Antioxidants and Pulmonary Function Among Police Officers

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Objective: To examine associations of dietary antioxidant intake and pulmonary function. **Methods**: Antioxidant data (vitamins A, C, D, E, magnesium, and omega-3 fatty acids) were abstracted from food frequency questionnaires. Pulmonary function was measured using American Thoracic Society criteria. We used analysis of variance to investigate associations. **Results**: Among 79 police officers (57% male), forced vital capacity was positively and significantly associated with vitamin A after adjustment for age, gender, height, race, smoking status, and pack-years of smoking, and with magnesium after adjustment for those risk factors plus total calories, all supplement use, and abdominal height. Among current/former smokers only, mean levels of all pulmonary function measures were significantly associated with vitamin E; smoking status significantly modified these relationships. **Conclusions**: Increased intake of vitamin A, vitamin E (among current/former smokers only), and magnesium was associated with better pulmonary function.

Poor pulmonary function has been shown to be an independent and major predictor of cardiovascular disease and mortality in some studies.[1–5] Results from observational studies suggest that antioxidants may have positive and protective effects on pulmonary function.[6–14]

Several cross-sectional and case-control studies have reported negative associations between antioxidant intake (measured in serum or plasma, or assessed from intake of fruits and vegetables) and common respiratory disorders such as cough, wheeze, asthma, and bronchitis; other studies report positive associations between antioxidant intake and pulmonary function.[6–10] Prospective cohort studies have also reported inverse associations for antioxidant intake with incidence of or mortality from respiratory disorders.[7,11,13] In one of these studies, the authors reported a more rapid decline in forced expiratory volume in one second (FEV_1) among participants who reported the greatest decrease in fresh fruit consumption over a seven-year period.[14]

Police officers have higher rates of mortality from several causes, including cardiovascular disease, than similar individuals in the general population.[15] Impaired pulmonary function is associated with increased risk of subclinical and clinical cardiovascular and cerebrovascular diseases.[1,16–18] In addition to several organizational stressors that police officers regularly encounter on the job, they are exposed to extremes in temperatures, air pollutants, and possibly pollutants arising from the effects of terrorist activities or during investigations of illegal amphetamine laboratories.[19–23] Police officers who work on night shift schedules may have less than healthy diets since some studies show an association between night shift work and lower consumption of foods that are rich in vitamins and other nutrients or an abnormal lipid profile.[24–26]

Observational studies are frequently conducted to investigate risk factors for pulmonary function. The aim of this study is to investigate modifiable factors in the diet that may be protective for pulmonary function in police officers. The main objectives are to investigate the cross-sectional association between several antioxidants (vitamins A, C, D, and E, omega-3 fatty acids, and magnesium) and pulmonary function, and to determine if smoking status modifies these associations.

METHODS

Participants

In 1999 and 2000, researchers at the University at Buffalo began a pilot study to investigate the health of police officers. They selected the Buffalo, New York police department, a midsized urban police department, as the sample site. Officers were selected into the study sample as long as they were sworn police officers and willing to participate. A random sample ($N = 115$) was generated from all 934 police officers in the Buffalo, New York police department using a computer-generated random number table. Women officers were oversampled to ensure adequate representation. All the random sample officers voluntarily agreed to participate in the study. Of the 115 officers, 81 had complete information on antioxidant variables and pulmonary function that met American Thoracic Society (ATS) guidelines.[27] Two officers who reported cancer and a heart attack were excluded from the analysis leaving a final sample of 79 officers (34 women and 45 men). Investigators obtained informed consent and Institutional Review Board approval, and the Center for Preventive Medicine at the University at Buffalo served as the data collection site.

Assessment of Antioxidants

Self-administered dietary questionnaires were completed by all officers. This dietary questionnaire is a modification of the National Cancer Institute's Health Habits and History Questionnaire, which was developed from dietary responses to the Second National Health and Nutrition Examination Survey.[28] The officers were asked to recall their food intake during the past 12 to 24 months and return the completed questionnaires to the clinic. The officers' responses were converted by investigators of the Buffalo Cardio-Metabolic Occupational Police Stress study of the National Institute for Occupational Safety and Health to the General Select (GSEL) Food Frequency Questionnaire (FFQ). The GSEL FFQ is the dietary questionnaire that is used by the Fred Hutchinson Cancer Research Center for the general population. A conversion codebook was developed to provide uniform standardized guidance and was especially useful for elements of the National Cancer Institute questionnaire that did not directly match the GSEL. The responses from the officers' diet questionnaires were transferred to the GSEL scantron

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form for analysis. Quality assurance measures included the conversion by each of the four investigators for five participants' surveys, followed by comparison of results and resolution of any differences through consensus. The other surveys were double verified by two investigators to guarantee that the conversion was done uniformly.

Staff at the Fred Hutchinson Cancer Research Center analyzed the dietary data using the Nutrition Data Systems for Research software.[29] This software uses the US Department of Agriculture Nutrient Database for Standard Reference as the primary data source and is supplemented by information from scientific literature and food manufacturers. This database is the major source of food composition data in the United States.[30] The research center staff identified 29 errors, the majority of which was nonresponse to the frequency of food eaten. Each error was individually investigated, corrected, and resubmitted to the Cancer Research Center for analysis. The nutrients investigated in this study include vitamins A, C, D, E, omega-3 fatty acids, and magnesium.

Assessment of Pulmonary Function

Spirometric measurement of FEV_1 and forced vital capacity (FVC) was performed during the morning hours at the Buffalo site. Spirometry was performed by a trained technician according to the ATS guidelines. The participant performed two to three practice maneuvers to become familiar with the technique. A minimum of three out of a maximum of eight acceptable FVC tests were then performed with the participant seated.[31,32] To determine the reproducibility of tests, a difference of $\leq$200mL between the two best maneuvers was required, on the basis of ATS recommendations.[27] Measured FEV_1 and FVC were obtained in liters, and used as dependent variables in the analysis.

We also used US population-based reference equations developed using the Third National Health and Nutrition Examination Survey data to estimate the percent-predicted values.[33] These predicted values allow for the comparison of the measured values to the expected pulmonary function for a healthy nonsmoker of the same age, race, gender, and height. Actual measured and predicted values of FEV_1 and FVC were then used to calculate the percent-predicted values, FEV_1% and FVC%, respectively, for all officers.

Assessment of Demographics and Covariates

Self- and interviewer-administered questionnaires were used to ascertain demographic characteristics, lifestyle behaviors, and medical history. Educational status was ascertained using a scale from "less than 12 years of school" to "graduate degree," which were collapsed into three levels to allow adequate numbers in each category. Weight and height were measured without shoes. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Abdominal height was taken with the participant in a supine position. A Holtain-Kahn abdominal caliper was used to measure the midsection, one inch above the iliac crests.[34] Three measurements of abdominal height (to the nearest 0.1 cm) were taken and the average value was used as the participant's abdominal height.

Smoking status was reported as current, former, or never. Officers were asked how frequently they consumed alcoholic beverages with one drink defined as a 12-oz can or bottle of beer, one medium glass of wine, or one shot of liquor. The total number of drinks per month (of each type) was summed and then divided by four to give the approximate total number of drinks consumed per week. Data on total calories were obtained from the dietary questionnaires discussed previously. Officers were asked to bring in all nutritional supplements that they had taken within the past 30 days. After identifying the vitamins/nutritional supplements, a dichotomized variable was created. If the officer had taken a vitamin or any nutritional supplement of any dosage, the variable was coded as 1 (ie, used), otherwise it was coded as 0 (ie, not used).

Sleep duration was assessed from questionnaire data where officers were asked how many hours, on average, they slept during each 24-hour period the previous five weekdays (ie, Sunday through Thursday) and during the previous weekend (ie, Friday and Saturday). The mean hours of sleep reported for weekdays were multiplied by five and the mean weekend hours multiplied by two. The sum of those two numbers was then divided by seven. Officers also reported the duration (hours per week, hours per weekend) and intensity (moderate, hard, very hard) of three types of physical activity (occupational, household, and sports) that they had engaged in during the previous seven days. These data were used to create a total physical activity score that was computed by summing the three types (ie, occupational, household, and sports) of physical activities performed during the weekdays and the weekend, then multiplied by one for moderate, two for hard, and three for very hard intensity.

Statistical Analysis

Descriptive statistics were calculated for the demographic and lifestyle characteristics. Associations for selected covariates with all antioxidants and pulmonary function measures were analyzed using analysis of variance (ANOVA) and covariance (ANCOVA), Pearson's correlation, and linear regression. The independent and dependent variables were checked to verify normal distributions and that none violated the assumptions for ANOVA/ANCOVA. Mean levels of pulmonary function were compared across tertiles of all antioxidants using ANOVA and ANCOVA.

Potential confounders were selected on the basis of information in the literature and/or their associations with the antioxidants and pulmonary function in this study. They included age, gender, race, height, smoking status, pack-years of smoking, caloric intake, nutritional supplement use, and abdominal height. Age, gender, race, and height were omitted from models of the FEV_1% and FVC% predicted values given that these variables were already taken into consideration in the predicted values. Alcohol was originally included but was later removed from the final model because inclusion had minimal effect on the association. Smoking status was included in the model using dummy variables, with the "never smokers" used as reference. Tests for trends across tertiles were obtained from linear regression models. All associations were also investigated while stratifying by smoking status (current/former vs. never smokers) to examine associations within never smokers in particular, and to assess effect modification. For effect modification analyses, the cutpoint for statistical significance was set at 0.20 to take into consideration the reduced power inherent in such analyses. All analyses were performed using SAS version 9.1.[35]

RESULTS

Among the 79 police officers in our study, the mean age was 39.4 years (SD = 7.3 years); 57% were male; and 76% were white (Table 1). Forty-five percent of officers reported being never smokers, and the mean pack-years of smoking among ever smokers was 15.7 (SD = 13.6). The values (mean $\pm$ SD) of FEV_1 and FVC were 3.79 $\pm$ 0.78 and 4.71 $\pm$ 1.0 L, respectively. The mean FEV_1% was 102.1 and the mean FVC% was 102.8.

Table 2 shows FEV_1 and FVC presented by demographic and lifestyle variables. Alcohol consumption was positively associated with FEV_1 ($r = 0.2258$; $P = 0.057$). BMI was not significantly associated with any of the measures but abdominal height showed borderline significance with FEV_1 ($r = 0.2270$; $P = 0.055$) and was significantly and inversely correlated with FVC ($r = -0.2506$; $P = 0.034$). Surprisingly, pack-years was not significantly associated with any of the pulmonary function measures. Similar results were obtained with FEV_1% and FVC% for all covariates investigated (data not shown).

All antioxidants were also analyzed by demographic and lifestyle variables and the results are presented in Table 3. BMI

TABLE 1. Demographic and Other Characteristics, 1999–2000

Characteristics	Mean	SD	Range
Age (yr)	39.4	7.3	26−60
Height (cm)	174.0	9.1	157.8−196.5
BMI (kg/m^2)	27.7	4.1	19.5−37.1
Abdominal height (cm)	20.6	3.2	14.3−32.5
Alcohol (drinks/wk)	2.1	2.9	0−15
Physical activity score	12.8	18.8	0−120
Pack-years of smoking (current and former ($n = 41$))	15.7	13.6	0.5−54.0
Vitamin A (μg)	799.6	650.9	106.4−4198.0
Vitamin C (mg)	114.1	99.2	3.97−510.0
Vitamin D (μg)	4.8	3.9	0.29−20.6
Vitamin E (IU)	14.6	14.1	1.50−74.4
Omega-3 fatty acids (g)	1.6	0.88	0.20−5.15
Magnesium (mg)	257.7	146.0	43.2−719.2
Calories (kcal)	1703.4	925.9	337.3−5257.0
FEV_1 (L)	3.79	0.78	2.28−5.70
FVC (L)	4.71	0.95	2.75−6.89
FEV_1% predicted	102.1	12.1	64.5−133.0
FVC% predicted	102.8	12.6	63.7−136.3
	n	**%**	
Gender			
Female	34	43.0	
Male	45	57.0	
Race/Ethnicity			
Caucasian	60	76.0	
African American	15	19.0	
Other	4	5.1	
Education			
≤High school/general education development	15	19.0	
<4 yrs college	39	49.4	
≥4 yrs college	25	31.7	
Smoking status			
Current	16	20.5	
Former	27	34.6	
Never	35	44.9	
Nutritional supplement use			
No	35	44.3	
Yes	44	55.7	
Sleep (hours per 24-hour period)			
0–5.9	25	31.7	
6.0–6.9	26	32.9	
≥7.0	28	35.4	

TABLE 2. Univariate Associations of Pulmonary Function with Demographic and Lifestyle Variables, 1999–2000

Characteristics	FEV_1	FVC
BMI* (kg/m^2)	−0.1453 (0.223)	−0.0745 (0.534)
Abdominal height* (cm)	−0.2270 (0.055)	−0.2506 (0.034)
Alcohol* (drinks/wk)	0.2258 (0.057)	0.1369 (0.252)
Pack-years of smoking*	−0.0461 (0.701)	−0.0625 (0.602)
Physical activity score*	0.0192 (0.873)	−0.0710 (0.554)
Calories* (kcal)	0.1603 (0.179)	0.1690 (0.156)
Education (mean ± SE)		
≤High school/general education development	3.68 ± 0.13	4.56 ± 0.16
<4 yrs college	3.42 ± 0.10	4.28 ± 0.13
≥4 yrs college	3.70 ± 0.12	4.59 ± 0.15
P†	0.879	0.850
Smoking status (mean ± SE)		
Current	3.47 ± 0.14	4.27 ± 0.17
Former	3.64 ± 0.11	4.50 ± 0.14
Never	3.47 ± 0.11	4.39 ± 0.14
P‡	0.347	0.441
Sleep (mean ± SE)		
0–5.9	3.53 ± 0.12	4.43 ± 0.15
6.0–6.9	3.54 ± 0.12	4.40 ± 0.15
≥7.0	3.57 ± 0.11	4.44 ± 0.14
P†	0.785	0.954

All results were adjusted for age, height, gender, and race. Results for the continuous variables are partial Pearson's correlation coefficients and related *P* values. Results for the categorical variables are mean ± SE and were obtained from ANCOVA models.

*Values represent coefficient (*P*).

†*P* values are obtained from orthogonal linear contrasts.

‡*P* values are for any differences between the three means.

and abdominal height were inversely and significantly associated with magnesium. As with the pulmonary function measures, pack-years of smoking was also not significantly related to any of the antioxidants; however, smoking status was significantly associated with vitamin A (current smokers had the highest mean level, $P = 0.011$) and magnesium (former smokers had the highest mean level, $P = 0.003$). All antioxidants were significantly correlated with one another except for omega-3 fatty acids, which were not significantly correlated with any of the other antioxidants (data not shown).

The associations between the antioxidants and FEV_1 are presented in Table 4. Magnesium was significantly associated with FEV_1 after adjustment for age, gender, height, race, smoking status, and pack-years of smoking; low tertile = 3.40 ± 0.11 L, medium tertile = 3.58 ± 0.12 L, high tertile = 3.66 ± 0.11 L, adjusted $P = 0.049$. After further adjustment for calories, nutritional supplement use, and abdominal height, the association was only slightly attenuated but no longer significant, $P = 0.203$. For all of the other antioxidants, increasing mean levels of FEV_1 were generally observed across increasing tertiles, but the results were not statistically significant. Results for FEV_1% were similar to those obtained for FEV_1.

The associations between the antioxidants and FVC are presented in Table 5. Vitamin A was significantly associated with FVC after adjustment for age, gender, height, race, smoking status, and pack-years of smoking ($P = 0.036$), but not after further adjustment for calories, nutritional supplement use, and abdominal height ($P = 0.156$). Magnesium was significantly associated with FVC after adjustment for all risk factors ($P = 0.048$). For vitamin E, increasing mean levels of FVC were observed across increasing tertiles, but the results were not statistically significant. Results for FVC% were similar to those obtained for FVC.

In Table 6, adjusted mean levels of FEV_1 and FEV_1% by antioxidant tertiles are presented stratified by smoking status. Among current or former smokers, mean levels of FEV_1 and FEV_1% increased with increasing tertiles of vitamin E, $P = 0.003$ and

TABLE 3. Adjusted Associations of Antioxidants with Demographic and Lifestyle Variables, 1999–2000

Characteristics	Vitamin A	Vitamin C	Vitamin D	Vitamin E	Omega-3 FA	Magnesium
BMI* (kg/m^2)	−0.1053 (0.369)	0.0790 (0.501)	−0.0826 (0.481)	−0.1035 (0.377)	0.2420 (0.037)	−0.2427 (0.036)
Abdominal height* (cm)	−0.1168 (0.319)	0.1305 (0.264)	−0.0316 (0.788)	−0.1121 (0.339)	0.2161 (0.063)	−0.2289 (0.048)
Alcohol* (drinks/wk)	0.0219 (0.852)	−0.0868 (0.459)	0.2186 (0.060)	0.0585 (0.618)	0.0210 (0.858)	0.1857 (0.111)
Pack-years of smoking*	−0.0441 (0.707)	−0.1267 (0.279)	−0.1760 (0.131)	−0.0884 (0.451)	0.1604 (0.169)	−0.0681 (0.561)
Physical activity*	−0.1512 (0.196)	0.3195 (0.005)	−0.0187 (0.874)	−0.0509 (0.664)	−0.1318 (0.260)	−0.0412 (0.726)
Education (mean ± SE)						
≤High school/general education development	836.7 ± 75.3	109.3 ± 18.5	4.09 ± 0.62	13.5 ± 1.9	1.7 ± 0.13	254.0 ± 10.2
<4 yrs college	769.2 ± 46.6	115.7 ± 11.5	5.44 ± 0.38	13.9 ± 1.2	1.6 ± 0.08	256.9 ± 6.3
≥4 yrs college	824.8 ± 58.8	114.6 ± 14.5	4.23 ± 0.49	16.3 ± 1.5	1.6 ± 0.10	261.1 ± 8.0
P†	0.902	0.825	0.861	0.261	0.659	0.592
Smoking status (mean ± SE)						
Current	888.7 ± 69.7	108.6 ± 18.0	5.20 ± 0.64	12.7 ± 1.9	1.7 ± 0.13	245.7 ± 9.2
Former	662.1 ± 53.8	99.4 ± 14.2	4.35 ± 0.51	13.9 ± 1.5	1.7 ± 0.10	278.1 ± 7.0
Never	863.3 ± 47.2	129.7 ± 12.1	4.91 ± 0.44	16.1 ± 1.3	1.6 ± 0.09	246.8 ± 6.2
P‡	0.011	0.271	0.565	0.261	0.572	0.003
Sleep (mean ± SE) (hours per 24 hours)						
0–5.9	714.3 ± 57.6	110.6 ± 14.6	5.57 ± 0.49	15.8 ± 1.5	1.5 ± 0.10	262.1 ± 8.0
6.0–6.9	830.9 ± 56.3	113.1 ± 14.1	4.19 ± 0.48	14.3 ± 1.5	1.6 ± 0.10	253.1 ± 7.8
≥7.0	846.8 ± 53.4	118.2 ± 13.4	4.68 ± 0.46	13.8 ± 1.4	1.7 ± 0.09	257.9 ± 7.4
P†	0.098	0.705	0.201	0.327	0.170	0.708

All results were adjusted for total calories. Results for the continuous variables are partial Pearson's correlation coefficients and related *P* values. Results for the categorical variables are mean ± SE and were obtained from ANCOVA models.

*Values represent coefficient (*P*).

†*P* values are from ANCOVA for linear trend.

‡*P* values are for any differences between the three means.

<0.001, respectively. No trends were observed among never smokers. Smoking status was a significant effect modifier of the relationship between vitamin E and both pulmonary function measures (interaction $P = 0.040$ and 0.014, respectively).

In Table 7, mean levels of FVC and FVC% by antioxidants are presented stratified by smoking status. These results were very similar to that observed for FEV_1 and FEV_1%. A strong positive association was observed for vitamin E with FVC and FVC% but only among current/former smokers, $P = 0.010$ and <0.001, respectively, and smoking status significantly modified these associations (interaction $P = 0.042$ and 0.017, respectively). Increasing mean values of FVC% were observed with increasing tertiles of magnesium among current/former smokers only, but the results were not statistically significant and smoking status did not significantly modify the association.

DISCUSSION

If the healthy worker effect were taken into consideration, one would expect police officers to be healthier overall than the general population, yet one study showed higher mortality rates among officers.[15] Police officers are regularly exposed to several organizational stressors that may contribute to poor pulmonary function.[19–21,36–39] In this study, we investigated protective dietary factors for pulmonary function in police officers. Some of our results are consistent with those of previous studies that demonstrated a positive association between dietary intake of some antioxidants and pulmonary function.

Antioxidants and Pulmonary Function

Magnesium

In our study, the association between magnesium and FEV_1 was statistically significant until adjustment for calories, but was slightly attenuated after further adjustment for nutritional supplement use and abdominal height. The association between magnesium and FVC was stronger than that between magnesium and FEV_1 and remained statistically significant after full adjustment. Smoking status did not significantly modify the association between magnesium and pulmonary function. We observed similar results with FEV_1% and FVC%. Higher magnesium intake was found to be associated with better FEV_1 in a cross-sectional study of 2633 adults.[8] The regression coefficients were reduced after adjustment for smoking and social class but the estimates remained significant. Longitudinal analysis showed no significant relationship between magnesium intake and decline in FEV_1.

Vitamin A

We observed increasing levels of FEV_1 and FVC with increasing tertiles of vitamin A. The trends were stronger with FVC although none of the associations, including those with FEV_1% and FVC%, were statistically significant. This nonsignificant finding may be in part due to decreased statistical power. Stratification by smoking status showed that a nonsignificant trend was only present among never smokers, but smoking status did not modify the association.

McKeever and colleagues[8] found no relationship between vitamin A intake and pulmonary function. Bodner and colleagues[39]

TABLE 4. Adjusted Mean Levels of FEV_1 (Liters) by Tertiles of Antioxidants, 1999–2000

	Antioxidant Tertiles			
	Low (*n* = 26)	Medium (*n* = 27)	High (*n* = 26)	*P**
Vitamin A (μg)				
Model 1	3.37 ± 0.11	3.62 ± 0.11	3.69 ± 0.11	0.107
Model 2	3.38 ± 0.11	3.59 ± 0.11	3.68 ± 0.11	0.085
Model 3	3.37 ± 0.12	3.58 ± 0.12	3.69 ± 0.13	0.325
Model 4	3.35 ± 0.12	3.57 ± 0.11	3.65 ± 0.13	0.415
Model 5	3.37 ± 0.12	3.55 ± 0.12	3.66 ± 0.13	0.454
Vitamin C (mg)				
Model 1	3.48 ± 0.11	3.56 ± 0.11	3.64 ± 0.12	0.632
Model 2	3.47 ± 0.11	3.57 ± 0.12	3.60 ± 0.12	0.707
Model 3	3.51 ± 0.11	3.60 ± 0.12	3.54 ± 0.13	0.510
Model 4	3.49 ± 0.11	3.54 ± 0.12	3.53 ± 0.13	0.588
Model 5	3.50 ± 0.12	3.52 ± 0.12	3.54 ± 0.14	0.460
Vitamin D (μg)				
Model 1	3.44 ± 0.11	3.49 ± 0.11	3.76 ± 0.12	0.145
Model 2	3.45 ± 0.11	3.47 ± 0.12	3.74 ± 0.12	0.183
Model 3	3.47 ± 0.11	3.46 ± 0.12	3.72 ± 0.12	0.601
Model 4	3.45 ± 0.11	3.45 ± 0.12	3.69 ± 0.12	0.738
Model 5	3.46 ± 0.12	3.44 ± 0.12	3.69 ± 0.13	0.816
Vitamin E (IU)				
Model 1	3.43 ± 0.10	3.51 ± 0.10	3.81 ± 0.11	0.114
Model 2	3.43 ± 0.11	3.50 ± 0.10	3.79 ± 0.12	0.105
Model 3	3.40 ± 0.12	3.49 ± 0.10	3.83 ± 0.13	0.423
Model 4	3.39 ± 0.12	3.46 ± 0.11	3.79 ± 0.13	0.511
Model 5	3.38 ± 0.12	3.48 ± 0.11	3.79 ± 0.14	0.549
Omega-3 FA (g)				
Model 1	3.47 ± 0.11	3.46 ± 0.13	3.63 ± 0.10	0.117
Model 2	3.47 ± 0.12	3.43 ± 0.13	3.62 ± 0.10	0.142
Model 3	3.52 ± 0.14	3.46 ± 0.14	3.59 ± 0.11	0.630
Model 4	3.47 ± 0.14	3.43 ± 0.14	3.57 ± 0.11	0.398
Model 5	3.41 ± 0.14	3.42 ± 0.14	3.62 ± 0.12	0.177
Magnesium (mg)				
Model 1	3.40 ± 0.11	3.59 ± 0.12	3.69 ± 0.11	0.028
Model 2	3.40 ± 0.11	3.58 ± 0.12	3.66 ± 0.11	0.049
Model 3	3.41 ± 0.13	3.58 ± 0.12	3.66 ± 0.13	0.133
Model 4	3.37 ± 0.13	3.56 ± 0.12	3.63 ± 0.13	0.111
Model 5	3.38 ± 0.13	3.54 ± 0.12	3.65 ± 0.13	0.203

Results are mean ± SE. Model 1: Adjusted for age, gender, height, and race. Model 2: Adjusted for age, gender, height, race, smoking status, and pack-years of smoking. Model 3: Adjusted for age, gender, height, race, smoking status, pack-years of smoking, and calories. Model 4: Adjusted for age, gender, height, race, smoking status, pack-years of smoking, calories, and nutritional supplement use. Model 5: Adjusted for age, gender, height, race, smoking status, pack-years of smoking, calories, nutritional supplement use, and abdominal height.

**P* values for trend were obtained from multiple linear regression models.

TABLE 5. Mean Levels of FVC (Liters) by Tertiles of Antioxidants, 1999–2000

	Antioxidant Tertiles			
	Low (*n* = 26)	Medium (*n* = 27)	High (*n* = 26)	*P**
Vitamin A (μg)				
Model 1	4.20 ± 0.13	4.47 ± 0.14	4.64 ± 0.14	0.034
Model 2	4.20 ± 0.14	4.46 ± 0.14	4.63 ± 0.14	0.036
Model 3	4.17 ± 0.15	4.45 ± 0.15	4.66 ± 0.16	0.149
Model 4	4.18 ± 0.16	4.45 ± 0.15	4.68 ± 0.16	0.138
Model 5	4.21 ± 0.16	4.44 ± 0.15	4.70 ± 0.17	0.156
Vitamin C (mg)				
Model 1	4.34 ± 0.13	4.36 ± 0.14	4.63 ± 0.15	0.278
Model 2	4.33 ± 0.14	4.37 ± 0.15	4.59 ± 0.16	0.360
Model 3	4.36 ± 0.14	4.39 ± 0.15	4.55 ± 0.17	0.983
Model 4	4.37 ± 0.15	4.40 ± 0.16	4.55 ± 0.17	0.960
Model 5	4.40 ± 0.15	4.38 ± 0.16	4.56 ± 0.18	0.788
Vitamin D (μg)				
Model 1	4.30 ± 0.13	4.34 ± 0.14	4.68 ± 0.15	0.131
Model 2	4.31 ± 0.14	4.30 ± 0.15	4.67 ± 0.15	0.166
Model 3	4.35 ± 0.15	4.30 ± 0.15	4.64 ± 0.16	0.589
Model 4	4.36 ± 0.15	4.31 ± 0.15	4.65 ± 0.16	0.558
Model 5	4.39 ± 0.15	4.31 ± 0.15	4.66 ± 0.16	0.613
Vitamin E (IU)				
Model 1	4.30 ± 0.13	4.34 ± 0.13	4.76 ± 0.14	0.054
Model 2	4.30 ± 0.13	4.34 ± 0.13	4.74 ± 0.15	0.068
Model 3	4.27 ± 0.15	4.33 ± 0.13	4.78 ± 0.17	0.304
Model 4	4.28 ± 0.15	4.35 ± 0.14	4.79 ± 0.17	0.288
Model 5	4.26 ± 0.15	4.40 ± 0.15	4.79 ± 0.18	0.323
Omega-3 FA (g)				
Model 1	4.39 ± 0.14	4.23 ± 0.16	4.51 ± 0.13	0.170
Model 2	4.39 ± 0.15	4.19 ± 0.16	4.50 ± 0.13	0.197
Model 3	4.48 ± 0.17	4.25 ± 0.17	4.44 ± 0.14	0.943
Model 4	4.51 ± 0.18	4.26 ± 0.17	4.45 ± 0.15	0.996
Model 5	4.46 ± 0.18	4.25 ± 0.17	4.50 ± 0.15	0.636
Magnesium (mg)				
Model 1	4.23 ± 0.13	4.39 ± 0.14	4.67 ± 0.14	0.008
Model 2	4.22 ± 0.13	4.40 ± 0.15	4.65 ± 0.14	0.017
Model 3	4.18 ± 0.16	4.39 ± 0.15	4.69 ± 0.16	0.020
Model 4	4.19 ± 0.16	4.40 ± 0.15	4.69 ± 0.17	0.022
Model 5	4.21 ± 0.16	4.38 ± 0.15	4.72 ± 0.17	0.048

Results are mean ± SE. Model 1: Adjusted for age, gender, height, and race. Model 2: Adjusted for age, gender, height, race, smoking status, and pack-years of smoking. Model 3: Adjusted for age, gender, height, race, smoking status, pack-years of smoking, and calories. Model 4: Adjusted for age, gender, height, race, smoking status, pack-years of smoking, calories, and nutritional supplement use. Model 5: Adjusted for age, gender, height, race, smoking status, pack-years of smoking, calories, nutritional supplement use, and abdominal height.

**P* values for trend were obtained from multiple linear regression models.

conducted a nested case-control study and reported no independent associations between vitamin A and adult-onset wheeze. However, a case-control study conducted on children from Saudi Arabia found that vitamin A levels were significantly lower in children with asthma compared with healthy control children in all age categories.[40]

Vitamin C

Surprisingly, our results did not show significant associations between vitamin C and pulmonary function, before or after risk factor adjustment and after stratification by smoking status. Smoking status did not modify the association. Vitamin C is known to be a very potent antioxidant; so, despite the small sample size, we had expected to find at least borderline significant associations. It is possible that higher vitamin C levels, above what was reported for this cohort, are required for a positive association to be seen. Our results contradict the findings of several studies.[6–10,39,41] In their study, Schunemann and colleagues[6] reported that vitamin C showed a weaker association with pulmonary function compared with other antioxidants they investigated. Bodner and colleagues[39]

TABLE 6. Adjusted Mean Levels of FEV_1 (Liters) and FEV_1% Predicted by Tertiles of Antioxidants Stratified by Smoking Status, 1999–2000

	Current/Former Smoker (*n* = 43)				Never Smoker (*n* = 35)				
	Antioxidant Tertile				Antioxidant Tertile				
	Low	Medium	High	*P**	Low	Medium	High	*P**	*P*†
FEV_1 (L)									
Vitamin A (μg)	3.37 ± 0.19	3.60 ± 0.14	3.43 ± 0.20	0.570	3.39 ± 0.16	3.58 ± 0.20	3.81 ± 0.18	0.732	0.774
Vitamin C (mg)	3.56 ± 0.15	3.41 ± 0.18	3.48 ± 0.19	0.418	3.37 ± 0.18	3.70 ± 0.16	3.63 ± 0.19	0.632	0.512
Vitamin D (μg)	3.43 ± 0.16	3.40 ± 0.17	3.65 ± 0.16	0.467	3.49 ± 0.18	3.57 ± 0.17	3.76 ± 0.22	0.747	0.927
Vitamin E (IU)	3.14 ± 0.16	3.33 ± 0.15	4.02 ± 0.17	0.003	3.55 ± 0.17	3.62 ± 0.19	3.55 ± 0.23	0.200	0.040
Omega-3 FA (g)	3.44 ± 0.20	3.51 ± 0.17	3.56 ± 0.19	0.169	3.50 ± 0.22	3.36 ± 0.24	3.66 ± 0.17	0.627	0.629
Magnesium (mg)	3.44 ± 0.20	3.66 ± 0.19	3.51 ± 0.16	0.172	3.41 ± 0.17	3.61 ± 0.17	3.84 ± 0.23	0.552	0.785
FEV_1% predicted									
Vitamin A (μg)	97.8 ± 3.8	105.9 ± 2.7	102.7 ± 4.2	0.407	98.3 ± 3.9	102.5 ± 4.6	103.9 ± 4.3	0.712	0.598
Vitamin C (mg)	102.6 ± 3.2	99.9 ± 3.2	106.3 ± 4.0	0.959	95.7 ± 4.3	103.0 ± 3.8	104.1 ± 4.3	0.619	0.689
Vitamin D (μg)	101.2 ± 3.2	101.0 ± 3.2	106.8 ± 3.6	0.619	99.4 ± 4.5	99.3 ± 3.6	105.3 ± 4.3	0.744	0.916
Vitamin E (IU)	92.2 ± 3.3	100.7 ± 2.5	115.0 ± 3.2	<0.001	101.1 ± 4.0	101.1 ± 4.7	101.6 ± 4.9	0.440	0.014
Omega-3 FA (g)	101.6 ± 4.4	102.4 ± 2.9	104.0 ± 4.2	0.355	104.0 ± 3.7	100.7 ± 4.5	97.4 ± 4.8	0.642	0.743
Magnesium (mg)	97.8 ± 4.1	105.5 ± 3.0	103.9 ± 4.0	0.107	96.9 ± 4.2	99.2 ± 3.9	109.5 ± 5.1	0.361	0.606

Results are mean ± SE. FEV_1: Results are adjusted for age, gender, height, race, calories, nutritional supplement use, and abdominal height. FEV_1% predicted: Results are adjusted for calories, nutritional supplement use, and abdominal height.
**P* values for trend were obtained from multiple linear regression models.
† Interaction *P* value between antioxidants and smoking status.

TABLE 7. Adjusted Mean Levels of FVC (Liters) and FVC% Predicted by Tertiles of Antioxidants Stratified by Smoking Status, 1999 –2000

	Current/Former Smoker (*n* = 43)				Never Smoker (*n* = 35)				
	Antioxidant Tertile				Antioxidant Tertile				
	Low	Medium	High	*P**	Low	Medium	High	*P**	*P*†
FVC (L)									
Vitamin A (μg)	4.19 ± 0.23	4.54 ± 0.18	4.44 ± 0.25	0.573	4.25 ± 0.20	4.37 ± 0.24	4.87 ± 0.22	0.213	0.664
Vitamin C (mg)	4.44 ± 0.19	4.25 ± 0.23	4.53 ± 0.23	0.719	4.30 ± 0.23	4.59 ± 0.21	4.59 ± 0.24	0.742	0.716
Vitamin D (μg)	4.38 ± 0.20	4.23 ± 0.21	4.62 ± 0.20	0.406	4.43 ± 0.23	4.50 ± 0.22	4.68 ± 0.28	0.978	0.921
Vitamin E (IU)	3.88 ± 0.18	4.28 ± 0.17	5.12 ± 0.20	0.010	4.55 ± 0.21	4.51 ± 0.24	4.39 ± 0.29	0.506	0.042
Omega-3 FA (g)	4.46 ± 0.24	4.40 ± 0.21	4.44 ± 0.23	0.825	4.58 ± 0.26	4.11 ± 0.29	4.53 ± 0.21	0.902	0.809
Magnesium (mg)	4.15 ± 0.24	4.54 ± 0.22	4.58 ± 0.20	0.209	4.39 ± 0.22	4.42 ± 0.22	4.85 ± 0.29	0.130	0.630
FVC% predicted									
Vitamin A (μg)	96.5 ± 3.8	105.3 ± 2.8	105.1 ± 4.2	0.310	100.6 ± 4.2	101.2 ± 4.8	106.5 ± 4.6	0.403	0.458
Vitamin C (mg)	102.6 ± 3.2	98.4 ± 3.2	108.4 ± 4.0	0.949	97.7 ± 4.6	103.3 ± 4.1	106.6 ± 4.7	0.426	0.682
Vitamin D (μg)	102.0 ± 3.2	100.1 ± 3.3	106.8 ± 3.7	0.671	103.4 ± 4.9	100.5 ± 3.9	105.1 ± 4.6	0.824	0.815
Vitamin E (IU)	90.4 ± 3.2	101.2 ± 2.4	116.0 ± 3.1	<0.001	105.1 ± 4.2	102.0 ± 4.9	100.6 ± 5.2	0.611	0.017
Omega-3 FA (g)	103.3 ± 4.4	101.4 ± 2.9	104.3 ± 4.3	0.946	108.4 ± 3.7	98.4 ± 4.6	97.5 ± 4.9	0.372	0.890
Magnesium (mg)	94.7 ± 4.0	104.0 ± 3.0	108.2 ± 3.9	0.142	100.7 ± 4.4	98.0 ± 4.1	110.7 ± 5.4	0.151	0.592

Results are mean ± SE. FVC: Results are adjusted for age, gender, height, race, calories, nutritional supplement use, and abdominal height. FVC% predicted: Results are adjusted for calories, nutritional supplement use, and abdominal height.
**P* values for trend were obtained from multiple linear regression models.
† Interaction *P* value between antioxidants and smoking status.

reported that vitamin C was inversely related to current wheeze in individuals grouped in the manual social class and among current smokers but not among persons in another social class or among never smokers. It appeared that smokers in the manual social class were particularly susceptible to the adverse effects of deficiencies in vitamin C. In contrast, another study did not find a significant relationship for vitamin C with either FEV_1 or FVC.[42]

Vitamin D

We did not observe a significant association between vitamin D and pulmonary function. This was also an unexpected finding, as deficiency of vitamin D is known to be associated with inflammation and infections of the respiratory tract.[43]

Vitamin E

In our study, increasing FEV_1 and FVC were observed with increasing tertiles of vitamin E but the results were not statistically significant. Among current or former smokers, mean levels of FEV_1 and FVC increased with increasing tertiles of vitamin E, but interestingly, no association was observed among never smokers. The benefits of vitamin E appear to be more important in persons who smoke, possibly because smokers have higher levels of inflammation, therefore the effects of vitamin E are more readily observed. Smoking status significantly modified the relationship between vitamin E and four measures of pulmonary function. Results from a nested case-control study showed an inverse association between vitamin E and adult-onset wheeze after risk factor adjustment.[39] In a cross-sectional study, vitamin E was one of several antioxidants positively associated with pulmonary function.[6] When all vitamins were considered together, vitamin E was one of two antioxidants most strongly related to FEV_1 and FVC; it was also independently related to FEV_1% and FVC%. In another study, vitamin E was positively associated with FEV_1 before risk factor adjustment, but was not independently significant after adjusting for smoking history.[8] Hu and Cassano[44] reported that higher levels of vitamin E were associated with better pulmonary function. However, effect modification by smoking status was not significant. In contrast, a Dutch study found no association between intake of vitamin E and pulmonary function or respiratory symptoms.[45]

Other epidemiological studies reported effect modification by smoking status for the association between vitamin E and pulmonary function. Bodner and colleagues[39] reported that vitamin E was inversely related to current wheeze in individuals grouped in the manual social class and among current smokers but not among persons in another social class or among never smokers. The authors concluded that smokers in the manual social class were particularly susceptible to the adverse effects of deficiencies in vitamin E. In a cross-sectional study of elderly persons (aged 70 to 96 years), vitamin E was independently associated with both FEV_1 and FVC.[42] However, there was no interaction between current smoking and dietary intake of vitamin E in relation to either FEV_1 or FVC.

Omega-3 Fatty Acids

We did not find an association between omega-3 fatty acids and pulmonary function, nor did smoking status interact with omega-3 fatty acids. These results are consistent with those of some studies. In a cross-sectional study (MORGEN-EPIC) of 13,820 subjects, intake of docosahexaenoic acid, the most abundant omega-3 fatty acid was associated with a lower FEV_1, while other n-3 fatty acids that were investigated were unrelated to pulmonary function.[46] Also, increased intake of n-3 fatty acids did not appear to reduce the occurrence of doctor-diagnosed respiratory disorders. The authors also reported no interactions between omega-3 fatty acid and smoking status. Butland and colleagues[12] did not find a significant association between lung function and the frequency of fatty fish (a rich source of omega-3 fatty acids) consumption.

Biological Mechanisims

Exposures to occupational (eg, air pollution, shift work) and environmental (eg, cigarette smoking) factors may increase the amount of reactive oxygen species and reactive nitrogen species in human tissue.[19,21–23,47] Oxidative or nitrosative stress is created when there is an imbalance between the formation and neutralization of these free radicals. Oxidative stress causes many adverse processes including damage to cellular lipids, proteins, DNA, and cell membranes thus inhibiting their normal function.[47,48] The most likely mechanism by which antioxidants are associated with pulmonary function is through reduction of oxidative stress and inflammation in the lungs.[7,49–51] A deficiency of magnesium induces systemic inflammation and oxidative stress.[52–54] Vitamin C and other antioxidants appear to raise levels of intracellular glutathione, a potent antioxidant that is critical in reducing airway inflammation.[49] In addition, glutathione is able to regenerate two important antioxidants, vitamins C and E, back to their active forms.[48] In vitro and in vivo studies show that increased levels of antioxidants result in decreased DNA damage in epithelial tissue and improvement in lower airway inflammation.[49] Inflammation has been shown to be associated with lower values of FEV_1, FVC, FEV_1%, and FVC% among unhealthy and healthy individuals.[55–59]

Limitations and Strengths

Limitations in our study include the small sample size and the cross-sectional design that precludes inferences of temporality. Nutritional supplement use was included in all models but we did not have information on the quantity of supplements taken by the officers. It is possible that persons with very different consumption patterns in terms of supplement quantity may have been included in the same group. If this had been the case, the effect of this nondifferential misclassification bias would have been to dilute any associations observed. We did not investigate the association between pulmonary function and other potent antioxidant carotenoids such as lycopene. It is possible that officers with high consumption patterns of vitamins and magnesium also had high intake of other antioxidants and it would have been difficult to tease out the independent effects of these antioxidants in this study.

There are several strengths of this study. The standardized dietary assessment method of antioxidant intake is a strength, as the GSEL FFQ survey analysis provides a more general, long-term dietary pattern than the food record method that provides more specific detail for a short period.[60] This instrument was found to produce nutrient estimates similar to both the recording method and the short-term recall method.[61] The assessment of pulmonary function, using standardized spirometry conforming to ATS standards, is also a strength of this study. We were able to control for several important confounding factors (including the number of calories consumed) and examined potential effect modification. Another strength of this study was the inclusion of supplement use in the model, which, even though imperfect, would account for some extra sources of antioxidants. Finally, even though this study was conducted among police officers, these results may be generalizable to individuals in a variety of other settings.

In summary, the results of this study show that increased intake of magnesium and vitamin A were associated with higher levels of FVC but not FEV_1. Increased intake of vitamin E (among current/former smokers only) was associated with higher levels of both FVC and FEV_1. Many of the associations between the antioxidants and pulmonary function measures, although not significant, were positively related. These cross-sectional results do not imply causation, yet are consistent with findings from other studies. Future studies should be conducted in larger populations to confirm these findings.

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