the prevalence of cardiometabolic disorders between males and females.29 Overall, the high cardiometabolic risk of the farmworker population39 is particularly notable in the context of the rigors of farm labor, as well as the potentially young age of the laboring population, in this study.

In this investigation, we found significant associations between IOP and cardiometabolic risk factors in a young, predominately Hispanic/Latino, farmworker population in the Southeastern United States. Statistically significant positive correlations of several cardiometabolic risk factors (BMI, waist circumference, and DBP) with IOP were present in the overall population. Even after accounting for systemic BP, the positive correlation between obesity and IOP remained significant. We additionally found that both the HDL-cholesterol and HDL-cholesterol ratio were significantly correlated in females only, in our study population, suggesting a sex-specific difference in the association between cardiometabolic risk and IOP.

The mean IOP of our study population, 15.5 mm Hg, was similar to that found in several major studies, including the Beaver Dam, Blue Mountains, UK Biobank, and Beijing Eye studies.9,10,35,36 However, significant differences in the average IOP among ethnic populations may exist. Notably, both the mean IOP of our study population and the mean among only the Hispanic cohort (15.2 mm Hg) were slightly lower than that found in the most comparable population in the LALES (14.5 mm Hg).14 In our study, non-Hispanic blacks had the highest mean IOP, followed by non-Hispanic whites, and Hispanics (Table 2). Studies of predominately Caucasian populations, including the Rotterdam, UK Biobank, Beaver Dam, Framingham, and Blue Mountains studies, have reported mean IOPs between 14.6 and 17.0 mm Hg.9,10,26,37,38 Among East Asian populations, a large cross-sectional study reported a mean IOP of 11.6 mm Hg in a Japanese population,13 means of 12.139 and 14.0 mm Hg17 have been reported in Korean populations, and the Beijing Eye Study reported a mean of 15.7 mm Hg in a Chinese population.30 Reported mean IOP in Indian populations have ranged between 13.6 and 16.4 mm Hg and may be higher in urban than rural areas.40–42 The average IOP in the predominately black (93%) Afro-Caribbean population of the Barbados Eye Study was 18.1 mm Hg43 and 16.0 mm Hg among black American patients without glaucoma in the Baltimore Eye Survey.44 Differences in iris pigmentation and associated pigmented obstruction of the trabecular meshwork have been previously proposed to account for some ethnic variation of measured IOP.45,46 although the exact mechanisms underlying the disparities observed are highly complex and have yet to be fully elucidated.

There have been conflicting reports regarding the relationship between age and IOP in the literature, however, most population studies have reported a positive relationship between increasing age and IOP.10,14,38,47,48 Others have found no independent influence of age on IOP.35–37 and some studies of Japanese populations have actually reported a negative correlation between these 2 variables.13,49,50 In our study, no significant association between age and IOP was identified, although our population was unique compared with many previous studies performed in that 70% of the study population was under the age of 40. The study with the most comparable ethnic population, the LALES contrastingly reported a significant positive association between IOP and age, although patients aged 40 and above were recruited, and the average age of study participants was older, at 54.9 years.14,51 In addition to senescent reductions in aqueous outflow,52 age and IOP may be positively correlated due to the accompanying increase in medical comorbidities such as obesity, diabetes, and hypertension in older populations, which may also independently influence IOP.14,35,53

Our study demonstrated significantly higher IOP in males than in females, in agreement with some studies,13,37,54 although reported sex differences have overall been highly inconsistent in the literature, with most studies showing no significant difference between males and females.10,35,36,38,47,48 The LALES demonstrated higher IOP in females than males, but the difference was small and not regarded as clinically significant.14 Of note, the LALES differs from our study by its recruitment of a relatively higher proportion of females (58%), in contrast to our population, which demonstrated a comparable predominance of males (56%).51 The relationship between sex and IOP remains inconclusive, however, there is evidence suggesting that sex-specific levels of hormones and hormonal regulation could additionally play a role in the regulation of IOP.28

The positive association of systemic BP with IOP has been well-documented in numerous studies across different ethnic populations. Both SBP and DBP have been reported to positively correlate with IOP in many studies,11,14,36,37,55–57 although some have found a correlation only with SBP.10,35,54,36,38 In our study, a significant positive correlation between DBP and IOP only was found, with a 0.51 mm Hg increase in IOP corresponding to every 10 mm Hg increase in DBP. This was similar to the correlation demonstrated in the LALES, where every 10 mm Hg in DBP roughly correlated with a 0.45 mm Hg increase in IOP.14 Despite many studies demonstrating a link between systemic BP and IOP, the rationale behind this positive correlation remains incompletely characterized to date. Beyond a certain degree of ciliary perfusion, aqueous humor production by ultrafiltration has been demonstrated to vary independently of ciliary blood flow.59 Some have suggested that increased sympathetic tone or

**TABLE 5.** Partial Pearson and Linear Regression Coefficients for BMI With IOP

| Pearson Coefficient | B Coefficient (SE) |
|---------------------|--------------------|
| BMI* (kg/m²)        | 0.166              |
|                     | 0.116 (0.038)      |

*Adjusted for age, sex, ethnicity, SBP, and DBP. BMI indicates body mass index; DBP, diastolic blood pressure; IOP, intraocular pressure; SBP, systolic blood pressure.

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elevated systemic hormonal changes accompanying hypertensive states may also partially explain this observed relationship.60

Our study additionally found that there was a significant positive correlation of obesity with IOP in the total population. The correlation of BMI with IOP was stronger in males than in females, however, the correlation of waist circumference with IOP was stronger in females. Our findings in the total population are consistent with numerous prior studies across varied ethnic populations demonstrating a positive correlation between BMI and IOP.10,13,14,16,17,60 Obesity’s influence on IOP is likely multifactorial. Unlike other cardiometabolic risk factors, obesity may directly influence IOP mechanically through increases in intraorbital adiposity, episcleral venous pressure, and blood viscosity, all of which may contribute to a decreased aqueous outflow facility.61 We believe that the more central distribution of fat in females, around the hip and thighs, may explain the finding of a stronger waist circumference correlation in females than males.62

Previous investigations have established diabetes mellitus as positively correlating with elevated IOP10,14,16 although curiously, diabetes mellitus has less consistently been demonstrated to associate with primary open angle glaucoma.63–65 The LALES demonstrated a positive association with HbA1c and IOP.14 however in our investigation, no statistically significant relationship between fasting blood glucose or HbA1c and IOP, was able to be established. Both genetic and physiological mechanisms have been proposed to interpret the relationship between IOP and elevated blood glucose.66–68 Hyperglycemia in the postprandial state has been shown to be associated with a corresponding IOP elevation compared with the preprandial state in subjects tested, albeit to a greater degree in diabetic than non-diabetic individuals, suggesting that there may be a direct association between these biometric variables.66 Lipid parameters, including total cholesterol, LDL, HDL, and triglycerides have also been shown to correlate with IOP in several previous studies.10,15,39,68,69 Genomewide analyses also suggest a link between traits associated with IOP and total cholesterol level.70 A large meta-analysis reported that hyperlipidemic patients average a 0.51 mm Hg increase in IOP compared with their peers without hyperlipidemia, and that a 10 mg/dL increase in triglyceride levels corresponds to a 0.016 mm Hg increase in IOP.69 Studies in East Asian populations have demonstrated a significant negative correlation between HDL and IOP in both sexes,15,39,68 although no correlation between HDL and IOP was confirmed in a recent meta-analysis.69 Unlike previous studies showing positive correlations between other lipid parameters,10,15,39,68,69 no significant correlation with total cholesterol, triglycerides, or LDL was found in our study. In analyzing sex-specific associations between cardiometabolic risk and IOP, we found that HDL-cholesterol and HDL-cholesterol ratio were both significantly correlated in females but not in males. Furthermore, the direction of the HDL-cholesterol correlation was negative in females and positive, albeit statistically insignificant, in males. Interaction of sex with log-transformed HDL-cholesterol was found to be significant. Thus, a valid statistical difference in the relationship between HDL-cholesterol and IOP existed between the sexes in our study population.

To our knowledge, our study is novel in its investigation of the relationship between multiple cardiometabolic parameters and IOP in a younger (mean age <40), predominately Hispanic/Latino population, and also the first to show correlations of different directions between HDL and IOP among the 2 sexes. In addition, our study is unique in its contribution to the relatively sparse literature on the farmworker population, which has traditionally remained underserved. Our study was limited by its moderate sample size compared with landmark epidemiologic studies, as well as its cross-sectional nature, which prevented the establishment of any causal relationships between risk factors and IOP. In addition, the nature of the farmworker population may somewhat limit its generalizability, but it is reasonable to believe our findings apply more broadly to Hispanic/Latino populations. Although IOP measurements were not obtained by the gold standard Goldmann applanation tonometry, the use of the Tono-Pen was sufficient and appropriate for a field setting, and the mean IOP demonstrated in our study was in agreement with major epidemiologic studies.9,10,35,36 Another limitation was the lack of central corneal thickness measurement in our investigation, as central corneal thickness influences IOP, but also varies with age, ethnicity, and sex.71

CONCLUSIONS

The results of this study highlight the association of obesity among other cardiometabolic risk factors with elevated IOP in a younger population, reinforcing the results seen in previous studies. Considering BMI as an independent risk factor for IOP emphasizes the need for proper weight management to reduce the risk for elevated IOP, which itself is the hallmark risk factor for glaucoma and vision loss.

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