Vitamin C Deficiency and Depletion in the United States: The Third National Health and Nutrition Examination Survey, 1988 to 1994

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Objectives. We sought to determine prevalence rates of vitamin C deficiency and depletion in the United States.

Methods. We used data from the Third National Health and Nutrition Examination Survey to assess intake of dietary, supplemental, and serum vitamin C.

Results. Mean intakes and serum levels of vitamin C were normal; however, vitamin C deficiency and depletion were common (occurring among 5%–17% and 13%–23% of respondents, respectively). Smokers, those who did not use supplements, and non-Hispanic Black males had elevated risks of vitamin C deficiency, while Mexican Americans had lower risks.

Conclusions. Health professionals should recommend consumption of vegetables and fruits rich in vitamin C and should recommend supplementation for individuals at risk of vitamin C deficiency. (*Am J Public Health*. 2004;94:870–875)

Health professionals in the United States generally consider overt vitamin C deficiency, or scurvy, to be a disease of historical significance.[1] Despite numerous case studies in the recent medical literature,[2–19] scurvy is now presumed to be an uncommon disease in developed nations,[20] and patients who present with low-grade inflammation, fatigue, limping, gum bleeding, or swollen extremities may not be screened for vitamin C deficiency.[15,17,21,22] Furthermore, because the signs and symptoms of scurvy are similar to those of other conditions (e.g., vascultitis, rheumatic disorders, reduced lung function), patients with vitamin C deficiency initially may be misdiagnosed and prescribed medication without receiving proper therapy.[17,23]

In the United States, mean vitamin C intakes usually exceed the recommended dietary allowances (RDAs) of 75 and 90 mg per day for women and men, respectively.[24] Elevated mean intakes, however, mask the fact that numerous US residents underconsume vitamin C. Data from the US Department of Agriculture's 1994 to 1996 Continuing Survey of Food Intakes by Individuals showed that 18% of US adults consumed less than 30 mg per day of vitamin C, despite an overall mean intake of 95 mg per day.[25] The data from this survey further indicated that 14% of male and 20% of female 13- to 18-year-olds consumed less than 30 mg per day of vitamin C (RDAs are 65 and 75 mg per day for girls and boys, respectively).[26]

In addition to low dietary intakes, numerous reports have indicated that cigarette smokers are at increased risk of low serum vitamin C owing to the free-radical-quenching role of vitamin C (i.e., the ability to render oxidants harmless),[27–29] and the most recent data from the 2000 Behavioral Risk Factor Surveillance System indicate that 23% of US adults smoke cigarettes.[30] At the same time, most Americans are not consuming the recommended number of servings of vegetables and fruits or taking vitamin supplements.[20,31] Currently, the second leading cause of death in the United States is cancer; as a preventive measure, high vitamin C intakes may reduce the risk of oral, esophageal, stomach, and breast cancers.[20] Serum vitamin C levels have been assessed in international studies,[32–34] but little is known regarding vitamin C status among American children and adults. The present study was conducted to determine the prevalence of vitamin C deficiency and depletion in the United States.

METHODS

The National Center for Health Statistics conducted the Third National Health and Nutrition Examination Survey (NHANES III) to assess the health status of children and adults in the United States. In this cross-sectional survey, personal household information was collected and health examinations conducted with 30 818 individuals 2 months and older; household interviews were conducted over a 6-year period (1988–1994). Adults 60 years or older, non-Hispanic Blacks, and Mexican Americans were purposively oversampled to produce more precise estimates for these population groups. Detailed descriptions of the plan and operation of the survey, including informed consent, have been reported previously.[35]

The sample for this study (n = 15 769) included civilian, noninstitutionalized children and adults aged 12 to 74 years. Data regarding demographic characteristics, socioeconomic status, dietary habits, and health history were collected during the household interview. In addition, self-reported race/ethnicity was recorded during the household interview and coded as non-Hispanic White, non-Hispanic Black, or Mexican American.

Quantitative dietary data were collected via 24-hour dietary recalls during the clinic examination, and results were coded with the US Department of Agriculture nutrient database (included with the NHANES III CD-ROM).[36] Respondents were queried regarding the supplements they used and how many times they had taken each supplement during the preceding month. As a means of estimating vitamin C intakes from supplements, a monthly total was calculated and then divided by 30 to derive daily supplemental vitamin C intake (as described by Will et al.[37]). Physical examinations, including venipunctures, were conducted in mobile examination centers ap-

proximately 2 to 4 weeks after household interviews. Overall, NHANES III response rates were 86% for the household interview and 78% for the physical examination.[35]

Participants were asked to fast overnight before arriving in the morning at the mobile examination center for assessment. Serum vitamin C was measured at the Centers for Disease Control and Prevention in Atlanta via isocratic high-performance liquid chromatography with electrochemical detection.[38] The coefficient of variation for the vitamin C assay averaged 5.8%.[38] (The term *vitamin C* was defined as comprising all compounds that exhibit the activity of ascorbic acid, including dehydroascorbic acid reduced during analysis.) Serum vitamin C levels, ranging from 0.0 µmol/L to the upper cutoff point of 170 µmol/L, were categorized according to internationally established limits: deficiency (less than 11 µmol/L), depletion (11–28 µmol/L), or normal (more than 28 µmol/L).[33,39,40] Several participants (n=21) were excluded from analyses because their serum vitamin C levels were quite high (more than 170 µmol/L) and of dubious validity.

Respondents 17 years and older were questioned about tobacco use on 2 separate occasions. As part of the household interview, respondents who reported that they had smoked at least 100 cigarettes in their lifetime were asked whether they currently smoked cigarettes. During the private interview conducted in the mobile examination center, all respondents—including those who had not reported any tobacco use in the household interview—were questioned about their use of cigarettes during the past 5 days.

The NHANES III CD-ROM is equipped with the Statistical Export and Tabulation System (SETS), which we used to export data into SPSS 10.0 (SPSS Inc, Chicago, Ill) for data reduction. We conducted all analyses using SPSS and SUDAAN (version 7.5; Research Triangle Institute, Research Triangle Park, NC), which is a statistical program that takes into account the NHANES sampling weights and the survey's complex design. We used sample weights, based on probability of selection, to adjust for nonresponse; weights were poststratified to the US Bureau of Census 1990 estimates of the total US population.

TABLE 1—Mean (±SEM) Vitamin C Intakes and Serum Vitamin C Levels

Gender and Age, y	No.	Population Size[a]	Dietary Vitamin C, mg	Total Vitamin C,[b] mg	Serum Vitamin C, µmol/L
Male					
12–17	975	9.59	117±5	145±7	46.0±1.7
18–24	1011	11.00	125±6	179±16	36.9±1.1
25–44	2649	36.53	119±4	202±14	36.3±1.1
45–64	1765	20.39	110±4	210±16	38.0±1.1
65–74	955	7.61	118±5	194±9	44.9±1.1
Female					
12–17	1133	9.14	101±5	145±23	50.0±1.7
18–24	1186	12.04	102±5	159±6	43.7±1.7
25–44	3212	37.66	91±2	164±5	42.6±1.1
45–64	1916	22.05	97±4	206±11	47.7±1.1
65–74	967	8.95	107±3	198±10	55.1±1.1

[a]In millions, using weights obtained from NHANES III.
[b]Dietary vitamin C plus supplements.

To improve the normality of the distributions of dietary and serum vitamin C, we log-transformed data before conducting statistical analyses. We assessed data using tabulation to document vitamin C deficiency and depletion. We used odds ratios (ORs) and 95% confidence intervals (CIs) to estimate relative prevalence rates of vitamin C deficiency, with serum vitamin C levels below 11 µmol/L as a cutoff. We used Pearson's correlation coefficient to assess the relationship between total vitamin C intakes and serum vitamin C. In the case of all tests, we considered 2-tailed *P* values less than .05 to be statistically significant.

RESULTS

Mean dietary intakes and serum levels of vitamin C were within normal ranges, as indicated in Table 1. In the case of all age groups, mean vitamin C intakes from diet alone exceeded the RDA, ranging from 110 to 125 mg per day for males and 91 to 107 mg per day for females. Supplemental vitamin C resulted in mean total vitamin C intakes being even higher, ranging from 145 to 210 mg per day for males and 145 to 206 mg per day for females. Mean serum vitamin C levels ranged from 36.3 to 46.0 µmol/L and 42.6 to 55.1 µmol/L for males and females, respectively. As shown in Figure 1, total vitamin C intakes from diet and supplements were linearly related to serum vitamin C levels among both males ($r=0.41$, $P<.0001$) and females ($r=0.42$, $P<.0001$) across all age groups.

Table 2 shows that, overall, 14% of males and 10% of females were vitamin C deficient, as indicated by serum vitamin C values. The percentages of 12- to 17-year-old males and females who were vitamin C deficient were low (5%–6%) relative to other groups. Among all age groups, the percentage of males with vitamin C deficiency was greater than that of females, reaching a peak of 17% among 25- to 64-year-olds. Among females, the greatest prevalence (12%) of vitamin C deficiency was found among 25- to 44-year-olds.

Across all age groups, proportionately more males and females exhibited vitamin C depletion than vitamin C deficiency. Among males, rates of vitamin C depletion ranged from 15% among 65- to 74-year-olds to 23% among 25- to 44-year-olds. Among females, the lowest rate of vitamin C depletion (13%) was found among 65- to 74-year-olds, and the highest rate (20%) was found among 25- to 44-year-olds.

Table 3 lists odds ratios related to risk of vitamin C deficiency. As a group, current smokers had the highest risk of vitamin C deficiency. The odds ratio of vitamin C deficiency among smokers was high in the case

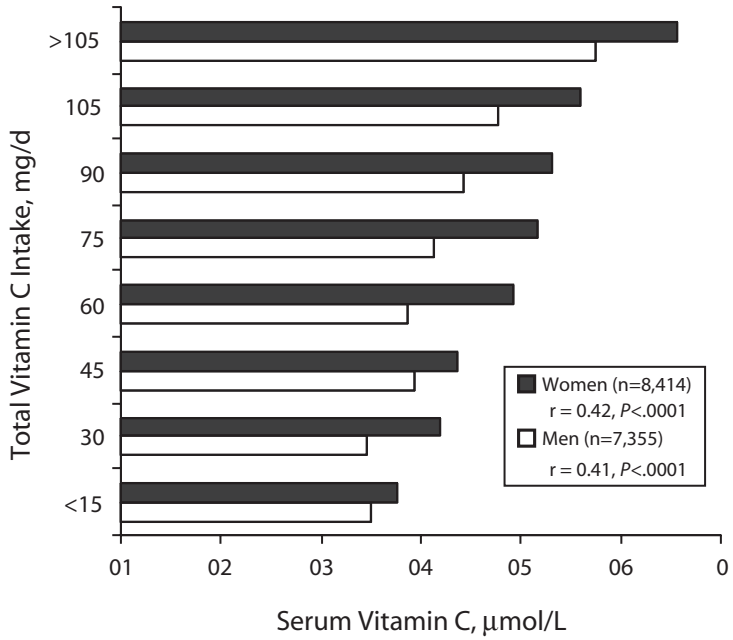

FIGURE 1—Mean vitamin C intakes, stratified by serum vitamin C levels.

TABLE 2—Percentages of Vitamin C Deficiency, Depletion, and Normal Serum Values Among US Males and Females

Gender and Age, y	Serum Vitamin C Value		
	<11 µmol/L, %	11–28 µmol/L, %	>28 µmol/L, %
Male			
12–17 (n = 975)	6	17	77
18–24 (n = 1011)	13	22	65
25–44 (n = 2649)	17	23	60
45–64 (n = 1765)	17	20	63
65–74 (n = 955)	11	15	74
Overall	14	20	66
Female			
12–17 (n = 1133)	5	15	80
18–24 (n = 1186)	11	19	70
25–44 (n = 3212)	12	20	68
45–64 (n = 1916)	10	15	75
65–74 (n = 967)	6	13	81
Overall	10	17	73

of both males (OR=3.6; 95% CI=3.2, 4.1) and females (OR=4.2; 95% CI=3.6, 4.9). Both males (OR=3.3; 95% CI=2.8, 4.0) and females (OR=3.1; 95% CI=2.6, 3.7) who had not used nutrient supplements in the past month had an increased risk of vitamin C deficiency. Non-Hispanic Black males had a slightly increased risk of vitamin C deficiency (OR=1.2; 95% CI=1.1, 1.5) relative to White males, while Mexican American males (OR=0.83; 95% CI=0.71, 0.97) and females (OR=0.80; 95% CI=0.66, 0.96) both had a lower risk of vitamin C deficiency than White males and females.

DISCUSSION

These nationwide data indicate that a considerable number of US residents are vitamin C deficient or depleted. Although our findings are contrary to the accepted notion that vitamin C status in the United States is within normal limits, previous work corroborates these data. Dickinson et al.[41] assessed NHANES II (in which data were collected from 1976 to 1980) and reported that vitamin C depletion occurred in up to 25% of nonsmoking men and up to 50% of adult male smokers. In smaller, more recent studies, Johnston and colleagues[42,43] reported vitamin C depletion in approximately 21% of university students (n=98) and 30% of outpatients presenting to a local health maintenance organization laboratory (n=494). Johnston et al.[42] further reported that 6.3% of their outpatient sample had plasma ascorbic acid concentrations indicative of vitamin C deficiency.

We found moderately strong correlations (r=0.41 and r=0.42 for men and women, respectively) between total vitamin C intakes and serum vitamin C levels, as did Loria et al.[40] using NHANES II data (r=0.54) and Sinha et al.[44] (r=0.56) in a case–control study. These values are higher than that reported by Drewnowski et al.[45] for the correlation between serum vitamin C and total vegetable and fruit intakes (r=0.29). In that study, however, use of supplemental vitamin C was not reported. Measuring supplemental vitamin C is of crucial importance in analyses because total vitamin C intakes and serum vitamin C have an S-shaped relationship. When intakes exceed 70 mg per day, excess vitamin C is excreted in the urine, causing the correlation to flatten off as vitamin C intakes increase.[46]

Consistent with data reported from NHANES II,[40] our data showed that elderly US residents (aged 65 years or older) had a lower prevalence of vitamin C deficiency and depletion than members of other adult age groups. These results differ from those of Bates et al.,[47] who found that 33% of their sample of community-dwelling British adults 65 years or older (n=1310) consumed less than the United Kingdom's reference nutrient intake[48] for vitamin C. Bates et al.[47] further reported that 14% of their

TABLE 3—Effects of Smoking, Supplement Use, and Ethnicity on Vitamin C Deficiency

	Serum Vitamin C Value		Odds Ratio
	<11 μmol/L, %	≥11 μmol/L, %	(95% Confidence Interval)
Male			
Smoking status			
Nonsmokers (n = 4429)	11	89	1.0
Smokers (n = 2115)	31	69	3.6 (3.2, 4.1)
Supplement use			
Yes (n = 2119)	7	93	1.0
No (n = 5226)	20	80	3.3 (2.8, 4.0)
Race/ethnicity			
Non-Hispanic White (n = 2613)	16	84	1.0
Non-Hispanic Black (n = 2115)	19	81	1.2 (1.1, 1.5)
Mexican American (n = 2346)	13	87	0.83 (0.71, 0.97)
Female			
Smoking status			
Nonsmokers (n = 5776)	7	93	1.0
Smokers (n = 1686)	25	75	4.2 (3.6, 4.9)
Supplement use			
Yes (n = 3204)	5	95	1.0
No (n = 5204)	14	86	3.1 (2.6, 3.7)
Race/ethnicity			
Non-Hispanic White (n = 3039)	11	89	1.0
Non-Hispanic Black (n = 2605)	13	87	1.2 (1.0, 1.4)
Mexican American (n = 2379)	9	91	0.80 (0.66, 0.96)

sample had plasma vitamin C levels below 11 μmol/L, indicative of vitamin C deficiency. In the same study, 40% of elderly individuals residing in nursing homes or residential homes (n=423) had plasma vitamin C levels below 11 μmol/L, with a mean level of 24.4 μmol/L.[47]

Seniors are more likely than individuals in other age groups to purchase and use nutrient supplements,[49–52] and vitamin C consistently ranks as one of the most frequently purchased supplements.[40] Previous research has shown that consumption of vitamin C supplements results in a doubling of total vitamin C intake,[44,46] and we showed that individuals who had not used supplements in the previous month had a greatly increased risk of vitamin C deficiency (odds ratios of 3.3 and 3.1 for males and females, respectively). Furthermore, McKay et al.[50] noted that supplementation with 250 mg of vitamin C for 8 weeks resulted in a 29% increase in plasma concentrations of vitamin C in a group of community-dwelling, healthy seniors. For many years, physicians, dietitians, and other health professionals have hesitated to discuss supplementation with patients, partly to avoid implying that supplements can substitute for a healthy eating plan; however, this paradigm may be changing. Recently, Fletcher and Fairfield[53] recommended that all US adults take a multivitamin every day to reduce their risk of chronic disease, and additional dialogue is needed to determine appropriate levels of supplementation.

In the United States, individuals who take supplements are least likely to need them,[44] and several studies have noted that cigarette smokers are unlikely to purchase supplements.[29,54] We showed that cigarette smokers had a high risk of vitamin C deficiency (odds ratios of 3.6 and 4.2 among male and female smokers, respectively). Vitamin C is a strong reducing agent (i.e., an electron donor), both in vivo and in vitro, and the lower level of serum vitamin C reported among smokers probably is caused by higher turnover of vitamin C owing to its antioxidant activity.[55,56] The Food and Nutrition Board of the National Academy of Sciences recommends that individuals who smoke consume an additional 35 mg of vitamin C per day (110 and 125 mg per day for adult females and males, respectively).[24] In all likelihood, this additional vitamin C is not sufficient to combat the oxidative damage that results from cigarette smoking. High intakes of vitamin C, as achieved by supplementation, may be appropriate for smokers, especially those who do not consume ample servings of vegetables and fruits rich in vitamin C.

Race/ethnicity-specific data regarding vitamin C status are sparse, but our data showed that non-Hispanic Black males had a slightly increased risk of vitamin C deficiency (OR=1.2). In cross-sectional studies, Koh et al.[57] and Loria et al.[40] reported that plasma ascorbic acid levels were significantly lower among Black than White residents of the United States, while Ness et al.[32] reported that London residents of Caribbean or West African descent had lower levels of plasma vitamin C than did Whites. These lower serum levels seem to be the result of poorer dietary intakes[40] rather than any genetic differences in vitamin C absorption or use.

Furthermore, Vitolins et al.[52] reported that Black residents of the United States were significantly (P=.001) less likely to use supplements than were Whites or Native Americans. In comparison with non-Hispanic Blacks, we showed that Mexican American males and females had significantly lower risks of vitamin C deficiency (OR=0.83 and OR=0.80, respectively). Because it involves common consumption of chiles, tomatoes, and squashes, the traditional Mexican diet is rich in vitamin C and other nutrients.[58] However, Mexican Americans are at increased risk of chronic diseases related to hypertension, overweight, and type 2 diabetes, and thus further research is warranted to better understand food availability, eating habits, and disease outcomes in this population.[59–61]

Internationally, vitamin C deficiency is frequently observed when vegetable and fruit intakes are limited as a result of lack of availability, high prices, and poor storage capacity.[33] One would not assume vitamin C deficiency to be common in America, given the variety of US diets; however, Chiplonkar

et al.[34] reported that the prevalence of vitamin C deficiency among Western Indian adults was quite similar to what we reported here for the United States. Vegetables and fruits serve as primary contributors to total vitamin C intake,[10,42,48] and although numerous Americans are meeting the National Cancer Institute's "5-a-day" goal for vegetables and fruits,[62] many of the vegetables and fruits typically consumed are not good sources of vitamin C. The leading vegetables and fruits consumed in the United States—in descending order of consumption—are iceberg lettuce, raw tomatoes, french fries, bananas, and orange juice, representing nearly 30% of all vegetables and fruits consumed by US adults[25,31]; of these foods, however, only orange juice is a rich source of vitamin C. Broccoli, strawberries, kale, and grapefruit all are rich sources of vitamin C, but, combined, they represent less than 2% of all vegetable and fruit consumption in the United States.[31]

The amount of vitamin C in any particular food may differ considerably from what is listed in a nutrient database or food label. Vitamin C—the least stable of the vitamins—is readily destroyed by exposure to air,[48] and degradation is accelerated further by exposure to heat, alkali, and metals.[63] In fact, normal cooking of vegetables and fruits can reduce their vitamin C content by 20% to 40%.[10] Johnston and Bowling[64] assessed vitamin C oxidation in orange juice and found that the amount of ascorbic acid per 8 fl oz (240 mL) dropped as the expiration date approached, with a decomposition rate of approximately 2% ascorbic acid per day once the container of juice was opened.

One limitation of the present study was that our measure of vitamin C status was based on a single blood sample. Because vitamin C is water soluble and is not stored for a long period of time in body tissues, a single measurement of vitamin C may indicate only an individual's short-term (1–4 weeks) vitamin C status. Although single 24-hour dietary recalls do not fully describe a given individual's eating habits, the 1-day recall method applied to a large population is more effective than more complex and expensive methods when the goal is to determine group means.[65] In addition, all large-scale nutrition surveys have the potential for underestimating food and nutrient intakes. In the present case, however, the 24-hour dietary recalls were administered via standardized, computerized probes; edited carefully for completeness; and verified to determine the accuracy of extreme values.[35] Trained study staff, whose performance was monitored routinely, completed the dietary interviews in private rooms, and nearly all (95%) of the participants provided 24-hour dietary recalls. For these reasons, we believe that our dietary data provide a relatively complete assessment of vitamin C intakes.

In conclusion, our data indicate that a considerable number of children and adults in the United States are vitamin C deficient or depleted. Health professionals should continue to recommend consumption of vegetables and fruits, especially those that are rich in vitamin C. In addition, vitamin C supplementation should be discussed with all patients, but especially those who are at the greatest risk of vitamin C deficiency: cigarette smokers and poor eaters. ■

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Contributors

J.S Hampl drafted the article, and C.A. Taylor and C.S. Johnston contributed to critical revisions of the article. J.S Hampl and C.A. Taylor were responsible for acquisition of the data. All of the authors were involved with the study's conception and design and the analysis of data.

Human Participant Protection

No protocol approval was needed for this study.

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