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Healthy Eating Index 2005 and selected macronutrients are correlated with improved lung function in humans

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Abstract

A number of dietary components have been associated with lung function. However, a comprehensive measure of a healthy diet has not been compared with lung function. Herein, we test the hypothesis that a healthy overall diet, as assessed by the Healthy Eating Index 2005 (HEI-2005), will be associated with increased lung function. This is an investigation using the Atherosclerosis Risk in Communities Research Materials obtained from the National Heart Lung Blood Institute. The study surveyed dietary habits of 15 567 American subjects from 4 communities in 1987 to 1990. Spirometric measures of lung function were also taken at entry to the study and a second time 3 years later. Based on food and nutritional data collected by food frequency questionnaire, an HEI-2005 score was calculated for each subject. This total score, together with its 12 components scores and associated macronutrient, was compared with lung function results by linear regression. Models were controlled for smoking behavior, demographics, and other important covariates. The HEI-2005 total scores were positively associated with forced expiratory volume in 1 second per forced vital capacity (FEV(1)/FVC) at visit 1 (β = .101 per increase in 1 quintile of HEI-2005) and visit 2 (β = .140), and FEV(1) as percentage of the predicted FEV(1) at visit 2 (β = .215) (P < .05). In addition, HEI-2005 component scores that represented high intakes of whole grains (β = .127 and .096); saturated fats (β = −.091); and solid fats, alcohol, and added sugar (β = −.109 and −.131) were significantly associated with FEV(1)/FVC at either visit 1 or visit 2. Intakes of total calories (β =−.082 at visit 1) and saturated fatty acids (β = −.085 at visit 2) were negatively associated with FEV(1)/FVC. Dietary polyunsaturated fatty acids (β = .085 and .116) and long-chain omega-3 fatty acids (β = .109 and .103), animal protein (β = .132 and .093), and dietary fiber (β = .129) were positively associated with lung health. An overall healthy diet is associated with higher lung function.

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ABSTRACT

A number of dietary components have been associated with lung function. However, a comprehensive measure of a healthy diet has not been compared with lung function. Herein, we test the hypothesis that a healthy overall diet, as assessed by the Healthy Eating Index 2005 (HEI-2005), will be associated with increased lung function. This is an investigation using the Atherosclerosis Risk in Communities Research Materials obtained from the National Heart Lung Blood Institute. The study surveyed dietary habits of 15 567 American subjects from 4 communities in 1987 to 1990. Spirometric measures of lung function were also taken at entry to the study and a second time 3 years later. Based on food and nutritional data collected by food frequency questionnaire, an HEI-2005 score was calculated for each subject. This total score, together with its 12 components scores and associated macronutrient, was compared with lung function results by linear regression. Models were controlled for smoking behavior, demographics, and other important covariates. The HEI-2005 total scores were positively associated with forced expiratory volume in 1 second per forced vital capacity (FEV(1)/FVC) at visit 1 ($\beta = .101$ per increase in 1 quintile of HEI-2005) and visit 2 ($\beta = .140$), and FEV(1) as percentage of the predicted FEV(1) at visit 2 ($\beta = .215$) ($P < .05$). In addition, HEI-2005 component scores that represented high intakes of whole grains ($\beta = .127$ and .096); saturated fats ($\beta = -.091$); and solid fats, alcohol, and added sugar ($\beta = -.109$ and $-.131$) were significantly associated with FEV(1)/FVC at either visit 1 or visit 2. Intakes of total calories ($\beta = -.082$ at visit 1) and saturated fatty acids ($\beta = -.085$ at visit 2) were negatively associated with FEV(1)/FVC. Dietary polyunsaturated fatty acids ($\beta = .085$ and .116) and long-chain omega-3 fatty acids ($\beta = .109$ and .103), animal protein ($\beta = .132$ and .093), and dietary fiber ($\beta = .129$) were positively associated with lung health. An overall healthy diet is associated with higher lung function.

1. Introduction

The US Department of Agriculture establishes a food guide that converts the foods and nutrients recommended in the Dietary Guidelines for Americans and the Dietary Reference Intakes into actual food intakes [1]. The food guide formed the basis for the Food Guide Pyramid and more recent guides, which are used to advise Americans on healthy eating [1]. The Healthy Eating Index 2005 (HEI-2005) was created by work-groups of experts in the fields of nutrition, economics, and psychometrics to score diets based on the dietary recommendations published in the Dietary Guidelines for Americans in 2005 [2]. The HEI-2005 ranks diets high if the foods consumed provide essential nutrients in adequate amounts and also include lower amounts of foods that negatively affect health [2]. Many reports on the relations between diet and cardiovascular diseases or diet-related cancers have supported the recommendations of the Dietary Guidelines for increasing fruits and vegetables and reducing sodium and saturated fats, as verified by the HEI-2005 [3-5].

Data from the Centers for Disease Control and Prevention demonstrate that chronic lower respiratory disease was the third leading cause of death among Americans in 2010 [6]. Chronic obstructive pulmonary disease (COPD) is a slowly progressive disease affecting the airways and pulmonary parenchyma leading to dyspnea, chronic cough, and respiratory failure. Chronic obstructive pulmonary disease is the pathologic consequence of lung function decline and is monitored by spirometric measurements, including forced expiratory volume in 1 second (FEV(1)) and forced vital capacity (FVC). Chronic obstructive pulmonary disease is partially classified by a forced expiratory volume in 1 second as a percentage of FVC (FEV(1)/FVC) ratio of less than 0.70 and an FEV(1) less than 80% of that predicted by age, sex, ethnicity, and standing height [7]. Although the most notable risk factor for COPD is cigarette smoking, other factors including air pollution, persistent respiratory infections, genetic disorders, asthma, and dietary factors also contribute to lung function decline leading to COPD [8-11].

Previous reports have shown that dietary intake influences lung function. An inverse association has been shown between COPD and consumption of fruits and vegetables in a case-control study [12]. Whole grains and fiber have been shown to have an inverse association in both a cross-sectional study and a longitudinal follow-up study of 16 years [13,14]. A cross- sectional study has shown that docosahexaenoic acid may be protective [15,16]. Overall dietary patterns rich in fruits, vegetables, and fish have been linked to improved lung function in longitudinal studies in both men and women [17,18].

The Healthy Eating Index (HEI) is derived from the Dietary Recommendations for Americans, which is largely focused on preventing vascular diseases with recommendations on salt intake, saturated fat intake, and excess sugar intake. The HEI-2005 is built around these largely vascular oriented recommendations [2]. Others have sought to extend the reach of these recommendations by assessing the effectiveness of HEI-2005 in predicting outcomes from various nonvascular diseases, including prostate cancer, [4] cognitive function [19], and bone health [20].

Because of interest in extending the application of the HEI beyond the vascular diseases and given the importance of COPD as a cause of death at a rate just below vascular diseases, the hypothesis of this study is that higher overall diet quality will be associated with higher lung function. In addition, component scores from the HEI-2005 and individual macronutrients will illuminate dietary strategies for improved lung function.

2. Methods and materials

2.1. Subjects

This manuscript was prepared using Atherosclerosis Risk in Communities (ARIC) Research Materials obtained from the National Heart Lung Blood Institute Biologic Specimen and Data Repository Information Coordinating Center and does not necessarily reflect the opinions or views of the ARIC research groups or the National Heart Lung Blood Institute. Acquisition of this data set was approved by the Institutional Review Board of Appalachian State University. Details of the ARIC study are described elsewhere [21]. Atherosclerosis Risk in Communities participants were recruited from 4 communities across the United States with the intention of creating a biracial cohort of approximately 20% black. The study protocol was approved by institutional review boards at each clinical site. The initial cohort consisted of 15567 men and women aged 45 to 64 years. Participants were invited to clinical evaluations every 3 years. Data for this analysis were taken from visit 1, 1987 to 1989, and visit 2, 1990 to 1992. Diet, nutrients, HEI-2005 scores, and covariates were taken only from visit 1. Lung function measures were taken from both visits 1 and 2.

Subjects with incomplete data, including spirometry (1794 from visit 2), HEI-2005 score (1196), or covariates (smoking status [114], physical activity [59], height [4], body mass index [BMI] [10]), were excluded from the analysis. To lower the possibility of reverse causation, subjects who identified themselves as still having chronic bronchitis or emphysema were removed from the analysis (749). Also removed were participants with FEV(1)/FVC less than 40% (63 from visit 1 and 60 from visit 2) and 2 subjects with forced expiratory volume in 1 second as a percentage of predicted FEV(1) (%FEV) more than 190% in visit 2. The final number for the primary analysis was 12532.

2.2. Lung function

Lung function measurements were taken with a water-seal spirometer (Collins Medical, Inc, Braintree, MA) and recorded using Pulmo-Screen II software (PDS Healthcare Products, Inc, Louisville, CO). These measures include FEV(1) and FVC. Spirometry was conducted in accordance with the American Thoracic Society/European Respiratory Society guidelines [22]. Sex- and ethnicity-specific predicted values for FEV(1), adjusted for age and height, were calculated [23]. Predicted values for blacks were 12% lower than for whites. Forced expiratory volume in 1 second as a percentage of predicted FEV(1) was calculated. Forced expiratory volume in 1 second as a percentage of FVC was also calculated.

2.3. Dietary assessment

Participants were interviewed by trained staff about their usual dietary intakes over the past year with a modified version of the semiquantitative food frequency questionnaire used and validated by Willet in the Nurses' Health Study [24]. Based on the results, nutrient composition of the usual diet was calculated using the frequency of consumption of each food and its nutrient composition from the US Department of Agriculture Nutrient Composition Table [25,26]. Subjects with a total calorie intake of less than 200 (4) and greater than 5000 (48) were removed from the analysis.

The HEI-2005 is a scoring method used to assess and measure adherence to federal dietary guidelines, including the Dietary Guidelines for Americans in 2005 and MyPyramid [27,28]. In conducting this research analysis, the HEI-2005 scoring technique was followed using data from the ARIC food frequency questionnaire and nutrient derived data sets. Minor alterations were used in calculating HEI component scores to accommodate differences between optimal data required for the HEI-2005 and data available from the ARIC food frequency questionnaire. The oils component score was calculated using vegetable oil (grams per day) from the nutrient data. The saturated fats score was calculated from the saturated fats as a percentage of calories. The solid fats, alcohol, and added sugar (SoFAAS) score was estimated from data on these components in the ARIC nutrient data. A base solid fat intake level was calculated from the minimum amount of solid fat consumed by nonmeat eaters within this population. This value (20 g) was subtracted from participants' total fat intake and multiplied by 9 kcal/g to determine the excess solid fat calories consumed. Intake values of alcoholic beverages and added sugars were obtained using the ARIC nutrient derived data set from visit 1. Calories from alcoholic beverages were calculated using grams of ethanol. Calories from added sugars were obtained using grams of sucrose consumed. The HEI-2005 and its components were assessed by quintiles.

For SoFAAS, sodium, and saturated fats, the HEI-2005 scoring is inverse with low intakes being assigned high and healthier scores. To avoid confusion and make the interpretation more straightforward, these 3 subscores will be reported as all the others with low intakes receiving low scores and high intakes receiving high scores.

2.4. Other measurements

Black or nonblack ethnicity, age at first visit, and sex were identified. Body mass index (kilograms per square meter) and standing height were assessed by trained certified technicians. For smoking status, current smokers vs past and never smokers and cigarette years were recorded from interviews. Education was recorded as a 3-step scale, no high school degree, a high school degree, and education beyond high school. Total physical activity was quantified as tertiles of the sum of work, home, and leisure time activities. Total caloric intake was determined from the nutritional assessment. Macronutrients calculated from the nutritional assessment included animal protein, vegetable protein, total carbohydrates, dietary fiber, saturated fats, monounsaturated fats, polyunsaturated fats, sum of eicosapentaenoic acid and docosahexaenoic acid, and alcohol. Macronutrients intakes were divided by total calorie intake and assessed as quintiles.

2.5. Statistical analyses

The covariates in the regression models of lung function were age, female sex, black ethnicity, standing height (centimeters), BMI (kilograms per square meter), education level (3 levels), current smoking, cigarette years, physical activity (in tertiles), and total caloric intake. These were chosen based on previous literature [13,29,30]. More aggressive adjustments for smoking were considered, such as including former smoking as a separate variable, but these did not alter the outcomes substantially. The correlations of these terms and the independent variable, HEI-2005 quintiles, and the outcome variable, FEV(1)/FVC in visit 1, are described in Table 2. All of these are highly correlated with 1 or both of these variables. The interaction term black × BMI was found to significantly contribute to the regression models. This interaction did not eliminate the significant contributions of either black ethnicity or BMI and did itself contribute significantly ($P < .05$) to the analysis. All analyses after Table 2 were by multivariate linear regression with outcomes of FVC, forced expiratory volume, % FEV, and FEV(1)/FVC. Lung function measures for both visits 1 and 2 were included in the analyses. Quintiles of HEI-2005 score were created as were quintiles of all 12 component scores. Quintiles were also created and analyzed for the major macronutrients as a percentage of total caloric intake. Trend analyses for the independent dietary variables reported the covariate adjusted β per increase in 1 dietary quintile considering the quintile indicator variable as a single linear variable. Stratified analysis by sex, ethnicity, and smoking status was performed based on the suggested findings of previous investigators of differences in dietary effects by these subgroups [13,14,18,29]. SPSS version 20 (IBM Corp, Armonk,

Table 1 – Characteristics of participants from the ARIC cohort

Characteristic	Males	Females
n	5858	7214
Age at visit 1, y	54.4 ± 5.7	53.7 ± 5.6
Sex, %	45%	55%
Black ethnicity, %	20%	28%
Education, 3 levels	2.22 ± 0.76	2.12 ± 0.73
Education, post high school, %	42%	33%
Standing height, cm	176 ± 6	162 ± 6
BMI, kg/m^2	27.5 ± 4.1	27.7 ± 5.9
Current cigarette smoker, %	24%	22%
Cigarette years of smoking	418 ± 461	180 ± 304
Total calories, men	1758 ± 677	1495 ± 577
FVC for visit 1, L	4.59 ± 0.83	3.24 ± 0.60
FEV(1) for visit 1, L	3.39 ± 0.68	2.46 ± 0.48
FEV(1) % of predicted for visit 1	91.8 ± 15.3	97.7 ± 15.5
FEV(1)/FVC for visit 1, %	73.9 ± 7.4	76.0 ± 6.6
FVC for visit 2, L	4.38 ± 0.84	3.08 ± 0.59
FEV(1) for visit 2, L	3.22 ± 0.69	2.34 ± 0.47
FEV(1) % of predicted for visit 2	88.9 ± 16.2	95.9 ± 16.1
FEV(1)/FVC for visit 2, %	73.6 ± 7.8	76.0 ± 6.8
HEI-2005	48.7 ± 9.6	53.9 ± 9.7

Values are expressed as percentages or mean ± SD.

Table 2 – Average characteristics of participants from ARIC from visit 1 by quintiles of HEI-2005 and correlations with FEV(1)/FVC

Variables		Quintiles of HEI-2005 score					β per HEI-2005	P for HEI-2005	FEV(1)/FVC	P for FEV(1)/FVC
		1, low	2	3	4	5, high	Quintile	Trend	β	
HEI-2005,	M	37.5	45.3	51.0	57.0	65.4	6.7	<.001	0.139	<.001
1-100 score	F	37.9	45.4	51.1	57.3	66.0	6.8	<.001	0.114	<.001
Age, y	M	53.4	54.2	54.7	55.4	55.2	0.50	<.001	−0.164	<.001
	F	52.4	53.0	53.4	54.0	54.6	0.54	<.001	−0.143	<.001
Sex, %	F	36	46	57	65	72	9.3	<.001	1.0	<.001
Black, %	M	21	20	21	19	16	−0.6	.132	0.7	<.001
	F	28	31	31	26	24	−1.5	<.001	1.1	<.001
Education,	M	2.13	2.20	2.23	2.28	2.35	0.060	<.001	0.007	<.001
3 levels	F	1.97	2.05	2.10	2.15	2.23	0.071	<.001	0.004	.001
Height, cm	M	176	176	176	176	176	0.005	.932	−0.090	<.001
	F	162	162	162	162	162	−0.013	.803	−0.099	<.001
BMI, kg/m^2	M	27.4	27.5	27.6	27.7	27.3	0.035	.378	0.098	<.001
	F	27.4	27.8	28.1	27.6	27.4	−0.015	.766	0.156	<.001
Current	M	37	26	22	15	10	−6.4	<.001	−1.5	<.001
smokers, %	F	34	28	22	19	14	−4.7	<.001	−1.6	<.001
Cigarette years	M	518	423	382	355	320	−56	<.001	−19	<.001
	F	260	208	169	164	147	−27	<.001	−14	<.001
Physical activity,	M	2.10	2.20	2.21	2.25	2.31	0.056	<.001	0.004	.007
tertiles	F	1.78	1.82	1.88	1.96	2.02	0.069	<.001	0.002	.246
Calories per day,	M	2094	1822	1700	1516	1265	−196	<.001	−5	<.001
kcal	F	1859	1692	1544	1415	1195	−163	<.001	−2	.099

Abbreviations: M, male; F female. βs controlled for age and ethnicity where appropriate. Number of subjects = 12 532.

NY) were used for all data management functions and statistical analyses.

3. Results

All lung function measures decreased slightly between visits 1 and 2. In a paired *t* test, FEV(1)/FVC decreased significantly by 0.14%. The correlation coefficient for FEV(1)/FVC between visits 1 and 2 was 0.834. Table 1 shows the characteristics of the study cohort.

In Table 2, characteristics of subjects across quintiles of HEI-2005 and with lung function are shown. All characteristics were highly significant with 1 or both measures. These variables include control variables in the subsequent regression analysis.

Table 3 – Associations between quintiles of the HEI-2005 and its components with measures of lung function for the ARIC cohort, visits 1 and 2

HEI components	FVC		FEV(1)		%FEV(1)		FEV(1)/FVC	
	Visit 1	Visit 2	Visit 1	Visit 2	Visit 1	Visit 2	Visit 1	Visit 2
HEI-2005	NS	NS	NS	NS	.215 *	NS	.101 *	.140 **
Total fruits	NS	NS	NS	NS	NS	NS	NS	NS
Whole fruits	NS	NS	NS	NS	NS	NS	NS	NS
Total vegetables	NS	−.011 **	NS	NS	NS	NS	NS	NS
DGO Veg Legumes	NS	NS	NS	NS	NS	NS	NS	NS
Total grains	NS	NS	NS	NS	NS	NS	NS	NS
Whole grains	NS	NS	.010 ***	.006 *	.323 ***	.202 *	.127 **	.096 *
Milk	.011 ***	.015 ***	.010 ***	.011 ***	.312 ***	.354 ***	NS	NS
Meat and legumes	NS	−.012 ***	NS	−.007 *	NS	−.204 *	NS	NS
SoFAAS	.010 *	.013 **	NS	NS	NS	NS	−.109 *	−.131 *
Sodium	NS	NS	NS	NS	NS	NS	NS	NS
Saturated fats	NS	NS	NS	NS	NS	NS	NS	−.091 *
Oils	NS	NS	NS	NS	NS	NS	NS	NS

Values are expressed as beta per increase in 1 quintile of the intake variable. Linear regression models included age, female sex, black ethnicity, education (3 levels), total calories, physical activity (tertiles), current smoking, cigarette years, height, BMI, and interaction term black × BMI. Abbreviations: DGO Veg Legumes, dark green and orange vegetables and legumes; NS, not statistically significant.

* $P \leq .05$.

** $P \leq .01$.

*** $P \leq .001$.

The HEI-2005 was significantly positively correlated with FEV(1)/FVC at both visits 1 (β = .101) and 2 (β = .140). See Table 3. Components of HEI-2005 that contribute to this effect may include whole grains (β = .127 for visit 1 and .096 for visit 2), SoFAAS (β = −.109 for visit 1 and −.131 for visit 2), and saturated fats (β = −.091 for visit 2).

Macronutrient intakes in the ARIC cohort that were positively correlated with %FEV or FEV(1)/FVC in either visit 1 or visit 2 were animal protein (β = .132 for visit 1 and .093 for visit 2), dietary fiber (β = .129 for visit 2), polyunsaturated fatty acids (β = .085 for visit 1 and .116 for visit 2), omega-3 fatty acids (β = .109 for visit 1 and .103 for visit 2), and alcohol (β = .260 for visit 1 and .310 for visit 2). Negatively correlated intakes were total calories (β = −.082 for visit 1), saturated fatty acids (β = −.085 for visit 2), and medium-chain fatty acids (β = −.092 for visit 2). See Table 4.

In the stratified analysis, women had significant positive associations for %FEV for visit 1 (β = .368) and visit 2 (β = .294) with significant interaction terms. Among ethnicities, the diet-lung function associations were stronger among nonblacks for FEV (1)/FVC (β = .162 at visit 1 and .207 at visit 2) with significant interaction terms. The only significant association among the smoking subgroups was for %FEV for never smokers at visit 1 (β = .329) with no significant interaction terms. See Table 5.

Table 5 – Stratified analysis of association between HEI-2005 and %FEV and FEV(1)/FVC in visits 1 and 2 of the ARIC study

Subgroups	%FEV(1)		FEV(1)/FVC	
	Visit 1	Visit 2	Visit 1	Visit 2
Men	−.010; P = .950	−.153; P = .353	.096; P = .210	.168 *; P = .033
Women	.368 *; P = .012	.294; P = .053	.097; P = .106	.111 *; P = .065
Interaction	P < .001	P < .001	P = .384	P = .642
Nonblacks	.239 *; P = .043	.131; P = .293	.162 **; P = .002	.207 ***; P < .001
Blacks	.095; P = .696	.029; P = .909	−.134; P = .209	−.098; P = .345
Interaction	P = .038	P = .084	P = .004	P = .003
Never smokers	.329 *; P = .030	.224; P = .203	.121; P = .052	.097; P = .128
Former smokers	.104; P = .557	.021; P = .920	.146; P = .067	.151; P = .079
Current smoker	.075; P = .752	.227; P = .377	.046; P = .687	.204; P = .099
Interaction (current vs not current smoking)	P = .106	P = .670	P = .705	P = .375

Values are expressed as β per increase in 1 quintile of the intake variable. Linear regression models included, where appropriate, age, female sex, black ethnicity, education (3 levels), total calories, physical activity (tertiles), current smoking, cigarette years, height, and BMI, and interaction term black × BMI.

* $P \le .05$.

** $P \le .01$.

*** $P \le .001$.

4. Discussion

After controlling for a number of salient variables, a healthy eating pattern, as quantified by high HEI-2005 scores calculated from visit 1 dietary and nutrient data from the ARIC cohort, was positively associated with lung function, as expressed by FEV(1)/FVC and by %FEV. Our original hypothesis is accepted. The important contributing HEI-2005 components were increased whole grains and milk and decreased SoFAAS, and saturated fats. These findings are mirrored in the macronutrient correlations with lung function. Total calories and saturated fatty acids were negatively associated with FEV (1)/FVC. Dietary polyunsaturated fatty acids and long-chain omega-3 fatty acids, animal protein, and dietary fiber were positively associated with FEV(1)/FVC.

Agreement was found between lung function and the HEI-2005 components and the measures of macronutrient intake. For carbohydrates, the whole grain component and dietary fiber levels were both positively associated with higher lung

Table 4 – Associations of quintiles of macronutrient intake with lung function for the ARIC cohort, visits 1 and 2

Variable in quintiles	FVC		FEV(1)		%FEV(1)		FEV(1)/FVC	
	Visit 1	Visit 2	Visit 1	Visit 2	Visit 1	Visit 2	Visit 1	Visit 2
Total Calories (kcal/day)	NS	NS	NS	NS	NS	NS	−.082 *	NS
Animal Protein (%en)	NS	NS	NS	NS	NS	NS	.132 ***	.093 *
Vegetable Protein (%)	NS	NS	NS	NS	NS	NS	NS	NS
Carbohydrate (%en)	NS	NS	NS	NS	NS	NS	NS	NS
Dietary fiber (g/kcal)	NS	NS	NS	NS	.195 *	.201 *	NS	.129 **
Saturated fatty acids (%en)	NS	.008 *	NS	NS	NS	NS	NS	−.092 *
C4-C14 Saturated fatty acids (%en)	NS	.012 ***	NS	.006 *	NS	NS	NS	−.085 *
Monounsaturated fatty acids (%en)	NS	NS	NS	NS	NS	NS	NS	NS
Polyunsaturated fatty acids (%en)	NS	NS	NS	NS	NS	NS	.085 *	.116 **
Omega-3 fatty acids (%en)	NS	NS	NS	NS	.265 **	.259 **	.109 **	.103 *
Alcohol (%en)	.012 ***	.016 ***	.008 ***	.010 ***	.260 **	.310 **	NS	NS

Values are expressed as β per increase in 1 quintile of the intake variable.

Macronutrients are all normalized with total caloric intake. Linear regression models included age, female sex, black ethnicity, education (3 levels), total calories, physical activity (tertiles), current smoking, cigarette years, height, and BMI, and interaction term black × BMI.

Abbreviation: %en, calories from nutrient as a percentage of total calories.

* $P \le .05$.

** $P \le .01$.

*** $P \le .001$.

function. Saturated fatty acids were negatively associated with lung health, in agreement with the saturated fat component and with the SoFAAS component, the largest single component of the HEI-2005. However, sucrose alone was not correlated with lung function, and alcohol was positively associated only with %FEV. The negative effects observed for the saturated fats component were a novel finding, and it reflected the correlation of lung function with lower intakes of medium-chain fatty acids and higher intakes of polyunsaturated fatty acids and omega-3 fatty acids. The strong multivariate association seen for animal protein was not confirmed in the HEI-2005 meat and legume component. Interestingly, when both saturated fatty acid intake and animal protein intake were included in the same model, the significant association for each with lung function increased, suggesting the statistical independence of these factors. Dairy protein also contributes to the animal protein total and would help explain both the positive milk component association with lung function and the animal protein association. Interestingly, medium-chain fatty acids, common in dairy products, were negatively associated with lung function.

Other researchers have previously reported associations between foods or nutrient intakes and lung function or COPD. The cross-sectional association between lung function and whole grains and fiber intake in the ARIC cohort has been previously reported by Kan et al [13]. Other perspective studies, notably in the Nurses' Health Study and the Health Professionals Follow-up Study, found confirming results for fiber in a perspective study of diet and COPD with 16 years of follow-up [14]. Results from the MORGEN cross-sectional study of diet and COPD support the beneficial effect of whole grains [31]. Fruits and other potential sources of vitamin C and antioxidants have been found by others in perspective studies of diet and COPD to be associated with improved lung function [17,18,29].

In a previous cross-sectional investigations of both lipid intake and plasma lipids, Shahar et al [15,16] described a protective omega-3 effect on COPD in the ARIC cohort among former and current smokers, which was confirmed by dietary intakes in the present study. McKeever et al [30] found no association between intake of omega-3 fatty acids and FEV(1) or the symptoms of COPD in a cross-sectional study of Dutch adults; they also found a negative association with most other omega-6 polyunsaturated fatty acids and FEV(1) and a positive association with COPD. In a case-control study of an adult Japanese population, dietary omega-6 fatty acids were reported to be protective against COPD, but omega-3 fatty acids were not beneficial [32]. Of the few studies that have looked at the association of saturated fatty acid intake and lung function or COPD, few significant associations were reported [16,32,33].

A significant positive effect of alcohol intake on FEV(1) and %FEV was also found but not on FEV(1)/FVC. Many other investigators have found a similar salutary effect. Siu et al [34] examined records from 177721 members of a Japanese health plan and found that moderate alcohol intake was associated with higher spirometric lung function. Moderate alcohol consumption in the National Health and Nutrition Examination Survey (NHANES) III cohort was associated with improved lung function, whereas excessive intake was detrimental [35]. Relatively little alcohol was consumed by the ARIC cohort and 60% of the cohort as nondrinkers.

The relationships between saturated fats, polyunsaturated fats, and the omega-3 fatty acids and lung function suggest that atherosclerotic and inflammatory mechanisms may be involved in lung health. In a cross-sectional examination of the Nurses' Health Study, Fung et al [36] found that women with the highest HEI scores had lower levels of inflammatory markers. Low lung function and incident COPD appear to be significant risk factors, possibly through inflammatory mechanisms for small arterial elasticity, peripheral artery disease, and increased carotid intima-media thickness [37-41]. In fact, several authors have suggested and 1 has applied the use of statins in the treatment of COPD due both to the cholesterol-lowering and anti-inflammatory effects [42-44].

Other researchers have examined the association of the HEI on other diseases and conditions. Huffman et al [45] found a no overall association between HEI (the original 1995 version) and 10-year calculated risk of coronary heart disease risk among Cuban-Americans. Drewnowski et al [46] found with the SU.VI.MAX Study only a weak cross-sectional association between HEI and lower BMI and blood pressure. Bone turnover and HEI-2005 were examined by Hamidi et al [20] in NHANES 1999-2002. They found no association except for the HEI dairy component. For overall and cardiovascular mortality in an elderly cohort, Rathod et al [47] found a modest beneficial effect of a higher HEI score after 9.6 years of follow-up. McCullough et al [48] found, during 8 years of follow-up, that the HEI modestly predicted a reduction in the incidence of chronic diseases, primarily cancer and cardiovascular disease in men. Among these diseases and conditions, the original HEI or HEI-2005 was only a modest predictor of health.

The subgroup analysis also provided results at odds with previous studies of diet and lung function. Varraso et al [17,18] found consistent results between sexes when comparing dietary patterns and COPD when examining a prospective cohort of women and a cohort of men, whereas we found a significant interactive effect among men and women for % FEV. Another investigators found strong dietary differences among smokers and past smokers in the effects of antioxidant nutrients after 4 years of follow-up on FEV(1), whereas we find little difference among smoking groups in our cross-sectional analysis [29]. We did not include past smokers in our regression analysis as a separate group because it did not alter the model that included current smokers and pack-years.

When the analysis of HEI-2005 and lung function was separated by ethnicity, we found significant results among nonblack for FEV(1)/FVC. In a similar study of fiber and lung function in the ARIC cohort, Kan et al [13] found a similar fiber effect among blacks and whites, with a nonsignificant interaction term. We found a significant and negative interaction terms with lung function between HEI and black ethnicity and between BMI and ethnicity. This suggests that, at higher BMI and higher HEI, the lung function of blacks does not respond as positively as nonblacks.

It is interesting to note the relative magnitude of the HEI-2005 association with FEV(1)/FVC. Between visits 1 and 2, a 3-year period, this measure of lung function decreases by a small but significant 0.14% as a function of aging across the study cohort. The between-quintile β for HEI-2005 for visit 1 is .101 and for visit 2 is .140. Thus, moving down 1 quintile in healthy eating corresponds to a change approximately equivalent to 3 years change in FEV(1)/FVC with aging. Although in a cross-sectional study no causality can be assigned to this correlation, it is interesting to put the HEI-2005 effect in context of aging lung function.

This analysis has limitations. As a cross-sectional analysis, causation cannot be attributed to the associations between diet and lung function. We did have 2 sets of pulmonary measures taken 3 years apart. However, this time span was probably too short to consider longitudinal effects. In addition, we did not report any results that were marginally significant (.05 < P < .10). Although a number of these near-significant findings existed, any such association in a cohort of 12 532 was probably not materially significant. In our analysis, controlling for smoking, which is probably the single biggest cause of decline in lung function, was minimal compared with other reports. We considered other measures, such as former smokers, cigarette-years squared, and some interaction terms but found them all to have negligible effect on our outcomes of interest. As in other epidemiological studies, residual confounding for smoking, which is certainly the risk factor most consistently associated with lung function, might be present. We also did not control for the 4 ARIC study centers because these data were not available in the BioLINCC data set. Although we reported on 4 different lung function measures, we focused primarily on FEV(1)/FVC, which is contrary to what other authors have considered. Our use of this end point was primarily motivated by the GOLD definition of COPD as partly defined by low FEV(1)/FVC [7,49].

In conclusion, findings of the HEI-2005 analysis suggest that overall diet affects lung health. This report adds to the substantial existing evidence on this association. A healthy diet, as defined by the HEI-2005, is associated with higher lung function as defined by the ratio FEV(1)/FVC and %FEV. Macronutrients appear to play a significant role in this association, including a positive association with animal protein and polyunsaturated fats, including the fish oil omega-3 fatty acids. A negative association was found between lung function and total calories and dietary saturated fatty acids. The Dietary Guidelines for Americans and the Food Guide Pyramid as embodied in the HEI-2005 instrument also may be applied to making dietary recommendations with respect to lung function as well as to cardiovascular diseases and cancer.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at

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