Dietary Antioxidants and FEV$_1$ Decline: the Health, Aging and Body Composition Study

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Abstract

Increased antioxidant defenses are hypothesized to decrease age- and smoking-related decline in lung function.

The relation of dietary antioxidants, smoking, and forced expiratory volume in the 1st second of effort (FEV$_1$) was investigated in community-dwelling older adults in the Health, Aging, and Body Composition Study. 1,443 participants completed a food frequency questionnaire, self-reported smoking history, and had measurements of FEV$_1$ at both baseline and after 4 years of follow-up. The association of dietary intake of nutrients and foods with antioxidant properties and rate of FEV$_1$ decline was investigated using hierarchical linear regression models.

In continuing smokers (current smokers at both time points), higher vitamin C and higher intake of fruits and vegetables were associated with an 18 and 24 ml/year slower rate of FEV$_1$ decline compared to lower intake (P<0.0001 and 0.003, respectively). In quitters (current smoker at study baseline, quit during follow-up), higher intake was associated with an attenuated rate of decline for each nutrient studied (p<0.003, all models). In non-smoking participants, there was little or no association of diet and rate of decline in FEV$_1$.

The intake of nutrients with antioxidant properties may modulate lung function decline in older adults exposed to cigarette smoke.

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INTRODUCTION

Aging has been described as the accumulation of oxidative damage that is incompletely repaired by the body's antioxidant defenses.[1] This damage is caused by free radicals produced in the body via normal metabolic processes and inflammation, and by exogenous free radicals such as from smoking and noxious gases. In the lungs, aging is associated with declining lung function, and rate of decline increases with advancing age.[2] In older adults, steeper rates of decline are associated with both an increased risk of chronic obstructive pulmonary disease (COPD) and of all-cause mortality.[2, 3] Among the many harmful effects of cigarette smoking on lung tissue, smoke exposure contributes to oxidative stress and accelerates the "aging" of the lung, resulting in the greater reductions in lung function observed among persons with a history of cigarette smoking.[3–5]

The large surface area of the lungs is in constant contact with oxidants from the environment, but antioxidant defenses limit the associated damage. When these defenses are overwhelmed, oxidative stress can provoke and enhance both the inflammation[6] and antiprotease inactivation[7] associated with COPD and contribute directly to tissue damage[8]. Enhancing antioxidant defenses is hypothesized to reduce the accumulation of oxidative damage, thus potentially slowing the rate of decline in lung function associated with aging and smoking.

In support of this hypothesis, observational epidemiologic studies of dietary antioxidant intake, serum antioxidant concentration, and lung outcomes (spirometry at one time point, rate of decline in lung function, and risk of COPD) suggest that lower levels of antioxidant defense are associated with worse outcomes[9–14] and higher COPD mortality risk.[15] Although older adults are at the greatest risk of steep rates of decline in FEV_1 and may experience the greatest increases in quality of life with prevention, there is no research on the association between dietary antioxidants and FEV_1 in this age group. In addition, most studies of antioxidants and FEV_1 are cross-sectional, despite the expectation that rate of FEV_1 decline is a more informative indicator of mortality and COPD risk.[2] To address the need for longitudinal evidence in older populations, the authors tested the hypothesis that dietary antioxidants modify the association of smoke exposure with the rate of FEV_1 decline in a longitudinal cohort study of older adults.

MATERIALS AND METHODS

Study Participants

The Health, Aging, and Body Composition Study (Health ABC) is a prospective cohort of 3,075 community-dwelling older adults (aged 70–79 years at baseline in 1997; for further details: [16]). The Health ABC study was approved by the Institutional Review Boards of the University of Pittsburgh and the University of Tennessee; this study was approved by the Institutional Review Board at Cornell University.

Exclusion criteria included missing dietary or smoking data, or spirometry tests that were missing, unacceptable, or not reproducible (early coughs, early termination, high back extrapolated volume, and > 200 ml between two best FEV_1 values). Participants with prevalent lung disease (spirometry-defined or diagnosed COPD, diagnosed asthma) at study

baseline were excluded because disease may lead to relevant physiological or behavioral changes.

Study variables—Dietary antioxidant intake was determined at the 1-year follow-up using a modified Block food frequency questionnaire that was designed to assess intake in the year prior (further details [17]). The intake of nutrients with antioxidant properties was measured by whole food intake (fruits and vegetables) and by micronutrient intake calculated from all dietary sources of the antioxidant (vitamins C and E, and β-carotene).

Spirometry for this cohort was conducted at baseline and after 4 years using a horizontal dry rolling seal HF6 Spirometer (Sensor Medics Corporation, Yorba Linda, CA) according to standard guidelines[18]. Smoking exposure was self-reported at both visits and categorized as continuous (smoking at each visit), quit (smoking at baseline, but not at year 4 follow-up), former (history of smoking prior to baseline), and never (smoking <100 cigarettes in lifetime). Smoking pack-years (average packs smoked per day multiplied by number of years smoking) and current smoking status were included as covariates.

Data analysis—Hierarchical linear regression models were used to assess the association of antioxidant intake and cigarette smoking with FEV_1 rate of decline. Age, gender, height, race, years of education, family income, study site, pulmonary drug use, and total energy intake were included as covariates in all models. Height was included as a repeated measure to address any changes in spirometry secondary to kyphosis. Power terms and categorical variables of continuous antioxidant predictors were considered; no evidence of non-linearity was found, thus all models and all statistical tests of the hypothesis used continuous variables for dietary intake. Intake of fruits and vegetables were summed and represented with a single variable (servings per day). To test the interaction between measures of oxidative stress (smoking) and antioxidant status (dietary antioxidant intake, a continuous variable), product terms were computed. Given that interactions were conveyed by a set of variables (for example, the product of each smoking 'dummy' variable by antioxidant intake by time), *P* values convey the statistical significance of the set of terms. Reported rate of decline estimates are the beta coefficients for the elapsed time variable in the model after centering all terms interacting with elapsed time and selecting appropriate smoking reference groups. To illustrate the magnitude of the interaction between smoking and dietary intake, the estimated FEV_1 rate of decline for smokers at high and low antioxidant intake (defined as the 90th and the 10th percentile of the cohort distribution) were calculated.

All analyses were conducted using SAS v 9.1 (SAS, Cary, NC).

RESULTS

Of the 3,075 participants, 859 met exclusion criteria for disease or missing exposure variables (Table 1). Of the remaining 2,216 participants, 1,443 had valid spirometry at baseline and follow-up. Inclusion was associated with survivorship and, as expected, studied participants were more likely to be never smokers or to have smoked less on average over their lifetime.

Although dietary intake variables were modeled as continuous variables, results are presented as the comparison of high (90th percentile) and low (10th percentile) levels for illustrative purposes. In the groups hypothesized to have the highest burden of environmental and endogenous oxidative stress and inflammation (continuing smokers and quitters), a higher intake of nutrients and/or foods with antioxidant properties was consistently associated with a slower rate of decline (Table 2); there was little or no association of dietary intake with lung function decline in never and former smokers.

Statistical tests of the interactions of vitamins C and E, β-carotene and fruit/vegetable intake with cigarette smoking were highly statistically significant with P values of <0.0001, 0.003, 0.003 and 0.003, respectively (full model results provided in Supplemental Table 1).

Continuing smokers who consumed diets high in either vitamin C or vitamin E had slower rates of decline in FEV_1 (−25 and −29 ml/year) compared to continuing smokers who consumed diets *low* in these nutrients (−43 and −42 ml/yr). Continuing smokers who consumed diets high in fruits and vegetables had about half the rate of decline observed in continuing smokers who consumed diets *low* in fruits and vegetables. The rate of decline in continuing smokers did not differ by intake of β-carotene (Table 2).

In smokers who quit, high antioxidant intake was associated with greater attenuation in the rate of decline compared to associations described above for continuing smokers. In quitters with higher intake of nutrients with antioxidant properties changes in FEV_1 were positive; FEV_1 increased by about 1 to 2% in high intake groups, whereas it declined by about 2.5% in low intake groups. Thus, high vs. low intake was associated with a 70, 96, and 93 ml/year difference in rate of decline in FEV_1 for vitamins C, E, and β-carotene, respectively. A high intake of fruits and vegetables (vs. low) was associated with an attenuated rate of decline (attenuated by 41 ml/year, P interaction = 0.003) that was similar in magnitude to that observed in continuing smokers.

When dietary vitamin C, vitamin E, and β-carotene were included in the same model to account for possible overlap in the effects of these nutrients, a high intake of all three antioxidants (compared to low intake of all) was associated with a 12 ml/year slower decline in continuing smokers and a 98 ml/year difference in decline among quitters. The statistical significance of all terms was reduced, and the interaction between vitamin C, smoking status, and time had the lowest p-value (P=0.006). Little or no change in the results was observed with the addition of other potentially confounding variables including time-varying variables for co-morbidities (cardiovascular disease, diabetes, and hypertension), exercise, and time since last smoked.

In analyses of FVC, results were less consistent than for FEV_1. There was a statistically significant interaction of vitamin C intake and smoking on rate of decline in FVC (p=0.002) such that current smokers who were high consumers of vitamin C had about half the rate of decline as low consumers. Similar to findings for FEV_1, quitters with high consumption had positive changes in FVC, whereas quitters with low consumption had rates of decline similar to the overall mean. While the set of vitamin E interactions was statistically significant (p= 0.005), the pattern of effects was less consistent. Thus, the intake of vitamin E had little or no association with rate of decline in FVC in continuing smokers, but quitters with high vitamin E consumption had positive changes in FVC, whereas quitters with low consumption had approximately average rates of decline. Interactions between fruit/ vegetable or β-carotene intake and smoking on rate of FVC decline were not statistically significant although effects were in the same direction as FEV_1 analyses. For the FEV_1/FVC ratio outcome, all effects were in the same direction (less steep declines in smoke-exposed subgroups with higher consumption of nutrients and foods with antioxidant properties), but none of the interaction coefficients were statistically significant (data not shown).

DISCUSSION

Dietary antioxidant intake is a potentially modifiable predictor of the decline in FEV_1 in this longitudinal study of well-functioning older adults. In Health ABC Study participants, consuming a diet high in antioxidants was associated with an attenuated slope of decline in lung function in current smokers, the population subgroup at greatest risk of lung-related

disability and death. In smokers, higher intakes of vitamin C, vitamin E, β-carotene, and fruits and vegetables were associated with meaningful differences in the trajectory of change in FEV_1. In participants who continued to smoke over four years of follow-up, vitamin C and fruit and vegetable intake had the strongest associations; smokers with *high* intakes had 18 and 24 ml/year *lower* rate of decline in FEV_1 compared to smokers with low intakes. In participants who quit smoking, all dietary antioxidants had strong inverse associations with rate of decline: the rate of decline in FEV_1 was attenuated in quitters with *high* intakes of vitamin E, β-carotene, vitamin C and fruit compared to quitters with low intake. The association of fruits and vegetables with lung function decline was similar in continuing smokers and quitters, suggesting a broad role for these foods in persons who are smoke-exposed. While larger effects were noted for vitamins C, E, and β-carotene in quitters, confidence intervals were wide for this small subgroup.

Prior studies of younger adult populations reported associations between dietary antioxidant intake and rate of decline in FEV_1 similar in magnitude to the Health ABC Study findings. Changes over time in the consumption of fresh fruit were associated with rate of decline in FEV_1 in healthy British adults (age 18–73): participants with the largest *decrease* in fruit intake had a *steeper* rate of decline in FEV_1 (89 ml/year and 133 ml/year steeper for men and women) compared to participants with no change in fruit intake,[19] and effects were strongest among cigarette smokers. The British study also reported that average fruit intake (vs. change in fruit intake) had little or no association with rate of decline, underscoring the importance of appropriately timed measurements of dietary intake. In middle-aged Welshmen (age 45–59) followed for 5 years, the rate of FEV_1 decline was 10 – 15 ml/year *slower* in men with *high* apple intake compared to men with low intake; however, no associations were found for vitamins C, E, and β-carotene. Nottingham adults (age 18–70) consuming diets *high* in vitamin C (100 mg higher than low vitamin C diets) had an *attenuation* in the rate of decline in FEV_1 (by about 6 ml/yr), but no associations were found for vitamins A and E.[12] In a cohort of heavy smoking French adults (age 20–44), *higher* levels of serum β-carotene and serum vitamin E were associated with *slower* rates of decline in FEV_1.[20] None of the above-mentioned longitudinal studies are in the age range reported herein. Similarly, most of the cross-sectional studies that have investigated this hypothesis are in younger populations, and most reported positive associations between vitamins C and E, β-carotene, fruits and vegetables and lung outcomes,[9–15, 19–25] with the strongest effect sizes often identified in cigarette smokers.

In Health ABC never and former smokers, the intake of nutrients and foods with antioxidant properties had little or no association with the rate of decline in FEV_1. Similarly, when antioxidant terms were included in models without interactions with smoking status, the main effects were not statistically significant (data not shown). These findings are consistent with the hypothesis that a protective effect of nutrients with antioxidant properties is expected primarily in persons with a high burden of oxidative stress. Thus, the role of dietary antioxidants may be to provide additional functional capacity to reduce damage from exposure to oxidants. The findings suggest a testable hypothesis: non-smokers may not benefit from increasing the intake of nutrients with antioxidant properties because their overall level of oxidant burden is low enough to be well-managed by endogenous capacity.

The Health ABC study allows a closer look at the rate of decline in lung function associated with smoking status in a cohort of older adults. Of particular interest is the difference in rate of decline in FEV_1 between continuing smokers (44 ml/year) and quitters (31 ml/year), underscoring the significant functional improvements that may be attained with smoking cessation at advanced ages. Attenuating the rate of decline is especially important in smokers, because, on average, smokers have lower starting FEV_1 values, and are at greater risk of disability and death.

In the Health ABC study, spirometry was conducted beyond the time points studied, with additional measurements at 7 and 9 years of follow-up. Given that exposure (dietary antioxidants) was measured only once early in the follow-up period, it was important to carefully consider the optimal outcome to investigate the hypothesis. If the balance between antioxidants and oxidants in the lungs is hypothesized to affect the rate of decline in lung function, then *concurrent* measurements of diet, smoking parameters, and lung function are likely to be most informative. Thus, the longitudinal spirometry outcome data were limited to the time period closest to the dietary assessment time point. When the analysis was extended to include spirometry from later visits (7 and 9 years), the magnitudes of the associations were similar, but less statistically significant. In this vulnerable age group, many factors are associated with dietary changes, including new disease diagnoses, onset of functional impairment, changes in living situation, and loss of a spouse.[26–28] Thus, the strongest analytic approach is one that limits consideration of pulmonary function changes to the same time period in which diet was measured.

In any observational study of diet, unaddressed confounding is a concern in interpreting results. Variables representing the following potential confounders of the diet–rate of FEV_1 decline associations were considered in all models: body mass index, cigarettes/day, environmental oxidant exposure (study site, education, and family income were used as proxies for environmental exposures). There was little or no change in the reported associations when potential confounding by co-morbidities (covariates included prevalent and incident diagnoses of cardiovascular disease, diabetes, and hypertension) and exercise/ physical activity were considered.

While the hypothesis posits an effect of diet on the oxidant/antioxidant balance, the diet— rate of decline associations may be mediated through other biological pathways such as muscle strength or inflammation. The finding of similar associations with FVC raises the possibility of other pathways, although findings for the FVC outcome were less consistent. These data cannot definitively address the biological mechanisms, but support the need for further mechanistic studies.

The use of GOLD categories for defining prevalent COPD has been debated, especially in older populations.[29] When participants were excluded on the basis of lower limit of normal-defined COPD instead of GOLD-defined COPD, neither the size nor the strength of the observed associations was affected.

A strength of this study is the use of data from a large, prospective cohort study of elderly people; this population subgroup stands to benefit from research aimed at understanding how to prevent loss of lung function. The quality control standards for spirometry in Health ABC followed best practice, as evidenced by the excellent overall quality of the pulmonary function data. The use of two separate methods to estimate dietary intake of nutrients with antioxidant properties, micronutrients and whole foods, yielded similar results, suggesting that the findings represent true associations of diet and lung function. The consideration of simultaneous models including all nutrients diminishes the possibility that observed associations were primarily driven by a single dietary constituent.

There are also several limitations of the study. While the use of antioxidant supplements is expected to contribute to overall antioxidant status, this study did not record the dose and frequency of antioxidant supplement use. Survivor bias is of concern in a study of older adults: non-random loss-to-follow-up results in healthier participants at follow-up. Survivor bias is evident when participants contributing data at each measurement are compared: participants with follow-up data were younger, more often female, and smoked less. If participants who did not remain in the study had a greater burden of oxidative stress (given

their smoking history and age, this may be a reasonable hypothesis) then, in light of the findings in participants with the highest burden of oxidative stress, even stronger associations than those observed might be expected.

This study of older adults supports the hypothesis that nutrients with antioxidant properties are associated with a slower rate of FEV_1 decline in current and quitting smokers. Whether changing the intake of foods rich in nutrients with antioxidant properties will lead to a slower rate of decline in FEV_1 remains to be demonstrated; the results from the Health ABC cohort support this inference.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Table 1

Baseline Characteristics of Participants Included and Excluded From Analyses[1], Health, Aging, and Body Composition Study, Memphis, TN and Pittsburgh, PA; 1997-.

	Included Participants, by Cigarette Smoking Status				All Health ABC Participants	
	Continuing Smokers (n=75)[1]	Quitters (n=27)	Former Smokers (n=635)	Never Smokers (n=704)	Included (n=1441)	Excluded (n=1634)[2]
Age, years	72.8 (2.8)	74.6 (3.3)	73.5 (2.8)	73.5 (2.8)	73.5 (2.8)	73.8 (2.9)
Females (%)	39 (52%)	10 (37%)	229 (36%)	451 (64%)	731 (51%)	853 (52%)
Blacks (%)	47 (63%)	13 (48%)	203 (32%)	240 (34%)	505 (35%)	776 (48%)
Memphis, TN site (%)[3]	30 (40%)	11 (41%)	278 (44%)	332 (47%)	652 (45%)	896 (55%)
Former Smokers (%)					640 (44%)	764 (47%)
Current Smokers (%)					97 (7%)	221 (14%)
Packyears	44.7 (29.0)	38.9 (34.5)	28.3 (26.7)	--	30.3 (27.7)	38.6 (31.4)
Dietary Intake						
Vitamin C, mg/day	133 (87)	149 (96)	143 (72)	150 (77)	146 (76)	145 (80)
Vitamin E, α-TE/day	11.0 (6.0)	10.8 (6.1)	11.2 (7.2)	11.1 (6.8)	11.1 (6.9)	11.0 (6.9)
β-carotene, μg/day	3338 (2579)	2796 (2294)	3157 (2483)	3631 (2560)	3392 (2532)	3610 (3163)
Fruits, servings/day	1.6 (1.1)	1.7 (1.2)	1.9 (1.1)	2.2 (1.2)	2.0 (1.2)	1.9 (1.2)
Vegetables, servings/day	2.8 (2.0)	3.1 (3.0)	3.0 (1.9)	3.1 (1.9)	3.0 (1.9)	2.9 (1.9)
FEV_1 at baseline, ml[4]	2107 (48)	2198 (80)	2323 (17)	2358 (16)	2297 (13)	2011 (13)
Annual rate of decline, ml/yr[5]	44.3 (5.7)	31.7 (9.4)	50.9 (2.0)	49.4 (1.9)	49.5 (1.3)	43.8 (2.7)

Abbreviations: α-Tocopherol Equivalents (α-TE); Forced Expiratory Volume in the 1 second of effort (FEV_1); Chronic Obstructive Pulmonary Disease (COPD).

[1] Unless otherwise indicated, mean (SD) is reported.

[2] Number of participants excluded by reason for exclusion (categories not mutually exclusive): prevalent COPD, spirometry-defined (n=357), prevalent COPD, physician-diagnosed (n=228), prevalent asthma, physician-diagnosed (n=140), unacceptable quality on baseline spirometry (n=160), missing baseline spirometry (n=212), unacceptable quality on follow-up spirometry (n=129), missing follow-up spirometry (n=978).

[3] vs. Pittsburgh, PA site

[4] Calculated on those with an acceptable FEV_1 at study baseline; adjusted for age, gender, and race.

[5] Calculated only on those with an acceptable FEV_1 at both baseline and after 4 years of follow-up. Among excluded participants, this calculation is only possible on 354 participants. Values adjusted for age, gender, and race.

Table 2

The Association of Smoking with Annual Rate of Decline in Pulmonary Function Parameters[1] for High (90th percentile) vs. Low (10th percentile) Dietary Antioxidant Intake in the Health, Aging and Body Composition Study, Memphis, TN and Pittsburgh, PA; 1997-.

Nutrient (90th vs. 10th percentile)	Smoking Status	FEV₁ Decline mls/yr		FVC Decline mls/yr		FEV₁/FVC Decline	
		High Intake	Low Intake	High Intake	Low Intake	High Intake	Low Intake
Vitamin C[2] 236.5 vs. 65.2 mg/day	Continuous	−25 (−42, −8)	−43 (−58, −29)	−18 (−46, 11)	−40 (−64, −16)	−1.0 (−2.0, −0.1)	−2.4 (−3.1, −1.6)
	Quit[3]	18 (−13, 49)	−52 (−78, −26)	44 (−7, 95)	−34 (−78, 9)	−2.0 (−3.3, −0.7)	−2.8 (−3.9, −1.6)
	Former	−50 (−57, −44)	−36 (−42, −30)	−46 (−57, −35)	−22 (−32, −12)	−1.3 (−1.6, −1.0)	−1.4 (−1.7, −1.2)
	Never	−42 (−48, −37)	−39 (−45, −34)	−39 (−49, −29)	−34 (−44, −25)	−1.4 (−1.6, −1.1)	−1.3 (−1.5, −1.0)
Vitamin E[4] 19.5 vs. 5.1 α-TE/day	Continuous	−29 (−48, −9)	−42 (−57, −26)	−36 (−68, −3)	−29 (−55, −2)	−1.0 (−2.3, 0.3)	−2.4 (−3.3, −1.5)
	Quit[3]	37 (1, 74)	−59 (−86, −32)	78 (17, 139)	−47 (−92, −1)	−2.0 (−3.4, −0.6)	−2.7 (−3.8, −1.6)
	Former	−45 (−51, −39)	−41 (−46, −36)	−39 (−49, −29)	−28 (−37, −20)	−1.4 (−1.6, −1.1)	−1.4 (−1.6, −1.2)
	Never	−41 (−46, −35)	−41 (−46, −36)	−35 (−45, −25)	−38 (−46, −29)	−1.5 (−1.7, −1.2)	−1.2 (−1.4, −1.0)
β-carotene[5] 6592 vs. 1186 µg/day	Continuous	−40 (−59, −20)	−35 (−50, −20)	−37 (−70, −4)	−28 (−54, −3)	−1.7 (−2.8, −0.6)	−2.0 (−2.7, −1.2)
	Quit[3]	42 (−1, 84)	−51 (−77, −24)	62 (−9, 133)	−28 (−72, 16)	−2.0 (−3.8, −0.2)	−2.2 (−3.2, −1.1)
	Former	−41 (−48, −34)	−43 (−48, −38)	−34 (−45, −22)	−32 (−41, −24)	−1.4 (−1.7, −1.1)	−1.4 (−1.6, −1.2)
	Never	−43 (−49, −37)	−39 (−44, −34)	−38 (−48, −28)	−36 (−44, −27)	−1.3 (−1.6, −1.0)	−1.3 (−1.6, −1.1)
Fruits & Vegetables[6] 8 vs. 2 servings/day	Continuous	−21 (−41, −1)	−46 (−62, −31)	−12 (−45, 22)	−45 (−71, −18)	−1.6 (−2.7, −0.6)	−2.1 (−2.8, −1.3)
	Quit[3]	−7 (−33, 19)	−48 (−75, −20)	11 (−33, 54)	−21 (−67, 25)	−2.2 (−3.4, −1.0)	−2.7 (−3.9, −1.6)
	Former	−49 (−56, −42)	−37 (−44, −31)	−39 (−50, −27)	−28 (−39, −17)	−1.4 (−1.7, −1.1)	−1.3 (−1.6, −1.1)
	Never	−42 (−48, −36)	−40 (−46, −33)	−38 (−48, −28)	−35 (−46, −24)	−1.3 (−1.5, −1.0)	−1.3 (−1.6, −1.1)

Abbreviations: α-TE, α-Tocopherol Equivalents; FEV₁, Forced Expiratory Volume in the 1st second of effort; FVC, Forced Vital Capacity;

[1] Rate of decline estimated from hierarchical mixed models for each nutrient, adjusted for age, height, race, gender, pulmonary drug use, study site, years of education, family income, current cigarettes/day, and calorie intake (separate models for each antioxidant, all nutrient variables modeled as continuous variables, but presented as contrasts of high vs. low intake to illustrate effect size).

[2] P for interaction of vitamin C intake with smoking $P < 0.0001$ (FEV₁); $P = 0.002$ (FVC); and $P = 0.1$ (FEV₁/FVC).

[3] Quit category is comprised of smokers at baseline who quit during follow-up.

[4] P for interaction of vitamin E intake with smoking $P = 0.003$ (FEV₁); $P = 0.005$ (FVC); $P = 0.2$ (FEV₁/FVC).

[5] *P* for interaction of B-carotene with smoking *P* = 0.003 (FEV1); *P* =0.2 (FVC); *P* =0.9 (FEV$_1$/FVC).

[6] *P* for interaction of fruit and vegetable intake with smoking *P* = 0.003 (FEV1); *P* = 0.2 (FVC); *P* =0.8 (FEV$_1$/FVC).