The Influence of Smoking on Vitamin C Status in Adults

GORDON SCHECTMAN, MD, JAMES C. BYRD, MD, AND HARVEY W. GRUCHOW, PHD

Abstract: To further define the relation between smoking and vitamin C status, the dietary and serum vitamin C levels of 11,592 respondents in the second National Health and Nutrition Examination Survey (NHANES II) were analyzed. Smokers of 20 cigarettes daily had the lowest vitamin C dietary intake (79 mg, 95% CI:73, 84) and serum levels (0.82 mg/dl, 95% CI: 0.77, 0.86; 46.6 μmol/L, 95% CI: 43.7, 48.8), while smokers of 1–19 cigarettes daily had decreased vitamin C intake (97 mg; 95% CI: 90, 104 mg) and serum levels (0.97 mg/dl, 95% CI: 0.92, 1.03; 55.1 μmol/L, 95% CI: 52.2, 58.5) compared to respondents who had never smoked (109 mg, 95% CI: 105, 113 and 1.15 mg/dl, 95% CI: 1.11, 1.18; 65.3 μmol/L, 95% CI: 63.0, 67.0, respectively). This inverse association between both intake and serum levels of vitamin C and smoking was independent of age, sex, body weight, race, and alcoholic beverage consumption. Following further adjustment for dietary vitamin C intake, the negative correlation between cigarette smoking and serum vitamin C levels persisted. The risk of severe hypovitaminosis C (serum levels ≤ 0.2 mg/dl; 11.4 μmol/L) was increased in smokers, particularly when not accompanied by vitamin supplementation (odds ratio 3.0, 95% CI: 2.5, 3.6). These data suggest that even though smoking adversely affects preferences for vitamin C rich foods, the inverse association between smoking and serum vitamin C levels occurs independently of dietary intake. (*Am J Public Health* 1989; 79:158–162.)

Introduction

Preliminary reports have indicated adverse affects of smoking on vitamin C metabolism[1,2] and more recent studies have confirmed that serum vitamin C levels are lower in cigarette smokers than non-smokers.[3–7] These observations suggest that smoking directly lowers serum vitamin C levels,[8] although other factors including gender,[4,9] age,[4,10] and ethanol consumption[11–13] have also been reported to influence serum vitamin C concentrations. However, since cigarette smoking is not independent of age, sex, or alcohol use,[14] the relation between smoking and vitamin C status requires evaluation controlling for these potentially confounding variables. Several previous reports have partially addressed these concerns by stratifying participants according to age,[7,15,16] sex,[15,16] and level of vitamin C intake.[15] Within each stratum, vitamin C levels were decreased in smokers, suggesting that the relationship may indeed be independent of these factors. A univariate analysis of the United States second National Health and Nutrition Examination Survey (NHANES II) was consistent with these findings, as serum vitamin C levels were lower in smokers for each level of dietary vitamin C intake.[17]

The purpose of this study was to better define the independent relationship between cigarette smoking and vitamin C status, while controlling for potentially confounding variables using multivariate statistical techniques on data from NHANES II, conducted from 1976–80. NHANES II is a comprehensive population survey which included serum vitamin C measurements and a detailed dietary questionnaire from which nutrient intakes were calculated in a sample of over 11,000 adults. The association of cigarette smoking with serum vitamin C levels was analyzed while simultaneously adjusting for variables which significantly influenced serum vitamin C concentrations including age, sex, race, dietary vitamin C intake, ethanol consumption, and body mass index (BMI). In addition, the impact of smoking on the risk of marginal or frankly deficient serum vitamin C levels was determined.

From the Divisions of General Internal Medicine and of Biostatistics/Clinical Epidemiology, Medical College of Wisconsin. Address reprint requests to Gordon Schectman, MD, Assistant Professor, Division of General Internal Medicine, Medical College of Wisconsin, 8700 West Wisconsin Avenue, Milwaukee, WI 53226. This paper, submitted to the Journal February 18, 1988, was revised and accepted for publication June 13, 1988.

Methods

The NHANES II probability sample was selected so that population subgroups of special interest for nutritional assessment were oversampled. Among adults, the oversampled groups included persons over 60 years old and persons below poverty level. Sample weights were then computed for these subgroups so that the total sample closely estimated the noninstitutionalized civilian population. This sample weighting reflects the individual selection probability, adjustments for non-response, and poststratification adjustments. A complete description of the survey methods has been reported.[18]

Adults ages 18 to 74 years who attended a second examination visit following a preliminary interview were studied. However, respondents who did not have serum vitamin C concentrations measured (n=866), who did not record alcoholic beverage consumption (n=40), and who did not complete smoking histories (n=6) were excluded from the analysis. After these exclusions, 11,592 respondents remained eligible for the study. Appropriate sample weighting was used to adjust for possible non-response bias introduced because of failure to attend the second examination visit.[19] Those who attended the second visit but who were subsequently excluded (n=912) were similar to included subjects in the per cent who were male (46.6 vs 47.4 per cent), White (82 vs 89 per cent), currently smoking (32 vs 34 per cent), and in their mean age (46.7 vs 46.2 years).

Nutrient intakes were estimated from 24-hour recall interviews. Three-month food frequency reports provided recent intake of individual food items, including estimates for beer, wine, and liquor. Weekly frequencies of beer, wine, and liquor consumption were summed to estimate ethanol consumption. The use of vitamin and mineral supplements was determined by the question "Are you taking vitamins or supplements?" The vitamin content of supplements was excluded from the nutrient intake summaries and therefore the calculated vitamin C intake underestimates actual vitamin C consumption in those respondents taking supplements. For this reason, the use of supplements was included as a separate variable in the multivariate analysis assessing serum vitamin C levels.

NHANES II participants were originally divided into racial categories of "White", "Black", and "other". Individuals of Oriental extraction, American Indians, and Eskimos were listed in the "other" category and accounted for less than 1 per cent of the total study cohort; they were

included with Whites in this study. Body mass index (BMI) was measured as weight/height^2 (kg/m^2).

Serum vitamin C levels were measured in a central laboratory at the Centers for Disease Control (CDC) by the dinitrophenylhydrazine method.[20] Criteria from the Nutrition Canada Survey were used to classify risk of clinical scurvy.[21] Respondents with serum vitamin C levels of 0.2 mg/dl (11.4 μmol/L) or less were considered to be at high risk for clinical vitamin C deficiency (severe hypovitaminosis C), while those with serum concentrations of 0.4 mg/dl (22.7 μmol/L) or less were considered to be at marginal risk (marginal hypovitaminosis C).

Variance estimates were corrected for the complex sample design using the SUPERCARP program.[22] Multiple regression was used to determine the independent contribution of a variable to serum vitamin C levels, while simultaneously adjusting for all other variables.[23] An order of entry was determined using a stepwise regression model, however, regression coefficients were computed following the insertion of all variables into the model. For the regression equations, smoking status was categorized into six levels: never smoked, stopped for the previous year or longer (DC > 1 year), stopped within the past year (DC < 1 year), smoking less than 20 cigarettes daily (<1 PPD; mean 9.3 cigarettes), smoking 20 cigarettes daily (1 PPD), and smoking more than 20 cigarettes daily (>1 PPD; mean 35.1 cigarettes). This was done to compare serum vitamin C levels in cohorts of subjects who were currently smoking, had stopped smoking, or who had never smoked. In additional analyses, smoking status was also recorded as a continuous variable (i.e., number of cigarettes smoked daily). Odds ratios for smoking and nutrient supplements on the risk of hypovitaminosis C while controlling for possible confounding variables were determined by the Mantel-Haenzel procedure.[24,25]

Results

Table 1 shows univariate analyses for variables associated with both serum vitamin C levels and cigarette smoking prevalence. Serum vitamin C levels were significantly associated with gender, race, age, and body mass index. Males, when compared to females, Blacks when compared to Whites, and adults under the age of 60 years when compared with those over 60 had lower serum vitamin C levels and a higher prevalence of smoking. Heavier individuals (BMI > 27), on the other hand, had lower serum vitamin C concentrations and a lower prevalence of smoking. Higher ethanol intakes (>5 drinks daily) were associated with a higher likelihood of smoking, while a non-significant increase in vitamin C levels (p=0.09) was observed in those with more moderate consumption (1 to 5 drinks daily).

An inverse relation between cigarette smoking and dietary vitamin C intake is demonstrated in Table 2. The mean vitamin C intake for all smokers was 20% lower compared with non-smokers (86 mg, 95% CI: 83, 90 vs 108 mg, 95% CI: 106, 111 [not shown]). This decrease was particularly marked in individuals smoking 20 cigarettes daily. Smokers of less than 20 cigarettes daily had an intermediate vitamin C intake while individuals who stopped smoking for more than one year had a vitamin C intake (108 mg, 95% CI: 103, 113) similar to never smokers. This inverse association between smoking and dietary vitamin C intake persisted following adjustment for age, sex, race, ethanol intake, income and body weight.

TABLE 1—Dietary Vitamin C Intake, Serum Vitamin C Levels, and Smoking Frequency in Individuals by Category of Gender, Race, Age Tertiles, Body Mass Tertiles, and Alcohol Consumption

	N	Serum Vitamin C mg/dl* (95% CI)	Smokers (per cent)
Gender			
Male	5520	0.94 (0.90, 0.97)	40.5
Female	6072	1.12 (1.09, 1.16)	33.4
Race			
White	10430	1.05 (1.03, 1.08)	36.3
Black	1162	0.86 (0.80, 0.91)	41.2
Age (years)			
18–35	5178	1.14 (1.11, 1.18)	40.4
36–59	4614	1.01 (0.98, 1.04)	38.3
60–74	1800	1.02 (0.98, 1.06)	22.6
Body mass (BMI)			
Thin (<23)	4255	1.08 (1.05, 1.12)	43.1
Medium (23–27)	4090	1.05 (1.02, 1.08)	34.9
Heavy (>27)	3245	0.95 (0.91, 0.98)	30.9
Alcohol (drinks/weekly)			
None	3875	1.02 (0.98, 1.05)	25.5
1–5	4509	1.06 (1.02, 1.10)	39.5
>5	1947	1.01 (0.96, 1.06)	50.1

*To convert to μmol/L, multiply by 56.78

In addition to decreased vitamin C consumption, smokers had serum vitamin C levels which were 24 per cent lower than non-smokers (0.87 mg/dl, 95% CI: 0.86, 0.89 vs 1.13 mg/dl, 95% CI: 1.12, 1.14; 49.4 μmol/L, 95% CI: 48.8, 50.5 vs 64.2 μmol/L, 95% CI: 63.6, 64.7 [not shown]). As shown in Table 3, smokers of 20 cigarettes daily had the lowest serum vitamin C concentrations (0.82 mg/dl, 46.6 μmol/L), while serum vitamin C levels were highest in individuals who had either stopped smoking for longer than one year or who had never smoked. The decrease in serum vitamin C levels observed in smokers persisted, even after adjusting for differences in dietary intake, age, gender, body weight, race, and vitamin supplementation. In multiple regression analysis, smoking status was the most important non-nutritive predictor of serum vitamin C levels, explaining more of the total variance than did gender, race, BMI, or age (Table 4). In additional analyses, smoking status was entered into the regression equation as a continuous variable defined as the number of cigarettes smoked daily. The order of entry and regression coefficients in these analyses were similar to those shown in Table 4 (i.e., when smoking was entered as a non-continuous variable).

The regression curves plotting dietary vitamin C intake

TABLE 2—Effect of Smoking Status on Dietary Vitamin C Intake

		Dietary Vitamin Intake (mg)	
	N	Mean (95% CI)	Adjusted Mean*
Smoker			
>1 PPD	1288	83 (76, 89)	79
1 PPD	1396	79 (73, 84)	78
<1 PPD	1498	97 (90, 104)	97
Non-smoker			
DC < 1 yr	335	97 (79, 116)	92
DC > 1 yr	1870	108 (103, 113)	105
Never smoked	4815	109 (105, 113)	111

NOTES: >1 PPD—Greater than 1 pack per day; 1 PPD—One pack per day; <1 PPD—Less than one pack per day; DC < 1 yr—Stopped smoking within the past year; DC > 1 yr—Stopped for the previous year or longer.

*Mean vitamin C intake adjusted for age, sex, race, ethanol intake, monetary income, and body weight.

TABLE 3—Effect of Smoking Status on Serum Vitamin C Levels

	N	Serum Vitamin C Concentration (mg/dl)† Mean (95% CI)	Adjusted Mean*
Smoker			
>1 PPD	1288	0.83 (0.79, 0.88)	0.89
1 PPD	1454	0.82 (0.77, 0.86)	0.88
<1 PPD	1553	0.97 (0.92, 1.03)	0.99
Non-Smoker			
DC < 1 yr	346	0.99 (0.92, 1.06)	1.03
DC > 1 yr	1942	1.10 (1.06, 1.14)	1.11
Never Smoked	5009	1.15 (1.15, 1.18)	1.12

NOTES: >1 PPD—Greater than 1 pack per day; 1 PPD—Smoker of one pack per day; <1 PPD—Less than one pack per day; DC < 1 yr—Stopped smoking within the past year; DC > 1 yr—Stopped for the previous year or longer.

*Vitamin C serum level adjusted for age, sex, race, ethanol intake, body weight, dietary vitamin C intake, and supplementation status.

†To covert to μmol/L, multiply by 56.78

with serum vitamin C levels for smokers and non-smokers are shown in Figure 1. The slope of the two lines is similar, with a consistent difference in serum vitamin C levels between smokers and non-smokers of approximately 0.2 mg/dl (11.4 μmol/L), independent of the level of dietary vitamin C intake. Using the regression equations, an additional 133 mg of dietary vitamin C was calculated to be necessary to increase the serum vitamin C level in smokers to the level found in non-smokers.

To test the hypothesis that smoking increases the risk of hypovitaminosis C, the frequency of low serum vitamin C levels occurring in smokers was compared with non-smokers. Of all smokers, 7.4 per cent had serum vitamin C levels of 0.2 mg/dl (11.4 μmol/L) or less compared with 1.9 per cent of non-smokers who had similar vitamin C levels. An additional 19.7 per cent of smokers had serum vitamin C levels between 0.2 mg/dl (11.4 μmol/L) and 0.4 mg/dl (22.7 μmol/L), compared with 8.2 per cent of non-smokers. Since further adjusting for BMI and age did not affect mean serum vitamin C levels, only gender, race, and dietary vitamin C intake were used as controlling variables to determine the risk of smoking on marginal or severe hypovitaminosis C. After adjusting for gender and race, risk ratios for smoking of 3.5 (95% CI: 2.9, 4.2) for severe, and 3.1 (95% CI: 2.8, 3.5) for marginal hypovitaminosis C were obtained (Table 5). Further adjustment for dietary vitamin C intake resulted in a minor reduction in the odds ratio.

Of the total sample, 37 per cent reported taking vitamin

TABLE 4—Stepwise Regression of Variables Influencing Serum Vitamin C Levels

Independent Variable	Order of Entry	Regression Coefficients	95% Confidence Intervals
Supplements	1	−0.3254	−.3005, −.3503
Smoking status	2	0.0515	.0467, .0564
Vit. C intake	3	0.0013	.0012, .0015
Sex	4	0.1379	.1200, .1558
BMI	5	−0.0098	.0078, .0118
Race	6	−0.1601	.1181, .2022
Age	7	0.0018	.0010, .0026
ETOH		0.0016	−.0009, .0042

Total R^2: 0.29.
Vitamin and mineral supplement use, coded as 1 = Yes, 2 = No.
Smoking status coded as non-continuous variable—see text.
Sex coded as 1 = male, 2 = female.
Race coded as 1 = White (and "other"), 2 = Black.
ETOH is estimate of alcoholic drinks consumed weekly.

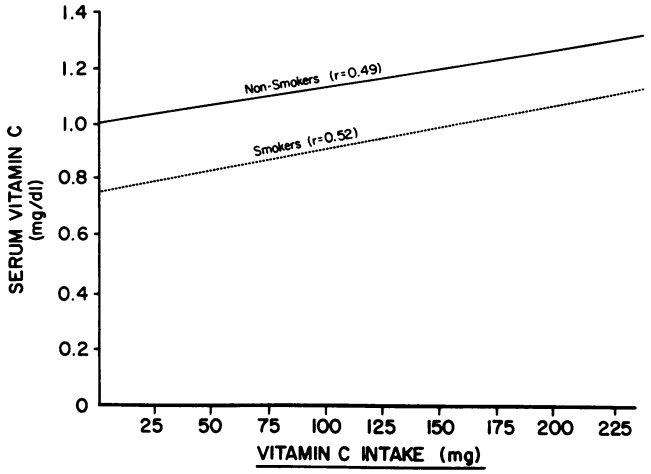

FIGURE 1—Linear Expression Curves for Smokers and Non-smokers Showing Relation between Dietary Vitamin C Intake and Serum Levels. (Adjusted for age, gender, race, body mass and vitamin supplementation. To convert serum levels to μmol/L, multiply by 56.78.)

or mineral supplements. The frequency of marginal hypovitaminosis C according to smoking and supplementation status is shown in Table 6. Smokers who did not take vitamin supplements had an 11.3 fold increased risk (95% CI: 9.6, 13.3) of marginal hypovitaminosis C compared with non-smokers who took supplements. Even smokers who took vitamin supplements were at increased risk of marginal hypovitaminosis C (odds ratio 2.5; 95% CI: 2.0, 3.1).

Discussion

Our analysis of the NHANES II data confirms that cigarette smoking is associated with decreased serum vitamin C levels. This association persisted despite correction for factors which independently affected serum vitamin C levels such as age, gender, race, and BMI. Dietary vitamin C intakes were lower in smokers than non-smokers, a finding which might potentially explain this inverse correlation. However, further adjustment for vitamin C consumption revealed that the association between smoking and serum levels was independent of dietary intake (Table 4). In fact, smoking status explained more of the total variance of serum vitamin C levels than did the self-reported dietary intake of vitamin C. Moreover, the increased risk of hypovitaminosis C in smokers was not substantially lowered when correcting for the decreased dietary vitamin C intake associated with smoking (Table 5). These observations suggest that cigarette smoking has an important influence on serum vitamin C levels which occurs predominantly via a mechanism independent of decreased dietary vitamin C consumption.

TABLE 5—Risk of Hypovitaminosis C in Smokers versus Non-smokers

	Unadjusted for Vitamin C Intake	Adjusted for Vitamin C Intake
Vitamin C Deficiency	Smoking Odds Ratio (95% CI)	Smoking Odds Ratio (95% CI)
Severe	3.5 (2.9, 4.2)	3.0 (2.5, 3.6)
Marginal	3.1 (2.8, 3.5)	2.8 (2.6, 3.1)

Unsupplemented subjects only.

TABLE 6—Combined Effect of Smoking and Vitamin Supplementation on Risk of Marginal Hypovitaminosis C

	Hypovitaminosis C Prevalence (%)	Risk of Hypovitaminosis C Odds Ratio (95% CI)*
Supplemented non-smokers	3.5	1.0
Supplemented smokers	9.8	2.5 (2.0, 3.1)
Unsupplemented non-smokers	14.5	3.9 (3.3, 4.7)
Unsupplemented smokers	35.7	11.3 (9.6, 13.3)

Inverse associations between smoking and vitamin C status have been previously reported. Most studies, however, have employed small sample sizes[3,5] or have been unable to control potentially confounding variables.[4,6,7] Pelletier stratified 4,500 Canadians participating in the Nutrition Canada National Survey into three categories of dietary vitamin C intake (0–30 mg, 30–100 mg, and over 100 mg) and analyzed serum vitamin C levels according to gender and age; an average 30 per cent reduction in serum levels were observed in smokers compared with non-smokers.[15] Ritzel, *et al,* determined that mean serum vitamin C levels were lower in smokers, independent of weekly citrus fruit consumption, in 4,053 healthy Swiss employees.[16] The risk of severe or marginal hypovitaminosis C was increased approximately threefold in smokers. Univariate analysis of NHANES II demonstrated a difference in serum vitamin C levels of 0.2 mg/dl (11.4 μmol/L) between smokers and non-smokers at each of six levels of dietary vitamin C intake.[17] These results are similar to the findings in this study using stepwise multiple regression to analyze the NHANES II data.

The lowered serum vitamin C levels in smokers could be due to either impaired vitamin C absorption or increased turnover. On the basis of studies measuring urinary vitamin C excretion in conjunction with the administration of known vitamin C intakes, Pelletier suggested the presence of impaired bioavailability but normal turnover of vitamin C in smokers.[26,27] On the other hand, Kallner, *et al,* measured vitamin C kinetics using radio-labeled ascorbic acid and demonstrated increased turnover in smokers but only small differences in absorption when compared to non-smokers.[28] Others have reported that smoking acutely increases urinary excretion of vitamin C, [29] also suggesting an accelerated metabolism in smokers. Interactions between vitamin C metabolism and a number of drugs have been described.[30,31] Identification of the responsible compound in tobacco smoke and the elaboration of its mechanism will require further study.

In this study, serum vitamin C levels were approximately 0.2 mg/dl (11.4 μmol/L) lower in smokers compared with non-smokers regardless of dietary vitamin C intake (Figure 1). Therefore, the impact of smoking to decrease serum vitamin C levels was proportionately greater in participants with initially low serum vitamin C levels. This resulted in a higher proportion of smokers with serum levels below the 0.2 mg/dl (11.4 μmol/L) or 0.4 mg/dl (22.7 μmol/L) range cutoffs for severe or marginal hypovitaminosis C. In this regard, the risk ratio for hypovitaminosis C was threefold greater in smokers when compared with non-smokers. Therefore, although the prevalence of severe and marginal hypovitaminosis C in NHANES II was low, certain subgroups, such as smokers not taking nutritional supplements, may be at substantial risk.

The significance of the increased risk of hypovitaminosis C produced by the interaction between smoking and serum vitamin C levels is not currently known. Although guidelines developed by the National Survey of Canada in 1973 suggested categories of high risk for serum vitamin C levels below 0.2 mg/dl (11.4 μmol/L), and of moderate risk for levels between 0.2 and 0.4 mg/dl [11.4 and 22.7 μmol/L],[21] the actual relation between low serum levels and clinical scurvy is not well defined. While serum levels in reported cases of scurvy are 0.4 mg/dl (22.7 μmol/L) or less,[32–34] individuals without clinical signs of scurvy may also have low serum levels.[35,36] However, because deficient vitamin C status has been associated with behavioral changes,[37,38] poor recovery from surgical procedures,[39] the presence of sublingual petechia,[40] and gingival disease,[41] and because the risk of overt scurvy is likely to be increased in this setting, the identification of individuals with hypovitaminosis C may have important implications. An assessment of the extent that hypovitaminosis C constitutes a true public health problem will require further studies to confirm that individuals with serum vitamin C levels below the cut-points used are truly at increased risk for adverse health outcomes.

The observed decrease in dietary vitamin C intake among smokers was unexpected. Although altered food preferences in smokers compared with non-smokers has been established,[42,43] a specific association of smoking with vitamin C intake is not well recognized. In the Caerphilly Heart Disease Study, smokers had a 22 per cent lower mean vitamin C intake compared with non-smokers,[44] similar to our findings in NHANES II. Our observation that vitamin C intake was lowest in individuals smoking 20 cigarettes or more daily, and that smokers who have stopped for greater than one year have intakes similar to individuals who have never smoked, suggest a specific aversive effect of smoking on vitamin C rich foods which may be reversible when smoking is discontinued. A more complete analysis from NHANES II of the effect of smoking on food preferences and vitamin intake will be reported separately.

Although an association between depressed vitamin C levels and smoking was determined to be independent of other potentially confounding variables, a cause and effect relationship cannot be assumed from this study. Prospective studies will be required both to prove that smoking directly affects vitamin C metabolism and to evaluate possible mechanisms. However, the cohort of participants who smoked less than 20 cigarettes daily had lower mean serum vitamin C levels than heavier smokers but higher than non-smokers, suggesting a dose-response effect. In addition, former smokers had higher serum levels than current smokers, indicating that the influence of smoking on serum vitamin C levels may be reversible. These observations suggest that the association between smoking and serum vitamin C levels may be causal.

This study is also limited by the methodological problems associated with estimating dietary intake in cross-sectional studies of free-living populations. Dietary recall of the preceding 24-hour period may not provide an accurate or representative assessment of current nutritional intake for an individual. However, this limitation is lessened when assessing the average intake of a group, since the group mean intake is less sensitive to day-to-day variability.[45] An additional shortcoming is that specific nutritional supplements were not systematically recorded and therefore were not included in the dietary analysis. This problem has been addressed in this study by either adjusting or stratifying for supplement use.

This analysis of NHANES II data confirms that cigarette smokers in the United States have lower serum concentrations of vitamin C than non-smokers, an association which persisted following adjustment for potentially confounding

factors. Because of these decreased levels, smokers had a three-fold increase in risk of marginally or severely deficient vitamin C status. Approximately 35 per cent of smokers had low serum levels placing them within one of these two categories. Although smokers taking vitamin supplements were also at increased risk of hypovitaminosis C compared with non-smokers, the prevalence of low serum vitamin C levels was much reduced in both smoking and non-smoking individuals taking supplements. This finding suggests that the increased vitamin C intake associated with vitamin supplementation may frequently prevent the low serum levels from occurring in smokers. As estimated by the regression curves in Figure 1, approximately 130 mg of additional dietary vitamin C daily would be required to overcome the adverse effect of cigarette smoking on serum vitamin C levels. Although vitamin C supplementation has been associated with altered protein and amino acid metabolism,[46] increased urinary oxalate excretion leading to calcium oxalate calculi,[47] diminished serum levels of vitamin B12,[48] and interference with urine tests for glucose and stool tests for occult blood,[49,50] these adverse effects have been reported only with daily vitamin C doses of one gram or more. Therefore, increasing the dietary vitamin C intake by an amount sufficient to correct the hypovitaminosis C associated with smoking should be well tolerated. Although the simplest and most direct method to increase the low serum vitamin C levels found in many smokers would be to stop smoking, increasing vitamin C consumption may be appropriate when cigarette cessation is unsuccessful.

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