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Association between blood pressure and retinal vessel diameters among police officers in the US Northeast

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Abstract

Objective—To examine relationships of blood pressure with central retinal arteriolar equivalent (CRAE) and central retinal venular equivalent (CRVE) among 242 police officers.

Methods—Computerized retinal images of each eye were taken. Mean values of CRAE and CRVE were compared across hypertension status categories using ANOVA and ANCOVA. Associations of mean arterial blood pressure (MABP) with CRAE and CRVE were obtained using regression models.

Results—CRAE were significantly narrower in officers with uncontrolled hypertension (142.8±2.7 µm), compared to those with controlled hypertension (153.6±2.7µm, p=0.0013) and those with no hypertension (156.4±1.0µm, p≤0.0001) after covariate adjustment. CRAE decreased by 3.43 µm for each 5 mmHG increase in MABP (p≤0.0001).

Conclusion—Uncontrolled hypertension was significantly associated with narrower retinal arterioles. No association was observed with retinal venules.

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Ethics Review and Approval: All participants signed written informed consent. The Institutional Review Board at the University at Buffalo, The State University of New York (SUNY), and the National Institute for Occupational Safety and Health (NIOSH) approved the studies.

AUTHOR CONTRIBUTIONS

JKG designed the study, analyzed data, and drafted the initial manuscript. LEC designed the study and drafted the initial manuscript. RK, LMG, CCM, and PB edited the manuscript for intellectual content, and reviewed and revised the manuscript. JMV and MEA reviewed and revised the manuscript and provided critical comments.

Keywords

Blood Pressure; Retinal Arteriolar Diameters; Retinal Venular Diameters; Police

INTRODUCTION

Hypertension is a leading risk factor for cardiovascular-related morbidity and mortality in the United States (U.S.) (1, 2). An estimated 67 million, 1 in every 3 adults, have hypertension, and only a half of them have their condition under control (3). Among U.S. workers, one in five workers (21.3%) had hypertension and 65% of workers under a physician's care had their hypertension under control in 1999–2004, according to National Health and Nutrition Examination Surveys (NHANES) (4).

NHANES also reported that the prevalence of high blood pressure has been much higher in protective service workers (25.7%) including police officers and firefighters, than in workers in the Professional specialty (engineers, scientists, health professionals, teachers, artists) (17.6%) (4). Police officers have unpredictable and stressful working environments such as responding to emergencies, performing first aid at accidents, shift work, and solving problems in their communities. The strenuous duties of police officers may contribute to elevated blood pressure (5–7) which is linked to adverse health outcomes (heart attack, stroke, chronic heart failure, and kidney disease). In addition, compared to other occupations, Davila and colleagues found that police officers are less likely to be aware of their hypertensive status and to take medicine to control the condition (4). An NHANES study found that workers in the Protective Service ranked the lowest in awareness of hypertension (50.6%), treatment (79.3%), and control (47.7%) compared to the other 40 occupations (4). It is of great concern that policing places high demands on the cardiovascular systems (5, 8, 9). Police officers have higher rates of cardiovascular risk factors and cardiovascular disease (CVD) morbidity than workers in other occupations (10–12).

Examining the retinal microvasculature, through retinal imaging techniques, provides a noninvasive way to assess microvascular health in vivo. Population-based studies have reported that elevated blood pressure is strongly associated with retinal arteriolar narrowing (13–18). Changes in the retinal microvasculatures, narrowing of the retinal arterioles and widening of the retinal venules, have been associated with subclinical and clinical CVD risk factors (hypertension, endothelial dysfunction, diabetes mellitus, and metabolic syndrome) (15–17, 19–26), and cardiovascular mortality (21, 27–29).

Although cross-sectional and longitudinal studies have reported that an association exists between hypertension and the retinal microvasculature (13–18, 30, 31), these investigations were conducted among the general population and not specifically among occupational cohorts. To the best of our knowledge, no study has addressed this issue among police officers. We therefore aimed to examine the association of blood pressure with retinal arteriolar diameter (central retinal arteriolar equivalent [CRAE]) and venular diameter (central retinal venular equivalent [CRVE]) in police officers.

METHODS

Study Setting and Sample

The present study was performed among police officers from the XXX [Blinded by request from JOEM] study. The study was conducted to investigate associations between occupational stressors and subclinical CVD in the high-stress occupation of police work. The XXX [Blinded by request from JOEM] collected the data from participants. The XXX [Blinded by request from JOEM] approved the study protocol, and informed consent was obtained from all participants.

To date, there are two main examinations in the XXX [Blinded by request from JOEM] study, the baseline and the follow-up examination. In the baseline XXX [Blinded by request from JOEM] examination (2004–2009), 464 active-duty police officers out of approximately 710 officers who were employed at the BPD in 2004 voluntarily agreed to participate and were examined. In the follow-up XXX [Blinded by request from JOEM] examination (2011–2014), data were collected for several of the variables obtained in the baseline XXX [Blinded by request from JOEM] study. An ancillary study (referred to as the microvascular study) was conducted in 2012–2016, in which retinal images and other microvascular data were collected for the first time. We merged data from the follow-up and the ancillary examinations only for this cross-sectional study. During the follow-up examination, 281 officers consented and participated. Among the 281 officers, 242 completed the retinal photography exam. Our final sample consisted of 242 police officers (65 women and 177 men), of whom 199 were active-duty officers and 53 were retired officers.

Assessment of blood pressure

Blood pressure (BP) was measured after the participants had rested in the supine position for about five minutes. Three BP measurements were taken two minutes apart. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were derived from the mean of the three respective measurements.

Mean arterial blood pressure (MABP) is defined as the average arterial pressure in an individual during a single cardiac cycle. Franklin and colleagues reported that DBP peaked at and subsequently declined after the age of 50 years, while SBP rose constantly with age (32). Thus depending upon the respective changes in SBP and DBP with older age, the MABP may actually tend to change less as individuals age. MABP is determined by the cardiac output (CO), systemic vascular resistance (SVR), and central venous pressure (CVP): MABP = (CO * SVR) + CVP (33). At normal resting heart rates, MABP traditionally has been approximated using the SBP and DBP by Gauer’s formula (34): MABP = (2/3)*SBP + (1/3)*DBP. In a recent study, Papioannou and colleagues found that the formula created by Wezler, Böger, and Meaney is much more efficient than the traditional formula: MABP = 0.412*SBP + 0.588*DBP = DBP + 0.412 * PP, where PP = SBP – DBP (35, 36). Therefore, our study used the formula by Wezler, Böger, and Meaney as a continuous variable of blood pressure.

Participants were asked to provide information on all medications used (medication name, reason for taking, size of dose, frequency of dose, and duration of use) during the past 30 days as of the examination. Hypertension was defined as SBP of 140 mmHg or higher, DBP of 90 mmHg or higher, or taking antihypertensive medications (37). To create a categorical variable of blood pressure, hypertension was further classified into 'controlled hypertension' (officers with SBP < 140 and DBP < 90 and taking medication) and 'uncontrolled hypertension' (officers with SBP ≥ 140 or DBP ≥ 90 regardless of medication use).

Assessment of retinal vessel diameters

Research associates in the XXX [Blinded by request from JOEM] were trained and certified to perform retinal photography by University of Wisconsin Department of Ophthalmology personnel. A non-mydriatic ophthalmic digital imaging system was used to take two digital images per eye (four images total per participant) through a non-pharmacologically dilated pupil. Participants were seated in a windowless room with the lights turned off to allow the pupils to dilate naturally in preparation for the retinal imaging examination. One image was centered on the macula and the second on the optic nerve.

The digital images were sent to the University of Wisconsin Department of Ophthalmology Ocular Epidemiology Reading Center to be graded in a masked fashion using a standardized protocol described as follows. Retinal vessel diameters were measured at the Reading Center using a computer-assisted technique based on a standard protocol and using the Parr-Hubbard-Knudtson formula (38). Trained graders, masked to participants' characteristics and using a computer software program measured the diameters of all arterioles and venules coursing through a specified area one-half to one disc diameter surrounding the optic disc. On average, between 7 and 14 arterioles and an equal number of venules were measured per eye. Individual arteriolar and venular measurements were combined into summary indices that reflected the average CRAE and CRVE based on the Parr-Hubbard-Knudtson (38, 39).

Covariates

Participants were given self-administered questionnaires to provide information about demographics (age, sex, race/ethnicity, education, etc.), lifestyle behaviors (smoking status, alcohol intake, physical activity, and sleep duration), and medical history. Age was defined at the time of the examination when BP and retinal images were captured. Smoking status was reported as 'current', 'former', or 'never' and included cigarette, cigar, and pipe smoking. Diabetes was defined as a fasting glucose level of ≥ 100 mg/dL or self-reported use of diabetic medication. Waist circumference was measured at the midpoint between the lowest part of the costal margin in the mid-axillary line and the highest point of the iliac crest. The average value of two measurements was used in the analyses. White blood cell (WBC) count was analyzed in Kaleida Health, Buffalo, New York.

Statistical Analysis

Means and frequencies of all variables by gender were compared using the chi-square and t-tests (Table 1). Retinal microvascular parameters (i.e., CRAE and CRVE) were analyzed as continuous variables. To investigate the associations of covariates with retinal microvascular parameters, analysis of variance (ANOVA), or Pearson's correlation coefficients were used (Table 2). Potential confounders were selected based on their association with both the hypertension status or retinal vascular parameters in this study and whether they were reported as confounders in previous investigations. The selected confounders and CRAE or CRVE risk factors were age, gender, race/ethnicity, smoking status, waist circumference, diabetes status, and WBC count. Tests for interaction by gender, race/ethnicity, smoking status, metabolic syndrome, and diabetes status were performed by including interaction terms in the model. The criterion for significance in effect modification analyses was set at $p<0.1$. We used ANOVA and ANCOVA to estimate mean levels of CRAE and CRVE across hypertension status (Table 3), and multiple regression estimated mean levels of CRAE and CRVE with MABP (Figure 1). All p-values presented were two-tailed and statistical significance was set at $p <0.05$ for all analyses, except for effect modification. Analyses were performed with the use of SAS software, version 9.3 (SAS Institute, Cary, NC).

RESULTS

The study sample included 242 police officers (73.1% men) with an average age of 48.7 years (Table 1). The prevalence of obesity (BMI ≥ 30 kg/m^2) was 41.3% overall, 48.6% in male officers and 21.5% in female officers. The prevalence of hypertension was 31.8% (n=77). Among officers with hypertension, 77.9% were taking antihypertensive medication (n=60). Among officers on antihypertensive medication, 90% were able to control their hypertension (n=54). There were 23 officers with uncontrolled hypertension (17 not medicated and 6 medicated). The blood pressure parameters (SBP, DBP, and MABP) were significantly different between men and women. The overall mean CRAE was 154.6 μm (SD=13.3) and the mean CRVE was 224.4 μm (SD=20.0). There was no significant difference between men and women for CRAE and CRVE.

Table 2 shows the unadjusted associations for selected covariates with the retinal vessel parameters. The mean CRAE were significantly higher in African American (158.3 ± 13.9) than White/Hispanic (153.7 ± 13.0) officers; similar associations were observed with CRVE. HDL cholesterol and glucose were significantly correlated with CRVE ($r= −0.183$, p=0.0044; $r=0.175$, p=0.0063 respectively). WBC count, CRP, and heart rate were significantly and positively correlated with CRVE ($r=0.199$, p=0.0019; $r=0.183$, p=0.0042; $r=0.179$, p=0.0053, respectively).

The associations between hypertension status and retinal vessel parameters are presented in Table 3. Officers with uncontrolled hypertension had a significantly narrower mean CRAE compared with those who had controlled hypertension (142.8 ± 2.7 vs. 153.6 ± 2.7 μm; p = 0.0013) and also those who did not have hypertension (142.8 ± 2.7 vs. 156.4 ± 1.0 μm; p < 0.0001), after adjusting for age, gender, race/ethnicity, smoking status, waist circumference, diabetes status, and WBC count. We did not observe a significant association between hypertension and CRVE.

Figure 1 shows the association between mean arterial blood pressure and the retinal vessel diameters. It shows that CRAE became narrower with increasing mean arterial blood pressure after adjusting for covariates (p-value for linear trend < 0.0001). Each 5 mmHG increase in MABP was significantly associated with a 3.43 μm decrease in CRAE. CRAE became increasingly narrower as DBP and SBP increased (−3.04 μm; p<0.0001, −2.09 μm;

p<0.0001, respectively) (Data not shown). CRVE was not significantly associated with MABP.

DISCUSSION

This study investigated the association of retinal arteriolar and venular diameters with blood pressure in police officers. The findings from our cross-sectional analysis indicate that officers with uncontrolled hypertension had a significantly narrower mean retinal arteriolar diameter than those with controlled hypertension and those without hypertension. Our results support those of previous studies (13, 18). Several studies found that use of antihypertension medication was associated with wider (i.e., better) retinal arteriolar diameter (40–43). Our study showed that officers whose hypertension was not controlled had a narrower mean CRAE compared to officers whose blood pressure was controlled. The prevalence of controlled hypertension among police officers in this study was 60%. Although this prevalence was similar to the prevalence rate of U.S. workers (4), continuous control of hypertension is necessary to prevent narrowing of the retinal arterioles.

In our study, hypertension status was not significantly associated with CRVE. While a Beaver Dam Eye study in America showed similar results to ours (18), a study conducted among Southeast Asians found that persons with hypertension had wider retinal venules than those with no hypertension (13).

A recent study by Howard and colleagues reported the effect of hypertensive medication on the retinal vascular diameter (40). The authors found that calcium channel blockers were associated with wider CRAE and b-blockers were marginally associated with wider CRVE (40). Our study had medication use information for each officer, but we were not able to analyze the association of specific medication use with CRAE and CRVE since the number of officers taking mediation was relatively small (only 13 officers on calcium channel blockers and 11 officers on b-blockers).

Blood pressure was inversely associated with CRAE in this study which is consistent with previous population-based studies (13, 15, 18). Wong and colleagues, in an investigation of the U.S. white population (n=4926, mean age=61), reported a similar narrowing of arterioles (18). However, the magnitude of the arterial diameter in this study was almost 20% narrower than that found by Wong and colleagues after the same adjustment for age and gender (−2.93μm /5mmHg, 95%CI [−3.99, −1.88] vs. −2.45/5mmHg, 95%CI [−2.70, −2.20], relatively). One possible explanation for this difference is that the sample of this study (police officers) was exposed to a more stressful and strenuous working environment than the sample population in Wong and colleagues’ study. Stress leads to increased blood pressure, which in turn is associated with narrower CRAE.

We also found that the retinal venular diameter was not related to blood pressure. Previous studies investigated this relationship. A Southeast Asian study revealed positive associations between retinal venular narrowing and MABP (13). However, other studies conducted in the U.S. and Australia showed similar results to ours, that is, no significant linear association between blood pressure and the retinal venular diameter (14, 18).

This study has several strengths and limitations. Because it is cross-sectional, we cannot infer causality or determine whether changes in the retinal vessel diameter preceded elevated blood pressure, or vice versa. We were unable to adjust for markers of sub-clinical atherosclerosis, such as carotid plaque or aorta calcification that may have influenced the retinal vascular diameters. In addition, there may have been misclassification of blood pressure status because SBP and DBP measurements during a single day examination were applied to the classification of hypertension. The strengths of this study include 1) adjustment for a variety of potential confounders and 2) use of standardized methods to assess blood pressure and retinal vessel diameters. Also, this study is the first to investigate the association between blood pressure and retinal vascular diameters among a certain occupational group. These results may be generalized to other workers in highly-stressed environments.

In conclusion, police officers with uncontrolled hypertension had a significantly narrower mean CRAE than those with no hypertension or controlled hypertension. Also, each 5 mmHg increase in MABP was associated with a 3.43μm narrowing in mean CRAE. Our findings are consistent with previous studies suggesting that decreased CRAE may reflect microvascular damage from elevated blood pressure. We concur with the statement by Jeganathan and colleagues that the assessment of retinal vascular diameters may provide insights into early microvascular effect of blood pressure (13). Longitudinal studies are needed to further investigate these associations.

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Abbreviations used

ANOVA	Analysis of variance
ANCOVA	Analysis of covariance
CRAE	Central retinal arteriolar equivalent
CRVE	Central retinal venular equivalent
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
MABP	Mean arterial blood pressure
NHANES	National Health and Nutrition Examination Survey
SBP	Systolic blood pressure
WBC	White blood cell

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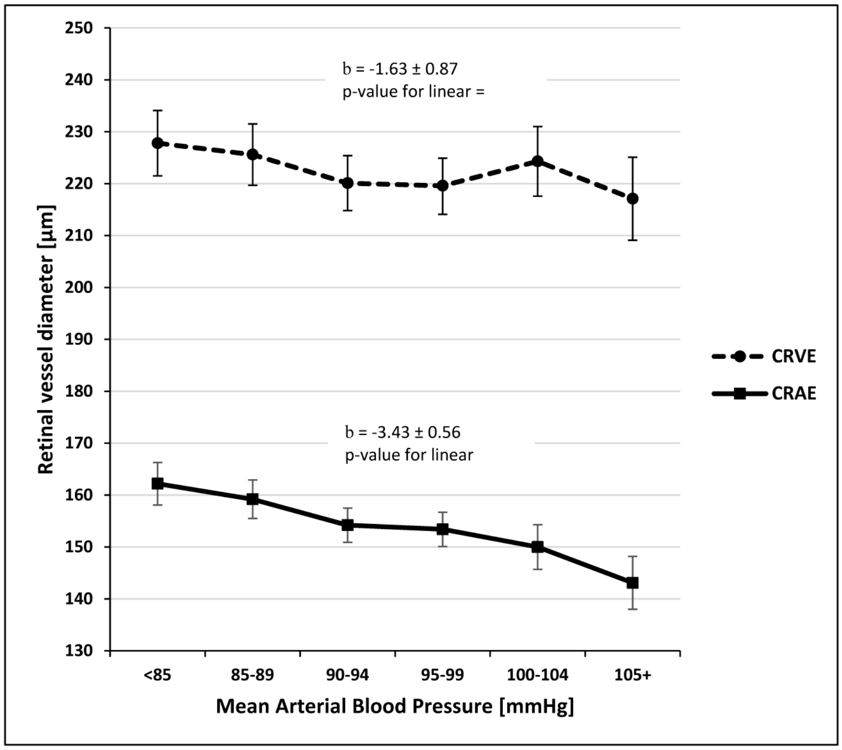

Figure 1.
Estimated retinal vessel diameters (CRAE & CRVE) with mean arterial blood pressure (MABP)
CRAE: Retinal arteriolar diameter
CRVE: Retinal venular diameter
The models was adjusted for age, gender, race/ethnicity, smoking status, waist circumference, diabetes, and WBC.
b is for every 5 mmHg increase in MABP.

Table 1

Characteristics of Participants by gender 2011–2016.

Characteristics	All (n=242)	Women (n=65)	Men (n=177)	
	Mean ± SD	Mean ± SD	Mean ± SD	P-value†
Age [years]	48.7 ± 8.1	48.6 ± 6.8	48.7 ± 8.5	0.9282
Years of service	21.4 ± 8.0	20.0 ± 6.8	21.9 ± 8.4	0.1102
Physical activity [hours/wk]	7.3 ± 8.0	6.2 ± 4.1	7.7 ± 9.0	0.0797
Alcohol intake [drinks/wk]	5.6 ± 9.9	2.7 ± 3.2	6.4 ± 11.3	0.0001
Sleep duration [hrs/day]	6.1 ± 1.2	6.0 ± 1.4	6.1 ± 1.1	0.7302
Body mass index [kg/m^2]	29.5 ± 4.7	27.2 ± 4.9	30.3 ± 4.4	<0.0001
Percent body fat [%]	26.8 ± 6.5	32.7 ± 6.0	24.6 ± 5.1	<0.0001
Waist circumference [cm]	97.3 ± 13.7	85.8 ± 11.5	101.6 ± 11.9	<0.0001
Glucose [mg/dL]	96.8 ± 20.0	91.8 ± 11.2	98.6 ± 22.1	0.0021
Triglyceride [mg/dL]	121.4 ± 86.5	94.1 ± 79.4	131.4 ± 87.1	0.0028
Total cholesterol [mg/dL]	197.3 ± 37.2	203.1 ± 35.7	195.2 ± 37.6	0.1459
HDL cholesterol [mg/dL]	48.5 ± 13.7	58.4 ± 16.1	44.9 ± 10.6	<0.0001
LDL cholesterol [mg/dL]	124.9 ± 34.0	126.6 ± 31.8	124.3 ± 34.8	0.6409
Vitamin D2 25(OH) [ng/mL]	1.8 ± 3.9	2.5 ± 6.0	1.5 ± 2.8	0.1833
Vitamin D3 25 (OH) [ng/mL]	29.2 ± 11.6	29.9 ± 12.2	28.9 ± 11.4	0.5649
White blood cell count (WBC)	5.8 ± 1.6	5.4 ± 1.4	5.9 ± 1.7	0.0312
C-reactive protein (CRP)	2.6 ± 3.0	2.9 ± 2.9	2.5 ± 3.1	0.4150
Heart rate [beats/60 sec]	64.7 ± 9.5	65.6 ± 8.9	64.3 ± 9.7	0.3301
Systolic blood pressure [mmHg]	116.7 ± 11.3	113.0 ± 12.1	118.0 ± 10.7	0.0021
Diastolic blood pressure [mmHg]	78.2 ± 7.9	75.3 ± 7.2	79.2 ± 7.9	0.0005
Mean arterial blood pressure [mmHg]	91.0 ± 8.4	87.8 ± 8.3	92.2 ± 8.1	0.0003
Retinal arteriolar diameter (CRAE) [µm]	154.6 ± 13.3	156.1 ± 15.7	154.1 ± 12.2	0.3419
Retinal venular diameter (CRVE) [µm]	222.4 ± 20.0	223.2 ± 22.1	222.1 ± 19.2	0.6870
	N (%)	N (%)	N (%)	P-value
Race/ethnicity				
White/Hispanic	193 (79.8)	44 (67.7)	149 (84.2)	0.0047
African American	49 (20.2)	21 (32.3)	28 (15.8)	
Education				
≤HS/GED	22 (9.1)	3 (4.6)	19 (10.7)	0.2196
< 4 yrs college	124 (51.2)	38 (58.5)	86 (48.6)	
≥4 yrs college	96 (39.7)	24 (36.9)	72 (44.7)	
Rank				
Patrol officer	127 (53.4)	38 (58.5)	89 (51.5)	0.6068
Sergeant/Lieut./Capt.	51 (21.4)	13 (20.0)	38 (22.0)	
Detec./Execu./Others	60 (25.2)	14 (21.5)	46 (26.6)	
Smoking status				
Current	50 (20.9)	8 (12.5)	42 (24.0)	0.0234

Characteristics	All (n=242)	Women (n=65)	Men (n=177)	
	Mean ± SD	Mean ± SD	Mean ± SD	P-value†
Former	75 (31.4)	28 (43.7)	47 (26.9)	
Never	144 (47.7)	28 (43.8)	86 (49.1)	
BMI [Kg/m^2]				
Normal (< 25.0)	34 (14.1)	23 (35.4)	11 (6.2)	<0.0001
Overweight (25–29)	108 (44.6)	28 (43.1)	80 (45.2)	
Obese (≥30)	100 (41.3)	14 (21.5)	86 (48.6)	
Metabolic Syndrome				
Yes (≥3 components)	74 (30.6)	13 (20.0)	61 (34.5)	0.0304
No	168 (69.4)	52 (80.0)	116 (65.5)	
Shiftwork (entire career)				
Day	121 (50.4)	49 (76.6)	72 (40.9)	<0.0001
Afternoon	78 (32.5)	10 (15.6)	68 (38.6)	
Night	41 (17.1)	5 (7.8)	36 (20.5)	
Sleep Quality				
Good	111 (47.8)	26 (41.3)	85 (50.3)	0.2209
Poor	121 (52.2)	37 (58.7)	84 (49.7)	
Diabetes				
Yes	15 (6.2)	2 (3.1)	13 (7.3)	0.3665
No	227 (93.8)	63 (96.9)	164 (92.7)	
Diabetes medication				
Yes	6 (2.5)	0 (0.0)	6 (3.4)	0.1957
No	236 (97.5)	65 (100.0)	171 (96.6)	
Hypertension status				
Yes uncontrolled/untreated	23 (9.5)	4 (6.2)	19 (10.7)	0.0252
Yes, controlled	54 (22.3)	8 (12.3)	46 (26.0)	
No	165 (68.2)	53 (81.5)	112 (63.3)	
Hypertension medication				
Yes	60 (24.8)	10 (15.4)	50 (28.3)	0.0400
No	182 (75.2)	55 (84.6)	127 (71.7)	

P-values were obtained from the Student's t-test (for continuous variables) and the Chi-square test or Fishers exact test (for categorical variables)

Table 2

Association between covariates and retinal vessel diameters 2011–2016

Characteristics	Retinal arteriolar diameter (CRAE)		Retinal venular diameter (CRVE)	
	Correlation	P-value	Correlation	P-value
Age [years]	−0.119	0.0652	−0.028	0.6673
Years of service	−0.174	0.0068	0.010	0.8797
Physical activity [hours/wk]	0.003	0.9666	−0.070	0.2768
Alcohol intake [drinks/wk]	−0.081	0.2127	0.009	0.8858
Sleep duration [hrs/day]	−0.015	0.8180	−0.030	0.6413
Body mass index [kg/m^2]	−0.028	0.6704	0.087	0.1763
Percent body fat [%]	−0.036	0.5862	0.038	0.5689
Waist circumference [cm]	−0.115	0.0733	0.039	0.5505
Glucose [mg/dL]	−0.028	0.6698	0.175	0.0063
Triglyceride [mg/dL]	0.066	0.3064	0.010	0.8809
Total cholesterol [mg/dL]	−0.119	0.0955	−0.050	0.4798
HDL cholesterol [mg/dL]	−0.018	0.7777	−0.183	0.0044
LDL cholesterol [mg/dL]	−0.083	0.2006	0.049	0.4448
Vitamin D2 25(OH) [ng/mL]	0.138	0.3231	0.236	0.0002
Vitamin D3 25 (OH) [ng/mL]	−0.110	0.0884	−0.287	<0.0001
White blood cell count (WBC)	0.095	0.1412	0.199	0.0019
C-reactive protein (CRP)	0.076	0.2408	0.183	0.0042
Heart rate [beats/60 sec]	0.032	0.6233	0.179	0.0053
	Mean ± SD	P-value	Mean ± SD	P-value
Gender				
Female	156.1 ± 15.7	0.2855	223.2 ± 22.1	0.6870
Male	154.1 ± 12.2		222.1 ± 19.2	
Race/ethnicity				
White/Hispanic	153.7 ± 13.0	0.0291	219.8 ± 18.9	<0.0001
African American	158.3 ± 13.9		232.4 ± 21.2	
Smoking status				
Current	153.9 ± 14.5	0.3123	220.9 ± 20.8	0.2969
Former	153.0 ± 14.1		220.3 ± 20.5	
Never	155.9 ± 12.3		224.6 ± 19.5	
BMI [kg/m^2]				
Normal (< 25.0)	156.9 ± 14.0	0.3169	220.2 ± 17.7	0.6587
Overweight (25–29)	155.2 ± 12.9		221.9 ± 20.4	
Obese (≥30)	153.2 ± 13.3		223.6 ± 20.5	
Metabolic Syndrome				
Yes	153.0 ± 14.6	0.1964	224.4 ± 22.8	0.3063
No	155.4 ± 12.6		221.5 ± 18.7	
Sleep Quality				

Characteristics	Retinal arteriolar diameter (CRAE)		Retinal venular diameter (CRVE)	
	Correlation	P-value	Correlation	P-value
Good	154.5 ± 14.9	0.8894	220.1 ± 20.9	0.1525
Poor	154.7 ± 11.9		223.9 ± 19.7	
Diabetes				
Yes	154.6 ± 13.3	0.9590	228.3 ± 26.1	0.2344
No	154.4 ± 12.8		222.0 ± 19.6	

Results were obtained from the Pearson correlation (for continuous variables) and the ANOVA (for categorical variables)

Table 3

Associations of hypertension status with retinal parameters.

	Hypertension Status†					
	No Hypertension (N=165) (a)	Controlled Hypertension (N=54) (b)	Uncontrolled Hypertension (N=23) (c)	P-values from pairwise comparison		
	Mean ± SE	Mean ± SE	Mean ± SE	(a) vs. (b)	(a) vs. (c)	(b) vs. (c)
Retinal arteriolar diameter (CRAE)						
Model 1	156.4 ± 1.0	153.2 ± 1.8	145.2 ± 2.7	0.1116	**0.0001**	**0.0139**
Model 2	156.4 ± 1.0	153.7 ± 1.8	144.3 ± 2.7	0.1920	**<0.0001**	**0.0038**
Model 3	156.4 ± 1.0	153.6 ± 2.7	142.8 ± 2.7	0.1921	**<0.0001**	**0.0013**
Retinal venular diameter (CRVE)						
Model 1	222.8 ± 1.6	221.8 ± 2.7	220.6 ± 4.2	0.7357	0.6222	0.8196
Model 2	223.1 ± 1.5	222.1 ± 2.6	218.0 ± 4.1	0.7552	0.2513	0.4012
Model 3	223.9 ± 1.5	220.5 ± 2.8	216.6 ± 4.2	0.3047	0.1037	0.4377

Model 1: unadjusted.

Model 2: adjusted for age, gender and race/ethnicity.

Model 3: adjusted for age, gender, race/ethnicity, smoking status, waist circumference, diabetes, and WBC count.

† Hypertension status was classified 3 groups: ‘No Hypertension’ defined as SBP<140 mmHg and DBP<90 mmHg and free from taking antihypertensive medication, ‘Controlled Hypertension’ defined as taking antihypertensive medication with SBP<140 and DBP<90, and ‘Uncontrolled Hypertension’ defined as SBP ≥ 140 or DBP ≥ 90 regardless of taking antihypertensive medication.